LA150 Documentation of Cross Sections, Heating, and Damage: Part A (Incident Neutrons) and Part B (Incident Protons) [1]

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Abstract

This Report contains summary information and figures depicting the Los Alamos ENDF evaluations that extend up to 150 MeV (the "LA150 Library"), developed for enhanced computational simulations of Accelerator-Driven Systems [1].

Information is included here for the following isotopes and elements important in radiation transport simulations of Accelerator-Driven Systems: ^{1,2}H, C, ^{14}N, ^{16}O, ^{27}Al, ^{28,29,30}Si, ^{31}P, Ca, ^{50,52,53,54}Cr, ^{54,56,57}Fe, ^{58,60,61,62,64}Ni, ^{63,63}Cu ^{93}Nb ^{182,183,184,186}W, ^{206,207,208}Pb. For each material we include:

1. Summary documentation from the ENDF file-1.
2. A summary printout of the total nonelastic, elastic, and production cross sections of light ejectiles, and the partial and total neutron kerma coefficients for neutron heating.
3. Figures showing: (1) the incident-energy-dependence of the nonelastic cross section and the production cross sections; (2) a 3-D representation of the light ejectile angle-integrated c.m. emission spectra; (3) a 3-D representation of the light ejectile Kalbach-preequilibrium-ratios (from which angular distributions can be determined); (4) elastic scattering angular distributions; (5) heating; (6) damage (for incident neutrons).

The figures, in particular, allow one to quickly assess trends in the evaluated data, and to ensure the absence of numerical errors in the ENDF-files. All the information was obtained in an automated manner from the LA150 evaluations. Much of this information is also available on the WWW at: *http://t2.lanl.gov/data/he.html*

This work, which focusses solely on the evaluated data, complements Ref. [1] which focusses on the physics involved, together with benchmark comparisons with experimental data.

[1] M.B. Chadwick, P.G. Young, S. Chiba, S.C. Frankle, G.M. Hale, H.G. Hughes, A.J. Koning, R.C. Little, R.E. MacFarlane, R.E. Prael, L.S. Waters, "Cross Section Evaluations to 150 MeV for Accelerator-Drive Systems and Implementation in MCNPX", Los Alamos Report LA-UR-98-1825, Nucl. Sci. Eng. **131**, 293 - 328 (1999).

[1]Supported by the LANL Accelerator Production of Tritium Program

PART A: INCIDENT NEUTRONS

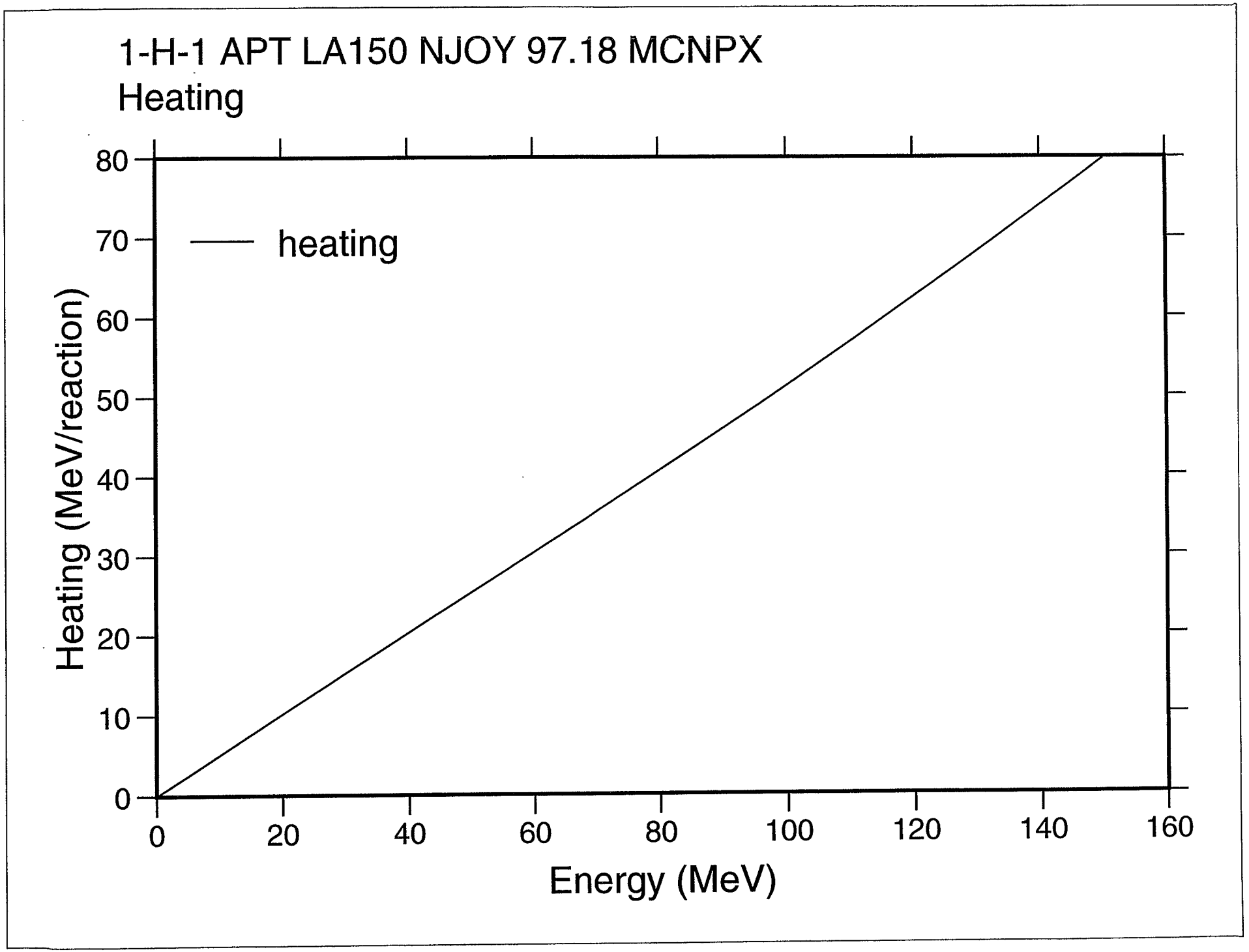
EVALUATION OF n+1H CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 TO 150 MEV

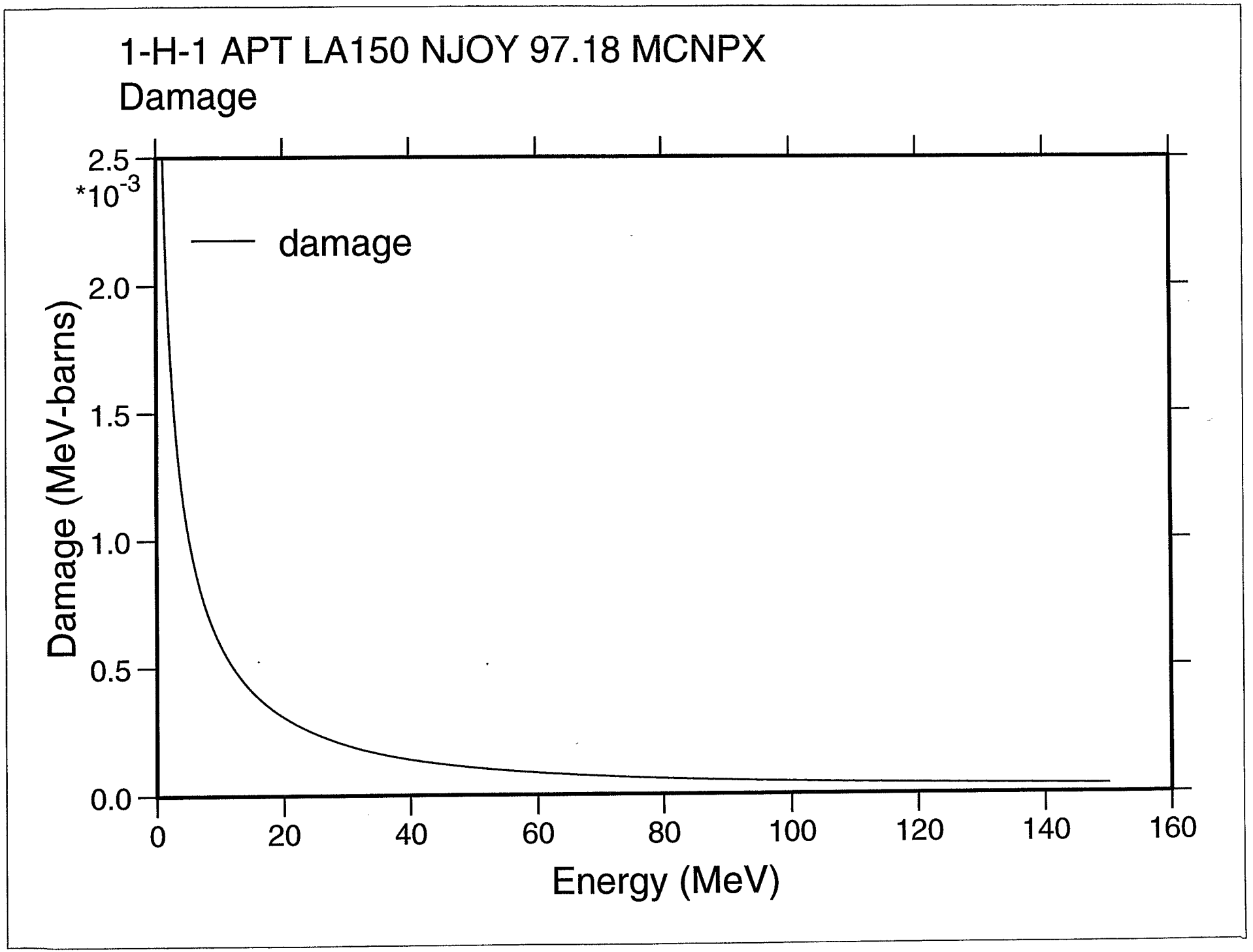
ENDF/B-VI Evaluation Revision, February, 1998

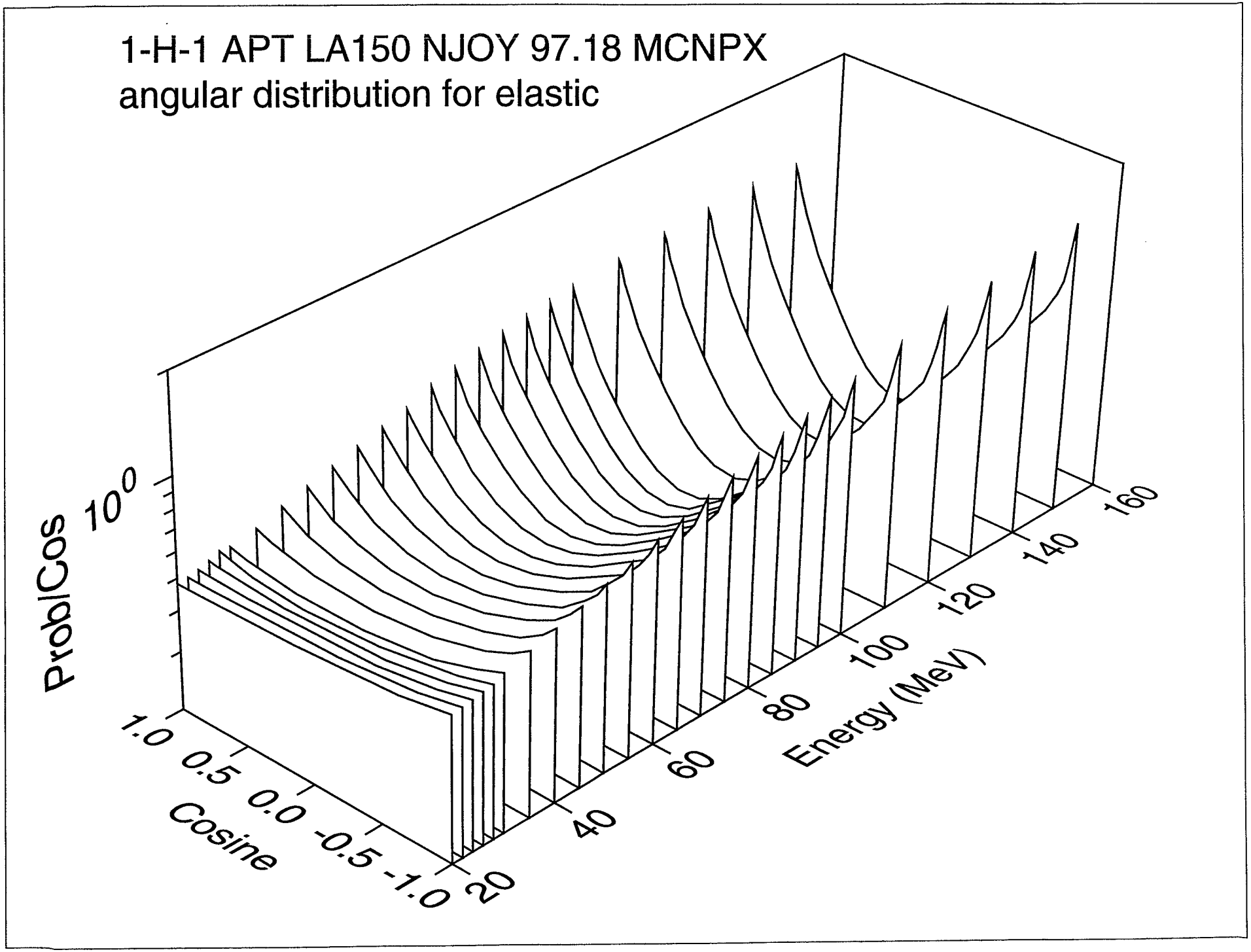
G. M. Hale and P. G. Young

This is an interim updating of the ENDF/B-VI Revision 2 (Release 5) evaluation to extend the incident neutron energy range from 100 to 150 MeV. The elastic scattering cross section from the R-matrix analysis used for ENDF/B-VI is matched in the energy region of 26 - 30 MeV to elastic cross sections from Arndt's phase-shift solution, VL40. Arndt's elastic cross section is used directly in the evaluation above the matching region to 150 MeV. A smooth extrapolation was made of MT=102 to 150 MeV.

This new evaluation has a smoother transition across the matching region than did the previous ENDF/B-VI file, and corresponds more closely to the recommendation of the EANDC standards subcommittee for n-p cross sections above 20 MeV. Proton kerma values calculated from this file deviate by no more than 2% from the previous ENDF/B-VI values at energies up to 100 MeV.


1-H-1 APT LA150 NJOY 97.18 MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
10
20
30
40
50
60
70
80
0
20
40
60
80
100
120
140
160


1-H-1 APT LA150 NJOY 97.18 MCNPX
Damage
damage
Damage (MeV-barns)
*10^-3
2.5
2.0
1.5
1.0
0.5
0.0
0
20
40
60
80
100
120
140
160
Energy (MeV)


1-H-1 APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic
ProbCos
10^0
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
20
40
60
80
100
120
140
160

EVALUATION OF n + 2H CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

P. G. Young, G. M. Hale, and M.B. Chadwick
3 February 1997

1. SUMMARY

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. Below 50 MeV the evaluation is based mainly on the ENDF/B-VI.3 (Release 3) evaluation by Young (Yo94).

To summarize, the following ENDF sections are utilized at all energies:

MF=3	MT= 1	Total Cross Section
	MT= 2	Elastic Scattering Cross Section
	MT= 3	Nonelastic Cross Section
	MT= 16	2H(n,2n)1H Cross Section
	MT=102	Radiative Capture Cross Section (Estimate Only at higher energies)
MF=4	MT= 2	Elastic Angular Distributions
MF=6	MT= 16	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The following modifications were made to the ENDF/B-VI.3 evaluation:

1. The (n,2n), elastic, and nonelastic cross sections were revised slightly above 10 MeV to better reflect experimental data;

2. The tabulated elastic scattering angular distributions (MF=4, MT=2) below 3.2 MeV and above 20 MeV were revised slightly to better reflect measurements. The results below 3.2 MeV are based on a couple-channels R-matrix analysis.

2. METHODOLOGY USED IN NEW EVALUATION

The neutron total cross section is based on ENDF/B-VI below 100 MeV and on experimental data between 100 and 200 MeV. The elastic scattering, nonelastic, and 2H(n,2n)1H cross sections were determined above 10 MeV in concert, using the fact that the nonelastic cross section essentially equals the (n,2n) cross section above En ~ 1 keV, and the elastic and nonelastic cross sections must sum to the total cross section. Note that we revised the existing ENDF/B-VI (n,2n) cross section at most energies between 10 and 100 MeV to improve the agreement with experimental data. We also included experimental data for the proton reaction cross section of 2H in our analysis, as we

determined empirically that it is entirely consistent with the neutron nonelastic (or reaction) cross section above an incident nucleon energy of about 20 MeV.

The elastic cross section and angular distributions below an incident energy of 4 MeV were validated by comparing to results of a coupled-channels R-matrix analysis. No changes were made to the existing ENDF/B-VI.2 cross section evaluation because the results were consistent with data and the R-matrix analysis; the elastic angular distributions below 3.2 MeV were replaced with tabulated distributions from the R-matrix analysis.

Several elastic scattering angular distribution measurements exist above 20 MeV which we fit with Legendre expansions to get integrated cross sections and to establish the evaluated angular distributions. Especially important are the measurements of Romero, Wang, and Howard, as well as the partial distributions of Yountz and Palmieri. We inferred nonelastic cross sections from the elastic scattering angular distribution measurements above 20 MeV, combined with our evaluated total cross section from experimental data.

We assume that the energy distributions of neutrons from 2H(n,2n)1H follow a pure three-body phase space distribution at all incident neutron energies and utilize LAW=6 in MF=6 to represent these energy distributions.

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[Ch97]. M.B. Chadwick, P G. Young, and G. M. Hale, "Evaluation of n + 2H Cross Sections," Group T-2 Progress Report for the Accelerator Production of Tritium Program, 1 January - 1 February 1997.

[Yo94]. P. G. Young, "n + D Evaluation to 100 MeV," Release 3, ENDF/B-VI evaluation, distributed April, 1995.

EVALUATION OF n + C CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

M. B. Chadwick and P. G. Young
19 June 1996

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI.1 (Release 1) evaluation by Fu (Fu90). The following minor modifications were made to the ENDF/B-VI.1 evaluation:

1. The energy range from En = 20 MeV to 32 MeV was replaced by the LANL evaluation (described below);

2. The elastic, nonelastic, and total cross sections from 19 to 20 MeV were varied to join smoothly with the higher energy values at 20 MeV.

3. The new flag, LCT=3, is used in MF=4,MT=2 to indicate that Legendre polynomials are used below 20 MeV and probability tabulations at higher energies. A small discontinuity exists for MF=4,MT=2 at 20 MeV where the two different representations join. The higher energy evaluation utilizes a tabulation in order to overcome the inaccuracies caused by the ENDF-6 limitation of 20 for the maximum number of Legendre coefficients.

INCIDENT NEUTRON ENERGIES > 20 MeV (12C analysis)

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT= 1	Total Cross Section
	MT= 2	Elastic Scattering Cross Section
	MT= 3	Nonelastic Cross Section
	MT= 5	Sum of Binary (n,n') and (n,x) Reactions
	MT=102	Radiative Capture Cross Section (Estimate Only)
MF=4	MT= 2	Elastic Angular Distributions
MF=6	MT= 5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission
MF=33	MT= 1	Covariance file for total cross section
	MT= 2	Covariance file for elastic cross section

MT= 3 Covariance file for nonelastic cross section
MT= 5 Covariance file for composite reaction cross sect.
MT=102 Covariance file for capture cross section

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + C12 and p + C12 reactions (Ch96a). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Coupled-channel and spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96b). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. Note that all other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation requires a modification of the original ENDF-6 format.

Preequilibrium corrections were performed in the course of the GNASH calculations using either Feshbach, Kerman, Koonin (FKK) theory [Ch93] or the exciton model of Kalbach (Ka77, Ka85). Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

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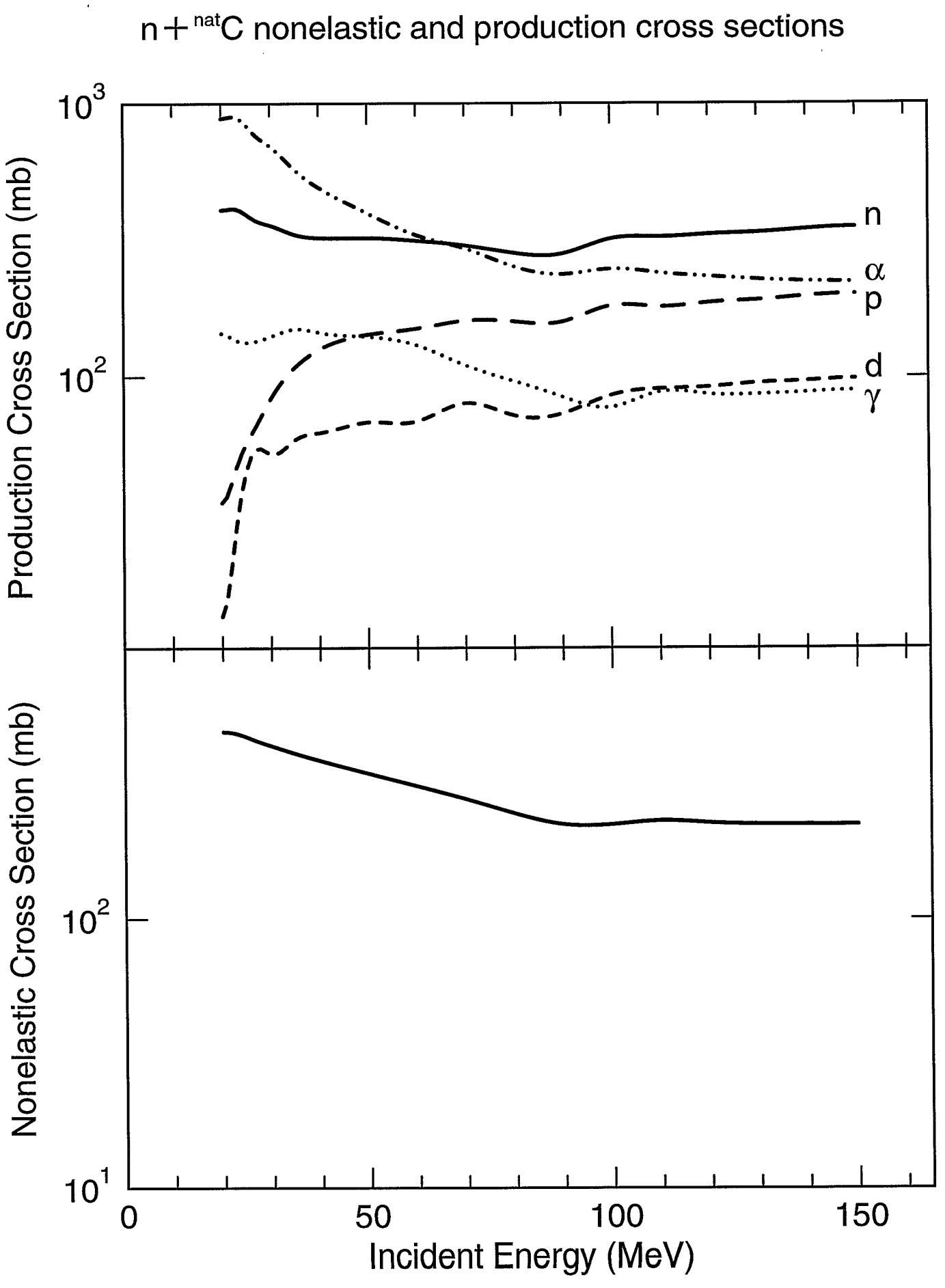
[Yo92]. P.G. Young, E.D. Arthur, and M.B. Chadwick, "Comprehensive Nuclear Model Calculations: Introduction to the Theory and Use of the GNASH Code," LA-12343-MS (1992).

6000 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

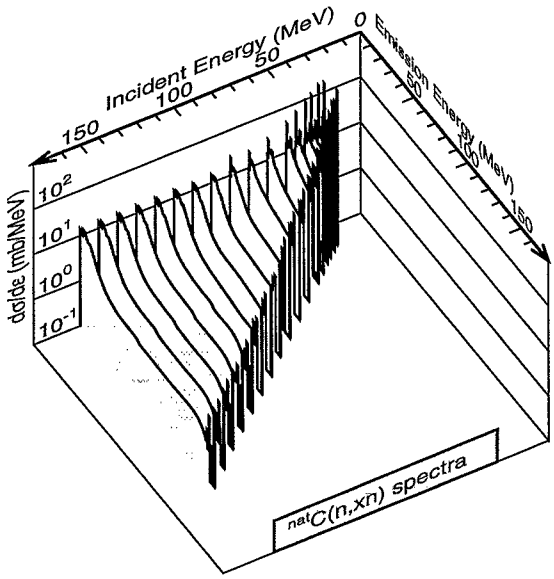
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	4.908E-01	1.016E+00	4.102E-01	3.449E-02	1.311E-02	0.000E+00	0.000E+00	8.833E-01	1.441E-01
2.300E+01	4.818E-01	9.220E-01	4.135E-01	4.652E-02	2.814E-02	0.000E+00	0.000E+00	8.932E-01	1.357E-01
2.700E+01	4.528E-01	9.040E-01	3.757E-01	6.592E-02	5.422E-02	0.000E+00	0.000E+00	7.662E-01	1.348E-01
3.000E+01	4.338E-01	8.610E-01	3.602E-01	8.299E-02	5.208E-02	0.000E+00	0.000E+00	7.001E-01	1.400E-01
3.500E+01	4.058E-01	7.980E-01	3.337E-01	1.083E-01	5.877E-02	0.000E+00	0.000E+00	5.759E-01	1.491E-01
4.000E+01	3.828E-01	7.280E-01	3.241E-01	1.257E-01	6.229E-02	0.000E+00	0.000E+00	4.950E-01	1.450E-01
5.000E+01	3.428E-01	6.030E-01	3.239E-01	1.425E-01	6.815E-02	0.000E+00	0.000E+00	3.995E-01	1.400E-01
6.000E+01	3.079E-01	5.040E-01	3.165E-01	1.497E-01	6.856E-02	0.000E+00	0.000E+00	3.320E-01	1.304E-01
7.000E+01	2.759E-01	4.280E-01	3.039E-01	1.602E-01	8.000E-02	0.000E+00	0.000E+00	2.964E-01	1.104E-01
8.000E+01	2.439E-01	3.680E-01	2.851E-01	1.591E-01	7.216E-02	0.000E+00	0.000E+00	2.543E-01	9.645E-02
9.000E+01	2.229E-01	3.170E-01	2.826E-01	1.584E-01	7.306E-02	0.000E+00	0.000E+00	2.372E-01	8.436E-02
1.000E+02	2.229E-01	2.620E-01	3.210E-01	1.815E-01	8.528E-02	0.000E+00	0.000E+00	2.482E-01	7.711E-02
1.100E+02	2.298E-01	2.140E-01	3.264E-01	1.802E-01	9.023E-02	0.000E+00	0.000E+00	2.401E-01	8.780E-02
1.200E+02	2.256E-01	1.840E-01	3.334E-01	1.864E-01	9.160E-02	0.000E+00	0.000E+00	2.330E-01	8.615E-02
1.300E+02	2.230E-01	1.550E-01	3.387E-01	1.907E-01	9.477E-02	0.000E+00	0.000E+00	2.271E-01	8.603E-02
1.400E+02	2.227E-01	1.320E-01	3.483E-01	1.972E-01	9.644E-02	0.000E+00	0.000E+00	2.238E-01	8.744E-02
1.500E+02	2.224E-01	1.130E-01	3.546E-01	2.007E-01	9.822E-02	0.000E+00	0.000E+00	2.223E-01	8.895E-02

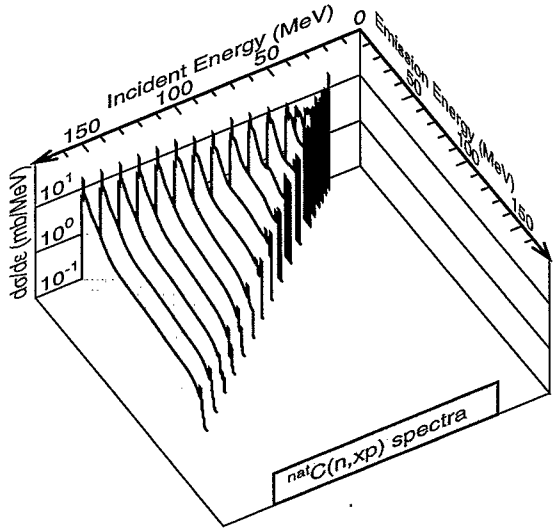
6000 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

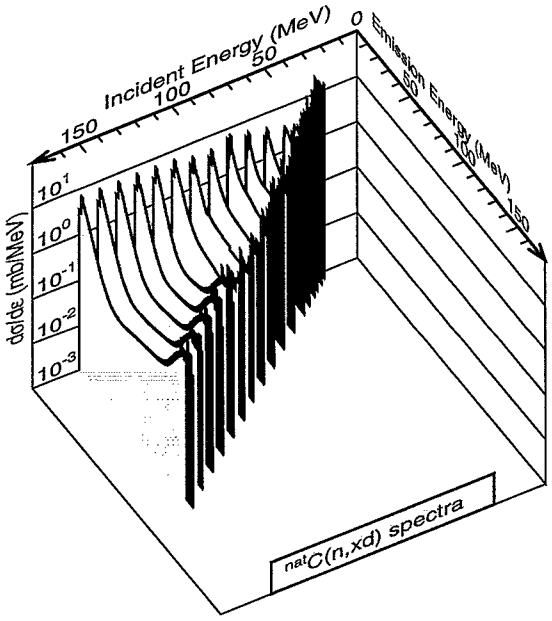
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	1.144E-01	3.360E-02	0.000E+00	0.000E+00	1.913E+00	3.534E-01	5.088E-01	2.923E+00
2.300E+01	1.808E-01	1.174E-01	0.000E+00	0.000E+00	2.140E+00	3.300E-01	4.378E-01	3.206E+00
2.700E+01	3.442E-01	3.250E-01	0.000E+00	0.000E+00	2.078E+00	4.055E-01	4.154E-01	3.569E+00
3.000E+01	5.059E-01	3.483E-01	0.000E+00	0.000E+00	2.149E+00	4.594E-01	3.870E-01	3.850E+00
3.500E+01	8.305E-01	4.939E-01	0.000E+00	0.000E+00	2.037E+00	5.559E-01	3.477E-01	4.265E+00
4.000E+01	1.119E+00	6.254E-01	0.000E+00	0.000E+00	1.908E+00	6.075E-01	3.089E-01	4.569E+00
5.000E+01	1.518E+00	8.790E-01	0.000E+00	0.000E+00	1.682E+00	6.380E-01	2.468E-01	4.964E+00
6.000E+01	1.974E+00	1.052E+00	0.000E+00	0.000E+00	1.415E+00	6.044E-01	2.033E-01	5.249E+00
7.000E+01	2.490E+00	1.331E+00	0.000E+00	0.000E+00	1.419E+00	5.807E-01	1.736E-01	5.994E+00
8.000E+01	2.982E+00	1.354E+00	0.000E+00	0.000E+00	1.271E+00	5.333E-01	1.535E-01	6.294E+00
9.000E+01	3.101E+00	1.478E+00	0.000E+00	0.000E+00	1.285E+00	4.983E-01	1.398E-01	6.502E+00
1.000E+02	3.261E+00	1.715E+00	0.000E+00	0.000E+00	1.447E+00	5.186E-01	1.264E-01	7.068E+00
1.100E+02	3.707E+00	2.460E+00	0.000E+00	0.000E+00	1.387E+00	5.490E-01	8.015E-02	8.183E+00
1.200E+02	4.201E+00	2.646E+00	0.000E+00	0.000E+00	1.408E+00	5.448E-01	6.834E-02	8.869E+00
1.300E+02	4.667E+00	2.948E+00	0.000E+00	0.000E+00	1.448E+00	5.453E-01	5.708E-02	9.666E+00
1.400E+02	5.204E+00	3.163E+00	0.000E+00	0.000E+00	1.479E+00	5.724E-01	4.814E-02	1.047E+01
1.500E+02	5.671E+00	3.442E+00	0.000E+00	0.000E+00	1.515E+00	5.975E-01	4.075E-02	1.127E+01

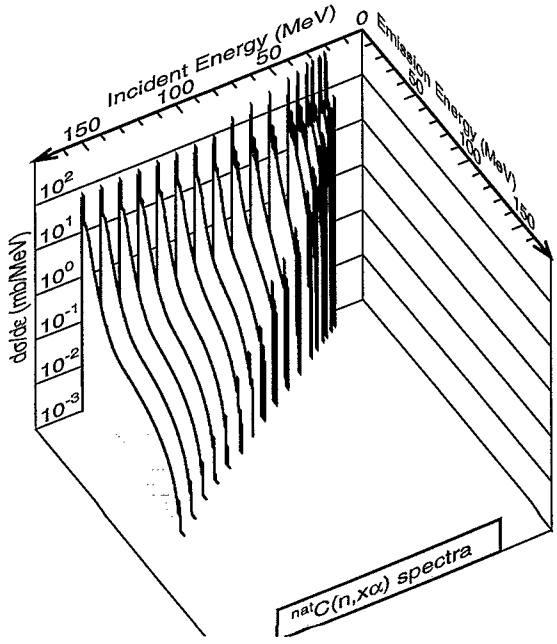

n + natC nonelastic and production cross sections
Production Cross Section (mb)
10^3
10^2
n
α
p
d
γ
Nonelastic Cross Section (mb)
10^2
10^1
0
50
100
150
Incident Energy (MeV)

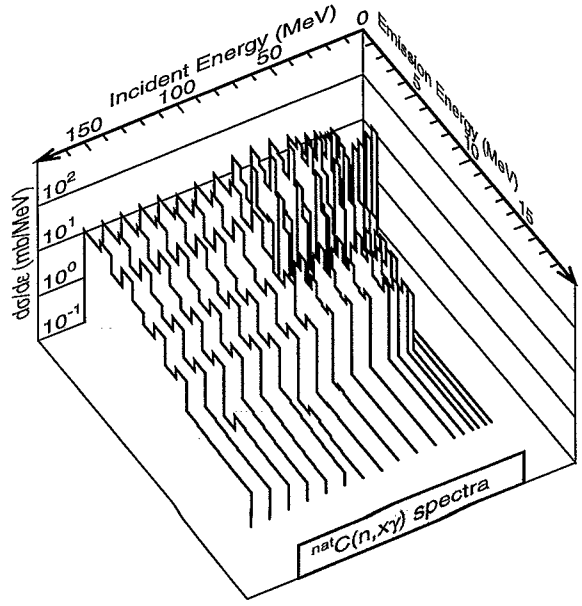
n + ^{nat}C angle-integrated emission spectra



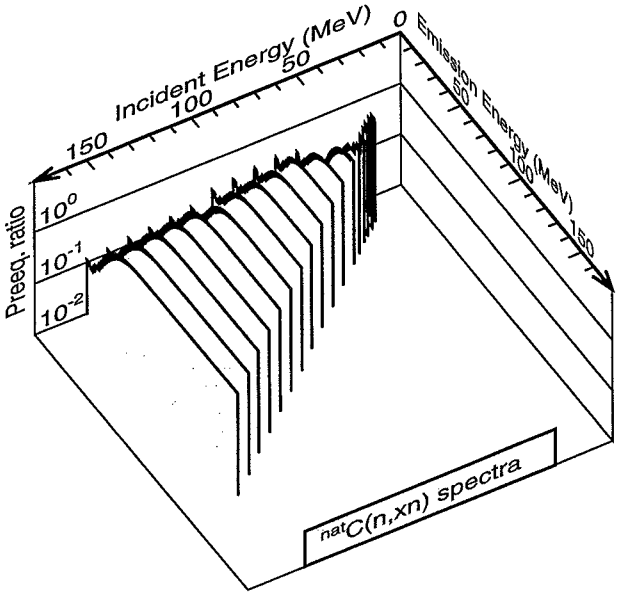


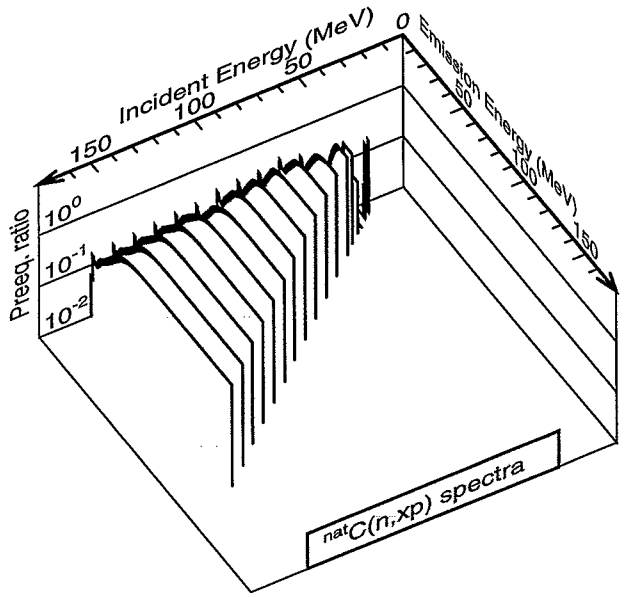


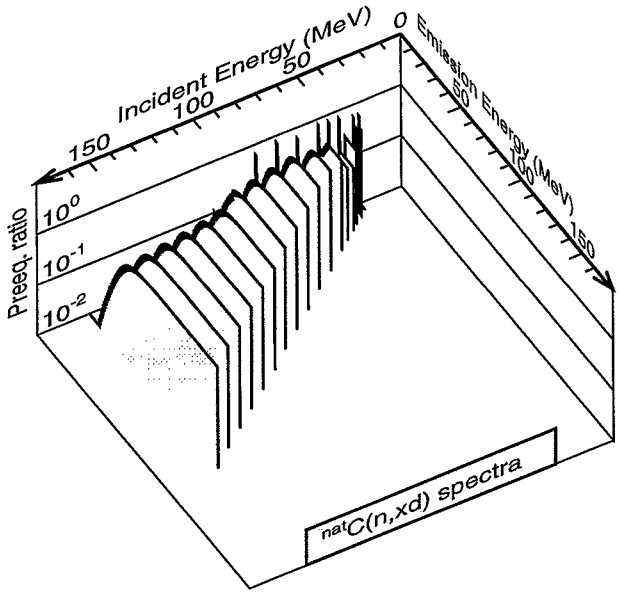


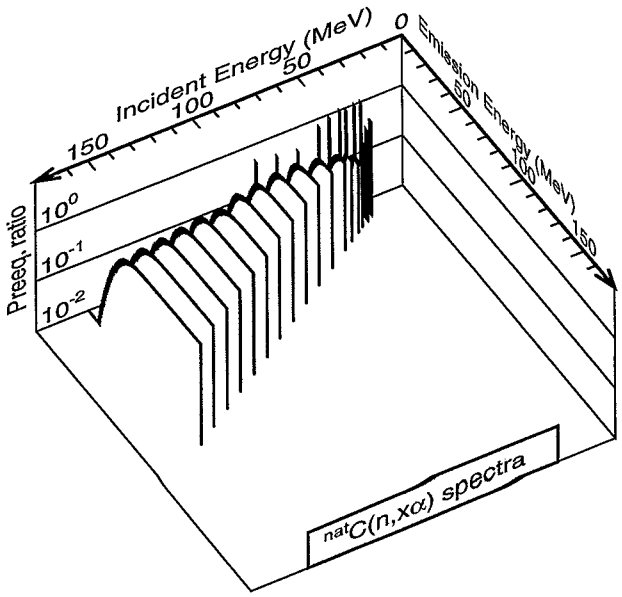


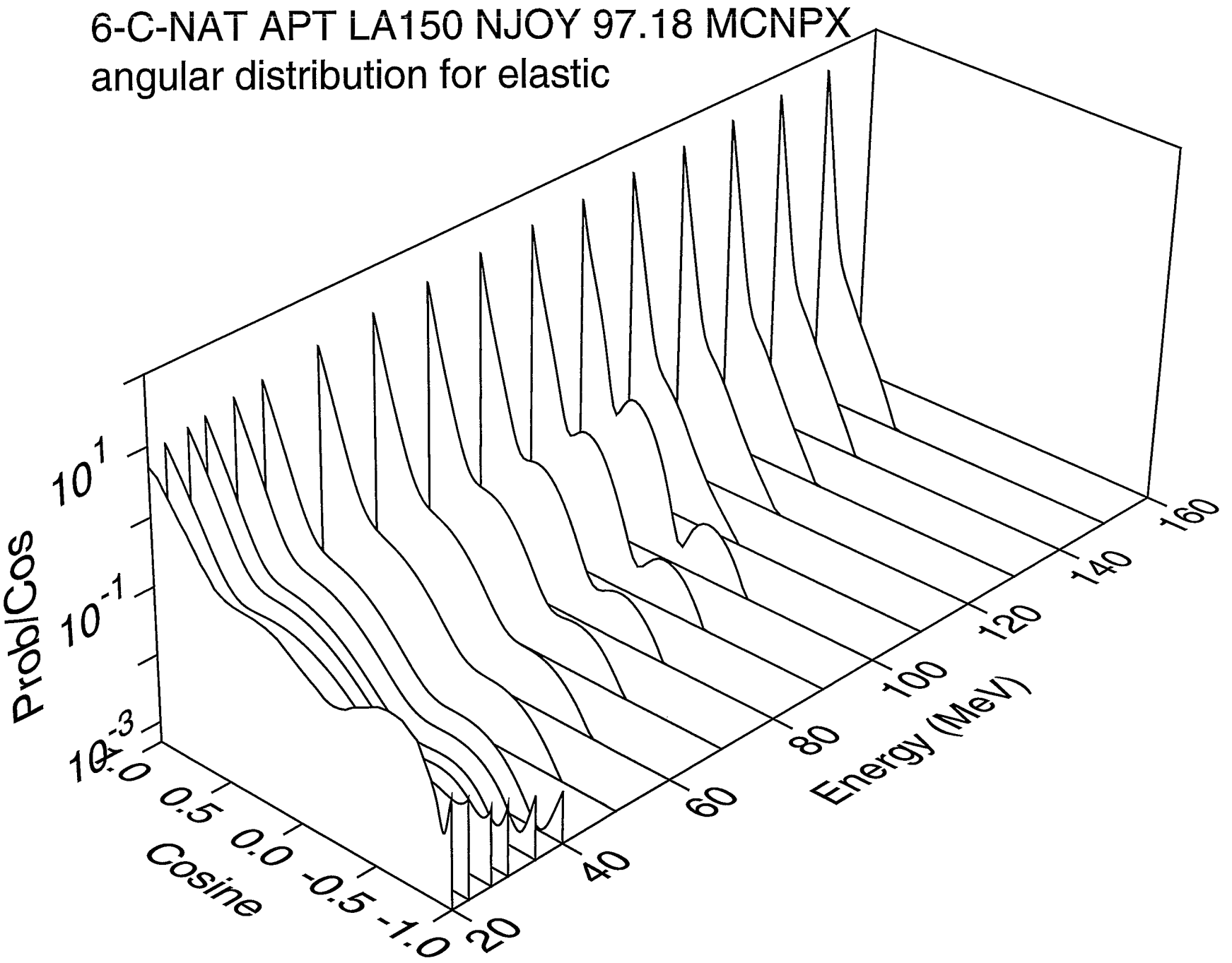
n + ^{nat}C Kalbach preequilibrium ratios

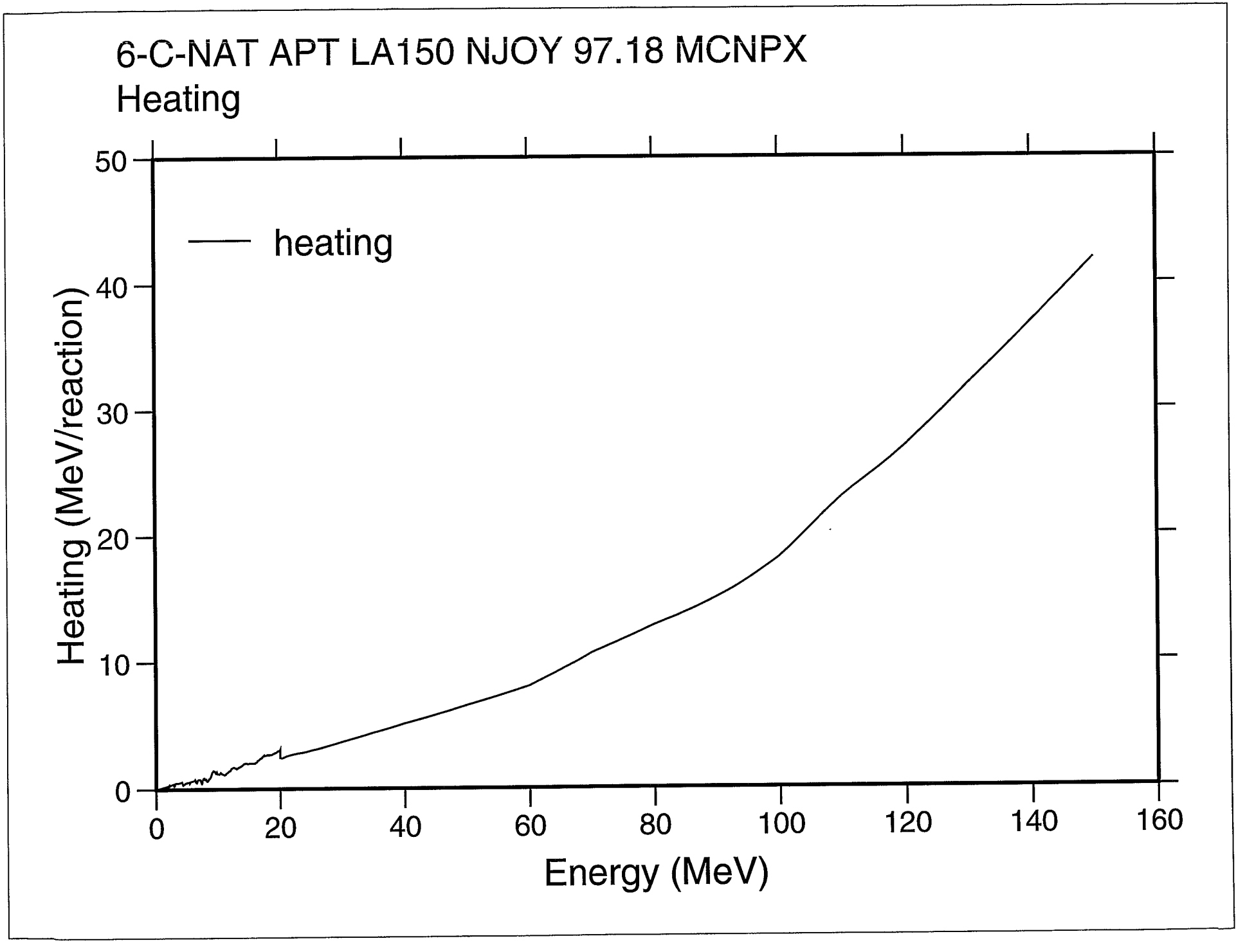


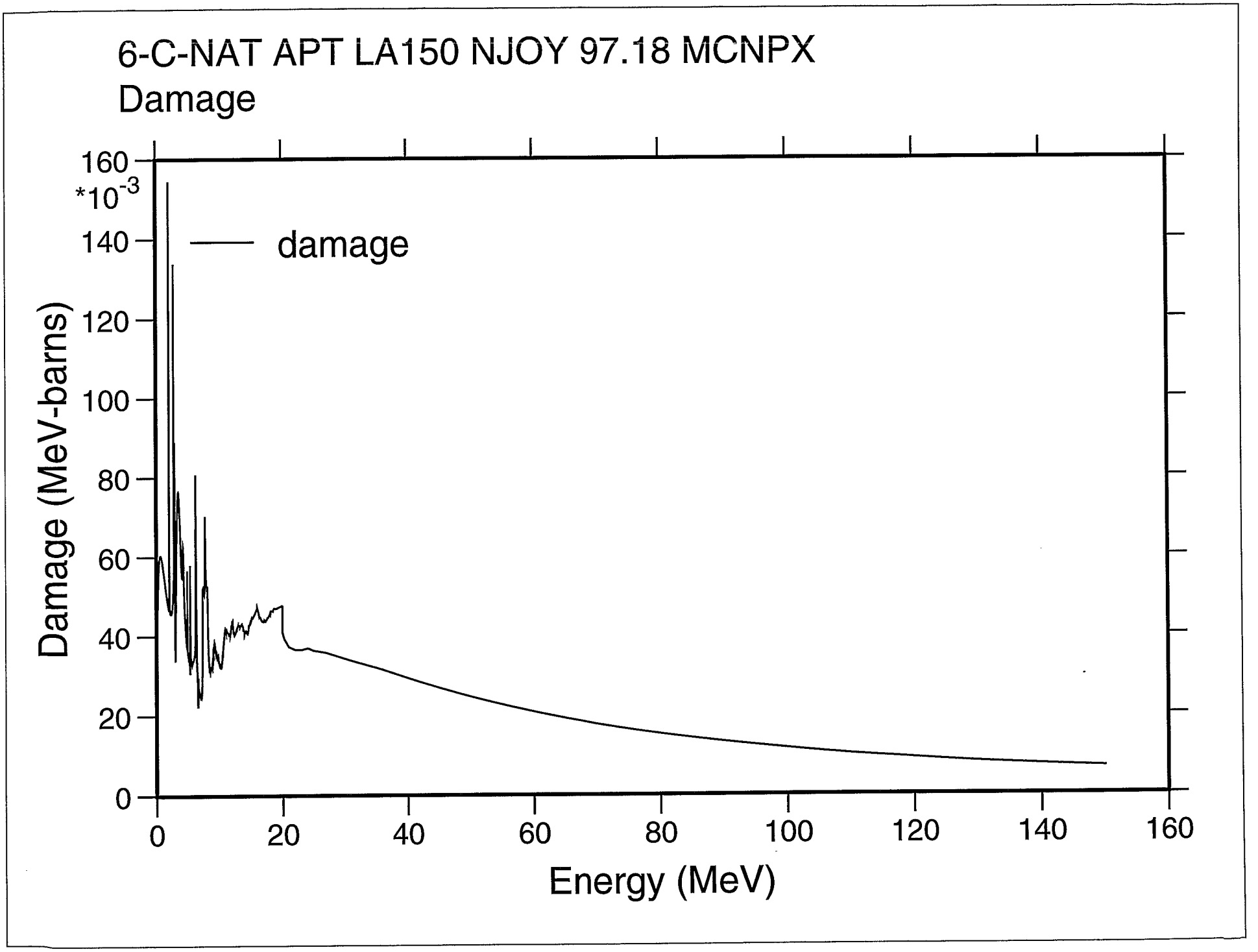







6-C-NAT APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic
Prob/Cos
10^{1}
10^{-1}
10^{-3}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
20
40
60
80
100
120
140
160


6-C-NAT APT LA150 NJOY 97.18 MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
10
20
30
40
50
0
20
40
60
80
100
120
140
160


6-C-NAT APT LA150 NJOY 97.18 MCNPX
Damage
damage
Damage (MeV-barns)
*10^-3
160
140
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF n + 14N CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

M. B. Chadwick and P. G. Young
7 August 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI.3 (Release 3) evaluation by P. G. Young, G. M. Hale, and M. B. Chadwick [Yo94].

INCIDENT NEUTRON ENERGIES > 20 MeV

The ENDF/B-VI Release 3 evaluation of n + 14N data extends to 40 MeV and includes cross sections and energy-angle data for all significant reactions. The present evaluation utilizes a more compact composite reaction spectrum representation above 20 MeV in order to reduce the length of the file, and we have only included the ENDF/B-VI data below 20 MeV. No essential data for applications is lost with our representation above 20 MeV. 8

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT= 1	Total Cross Section
	MT= 2	Elastic Scattering Cross Section
	MT= 3	Nonelastic Cross Section
	MT= 5	Sum of Binary (n,n') and (n,x) Reactions
MF=4	MT= 2	Elastic Angular Distributions
MF=6	MT= 5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, Tritons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + N14 and p + N14 reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

DETAILS OF THE n + N-14 ANALYSIS

GNASH calculations [Yo92,Ch94] were performed for neutron and proton reactions on nitrogen up to 150 MeV, and the calculated results were benchmarked against experimental data. For neutrons below 100 MeV, the present evaluation made extensive use of our previous work [Ch96a]. Very minor differences with this earlier work exist due to recent developments in the GNASH code. Much use was made of measured data in the evaluation, since an accurate modeling of reactions on a light nucleus is difficult. In this way we were able to obtain a fairly good description of the emission spectra of secondary particles and gamma rays. Additionally, the (angle-integrated) emission spectra of heavy recoils were calculated using our model described in Ref. [Ch96]. Some additional information on this evaluation can be found in Ref. [Ch97].

Between 20 and 150 MeV, the optical models used (the neutron potential of Islam below 60 MeV [Is88]; Madland's potential [Ma88] at higher energies, with Lane transformations for the proton potential) provided a reasonably good description of measured reaction cross section data. But since a very accurate description of the reaction cross section is important for determining secondary particle spectra, we slightly modify the calculated results to better describe the experimental data, and renormalize the calculated transmission coefficients accordingly. The SCAT2 code [Be92] was used to calculate the transmission coefficients. No measurements for the neutron reaction cross section on nitrogen exist above about 50 MeV. However, systematics have been determined from a number of target elements at 95 MeV by DeJuren [De50], and for 100 MeV protons by Kirby and Link [Ki66] (at this energy the proton and neutron reaction cross sections would be expected to be very similar). We have, therefore, used these systematics to guide our evaluated reaction cross sections. Additionally, below 50 MeV we have also been guided by the proton-induced reaction cross sections of Carlson et al. [Ca75]. Experimental total elastic scattering values of Islam et al. [Is88], Olsson et al. [Ol90], and Petler et al. [Pe85] were obtained by subtracting their angle-integrated elastic data from the evaluated total cross sections (see below).
The evaluated total cross section was obtained by slightly modifying the optical model results to agree with data, principally the new high-accuracy results of Finlay et al. [Fi93].

We use the ENDF/B-VI total cross section below 40 MeV recently evaluated by Young [Yo94].

Preequilibrium spectra for incident energies below 100 MeV were taken from our previous work [Ch96], where they were evaluated from a combination of FKK calculations [Ch93], and measured emission spectra data, whilst ensuring that unitarity is conserved (i.e., making sure the sum of primary emitted preequilibrium spectra does not exceed the reaction cross section). This approach has the advantage of facilitating a good representation of emission spectra experimental data. However, the lack of such data above 100 MeV prohibits its extension to higher energies, and therefore above 100 MeV, exciton model calculations were utilized from the GNASH code [Ka77, Ka85]. This results in some (small) discontinuities around 100 MeV in the production cross sections, though the impact of this is negligible for most applications.

Nuclear level densities were determined using the Ignatyuk model [Ig75], as implemented by Arthur et al. [Yo92]. Pairing energies were obtained from the Cook systematics with the Los Alamos extensions to light nuclei from [Ar83]. This continuum level density formulation is matched continuously onto discrete low-lying levels at the lower excitation energies. Discrete level information (energy, spin, parity, gamma-ray branching ratios) is tabulated for each nuclide in an input file, which is based on the Ajzenberg-Selove compilations. For each nucleus we performed a level-density analysis and determined the excitation energy at which we judged the level data complete. Gamma-ray transmission coefficients were obtained from the Kopecky-Uhl model [Ko92].

An important test of the accuracy of the data libraries is that the evaluated emission spectra of light particles (A < 5) should be consistent with the measurements by Subramanian et al. of UC-Davis [Su86]. We have compared our calculated (lab frame) angle-integrated emission spectra of protons, deuterons, and alphas, with these measurements, with good agreement. The structure seen at high emission energies is due to the inclusion of discrete nuclear levels in our calculations. Also, kerma factors obtained from the evaluated cross sections are in fairly good agreement with experimental data [Ch96].

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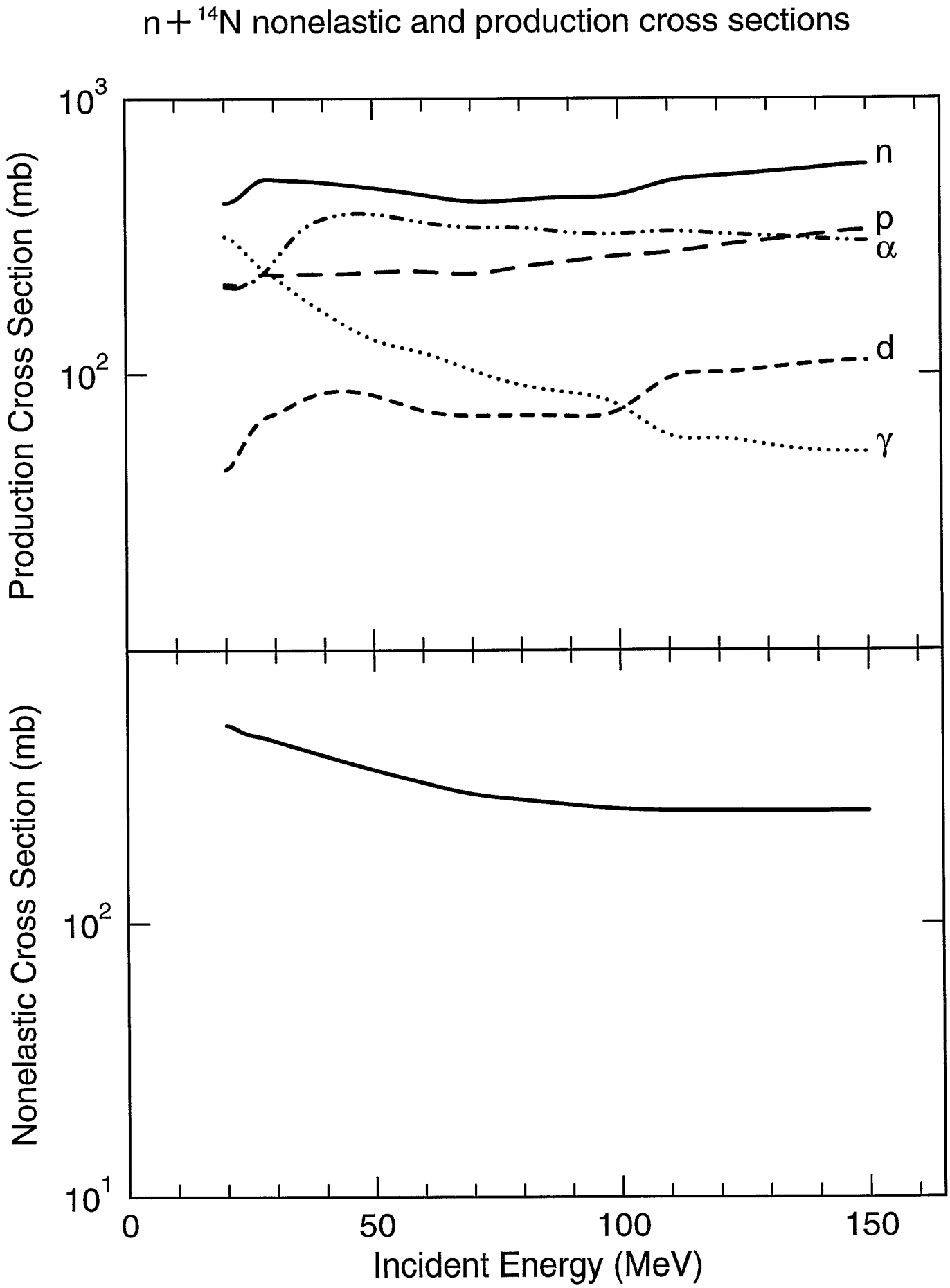
7014 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

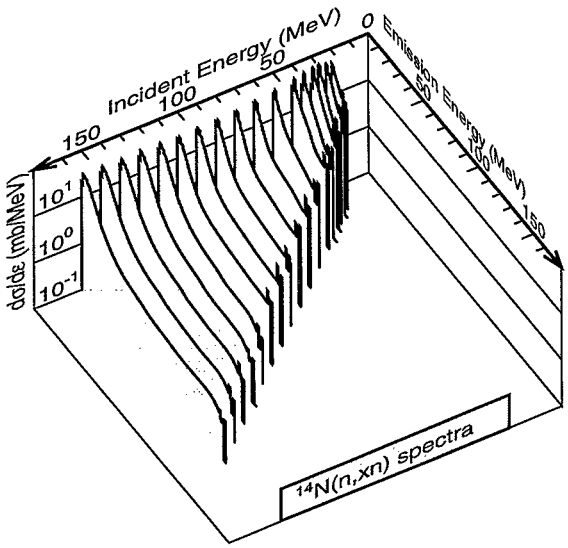
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	5.310E-01	1.019E+00	4.184E-01	2.068E-01	4.482E-02	0.000E+00	0.000E+00	2.116E-01	3.155E-01
2.300E+01	5.040E-01	9.610E-01	4.403E-01	2.066E-01	5.275E-02	0.000E+00	0.000E+00	2.099E-01	2.912E-01
2.700E+01	4.819E-01	9.541E-01	5.038E-01	2.286E-01	6.724E-02	0.000E+00	0.000E+00	2.246E-01	2.457E-01
3.000E+01	4.649E-01	9.291E-01	5.084E-01	2.288E-01	7.140E-02	0.000E+00	0.000E+00	2.565E-01	2.247E-01
3.500E+01	4.365E-01	8.845E-01	5.026E-01	2.300E-01	7.937E-02	0.000E+00	0.000E+00	3.264E-01	1.922E-01
4.000E+01	4.100E-01	8.390E-01	4.950E-01	2.299E-01	8.538E-02	0.000E+00	0.000E+00	3.664E-01	1.676E-01
5.000E+01	3.646E-01	7.024E-01	4.726E-01	2.337E-01	8.362E-02	0.000E+00	0.000E+00	3.804E-01	1.334E-01
6.000E+01	3.270E-01	5.970E-01	4.469E-01	2.355E-01	7.353E-02	0.000E+00	0.000E+00	3.559E-01	1.191E-01
7.000E+01	2.971E-01	4.909E-01	4.230E-01	2.306E-01	7.033E-02	0.000E+00	0.000E+00	3.405E-01	1.033E-01
8.000E+01	2.830E-01	4.100E-01	4.285E-01	2.443E-01	7.055E-02	0.000E+00	0.000E+00	3.392E-01	9.118E-02
9.000E+01	2.710E-01	3.400E-01	4.368E-01	2.558E-01	7.003E-02	0.000E+00	0.000E+00	3.256E-01	8.536E-02
1.000E+02	2.620E-01	2.880E-01	4.466E-01	2.676E-01	7.362E-02	0.000E+00	0.000E+00	3.216E-01	7.675E-02
1.100E+02	2.582E-01	2.408E-01	4.999E-01	2.754E-01	9.599E-02	0.000E+00	0.000E+00	3.292E-01	5.983E-02
1.200E+02	2.578E-01	1.962E-01	5.224E-01	2.911E-01	1.010E-01	0.000E+00	0.000E+00	3.223E-01	5.815E-02
1.300E+02	2.571E-01	1.649E-01	5.393E-01	3.051E-01	1.046E-01	0.000E+00	0.000E+00	3.156E-01	5.506E-02
1.400E+02	2.568E-01	1.422E-01	5.578E-01	3.193E-01	1.091E-01	0.000E+00	0.000E+00	3.084E-01	5.241E-02
1.500E+02	2.568E-01	1.202E-01	5.749E-01	3.311E-01	1.112E-01	0.000E+00	0.000E+00	3.030E-01	5.183E-02

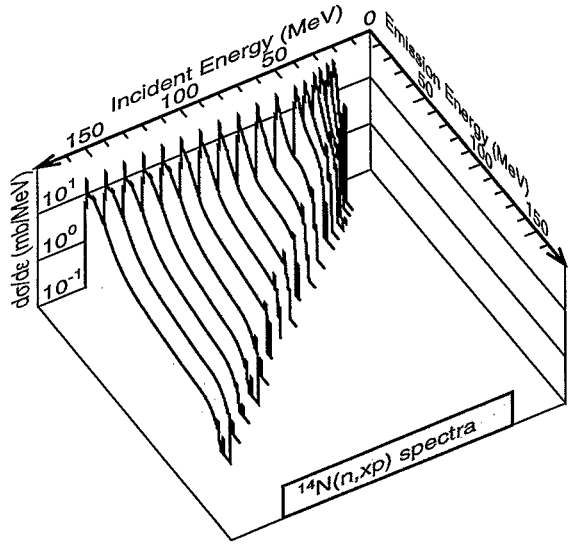
7014 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

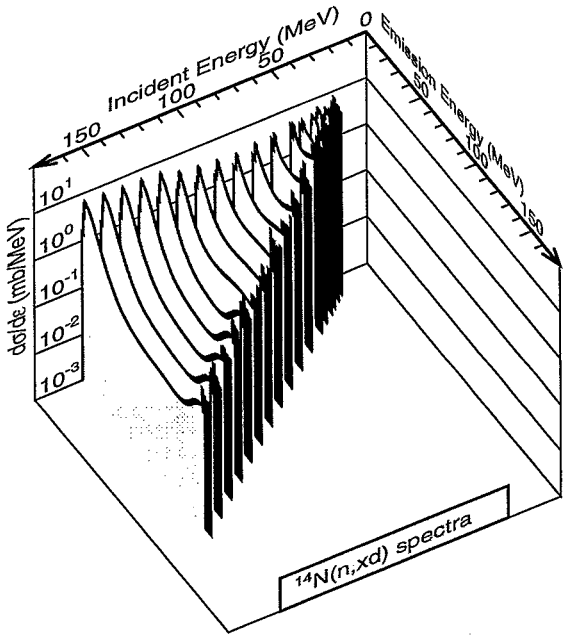
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	5.662E-01	2.053E-01	0.000E+00	0.000E+00	7.999E-01	6.289E-01	4.076E-01	2.608E+00
2.300E+01	6.807E-01	2.741E-01	0.000E+00	0.000E+00	9.211E-01	6.749E-01	3.616E-01	2.912E+00
2.700E+01	8.696E-01	3.971E-01	0.000E+00	0.000E+00	7.616E-01	7.123E-01	3.435E-01	3.084E+00
3.000E+01	9.811E-01	4.901E-01	0.000E+00	0.000E+00	8.306E-01	7.043E-01	3.248E-01	3.331E+00
3.500E+01	1.235E+00	6.745E-01	0.000E+00	0.000E+00	9.915E-01	6.654E-01	2.975E-01	3.864E+00
4.000E+01	1.406E+00	8.818E-01	0.000E+00	0.000E+00	1.115E+00	6.307E-01	2.754E-01	4.309E+00
5.000E+01	1.886E+00	1.110E+00	0.000E+00	0.000E+00	1.151E+00	5.511E-01	2.262E-01	4.924E+00
6.000E+01	2.371E+00	1.145E+00	0.000E+00	0.000E+00	1.188E+00	5.279E-01	1.932E-01	5.425E+00
7.000E+01	2.740E+00	1.268E+00	0.000E+00	0.000E+00	1.271E+00	4.905E-01	1.369E-01	5.906E+00
8.000E+01	3.116E+00	1.379E+00	0.000E+00	0.000E+00	1.371E+00	4.751E-01	1.118E-01	6.453E+00
9.000E+01	3.540E+00	1.435E+00	0.000E+00	0.000E+00	1.416E+00	4.694E-01	9.133E-02	6.952E+00
1.000E+02	3.902E+00	1.531E+00	0.000E+00	0.000E+00	1.479E+00	4.488E-01	7.649E-02	7.438E+00
1.100E+02	4.087E+00	1.839E+00	0.000E+00	0.000E+00	1.606E+00	4.114E-01	6.339E-02	8.007E+00
1.200E+02	4.673E+00	1.936E+00	0.000E+00	0.000E+00	1.635E+00	4.074E-01	5.123E-02	8.703E+00
1.300E+02	5.268E+00	1.960E+00	0.000E+00	0.000E+00	1.681E+00	4.063E-01	4.272E-02	9.358E+00
1.400E+02	5.831E+00	1.984E+00	0.000E+00	0.000E+00	1.709E+00	4.117E-01	3.651E-02	9.972E+00
1.500E+02	6.446E+00	1.969E+00	0.000E+00	0.000E+00	1.724E+00	4.195E-01	3.053E-02	1.059E+01

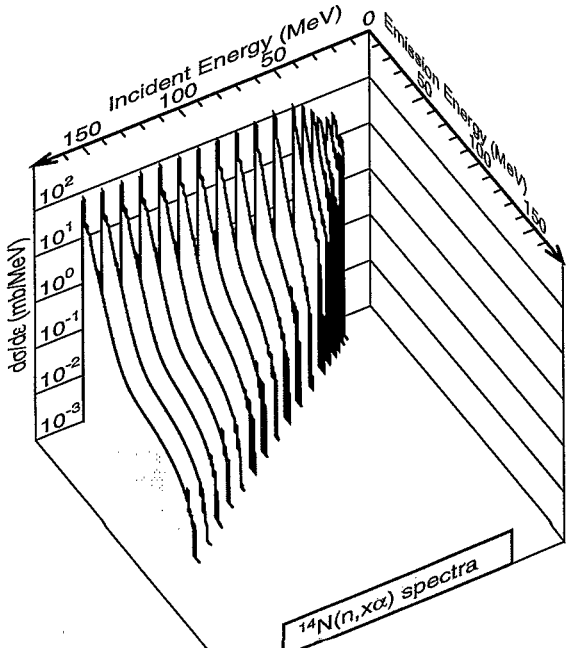

n + 14N nonelastic and production cross sections
Production Cross Section (mb)
10^3
10^2
n
p
α
d
γ
Nonelastic Cross Section (mb)
10^2
10^1
0
50
100
150
Incident Energy (MeV)

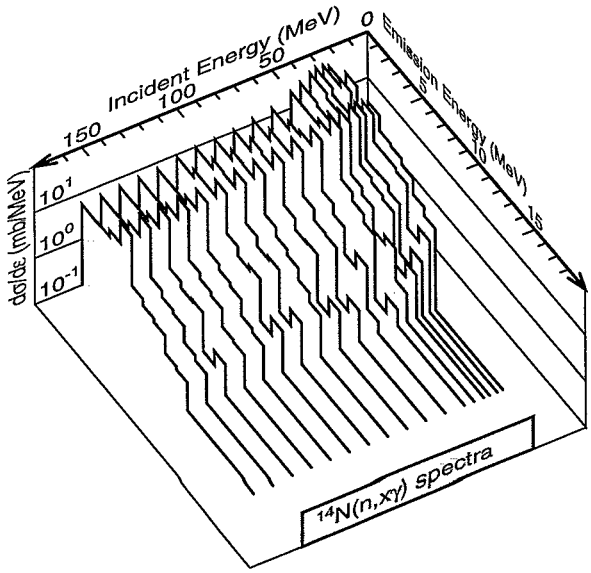
n + ^{14}N angle-integrated emission spectra



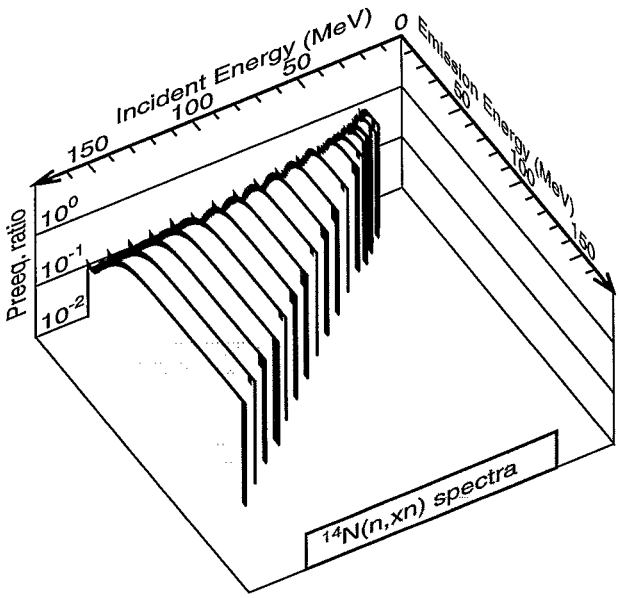


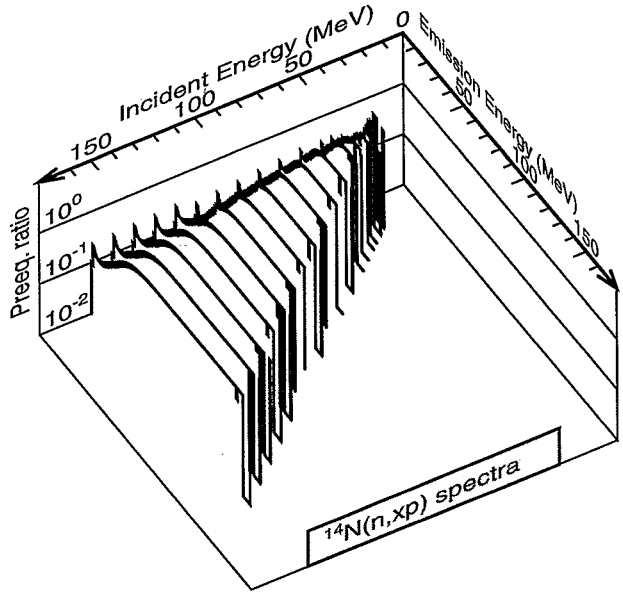


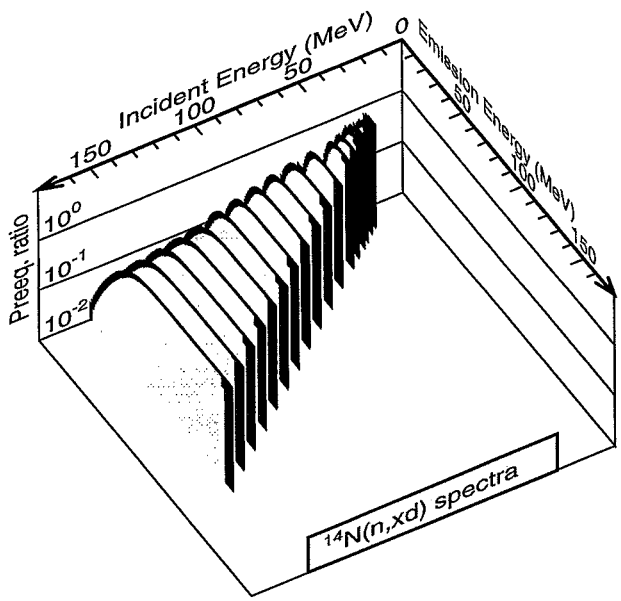


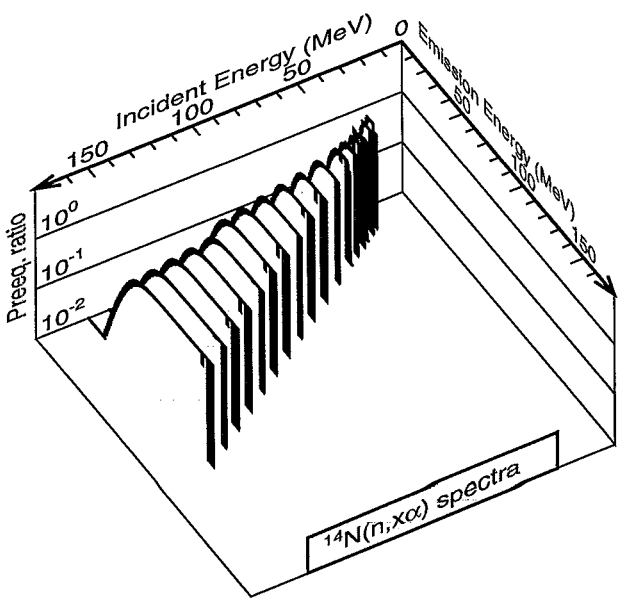


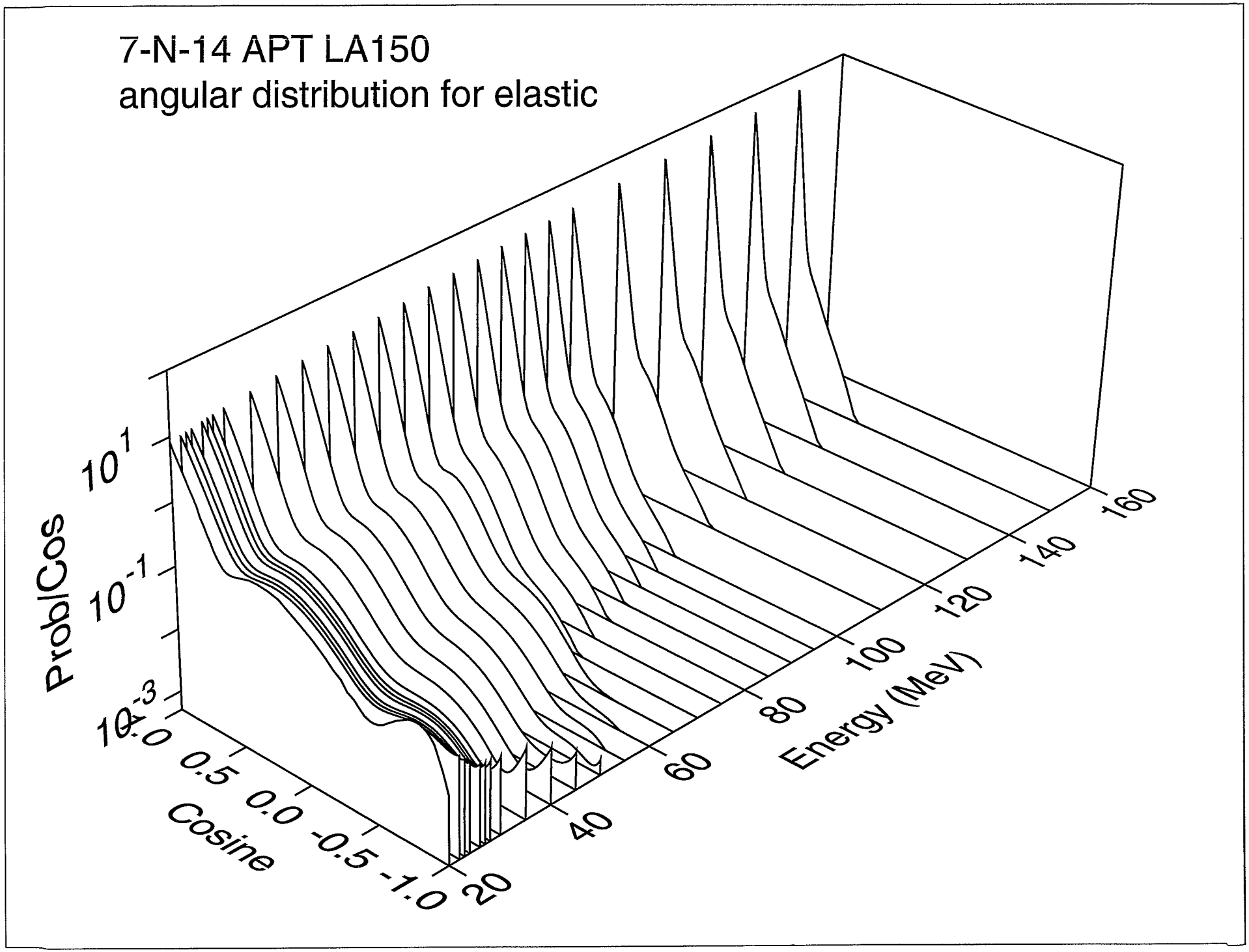
n + ^{14}N Kalbach preequilibrium ratios

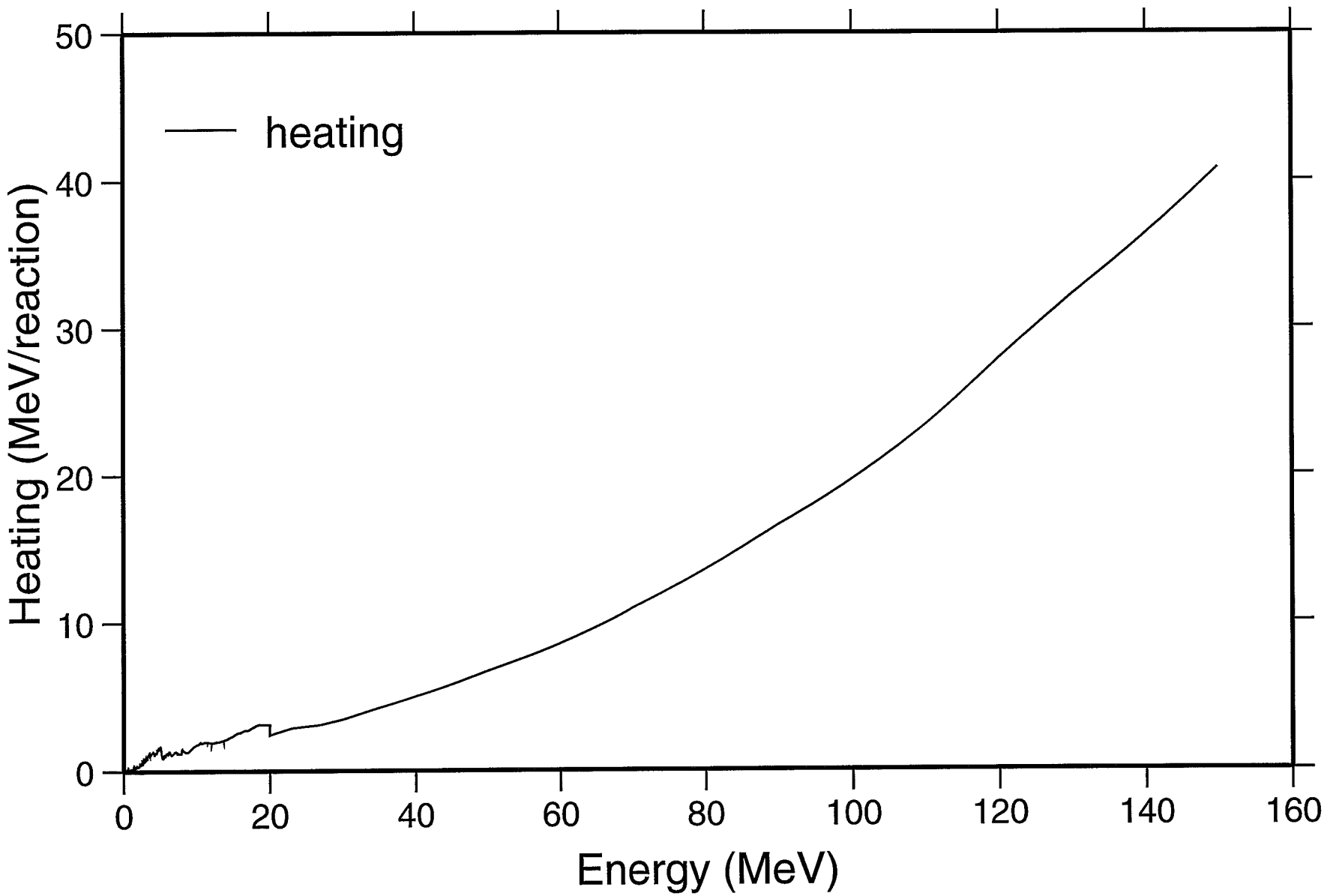


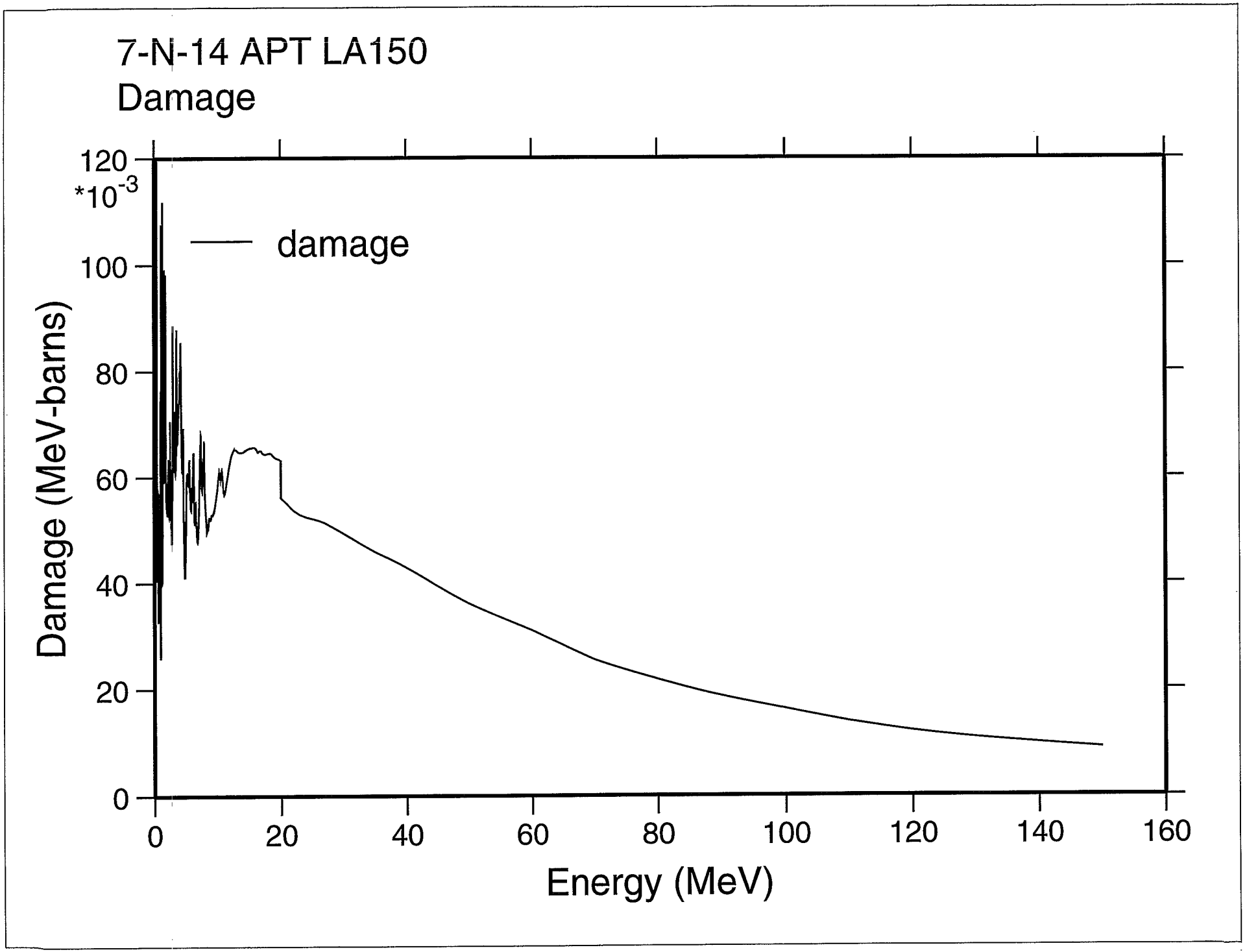







7-N-14 APT LA150
angular distribution for elastic
Prob/Cos
10^{1}
10^{-1}
10^{-3}
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


7-N-14 APT LA150
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
10
20
30
40
50
0
20
40
60
80
100
120
140
160


7-N-14 APT LA150
Damage
damage
Damage (MeV-barns)
*10^-3
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF n + 16O CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

M. B. Chadwick and P. G. Young
19 June 1996

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI.0 (Release 0) evaluation by Ha(92). The following minor modifications were made to the ENDF/B-VI.0 evaluation:

2. The (n,p) [and nonelastic] cross section from 19 to 20 MeV was varied slightly to join smoothly with the higher energy values at 20 MeV.

INCIDENT NEUTRON ENERGIES > 20 MeV

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT= 1	Total Cross Section
	MT= 2	Elastic Scattering Cross Section
	MT= 3	Nonelastic Cross Section
	MT= 5	Sum of Binary (n,n') and (n,x) Reactions
	MT=102	Radiative Capture Cross Section (Estimate Only)
MF=4	MT= 2	Elastic Angular Distributions
MF=6	MT= 5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + O16 and p + O16 reactions (Ch96a). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Coupled-channel and spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96b). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. Note that all other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation requires a modification of the original ENDF-6 format.

Preequilibrium corrections were performed in the course of the GNASH calculations using either Feshbach, Kerman, Koonin (FKK) theory [Ch93] or the exciton model of Kalbach (Ka77, Ka85). Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

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Distributions: Extensions to Higher Energies," Phys.Rev.C 37, 2350 (1988); see also C. Kalbach and F. M. Mann, "Phenomenology of Continuum Angular Distributions. I. Systematics and Parameterization," Phys.Rev.C 23, 112 (1981).

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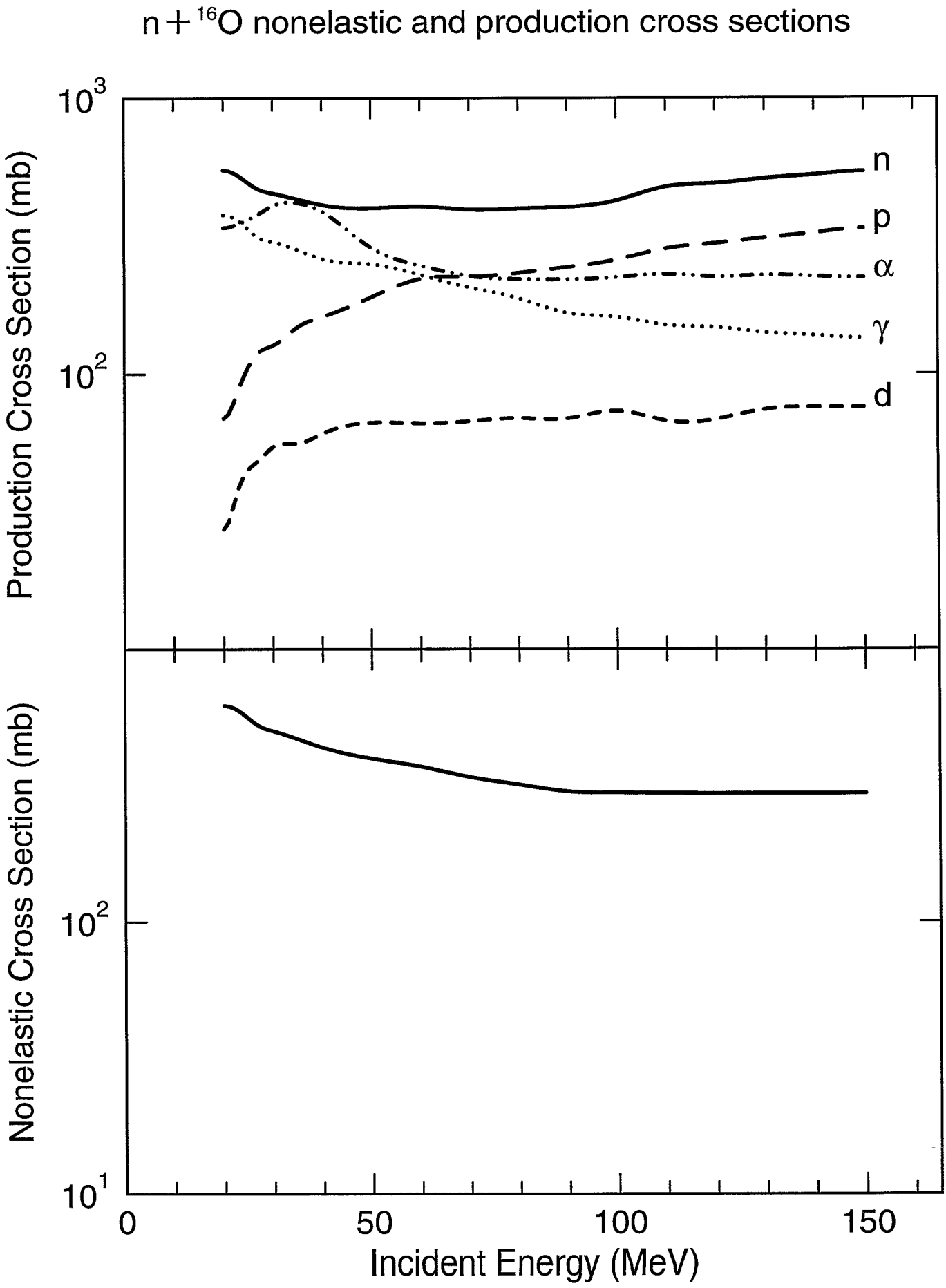
[Yo92]. P.G. Young, E.D. Arthur, and M.B. Chadwick, "Comprehensive Nuclear Model Calculations: Introduction to the Theory and Use of the GNASH Code," LA-12343-MS (1992).

8016 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

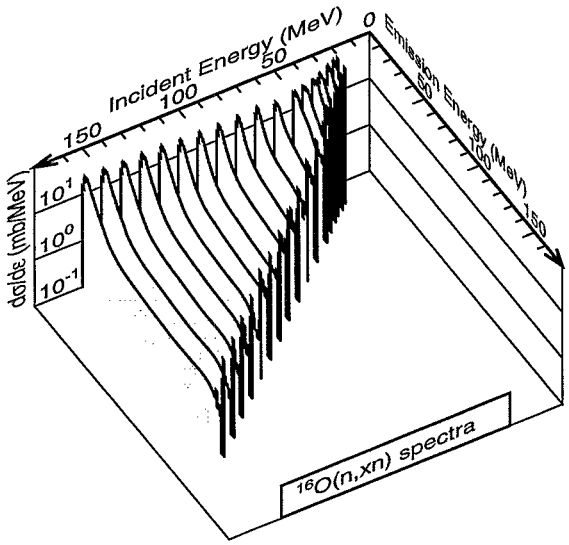
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	6.200E-01	1.020E+00	5.486E-01	6.899E-02	2.735E-02	0.000E+00	0.000E+00	3.406E-01	3.787E-01
2.300E+01	5.920E-01	1.054E+00	5.252E-01	8.761E-02	3.848E-02	0.000E+00	0.000E+00	3.517E-01	3.634E-01
2.700E+01	5.230E-01	1.071E+00	4.699E-01	1.195E-01	4.842E-02	0.000E+00	0.000E+00	3.801E-01	3.148E-01
3.000E+01	5.000E-01	1.059E+00	4.532E-01	1.269E-01	5.441E-02	0.000E+00	0.000E+00	4.086E-01	3.028E-01
3.500E+01	4.670E-01	1.012E+00	4.319E-01	1.481E-01	5.595E-02	0.000E+00	0.000E+00	4.193E-01	2.834E-01
4.000E+01	4.350E-01	9.670E-01	4.119E-01	1.614E-01	6.073E-02	0.000E+00	0.000E+00	3.905E-01	2.626E-01
5.000E+01	3.960E-01	8.150E-01	4.003E-01	1.905E-01	6.656E-02	0.000E+00	0.000E+00	2.887E-01	2.511E-01
6.000E+01	3.700E-01	6.800E-01	4.063E-01	2.221E-01	6.624E-02	0.000E+00	0.000E+00	2.484E-01	2.301E-01
7.000E+01	3.390E-01	5.730E-01	3.956E-01	2.263E-01	6.739E-02	0.000E+00	0.000E+00	2.276E-01	2.069E-01
8.000E+01	3.180E-01	4.890E-01	3.989E-01	2.331E-01	6.910E-02	0.000E+00	0.000E+00	2.216E-01	1.887E-01
9.000E+01	3.000E-01	4.210E-01	4.041E-01	2.446E-01	6.888E-02	0.000E+00	0.000E+00	2.210E-01	1.664E-01
1.000E+02	2.970E-01	3.400E-01	4.257E-01	2.599E-01	7.339E-02	0.000E+00	0.000E+00	2.247E-01	1.609E-01
1.100E+02	2.957E-01	2.800E-01	4.767E-01	2.850E-01	6.751E-02	0.000E+00	0.000E+00	2.305E-01	1.504E-01
1.200E+02	2.950E-01	2.380E-01	4.906E-01	2.982E-01	6.821E-02	0.000E+00	0.000E+00	2.257E-01	1.475E-01
1.300E+02	2.950E-01	2.050E-01	5.105E-01	3.122E-01	7.417E-02	0.000E+00	0.000E+00	2.286E-01	1.411E-01
1.400E+02	2.950E-01	1.760E-01	5.261E-01	3.251E-01	7.574E-02	0.000E+00	0.000E+00	2.263E-01	1.379E-01
1.500E+02	2.950E-01	1.480E-01	5.411E-01	3.377E-01	7.558E-02	0.000E+00	0.000E+00	2.240E-01	1.347E-01

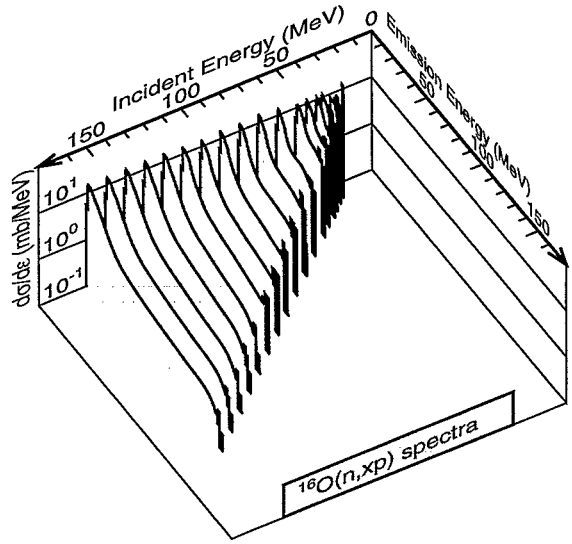
8016 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

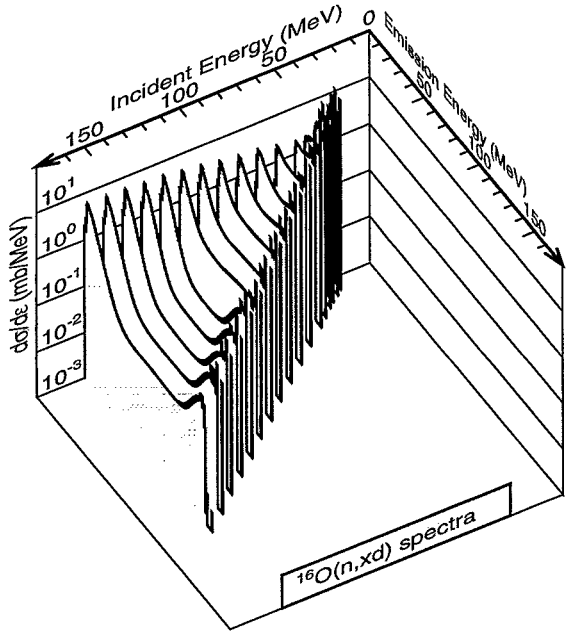
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	2.059E-01	8.326E-02	0.000E+00	0.000E+00	9.067E-01	6.713E-01	2.693E-01	2.136E+00
2.300E+01	3.068E-01	1.401E-01	0.000E+00	0.000E+00	1.018E+00	6.790E-01	2.696E-01	2.413E+00
2.700E+01	4.823E-01	2.145E-01	0.000E+00	0.000E+00	1.010E+00	6.032E-01	2.639E-01	2.574E+00
3.000E+01	5.800E-01	3.121E-01	0.000E+00	0.000E+00	1.046E+00	5.635E-01	2.553E-01	2.757E+00
3.500E+01	8.160E-01	4.444E-01	0.000E+00	0.000E+00	1.080E+00	5.277E-01	2.382E-01	3.107E+00
4.000E+01	1.008E+00	6.006E-01	0.000E+00	0.000E+00	1.088E+00	5.265E-01	2.251E-01	3.448E+00
5.000E+01	1.478E+00	8.029E-01	0.000E+00	0.000E+00	9.045E-01	5.736E-01	1.850E-01	3.943E+00
6.000E+01	2.082E+00	8.752E-01	0.000E+00	0.000E+00	8.724E-01	6.180E-01	1.448E-01	4.592E+00
7.000E+01	2.474E+00	1.019E+00	0.000E+00	0.000E+00	8.713E-01	6.059E-01	1.172E-01	5.087E+00
8.000E+01	2.728E+00	1.138E+00	0.000E+00	0.000E+00	9.032E-01	5.923E-01	9.740E-02	5.459E+00
9.000E+01	3.153E+00	1.141E+00	0.000E+00	0.000E+00	9.483E-01	5.669E-01	8.233E-02	5.892E+00
1.000E+02	3.574E+00	1.239E+00	0.000E+00	0.000E+00	9.985E-01	5.659E-01	6.559E-02	6.442E+00
1.100E+02	4.018E+00	1.120E+00	0.000E+00	0.000E+00	1.093E+00	5.706E-01	5.343E-02	6.855E+00
1.200E+02	4.620E+00	1.148E+00	0.000E+00	0.000E+00	1.095E+00	5.641E-01	4.497E-02	7.472E+00
1.300E+02	5.157E+00	1.188E+00	0.000E+00	0.000E+00	1.179E+00	5.671E-01	3.837E-02	8.129E+00
1.400E+02	5.777E+00	1.171E+00	0.000E+00	0.000E+00	1.206E+00	5.860E-01	3.262E-02	8.773E+00
1.500E+02	6.423E+00	9.620E-01	0.000E+00	0.000E+00	1.234E+00	6.053E-01	2.712E-02	9.251E+00

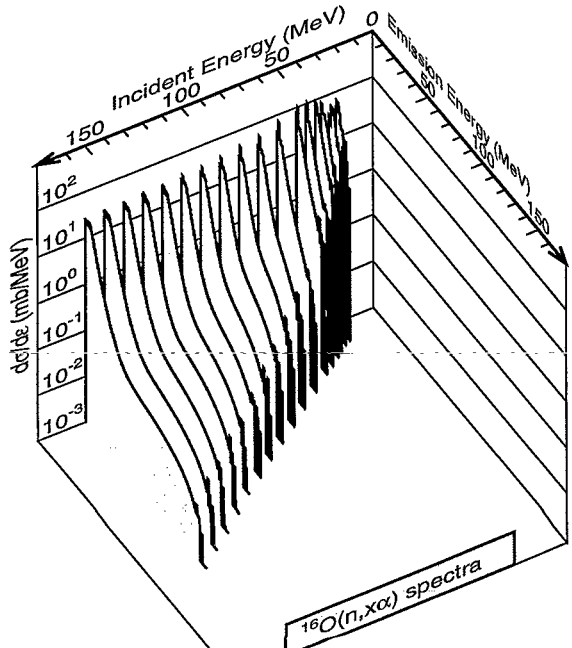

n + 16O nonelastic and production cross sections
Production Cross Section (mb)
10^3
10^2
n
p
α
γ
d
Nonelastic Cross Section (mb)
10^2
10^1
0
50
100
150
Incident Energy (MeV)

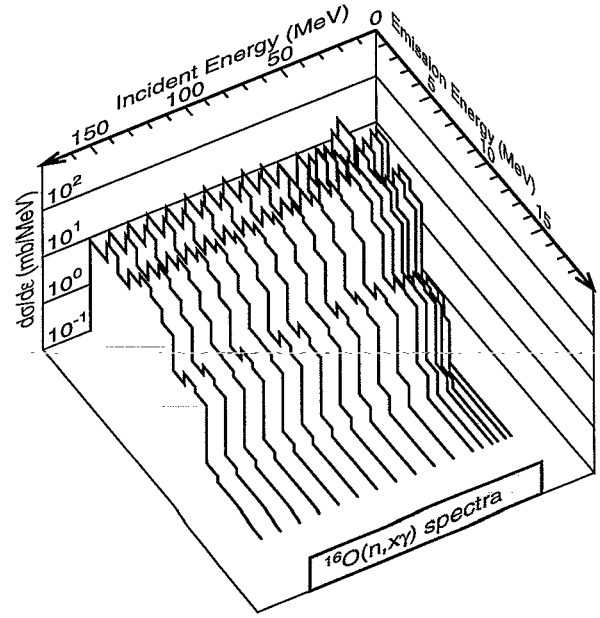
n + ^{16}O angle-integrated emission spectra



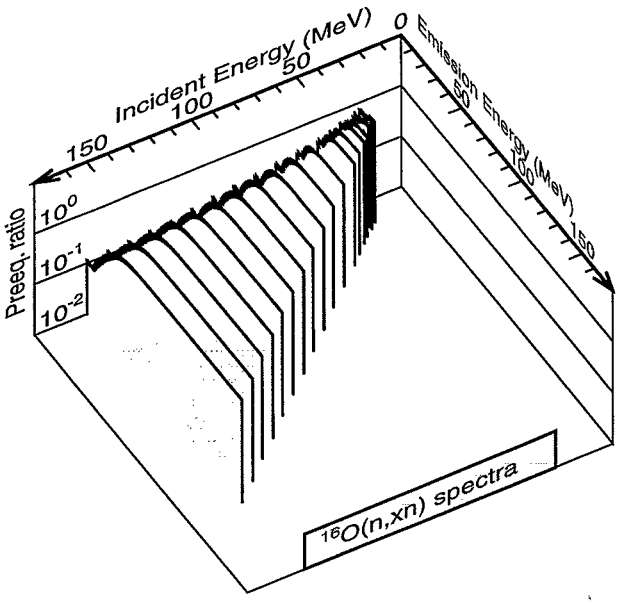


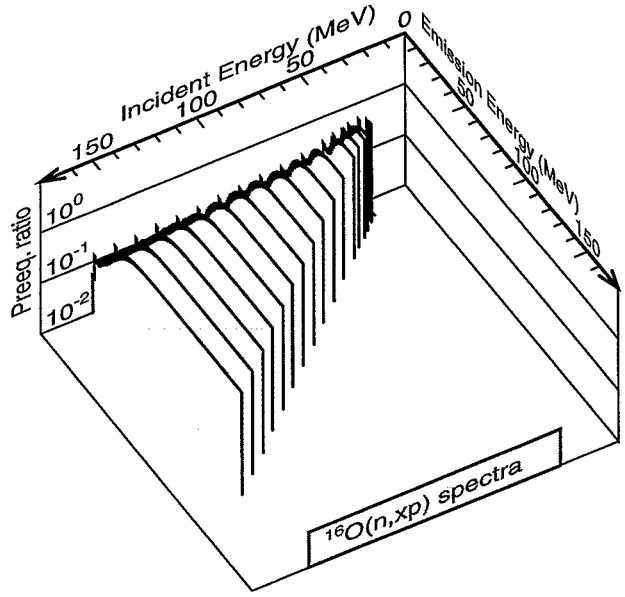


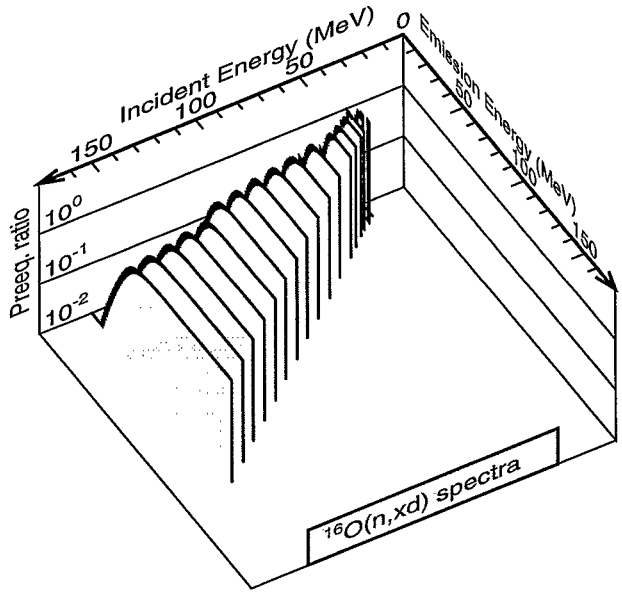


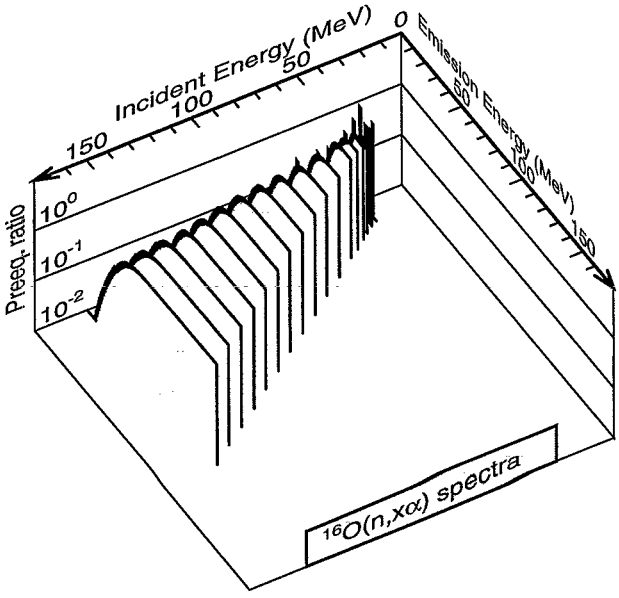


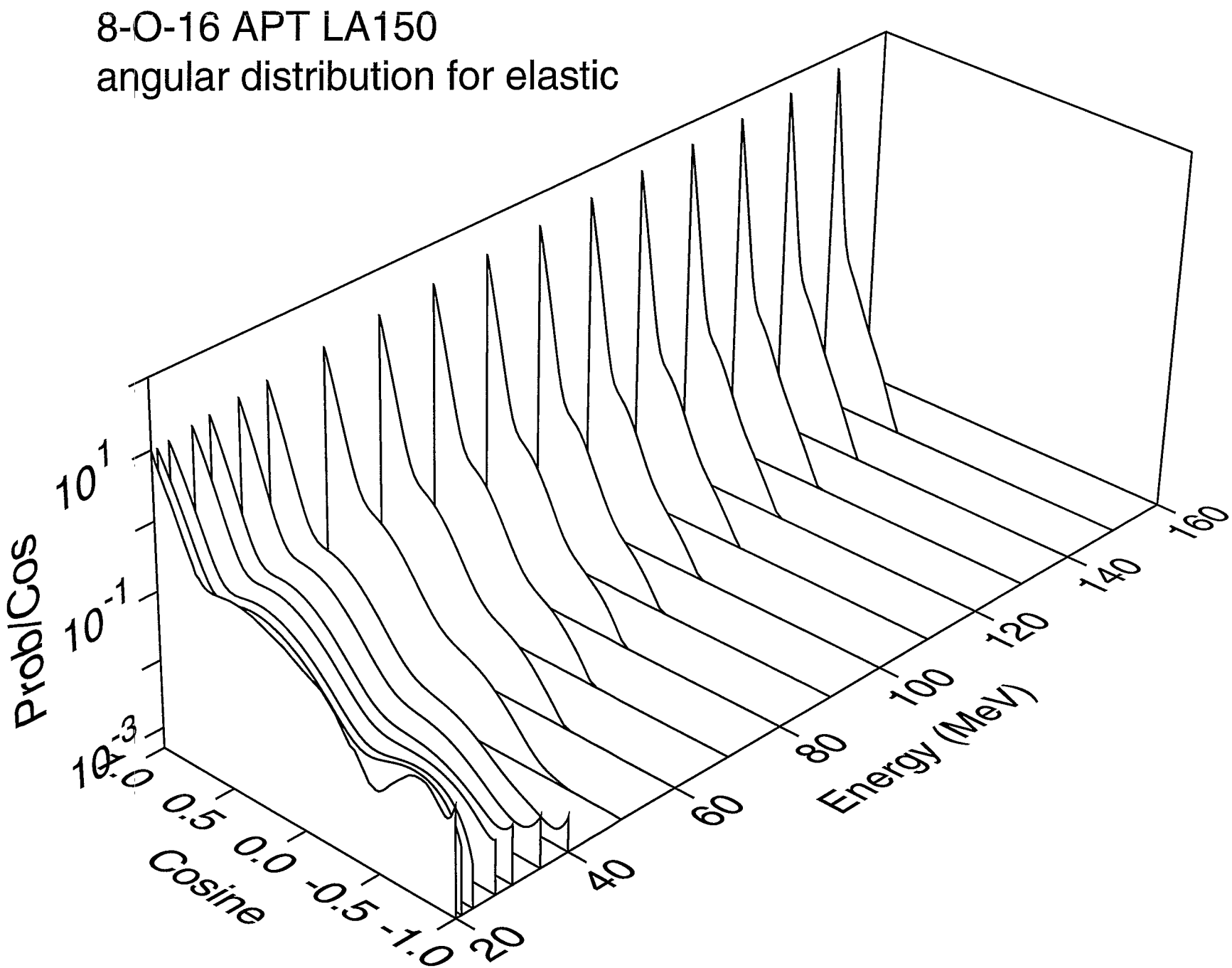
n + ^{16}O Kalbach preequilibrium ratios

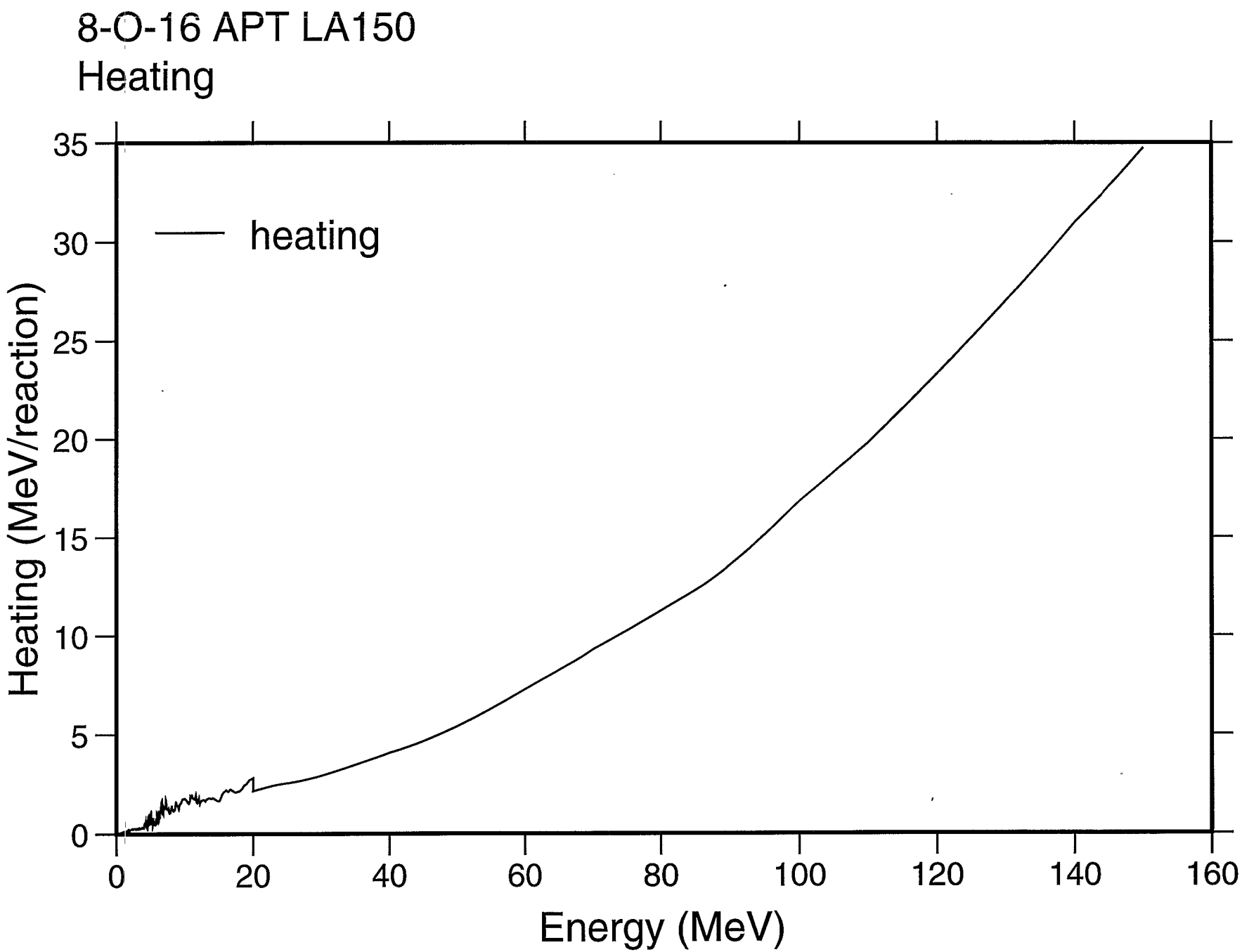


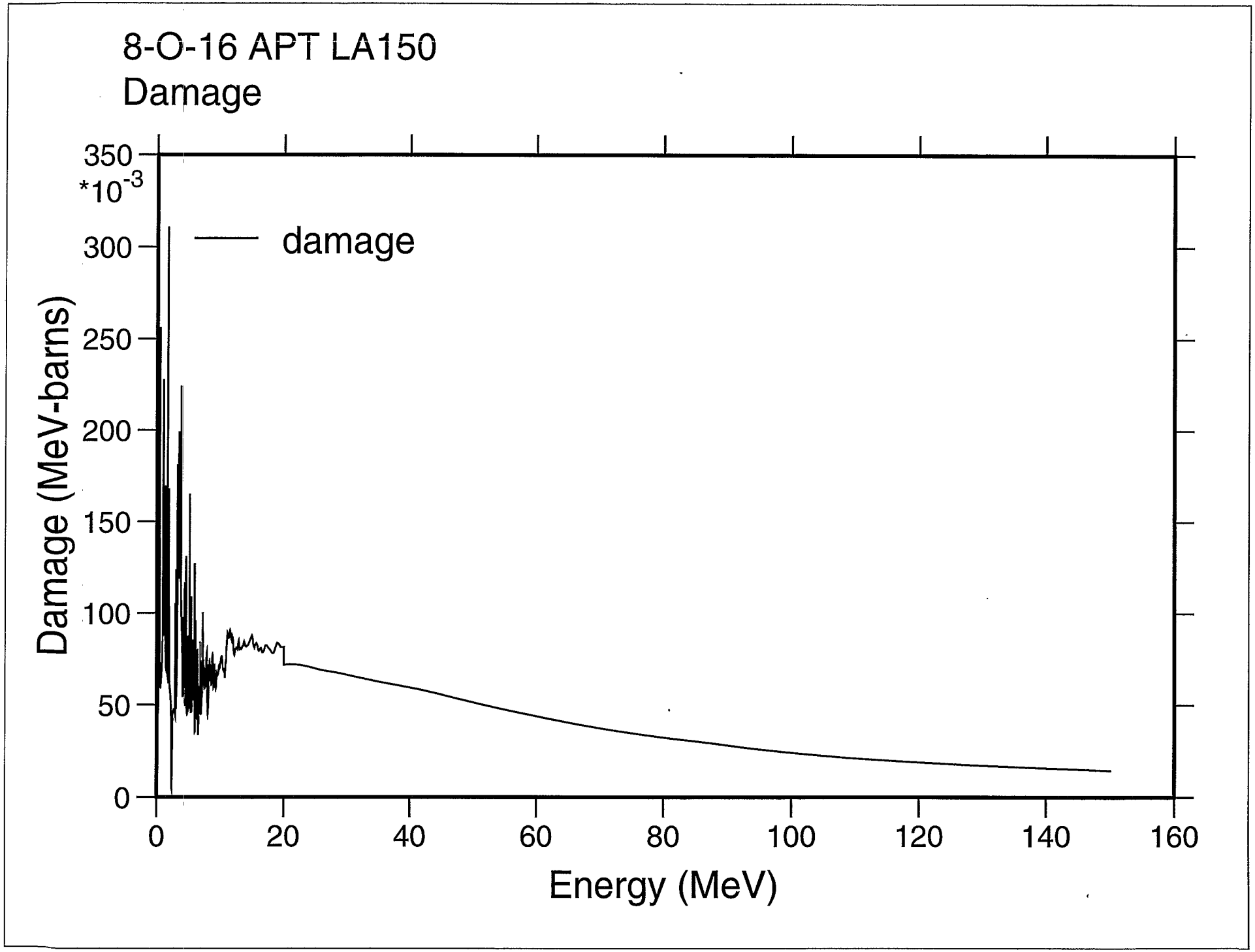







8-O-16 APT LA150
angular distribution for elastic
Prob/Cos
10^{1}
10^{-1}
10^{-3}
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


8-O-16 APT LA150
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
5
10
15
20
25
30
35
0
20
40
60
80
100
120
140
160


8-O-16 APT LA150
Damage
damage
Damage (MeV-barns)
*10^-3
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF n + 27Al CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

M. B. Chadwick and P. G. Young
10 February 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI.1 (Release 3) evaluation by Young (Yo94).

INCIDENT NEUTRON ENERGIES > 20 MeV

The ENDF/B-VI Release 3 evaluation extends to 40 MeV and includes cross sections and energy-angle data for all significant reactions. The present evauation utilizes a more compact composite reaction spectrum representation above 20 MeV in order to reduce the length of the file. No essential data for applications is lost with this representation. Additionally, we have modified the neutron reaction cross sections slightly to improve agreement with data above 20 MeV.

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT= 1	Total Cross Section
	MT= 2	Elastic Scattering Cross Section
	MT= 3	Nonelastic Cross Section
	MT= 5	Sum of Binary (n,n') and (n,x) Reactions
MF=4	MT= 2	Elastic Angular Distributions
MF=6	MT= 5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Al27 and p + Al27 reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics

(Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting..

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

The neutron total cross section was evaluated from available experimental data. From 20 - 40 MeV, the existing ENDF/B-VI.3 total cross section evaluation of Young was adopted; from 40 - 150 MeV, the evaluation was based primarily on Finlay's 1993 measurements (Fi93). The optical potential of Petler (Pe85), specially developed for n+Al elastic scattering, was used for neutrons up to 60 MeV, and above this energy the Madland global potential (Ma88) was used. For incident protons, the Petler neutron potential was modified to account for proton scattering up to 60 MeV, and again the Madland global potential was used at higher energies. For deuterons, the potential of Perey and Perey (Pe63) was used at all energies, and for tritons the Becchetti and Greenlees potential (Be71) was adopted. Finally, the potential of Arthur and Young (Ar80), based on the work of Lemos (Le72), was used for alpha particles at all energies. DWBA calculations were performed for inelastic scattering to low-lying states using the DWUCK code.

While the above optical potentials did describe the experimental neutron and proton nonelastic cross section data fairly well, we modified these theoretical predictions slightly to better agree with the measurements, and renormalized the transmission coefficients accordingly.

The present evaluation was greatly facilitated by Benck et al.'s (Be97) measurements of charged-particle producing reactions on Al for incident neutrons at 63 MeV at Louvain-la-Neuve, Belgium. Since these data represent the only neutron-induced emission spectra above 20 MeV, they have been invaluable for guiding, and testing, our calculations. The proton, triton, and alpha emission spectra in the Benck et al. measurements are described very well. However, our deuteron emission calculations compare poorly with the measurements. Fortunately this has only a small practical impact since deuteron emission is small compared to proton emission, and our calculated emission spectrum approximates the measured deuteron energy deposition (production cross section times average energy) reasonably well, which is important for heating calculations. The combination of equilibrium and preequilibrium reaction mechanisms included in the GNASH code account for the measured data rather well.

As an independent validation of our GNASH calculations using the exciton model, we have also performed FKK calculations. This was done by implementing a multistep reaction theory recently developed by Koning and Chadwick, which is particularly suited

to the simultaneous calculation of neutron and proton emission. The FKK theory describes the forward-peaking very well, as do our exciton model calculations using the phenomenological Kalbach angular distribution systematics.

As additional validation of the models used in our neutron evaluation, extensive comparisons were made to higher energy proton-induced measurements. In particular, the neutron and charged-particle emission spectra measured at the University of Maryland (Kalend et al. and Wu et al.) for 90-MeV protons, by Meier at Los Alamos for 113-MeV protons, and Bertrand and Peelle for 61-MeV protons are all reproduced reasonably by the present analysis (Ch97).

Another useful test of our model calculations, particularly for radionuclide production, can be made by comparing our theoretical predictions of discrete gamma-ray emission in Al27(n,xngamma) reactions with the recent LANSCE/WNR data taken by Vonach, Haight, and collaborators (Vo94) using the white neutron source. Preliminary comparisons show reasonably good agreement.

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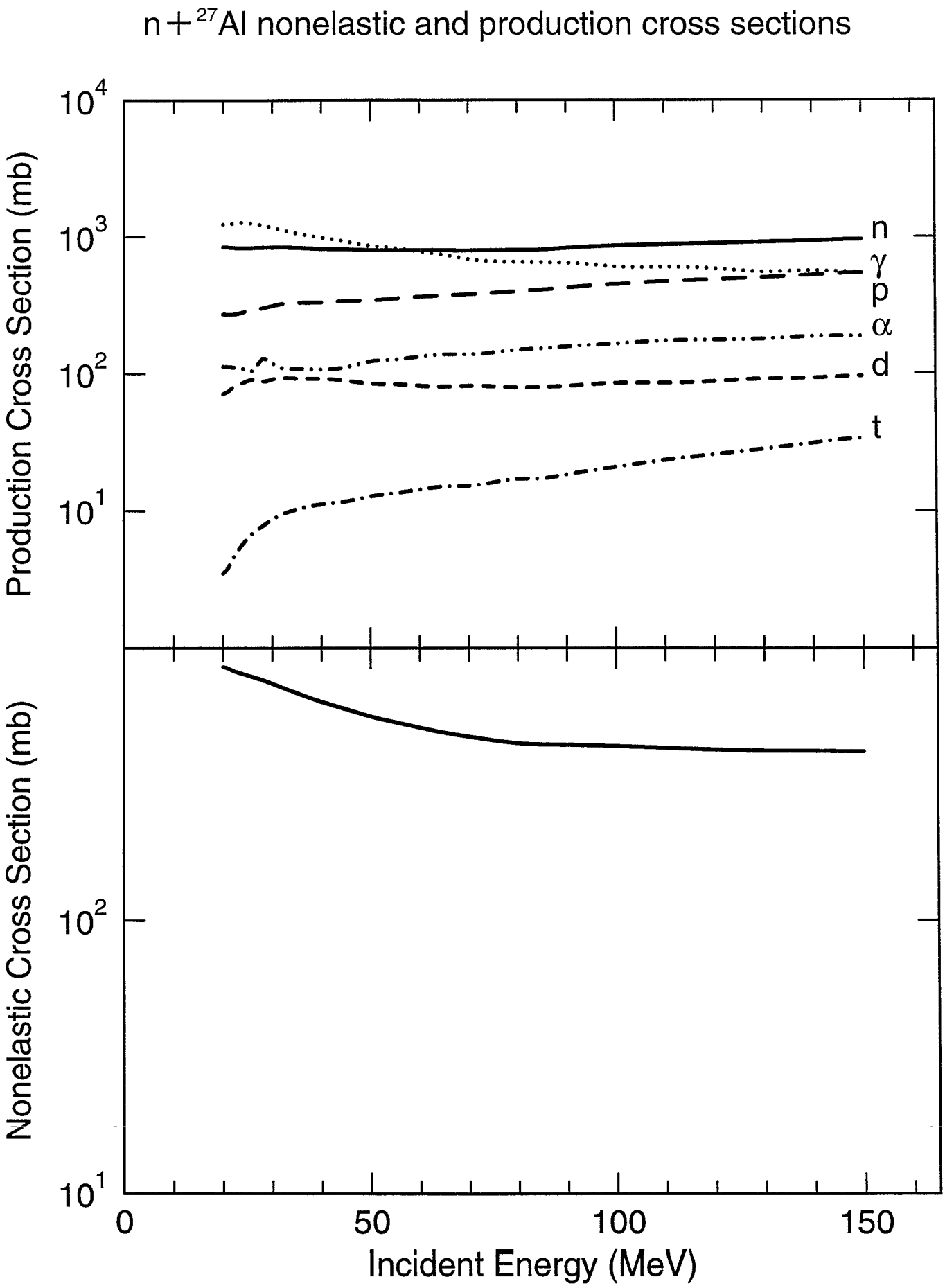
13027 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

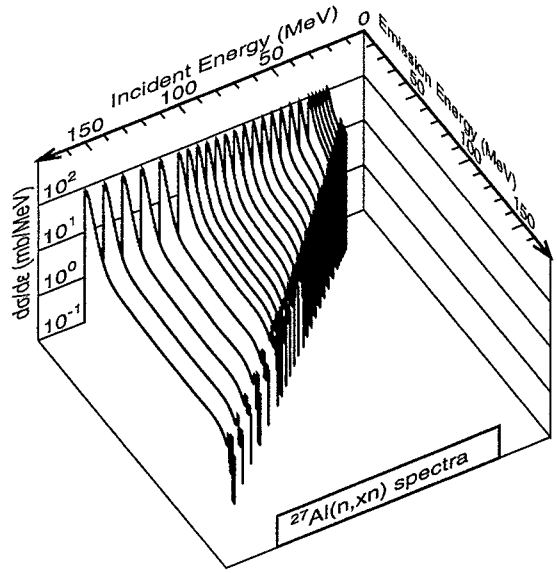
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	8.550E-01	9.450E-01	8.426E-01	2.713E-01	7.090E-02	3.483E-03	0.000E+00	1.125E-01	1.229E+00
2.200E+01	8.264E-01	9.973E-01	8.334E-01	2.707E-01	7.924E-02	4.474E-03	0.000E+00	1.111E-01	1.248E+00
2.400E+01	8.030E-01	1.046E+00	8.281E-01	2.801E-01	8.539E-02	5.698E-03	0.000E+00	1.087E-01	1.269E+00
2.600E+01	7.823E-01	1.090E+00	8.312E-01	2.939E-01	9.042E-02	6.831E-03	0.000E+00	1.047E-01	1.247E+00
2.800E+01	7.624E-01	1.123E+00	8.370E-01	3.004E-01	8.721E-02	7.706E-03	0.000E+00	1.286E-01	1.214E+00
3.000E+01	7.396E-01	1.146E+00	8.386E-01	3.129E-01	9.084E-02	8.653E-03	0.000E+00	1.192E-01	1.170E+00
3.500E+01	6.828E-01	1.187E+00	8.341E-01	3.298E-01	9.187E-02	1.027E-02	0.000E+00	1.085E-01	1.060E+00
4.000E+01	6.339E-01	1.186E+00	8.181E-01	3.320E-01	9.166E-02	1.114E-02	0.000E+00	1.075E-01	9.888E-01
4.500E+01	5.967E-01	1.152E+00	8.133E-01	3.405E-01	8.859E-02	1.169E-02	0.000E+00	1.116E-01	9.244E-01
5.000E+01	5.610E-01	1.114E+00	8.022E-01	3.439E-01	8.447E-02	1.271E-02	0.000E+00	1.226E-01	8.609E-01
5.500E+01	5.349E-01	1.058E+00	7.991E-01	3.545E-01	8.356E-02	1.344E-02	0.000E+00	1.268E-01	8.305E-01
6.000E+01	5.108E-01	9.992E-01	8.024E-01	3.655E-01	8.116E-02	1.423E-02	0.000E+00	1.330E-01	7.820E-01
6.500E+01	4.895E-01	9.405E-01	7.993E-01	3.728E-01	8.006E-02	1.499E-02	0.000E+00	1.382E-01	7.405E-01
7.000E+01	4.738E-01	8.812E-01	7.969E-01	3.804E-01	8.111E-02	1.517E-02	0.000E+00	1.382E-01	6.877E-01
7.500E+01	4.594E-01	8.206E-01	8.017E-01	3.892E-01	8.022E-02	1.605E-02	0.000E+00	1.425E-01	6.618E-01
8.000E+01	4.484E-01	7.616E-01	8.034E-01	3.998E-01	7.876E-02	1.706E-02	0.000E+00	1.492E-01	6.562E-01
8.500E+01	4.439E-01	7.030E-01	8.081E-01	4.105E-01	7.937E-02	1.720E-02	0.000E+00	1.524E-01	6.520E-01
9.000E+01	4.424E-01	6.496E-01	8.313E-01	4.244E-01	8.069E-02	1.834E-02	0.000E+00	1.575E-01	6.454E-01
9.500E+01	4.401E-01	5.979E-01	8.495E-01	4.401E-01	8.298E-02	1.958E-02	0.000E+00	1.612E-01	6.299E-01
1.000E+02	4.372E-01	5.508E-01	8.625E-01	4.500E-01	8.472E-02	2.079E-02	0.000E+00	1.650E-01	6.057E-01
1.100E+02	4.310E-01	4.640E-01	8.816E-01	4.729E-01	8.505E-02	2.335E-02	0.000E+00	1.733E-01	6.025E-01
1.200E+02	4.244E-01	4.036E-01	8.990E-01	4.886E-01	8.740E-02	2.565E-02	0.000E+00	1.762E-01	5.884E-01
1.300E+02	4.203E-01	3.527E-01	9.184E-01	5.061E-01	9.098E-02	2.815E-02	0.000E+00	1.790E-01	5.568E-01
1.400E+02	4.197E-01	2.973E-01	9.358E-01	5.278E-01	9.237E-02	3.109E-02	0.000E+00	1.863E-01	5.665E-01
1.500E+02	4.179E-01	2.651E-01	9.607E-01	5.459E-01	9.533E-02	3.361E-02	0.000E+00	1.873E-01	5.533E-01

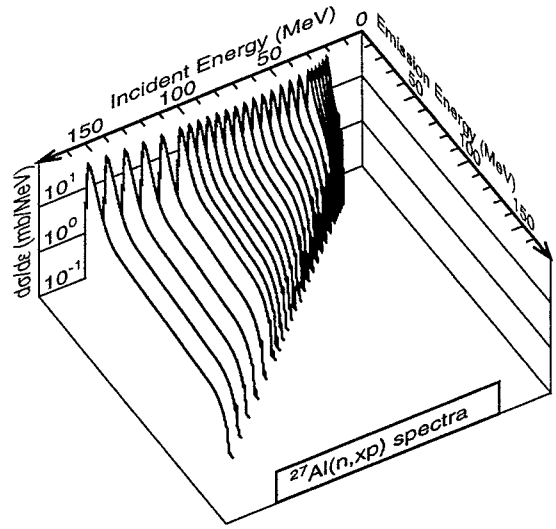
13027 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

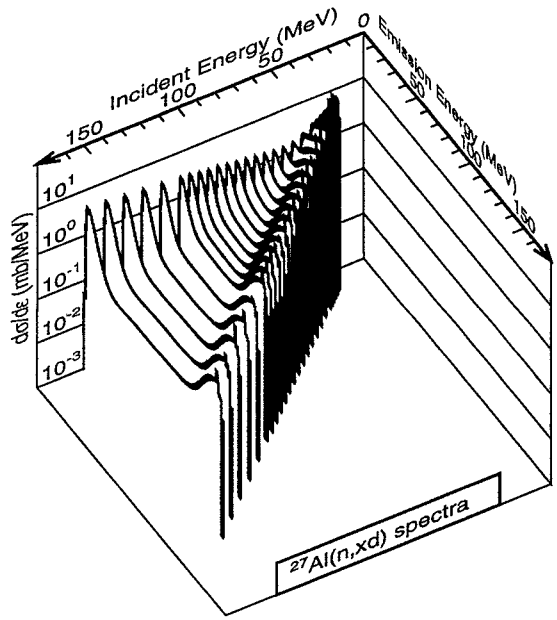
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	4.625E-01	1.940E-01	6.177E-03	0.000E+00	2.413E-01	2.631E-01	1.003E-01	1.267E+00
2.200E+01	5.263E-01	2.477E-01	9.195E-03	0.000E+00	2.550E-01	2.760E-01	1.015E-01	1.416E+00
2.400E+01	6.014E-01	3.015E-01	1.312E-02	0.000E+00	2.677E-01	2.884E-01	1.021E-01	1.574E+00
2.600E+01	6.740E-01	3.543E-01	1.735E-02	0.000E+00	2.736E-01	2.985E-01	1.022E-01	1.720E+00
2.800E+01	7.265E-01	3.730E-01	2.055E-02	0.000E+00	3.472E-01	3.104E-01	1.013E-01	1.879E+00
3.000E+01	8.054E-01	4.278E-01	2.490E-02	0.000E+00	3.359E-01	3.143E-01	9.974E-02	2.008E+00
3.500E+01	9.948E-01	5.322E-01	3.473E-02	0.000E+00	3.210E-01	3.214E-01	9.592E-02	2.300E+00
4.000E+01	1.147E+00	6.456E-01	4.291E-02	0.000E+00	3.265E-01	3.313E-01	9.067E-02	2.584E+00
4.500E+01	1.324E+00	7.307E-01	4.950E-02	0.000E+00	3.432E-01	3.378E-01	8.466E-02	2.870E+00
5.000E+01	1.468E+00	7.867E-01	5.644E-02	0.000E+00	3.778E-01	3.462E-01	7.956E-02	3.115E+00
5.500E+01	1.631E+00	8.696E-01	6.280E-02	0.000E+00	3.941E-01	3.534E-01	7.421E-02	3.385E+00
6.000E+01	1.809E+00	9.181E-01	6.839E-02	0.000E+00	4.127E-01	3.556E-01	6.940E-02	3.633E+00
6.500E+01	1.972E+00	9.804E-01	7.362E-02	0.000E+00	4.283E-01	3.598E-01	5.912E-02	3.873E+00
7.000E+01	2.141E+00	1.079E+00	7.692E-02	0.000E+00	4.286E-01	3.637E-01	5.403E-02	4.144E+00
7.500E+01	2.314E+00	1.128E+00	8.174E-02	0.000E+00	4.454E-01	3.691E-01	4.932E-02	4.388E+00
8.000E+01	2.509E+00	1.155E+00	8.681E-02	0.000E+00	4.678E-01	3.701E-01	4.504E-02	4.634E+00
8.500E+01	2.738E+00	1.245E+00	8.814E-02	0.000E+00	4.762E-01	3.750E-01	4.104E-02	4.963E+00
9.000E+01	2.967E+00	1.320E+00	9.265E-02	0.000E+00	4.967E-01	3.840E-01	3.753E-02	5.298E+00
9.500E+01	3.204E+00	1.419E+00	9.694E-02	0.000E+00	5.122E-01	3.896E-01	3.424E-02	5.656E+00
1.000E+02	3.417E+00	1.511E+00	1.012E-01	0.000E+00	5.299E-01	3.972E-01	3.131E-02	5.988E+00
1.100E+02	3.876E+00	1.580E+00	1.104E-01	0.000E+00	5.658E-01	4.040E-01	2.608E-02	6.562E+00
1.200E+02	4.283E+00	1.719E+00	1.178E-01	0.000E+00	5.867E-01	4.113E-01	2.248E-02	7.141E+00
1.300E+02	4.706E+00	1.891E+00	1.264E-01	0.000E+00	6.077E-01	4.285E-01	1.949E-02	7.779E+00
1.400E+02	5.191E+00	1.949E+00	1.367E-01	0.000E+00	6.400E-01	4.524E-01	1.630E-02	8.385E+00
1.500E+02	5.644E+00	2.084E+00	1.451E-01	0.000E+00	6.562E-01	4.748E-01	1.441E-02	9.019E+00

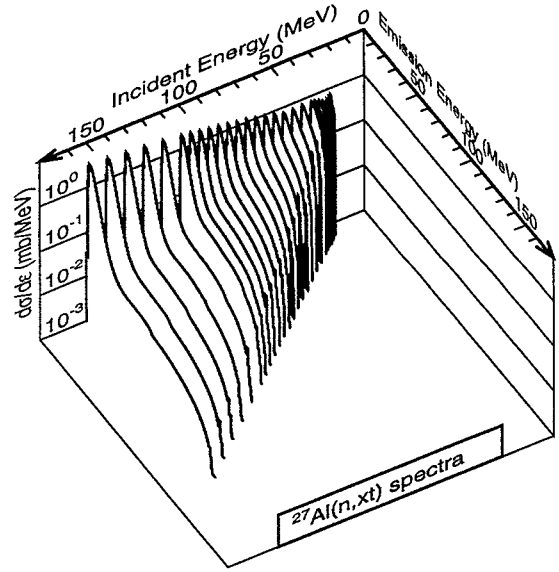

n + 27Al nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
n
γ
p
α
d
t
Nonelastic Cross Section (mb)
10^2
10^1
0
50
100
150
Incident Energy (MeV)

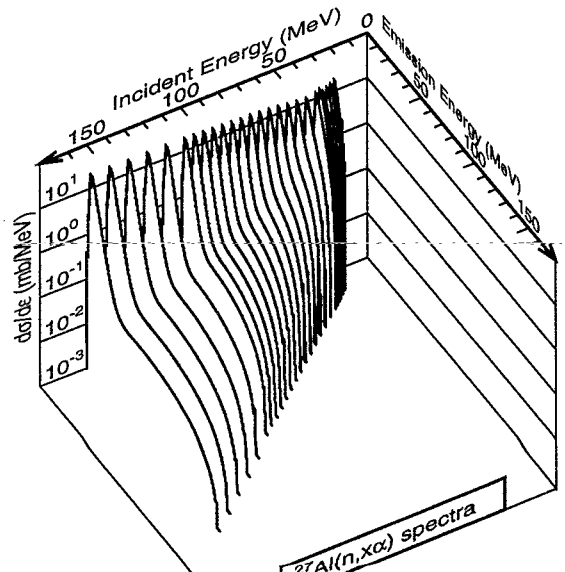
n + ^{27}Al angle-integrated emission spectra

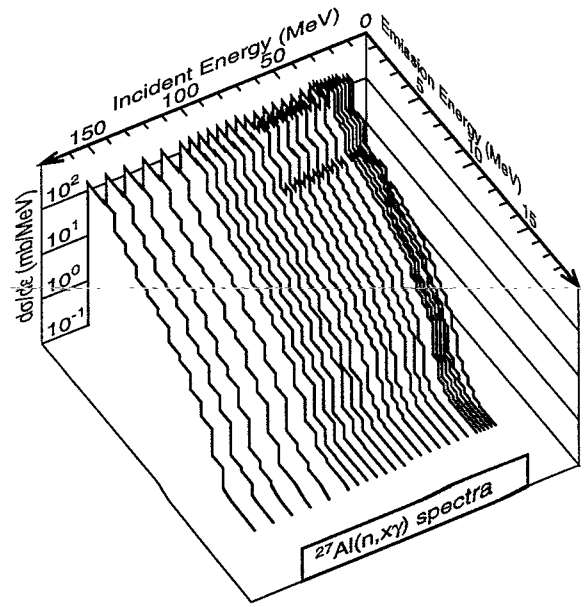




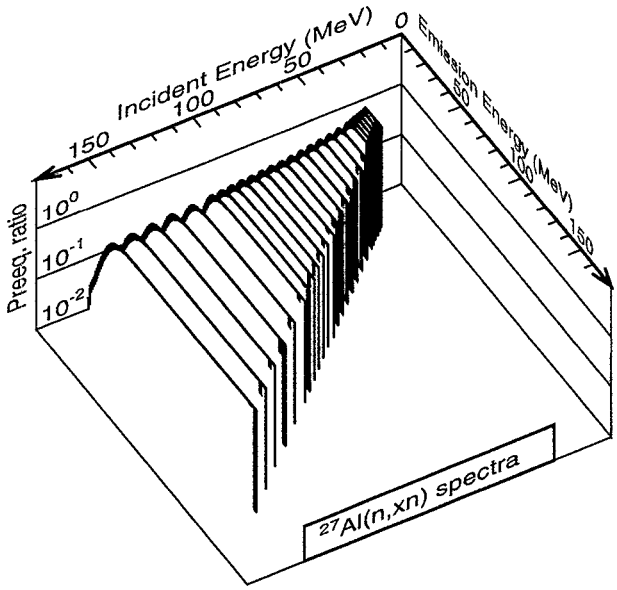


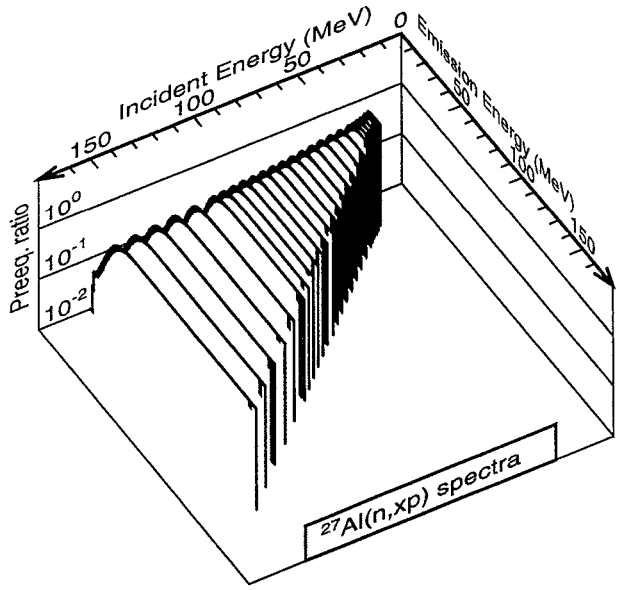


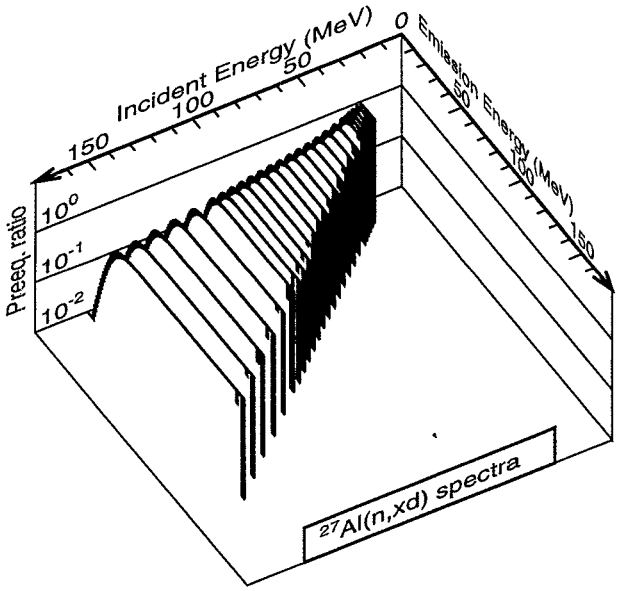


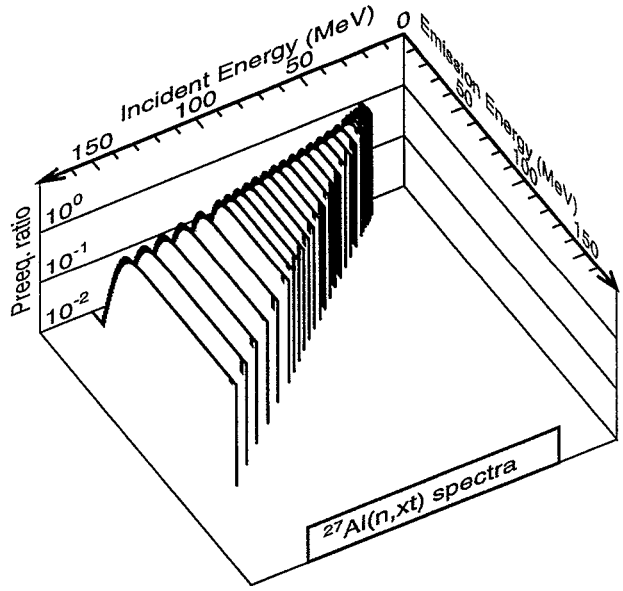


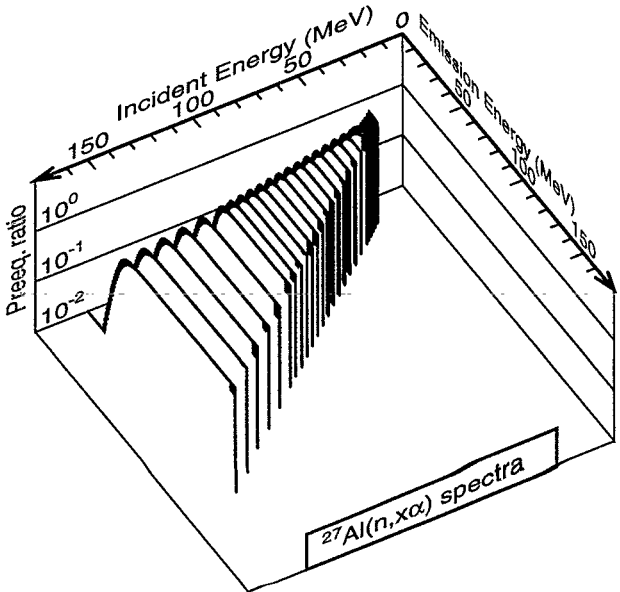
n + ^{27}Al Kalbach preequilibrium ratios

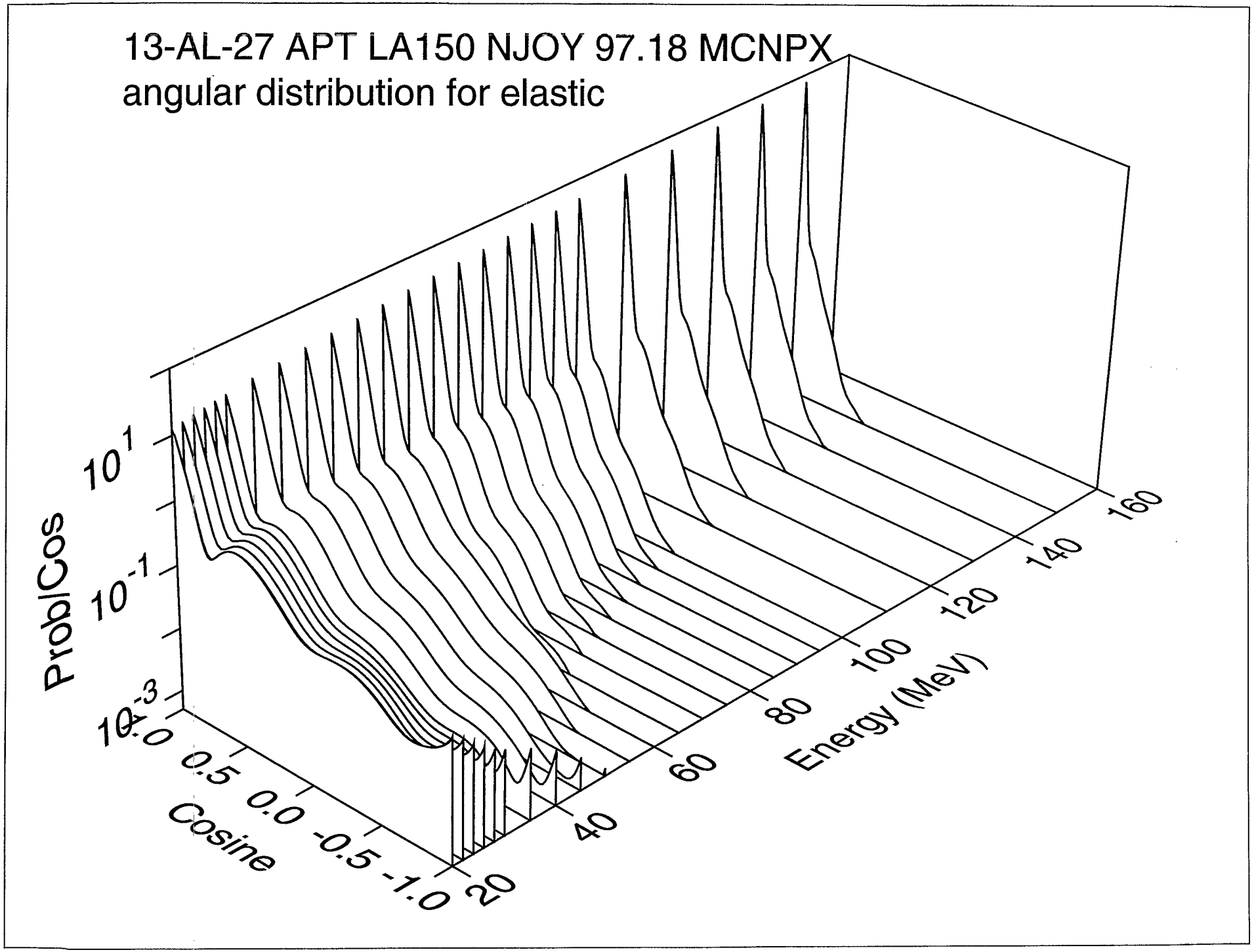


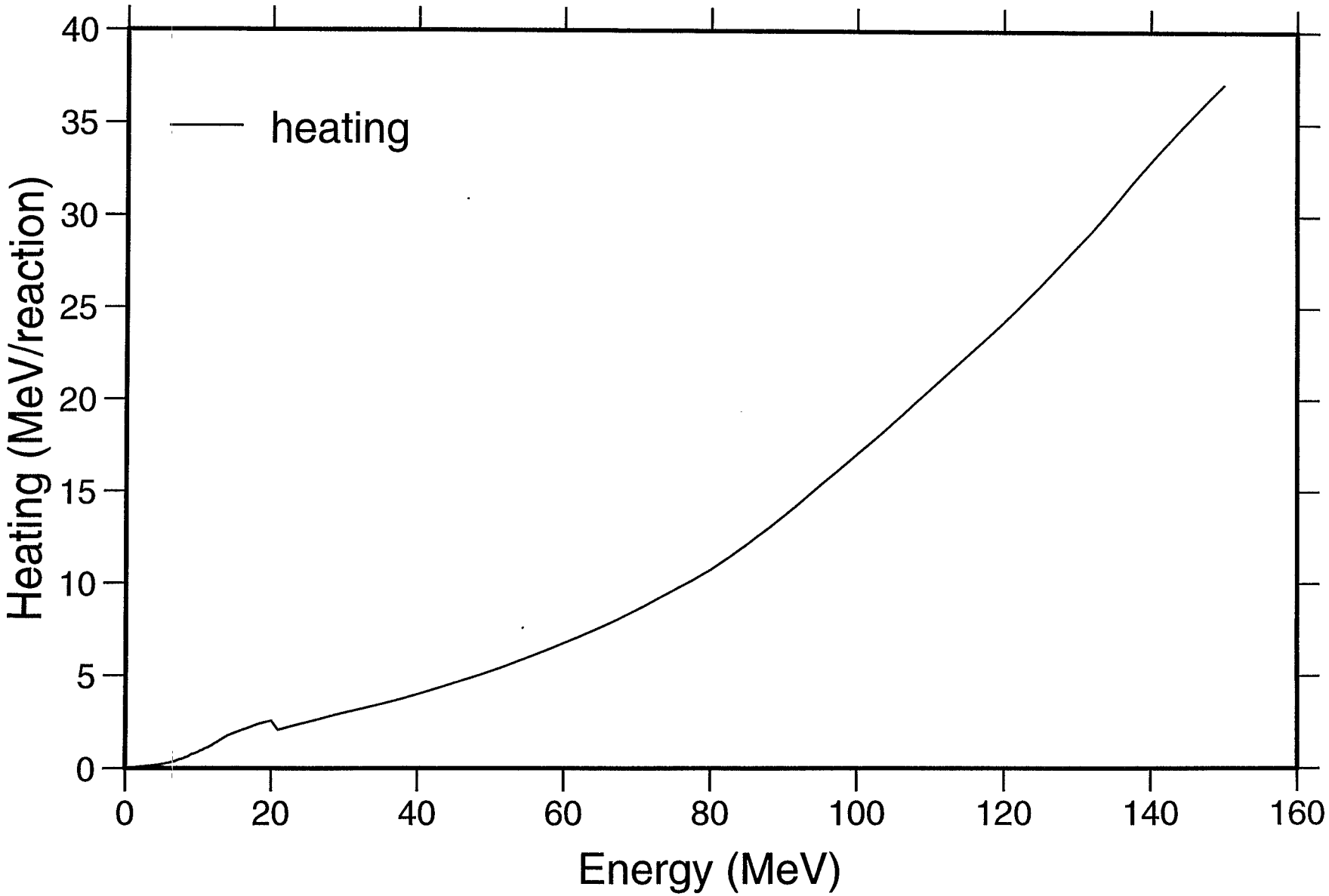


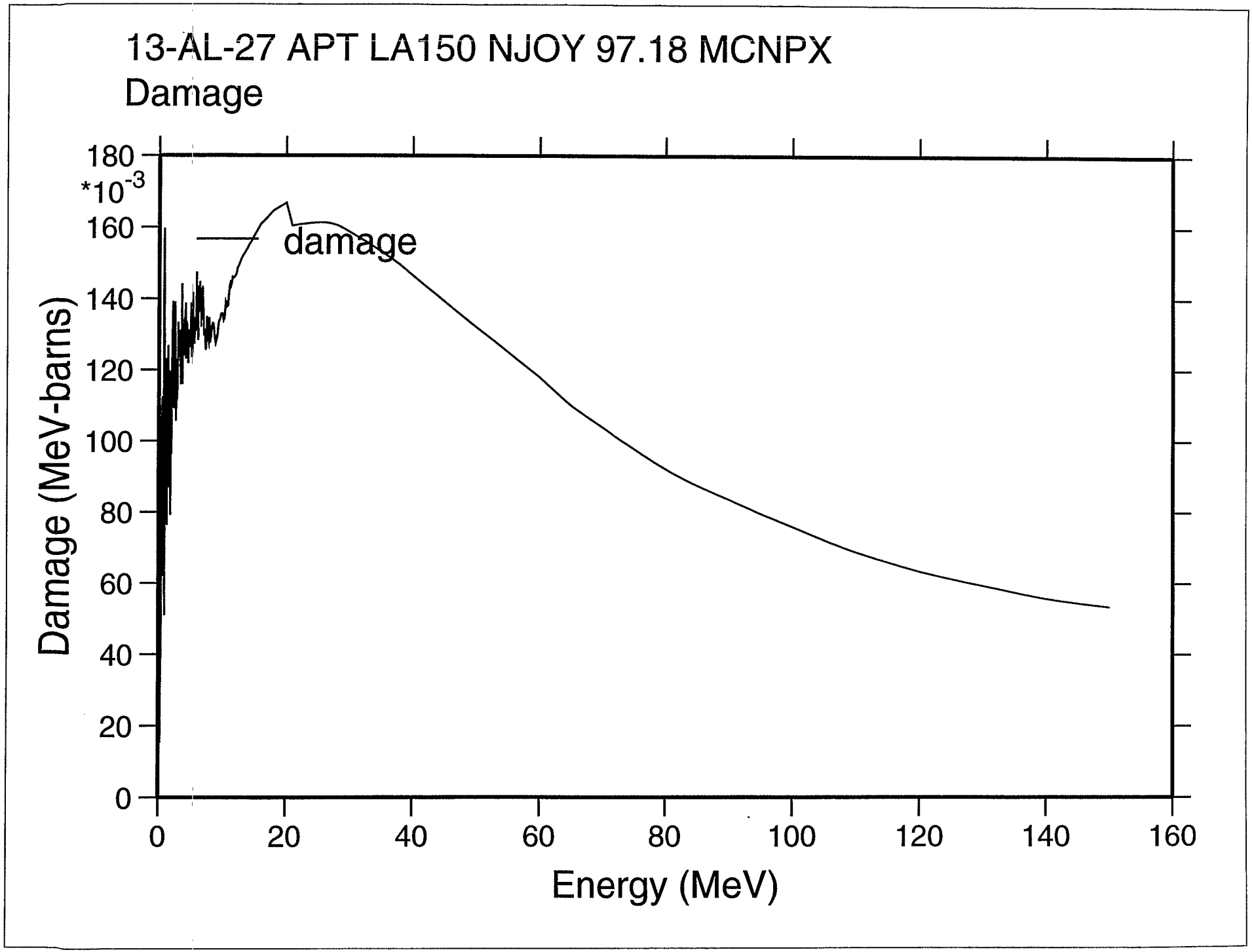







13-AL-27 APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic
Prob/Cos
10^{1}
10^{-1}
10^{-3}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
20
40
60
80
100
120
140
160


13-AL-27 APT LA150 NJOY 97.18 MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
5
10
15
20
25
30
35
40
0
20
40
60
80
100
120
140
160


13-AL-27 APT LA150 NJOY 97.18 MCNPX
Damage
damage
Damage (MeV-barns)
*10^-3
180
160
140
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF n + 28Si CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

M. B. Chadwick and P. G. Young
1 July 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI.5 (Release 5) evaluation by D. Hetrick, N. Larson, D. Larson, L. Leal, and S. Epperson.

INCIDENT NEUTRON ENERGIES > 20 MeV

The ENDF/B-VI Release 5 evaluation extends to 20 MeV and includes cross sections and energy-angle data for all significant reactions. The present evauation utilizes a more compact composite reaction spectrum representation above 20 MeV in order to reduce the length of the file. No essential data for applications is lost with this representation.

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT= 1	Total Cross Section
	MT= 2	Elastic Scattering Cross Section
	MT= 3	Nonelastic Cross Section
	MT= 5	Sum of Binary (n,n') and (n,x) Reactions
MF=4	MT= 2	Elastic Angular Distributions
MF=6	MT= 5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, Tritons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Si28 and p + Si28 reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

DETAILS OF THE n + SI-28 ANALYSIS

The neutron total cross section above 20 MeV was obtained by evaluating the experimental data, with a particular emphasis on the high-accuracy Los Alamos measurements by Finlay (Fi93).
The Madland global medium-energy optical potential (Ma88) was used for neutrons above 46 MeV, and the Wilmore-Hodgson potential [Wi64] was used for lower neutron energies. The Madland global medium-energy optical potential was used for protons above 28 MeV, and the Beccheti-Greenlees potential [Be69] was used for lower proton energies. In both cases the transition region to the Madland potential was chosen to approximately give continuity in the reaction cross section. For deuterons, the Perey [Pe63] global potential was used; for alpha particles the MacFadden potential [Ma66] was used; and for tritons the Beccheti-Greenlees potential [Be71] was used.

While the above optical potentials did describe the experimental proton nonelastic cross section data fairly well, we modified the theoretical predictions slightly to better agree with the measurements, and renormalized the transmission coefficients accordingly. In addition to using Si nonelastic proton cross section measurements, we also were guided by p+Al nonelastic data, scaled by A**2/3.

Coupled-channel optical model calculations were performed to determine inelastic scattering on 28Si, for the 0+, 2+, and 4+ states, as well as a DWBA calculation of the inelastic scattering to the 3- vibrational state, all performed with the ECIS code [Ra72]. Near 20 MeV neutron energy, inelastic scattering to these states has been measured by Alarcon and Rapaport [Al83], and Finlay et al., from Ohio University, and the inelastic cross sections to these collective states is in good agreement with the ORNL ENDF evaluation for 28Si. To produce continuity in the calculated inelastic cross sections up to 150 MeV, we performed a rotational band (0+, 2+, 4+) coupled channel calculation using the Madland medium energy potential (with its imaginary potential reduced by 20%, to approximately account for the coupling). Deformation parameters were chosen to reproduce the ENDF/B-VI cross sections at 20 MeV, resulting in values of beta_2=-0.365, beta_4=+0.22, in good agreement with

Rapaport's values of -0.37, 0.17 respectively. A vibrarional DWBA calculation (using ECIS) was performed for the 3- state resulting in beta-3=0.235 (Rapaport obtained 0.23).

Only 2 measurements exist for neutron-induced emission spectra above 20 MeV for 28Si. New data have been published by the Louvain group at the 1997 Trieste conference for 63 MeV Si(n,xz)

double-differential spectra (z=p,d,a ejectiles). Additionally, Haight et al. of Los Alamos have preliminary data for Si(n,xp), for neutrons up to 50 MeV, including emission spectra at four angles. Our calculations agree reasonably well with these measurements. While default level density parameters (using the Ignatyuk model) were utilized, in the case of 28Al the level density parameter was slightly modified to optimize agreement with the Abfalterer total level density measurements based on fluctuation analyses (Ab93).

As an independent validation of our GNASH calculations using the exciton model, we have also performed FKK calculations. This was done by implementing a multistep reaction theory recently developed by Koning and Chadwick, which is particularly suited to the simultaneous calculation of neutron and proton emission. The FKK theory describes the forward-peaking very well, as do our exciton model calculations using the phenomenological Kalbach angular distribution systematics.

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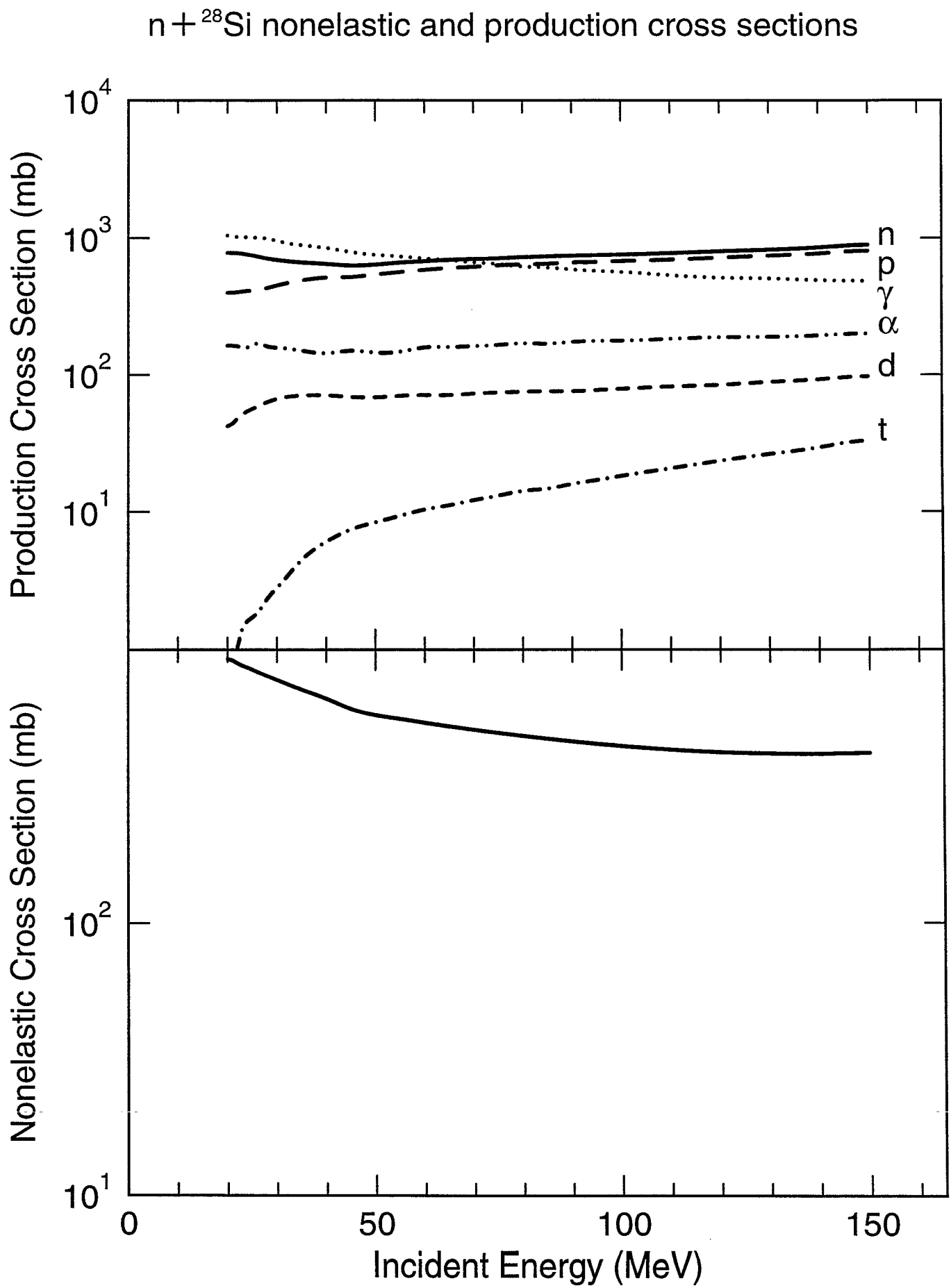
14028 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

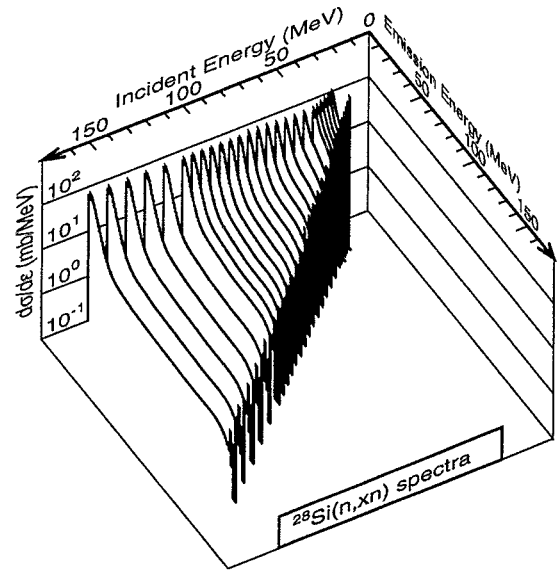
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	9.275E-01	9.125E-01	7.809E-01	3.991E-01	4.204E-02	4.389E-04	0.000E+00	1.626E-01	1.044E+00
2.200E+01	8.933E-01	9.867E-01	7.779E-01	4.033E-01	4.764E-02	1.039E-03	0.000E+00	1.611E-01	1.019E+00
2.400E+01	8.612E-01	1.045E+00	7.599E-01	4.123E-01	5.403E-02	1.620E-03	0.000E+00	1.575E-01	1.013E+00
2.600E+01	8.304E-01	1.095E+00	7.358E-01	4.149E-01	5.820E-02	1.838E-03	0.000E+00	1.691E-01	1.005E+00
2.800E+01	8.010E-01	1.133E+00	7.105E-01	4.323E-01	6.285E-02	2.337E-03	0.000E+00	1.608E-01	9.940E-01
3.000E+01	7.732E-01	1.164E+00	6.929E-01	4.520E-01	6.644E-02	2.814E-03	0.000E+00	1.572E-01	9.540E-01
3.500E+01	7.113E-01	1.217E+00	6.646E-01	4.913E-01	7.034E-02	4.481E-03	0.000E+00	1.499E-01	8.873E-01
4.000E+01	6.593E-01	1.232E+00	6.494E-01	5.153E-01	7.047E-02	6.093E-03	0.000E+00	1.436E-01	8.492E-01
4.500E+01	6.046E-01	1.228E+00	6.320E-01	5.203E-01	6.869E-02	7.459E-03	0.000E+00	1.498E-01	7.926E-01
5.000E+01	5.737E-01	1.191E+00	6.425E-01	5.424E-01	6.809E-02	8.417E-03	0.000E+00	1.451E-01	7.552E-01
5.500E+01	5.558E-01	1.130E+00	6.642E-01	5.663E-01	6.992E-02	9.335E-03	0.000E+00	1.472E-01	7.364E-01
6.000E+01	5.381E-01	1.062E+00	6.799E-01	5.878E-01	7.081E-02	1.036E-02	0.000E+00	1.575E-01	7.094E-01
6.500E+01	5.221E-01	9.959E-01	6.954E-01	6.067E-01	7.076E-02	1.116E-02	0.000E+00	1.587E-01	6.914E-01
7.000E+01	5.074E-01	9.346E-01	7.028E-01	6.190E-01	7.261E-02	1.216E-02	0.000E+00	1.612E-01	6.674E-01
7.500E+01	4.940E-01	8.680E-01	7.135E-01	6.344E-01	7.389E-02	1.310E-02	0.000E+00	1.645E-01	6.478E-01
8.000E+01	4.817E-01	8.073E-01	7.263E-01	6.443E-01	7.478E-02	1.416E-02	0.000E+00	1.690E-01	6.214E-01
8.500E+01	4.704E-01	7.466E-01	7.354E-01	6.499E-01	7.541E-02	1.472E-02	0.000E+00	1.678E-01	6.104E-01
9.000E+01	4.603E-01	6.967E-01	7.447E-01	6.647E-01	7.541E-02	1.595E-02	0.000E+00	1.729E-01	5.905E-01
9.500E+01	4.510E-01	6.470E-01	7.513E-01	6.703E-01	7.696E-02	1.704E-02	0.000E+00	1.758E-01	5.773E-01
1.000E+02	4.429E-01	6.021E-01	7.581E-01	6.798E-01	7.857E-02	1.824E-02	0.000E+00	1.766E-01	5.662E-01
1.100E+02	4.296E-01	5.264E-01	7.768E-01	6.962E-01	8.170E-02	2.066E-02	0.000E+00	1.821E-01	5.343E-01
1.200E+02	4.205E-01	4.606E-01	8.014E-01	7.206E-01	8.407E-02	2.343E-02	0.000E+00	1.872E-01	5.128E-01
1.300E+02	4.160E-01	4.030E-01	8.229E-01	7.447E-01	8.826E-02	2.624E-02	0.000E+00	1.887E-01	5.061E-01
1.400E+02	4.150E-01	3.530E-01	8.552E-01	7.727E-01	9.241E-02	2.934E-02	0.000E+00	1.933E-01	4.918E-01
1.500E+02	4.177E-01	3.103E-01	8.922E-01	8.090E-01	9.710E-02	3.281E-02	0.000E+00	1.995E-01	4.863E-01

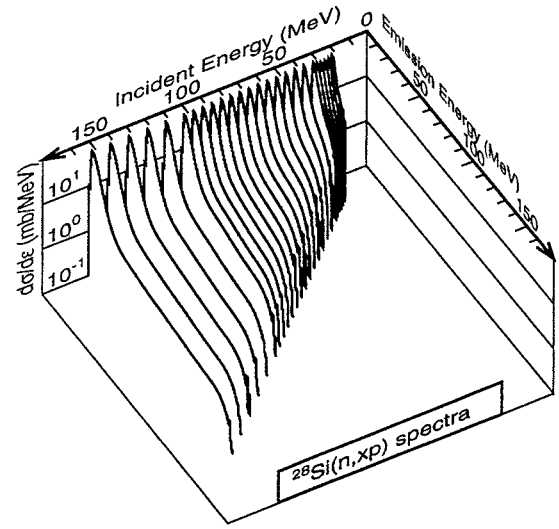
14028 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

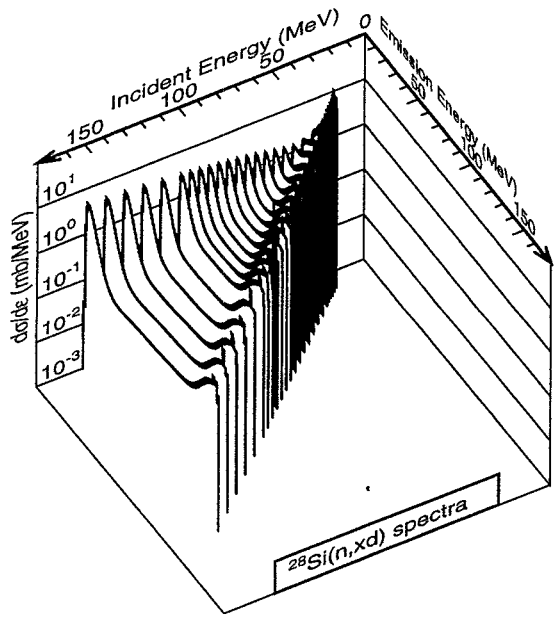
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	6.499E-01	9.151E-02	3.779E-04	0.000E+00	3.496E-01	2.839E-01	7.872E-02	1.454E+00
2.200E+01	7.252E-01	1.249E-01	1.236E-03	0.000E+00	3.683E-01	2.950E-01	9.139E-02	1.606E+00
2.400E+01	7.997E-01	1.647E-01	2.436E-03	0.000E+00	3.771E-01	3.027E-01	9.127E-02	1.738E+00
2.600E+01	8.480E-01	2.005E-01	3.352E-03	0.000E+00	4.208E-01	3.070E-01	9.018E-02	1.870E+00
2.800E+01	9.307E-01	2.426E-01	5.029E-03	0.000E+00	4.228E-01	3.107E-01	8.826E-02	2.000E+00
3.000E+01	1.018E+00	2.837E-01	6.763E-03	0.000E+00	4.280E-01	3.139E-01	8.600E-02	2.137E+00
3.500E+01	1.208E+00	3.695E-01	1.317E-02	0.000E+00	4.329E-01	3.258E-01	7.996E-02	2.429E+00
4.000E+01	1.406E+00	4.450E-01	2.038E-02	0.000E+00	4.326E-01	3.333E-01	7.337E-02	2.711E+00
4.500E+01	1.543E+00	5.061E-01	2.707E-02	0.000E+00	4.660E-01	3.386E-01	6.748E-02	2.948E+00
5.000E+01	1.731E+00	5.652E-01	3.362E-02	0.000E+00	4.648E-01	3.448E-01	7.899E-02	3.218E+00
5.500E+01	1.948E+00	6.468E-01	3.997E-02	0.000E+00	4.757E-01	3.561E-01	7.092E-02	3.537E+00
6.000E+01	2.144E+00	7.176E-01	4.570E-02	0.000E+00	5.153E-01	3.689E-01	6.383E-02	3.855E+00
6.500E+01	2.345E+00	7.708E-01	5.134E-02	0.000E+00	5.249E-01	3.750E-01	5.786E-02	4.125E+00
7.000E+01	2.528E+00	8.511E-01	5.710E-02	0.000E+00	5.378E-01	3.829E-01	5.285E-02	4.410E+00
7.500E+01	2.717E+00	9.210E-01	6.253E-02	0.000E+00	5.498E-01	3.884E-01	4.804E-02	4.686E+00
8.000E+01	2.896E+00	9.777E-01	6.804E-02	0.000E+00	5.689E-01	3.945E-01	4.390E-02	4.949E+00
8.500E+01	3.076E+00	1.034E+00	7.206E-02	0.000E+00	5.696E-01	3.957E-01	4.002E-02	5.188E+00
9.000E+01	3.274E+00	1.062E+00	7.754E-02	0.000E+00	5.903E-01	3.941E-01	3.691E-02	5.434E+00
9.500E+01	3.447E+00	1.130E+00	8.184E-02	0.000E+00	6.035E-01	3.973E-01	3.394E-02	5.693E+00
1.000E+02	3.626E+00	1.195E+00	8.638E-02	0.000E+00	6.128E-01	4.000E-01	3.132E-02	5.952E+00
1.100E+02	3.993E+00	1.316E+00	9.517E-02	0.000E+00	6.405E-01	4.067E-01	2.702E-02	6.479E+00
1.200E+02	4.404E+00	1.395E+00	1.051E-01	0.000E+00	6.704E-01	4.081E-01	2.338E-02	7.007E+00
1.300E+02	4.836E+00	1.535E+00	1.145E-01	0.000E+00	6.908E-01	4.286E-01	2.027E-02	7.626E+00
1.400E+02	5.307E+00	1.647E+00	1.251E-01	0.000E+00	7.183E-01	4.558E-01	1.759E-02	8.271E+00
1.500E+02	5.852E+00	1.766E+00	1.375E-01	0.000E+00	7.539E-01	4.796E-01	1.531E-02	9.004E+00

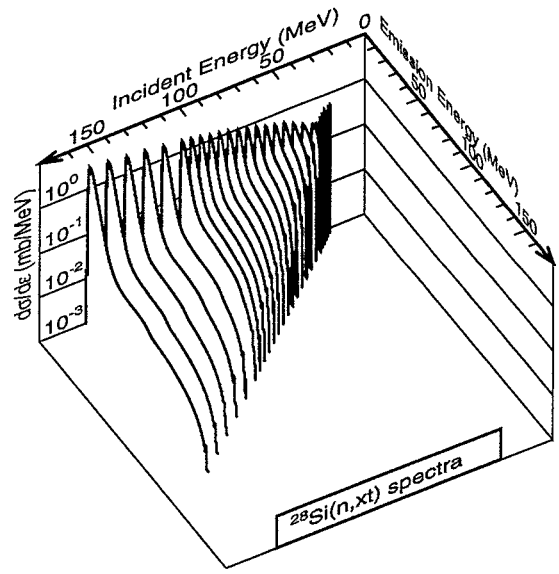

n + 28Si nonelastic and production cross sections
Production Cross Section (mb)
Nonelastic Cross Section (mb)
Incident Energy (MeV)
n
p
γ
α
d
t
10^4
10^3
10^2
10^1
0
50
100
150

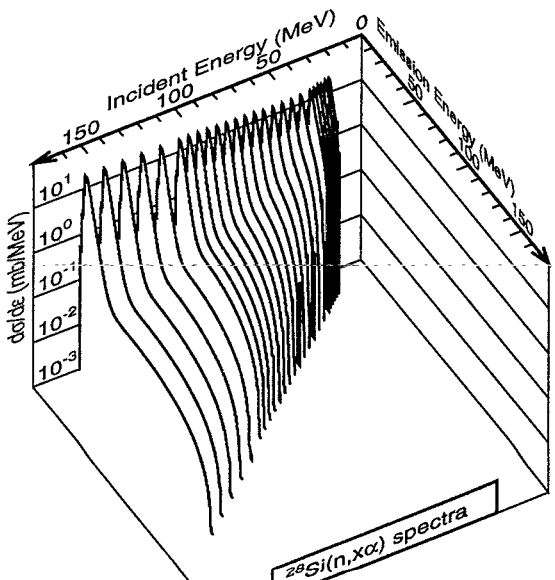
n + ^{28}Si angle-integrated emission spectra

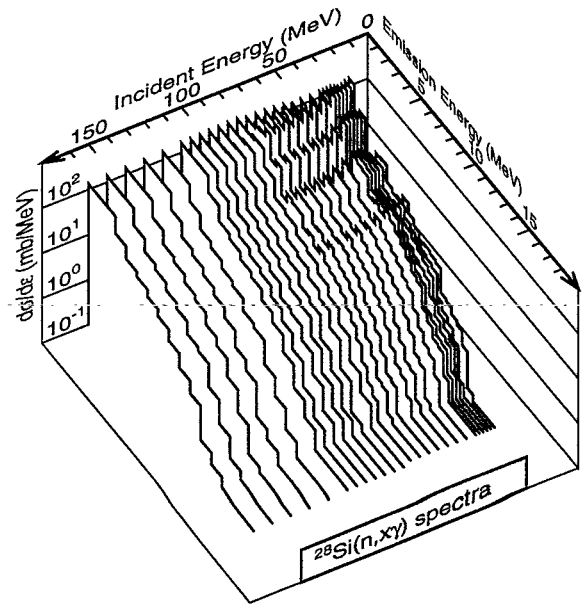




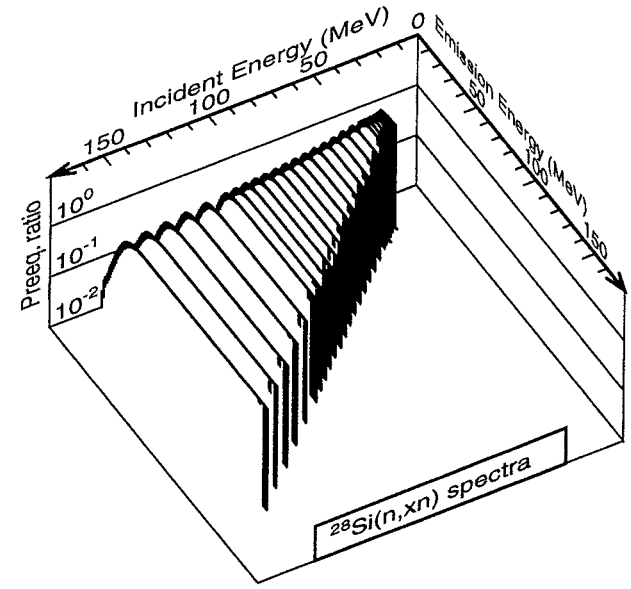


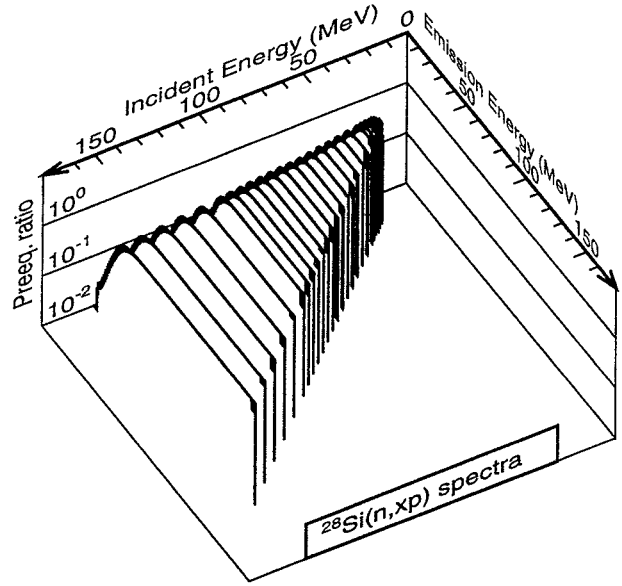


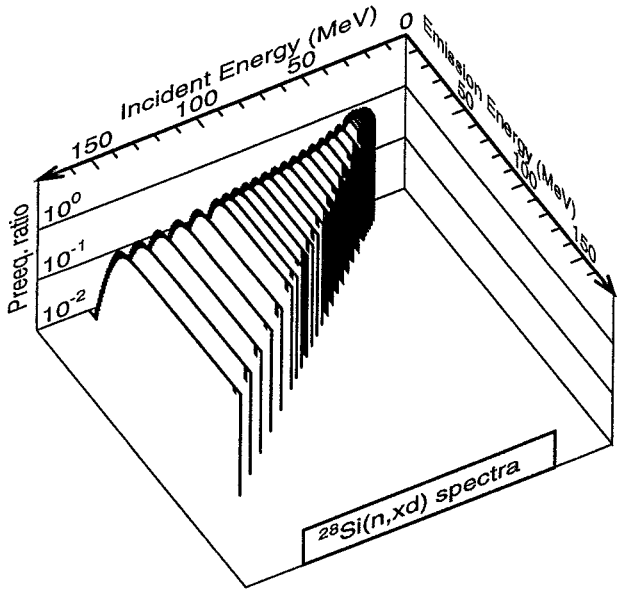


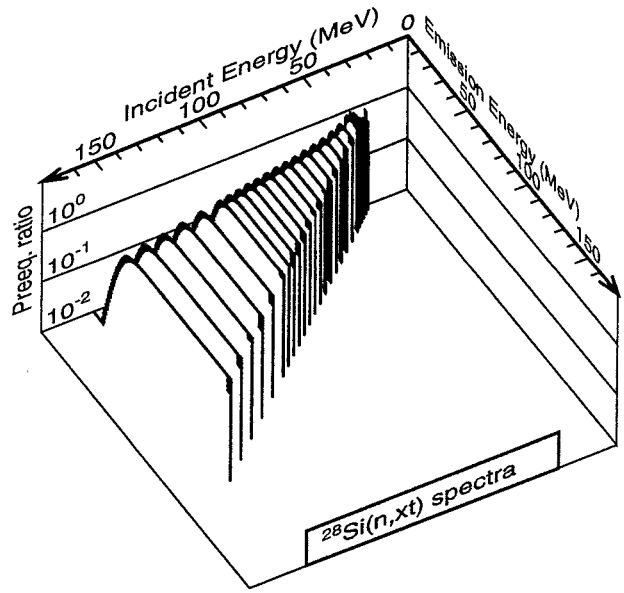


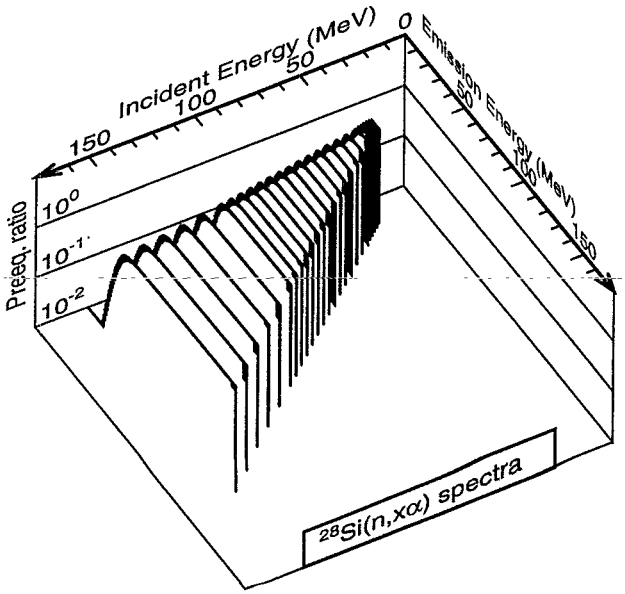
n + ^{28}Si Kalbach preequilibrium ratios

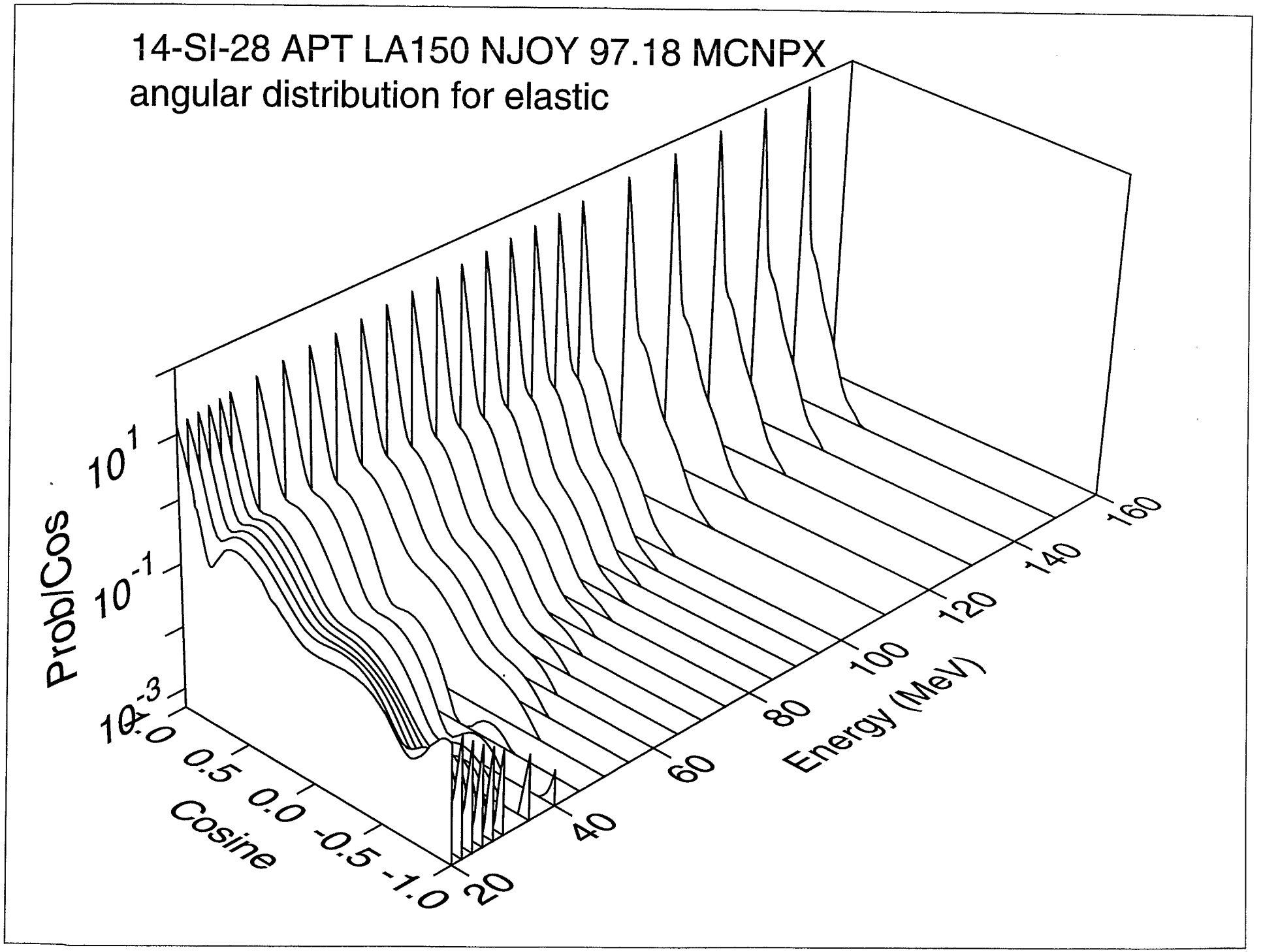


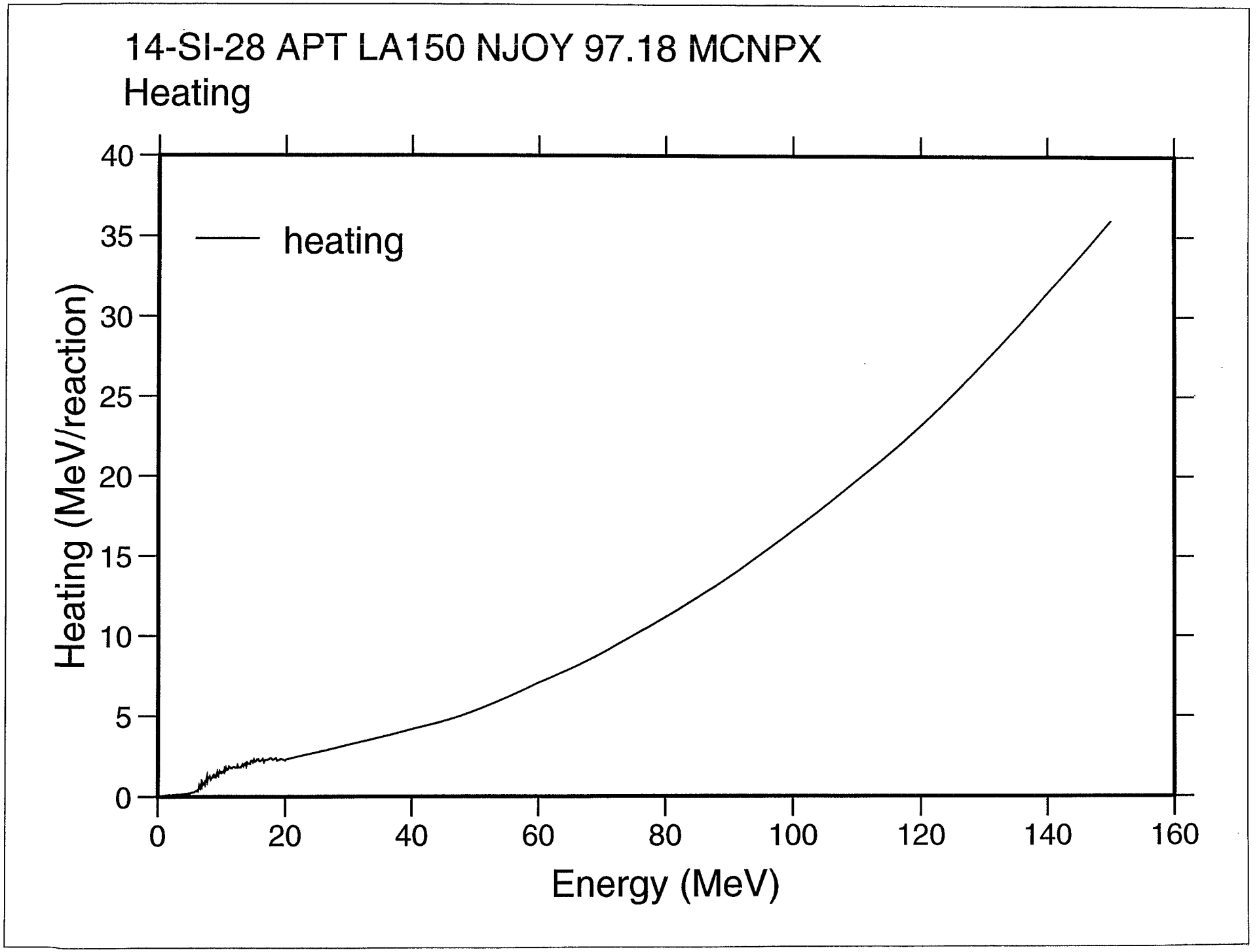


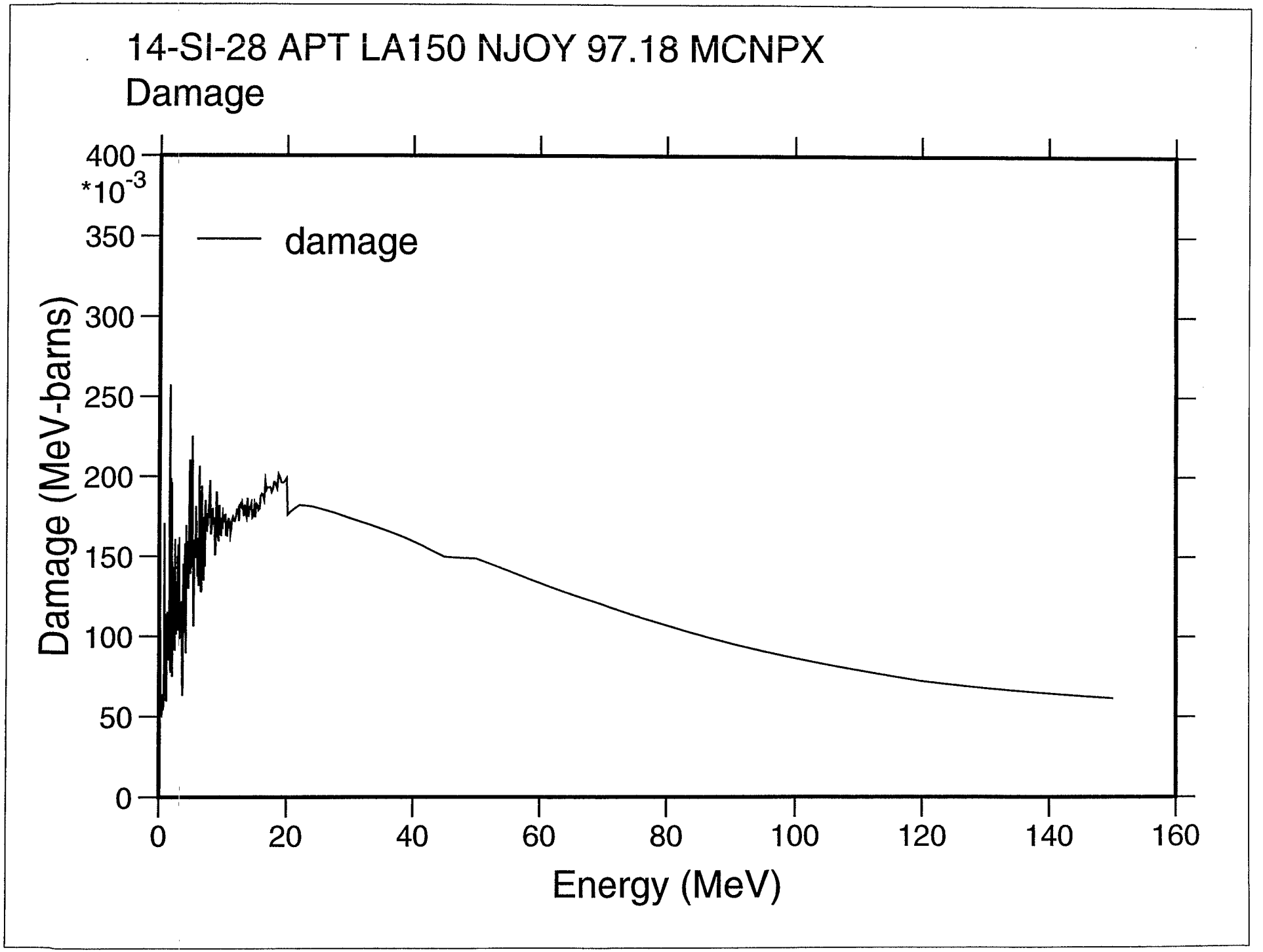







14-Si-28 APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic
Prob/Cos
10^{1}
10^{-1}
10^{-3}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
20
40
60
80
100
120
140
160


14-SI-28 APT LA150 NJOY 97.18 MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
5
10
15
20
25
30
35
40
0
20
40
60
80
100
120
140
160


14-SI-28 APT LA150 NJOY 97.18 MCNPX
Damage
damage
Damage (MeV-barns)
*10^-3
400
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF n + 29Si CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

M. B. Chadwick and P. G. Young
1 July 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI.5 (Release 5) evaluation by D. Hetrick, N. Larson, D. Larson, L. Leal, and S. Epperson.

INCIDENT NEUTRON ENERGIES > 20 MeV

The ENDF/B-VI Release 5 evaluation extends to 20 MeV and includes cross sections and energy-angle data for all significant reactions. The present evauation utilizes a more compact composite reaction spectrum representation above 20 MeV in order to reduce the length of the file. No essential data for applications is lost with this representation.

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT= 1	Total Cross Section
	MT= 2	Elastic Scattering Cross Section
	MT= 3	Nonelastic Cross Section
	MT= 5	Sum of Binary (n,n') and (n,x) Reactions
MF=4	MT= 2	Elastic Angular Distributions
MF=6	MT= 5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, Tritons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Si28 and p + Si28 reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

DETAILS OF THE n + SI-29 ANALYSIS

The neutron total cross section above 20 MeV was obtained by evaluating the nat-Si experimental data, with a particular emphasis on the high-accuracy Los Alamos measurements by Finlay (Fi93). The Si-28 total cross section, based on nat-Si data, was scaled by 1.02036 (an A**2/3 factor) for Si-29.

The Madland global medium-energy optical potential (Ma88) was used for neutrons above 46 MeV, and the Wilmore-Hodgson [Wi64] potential was used for lower neutron energies. The Madland global medium-energy optical potential was used for protons above 28 MeV, and the Beccheti-Greenlees [Be69] potential was used for lower proton energies. In both cases the transition region to the Madland potential was chosen to approximately give continuity in the reaction cross section. For deuterons, the Perey [Pe63] global potential was used; for alpha particles the MacFadden [Ma66] potential was used; and for tritons the Beccheti-Greenlees [Be71] potential was used.

While the above optical potentials did describe the experimental proton nonelastic cross section data fairly well, we modified the theoretical predictions slightly to better agree with the measurements, and renormalized the transmission coefficients accordingly. In addition to using Si nonelastic proton cross section measurements, we also were guided by p+Al nonelastic data, scaled by A**2/3. The Si-29 nonelastic cross section was taken by scaling the evaluated Si-28 value by 1.02036 (an A**2/3 factor).

Due to the small abundance of 29Si in nat-Si, a sophisticated DWBA treatment of inelastic scattering using a coupled-channels calculation was not undertaken (the rotational-vibrational collective structure of this nucleus is rather complicated). Instead, values for inelastic scattering obtained from the JENDL-3 evaluation (H.KITAZAWA et al.), for the 5/2+ (2.03 MeV) and 3/2+ (2.43 MeV) were extrapolated to higher energies using a 1/E variation.

The same preequilibrium input parameters were used as for Si-28, which was benchmarked against (n,xz) data from the Louvain group at 63 MeV, and against unpublished (n,xp) data by Haight et al. for neutrons up to 50 MeV. See our ENDF file-1 for n+28Si for more details.

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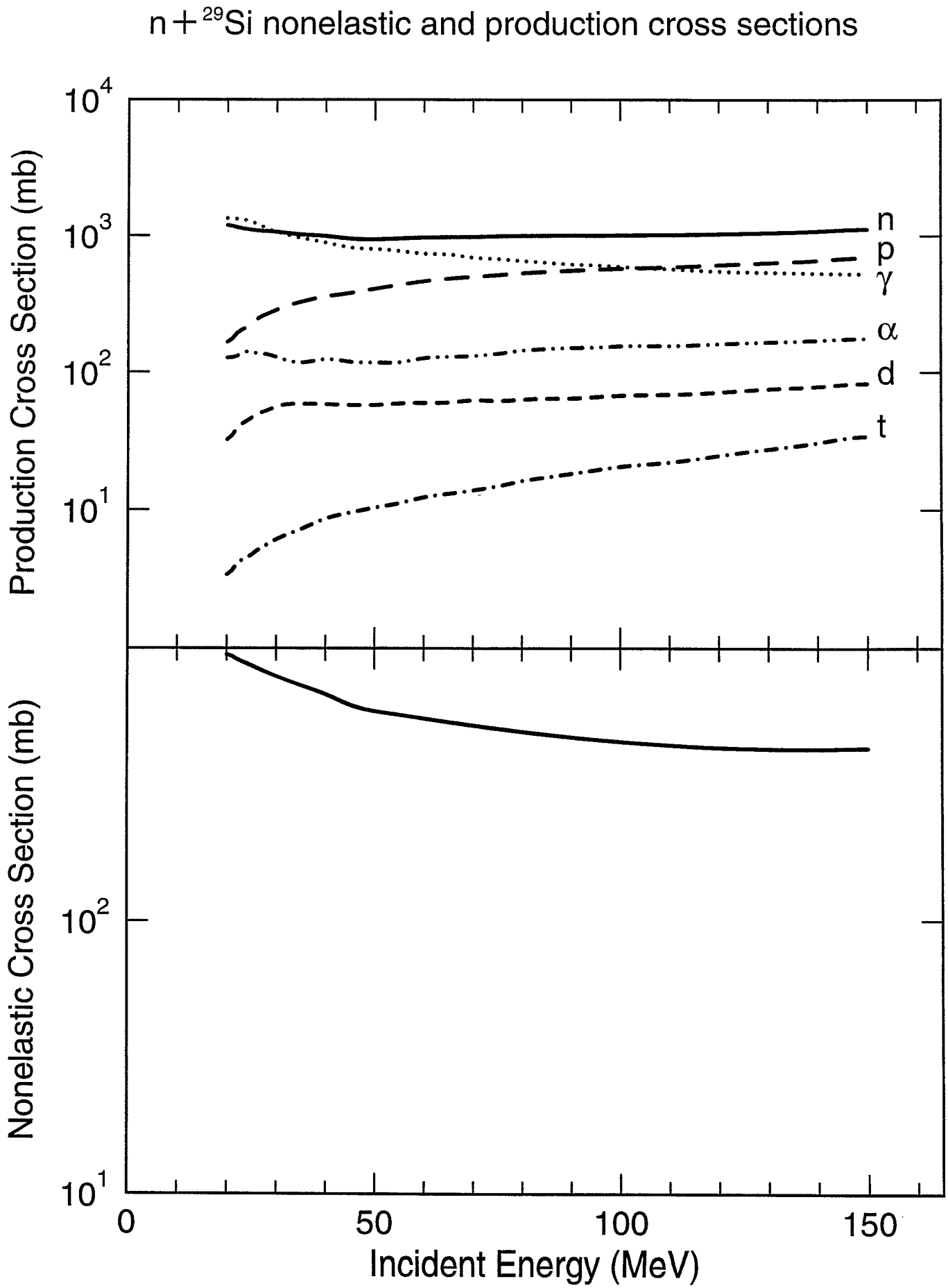
14029 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

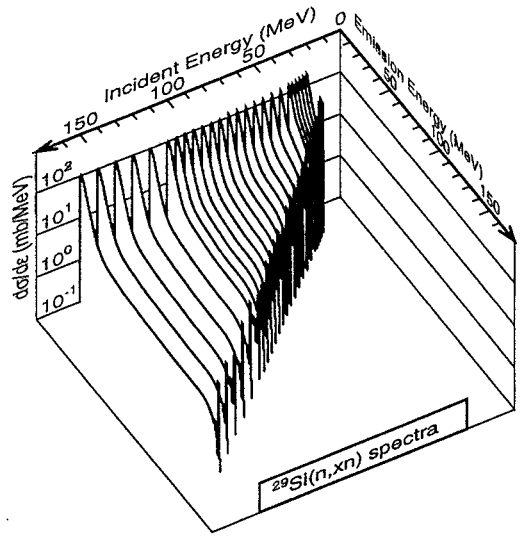
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	9.494E-01	9.341E-01	1.195E+00	1.660E-01	3.245E-02	3.399E-03	0.000E+00	1.274E-01	1.344E+00
2.200E+01	9.144E-01	1.010E+00	1.151E+00	1.930E-01	3.920E-02	4.073E-03	0.000E+00	1.314E-01	1.328E+00
2.400E+01	8.816E-01	1.070E+00	1.116E+00	2.135E-01	4.428E-02	4.476E-03	0.000E+00	1.413E-01	1.293E+00
2.600E+01	8.500E-01	1.121E+00	1.089E+00	2.439E-01	4.921E-02	5.075E-03	0.000E+00	1.375E-01	1.221E+00
2.800E+01	8.200E-01	1.160E+00	1.080E+00	2.652E-01	5.263E-02	5.592E-03	0.000E+00	1.350E-01	1.128E+00
3.000E+01	7.915E-01	1.191E+00	1.065E+00	2.853E-01	5.627E-02	6.106E-03	0.000E+00	1.285E-01	1.063E+00
3.500E+01	7.282E-01	1.245E+00	1.019E+00	3.274E-01	5.900E-02	7.253E-03	0.000E+00	1.176E-01	9.620E-01
4.000E+01	6.749E-01	1.261E+00	9.927E-01	3.581E-01	5.855E-02	8.640E-03	0.000E+00	1.244E-01	8.893E-01
4.500E+01	6.189E-01	1.257E+00	9.516E-01	3.796E-01	5.785E-02	9.539E-03	0.000E+00	1.188E-01	8.171E-01
5.000E+01	5.873E-01	1.219E+00	9.414E-01	4.075E-01	5.786E-02	1.036E-02	0.000E+00	1.176E-01	7.961E-01
5.500E+01	5.689E-01	1.157E+00	9.568E-01	4.361E-01	5.940E-02	1.115E-02	0.000E+00	1.182E-01	7.726E-01
6.000E+01	5.509E-01	1.087E+00	9.716E-01	4.641E-01	6.009E-02	1.229E-02	0.000E+00	1.267E-01	7.383E-01
6.500E+01	5.345E-01	1.019E+00	9.777E-01	4.846E-01	6.045E-02	1.305E-02	0.000E+00	1.295E-01	7.288E-01
7.000E+01	5.195E-01	9.567E-01	9.814E-01	5.004E-01	6.261E-02	1.382E-02	0.000E+00	1.319E-01	6.911E-01
7.500E+01	5.057E-01	8.885E-01	9.920E-01	5.142E-01	6.196E-02	1.481E-02	0.000E+00	1.366E-01	6.749E-01
8.000E+01	4.931E-01	8.264E-01	9.984E-01	5.306E-01	6.324E-02	1.619E-02	0.000E+00	1.443E-01	6.530E-01
8.500E+01	4.815E-01	7.643E-01	1.002E+00	5.429E-01	6.435E-02	1.726E-02	0.000E+00	1.479E-01	6.342E-01
9.000E+01	4.712E-01	7.132E-01	1.007E+00	5.540E-01	6.460E-02	1.830E-02	0.000E+00	1.508E-01	6.162E-01
9.500E+01	4.617E-01	6.623E-01	1.005E+00	5.646E-01	6.613E-02	1.946E-02	0.000E+00	1.521E-01	6.070E-01
1.000E+02	4.534E-01	6.164E-01	1.011E+00	5.730E-01	6.759E-02	2.062E-02	0.000E+00	1.553E-01	5.911E-01
1.100E+02	4.398E-01	5.388E-01	1.017E+00	5.865E-01	6.877E-02	2.216E-02	0.000E+00	1.560E-01	5.685E-01
1.200E+02	4.304E-01	4.714E-01	1.032E+00	6.082E-01	7.133E-02	2.479E-02	0.000E+00	1.609E-01	5.470E-01
1.300E+02	4.259E-01	4.125E-01	1.051E+00	6.317E-01	7.540E-02	2.767E-02	0.000E+00	1.660E-01	5.371E-01
1.400E+02	4.249E-01	3.613E-01	1.083E+00	6.588E-01	7.871E-02	3.085E-02	0.000E+00	1.712E-01	5.293E-01
1.500E+02	4.276E-01	3.176E-01	1.118E+00	6.908E-01	8.282E-02	3.422E-02	0.000E+00	1.762E-01	5.238E-01

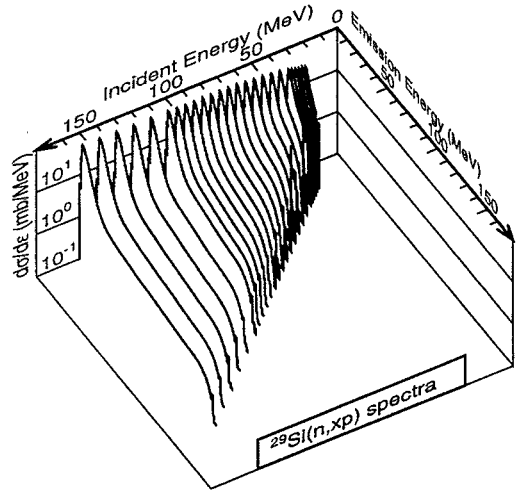
14029 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

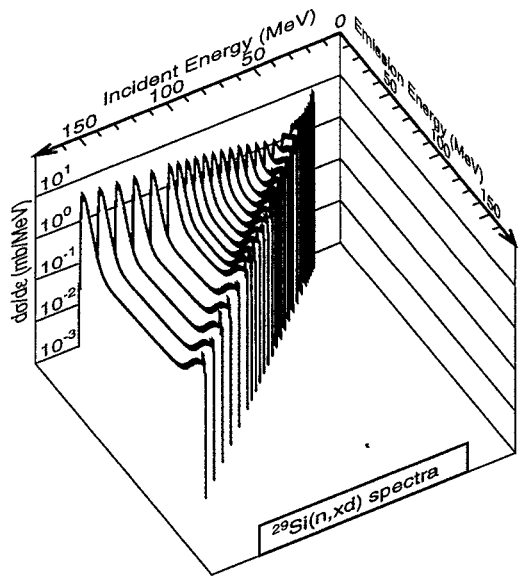
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	3.237E-01	6.756E-02	5.207E-03	0.000E+00	3.198E-01	2.689E-01	7.530E-02	1.060E+00
2.200E+01	3.995E-01	9.700E-02	7.221E-03	0.000E+00	3.383E-01	2.802E-01	8.866E-02	1.211E+00
2.400E+01	4.647E-01	1.268E-01	9.150E-03	0.000E+00	3.706E-01	2.883E-01	8.837E-02	1.348E+00
2.600E+01	5.511E-01	1.596E-01	1.177E-02	0.000E+00	3.736E-01	2.943E-01	8.717E-02	1.478E+00
2.800E+01	6.299E-01	1.887E-01	1.447E-02	0.000E+00	3.760E-01	2.972E-01	8.518E-02	1.591E+00
3.000E+01	7.150E-01	2.250E-01	1.737E-02	0.000E+00	3.681E-01	2.988E-01	8.286E-02	1.707E+00
3.500E+01	9.197E-01	2.978E-01	2.427E-02	0.000E+00	3.547E-01	3.045E-01	7.670E-02	1.978E+00
4.000E+01	1.101E+00	3.597E-01	3.126E-02	0.000E+00	3.792E-01	3.166E-01	7.010E-02	2.258E+00
4.500E+01	1.267E+00	4.132E-01	3.744E-02	0.000E+00	3.689E-01	3.158E-01	6.427E-02	2.467E+00
5.000E+01	1.455E+00	4.658E-01	4.266E-02	0.000E+00	3.688E-01	3.220E-01	7.421E-02	2.728E+00
5.500E+01	1.665E+00	5.315E-01	4.795E-02	0.000E+00	3.731E-01	3.333E-01	6.664E-02	3.018E+00
6.000E+01	1.867E+00	5.819E-01	5.294E-02	0.000E+00	3.986E-01	3.431E-01	5.999E-02	3.303E+00
6.500E+01	2.062E+00	6.294E-01	5.751E-02	0.000E+00	4.077E-01	3.487E-01	5.441E-02	3.560E+00
7.000E+01	2.245E+00	7.038E-01	6.182E-02	0.000E+00	4.164E-01	3.580E-01	4.972E-02	3.835E+00
7.500E+01	2.430E+00	7.252E-01	6.640E-02	0.000E+00	4.307E-01	3.605E-01	4.522E-02	4.058E+00
8.000E+01	2.607E+00	7.740E-01	7.151E-02	0.000E+00	4.571E-01	3.653E-01	4.135E-02	4.316E+00
8.500E+01	2.781E+00	8.235E-01	7.521E-02	0.000E+00	4.679E-01	3.685E-01	3.772E-02	4.554E+00
9.000E+01	2.959E+00	8.535E-01	7.899E-02	0.000E+00	4.791E-01	3.716E-01	3.481E-02	4.777E+00
9.500E+01	3.134E+00	9.088E-01	8.276E-02	0.000E+00	4.857E-01	3.737E-01	3.203E-02	5.017E+00
1.000E+02	3.308E+00	9.622E-01	8.641E-02	0.000E+00	4.976E-01	3.762E-01	2.958E-02	5.260E+00
1.100E+02	3.693E+00	1.035E+00	9.186E-02	0.000E+00	5.050E-01	3.718E-01	2.554E-02	5.722E+00
1.200E+02	4.079E+00	1.116E+00	9.971E-02	0.000E+00	5.280E-01	3.780E-01	2.214E-02	6.222E+00
1.300E+02	4.497E+00	1.234E+00	1.084E-01	0.000E+00	5.505E-01	3.962E-01	1.921E-02	6.806E+00
1.400E+02	4.970E+00	1.308E+00	1.184E-01	0.000E+00	5.777E-01	4.168E-01	1.670E-02	7.407E+00
1.500E+02	5.478E+00	1.403E+00	1.290E-01	0.000E+00	6.046E-01	4.454E-01	1.455E-02	8.075E+00

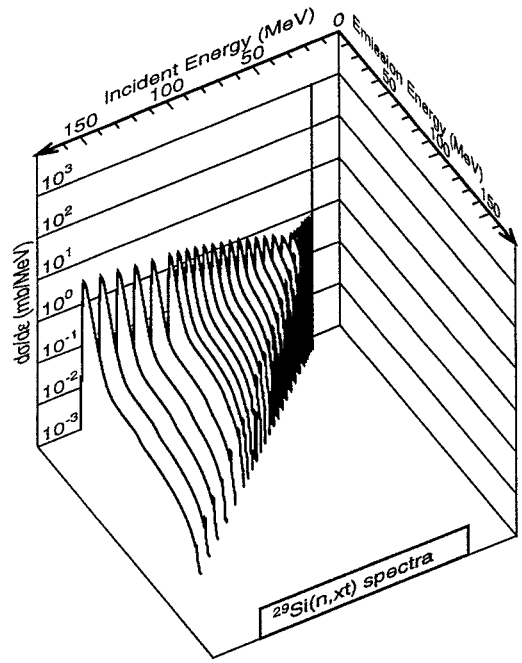

n + 29Si nonelastic and production cross sections
Production Cross Section (mb)
Nonelastic Cross Section (mb)
Incident Energy (MeV)
n
p
γ
α
d
t
10^4
10^3
10^2
10^1
0
50
100
150

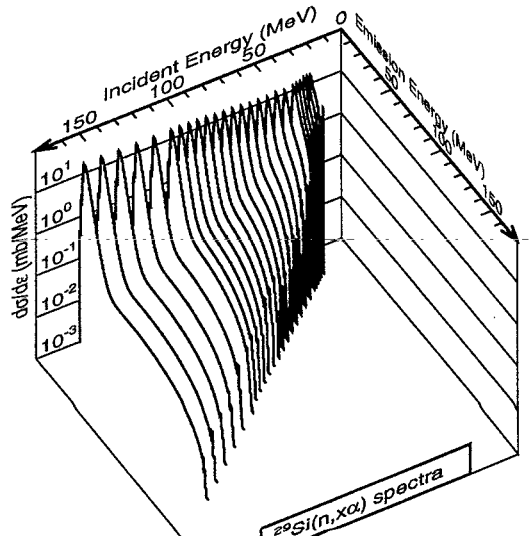
n + ^{29}Si angle-integrated emission spectra

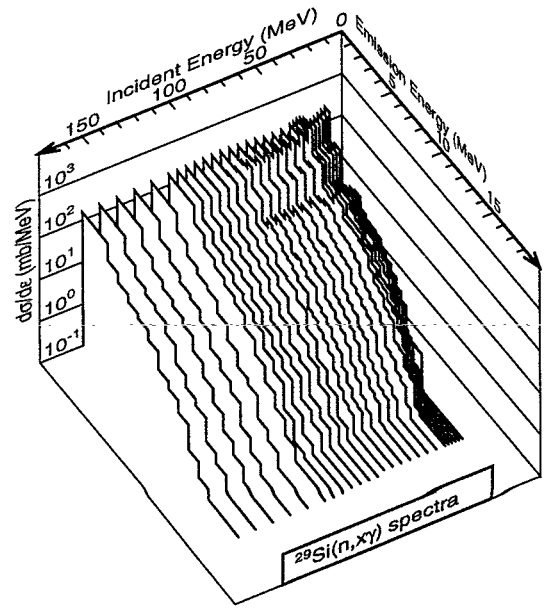




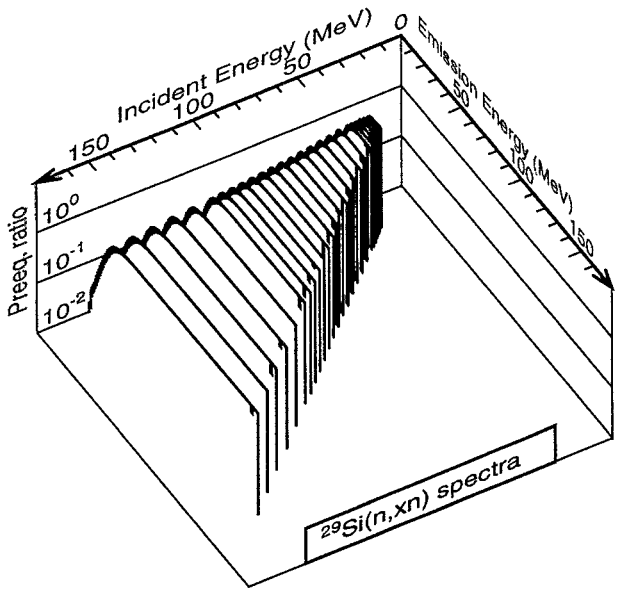


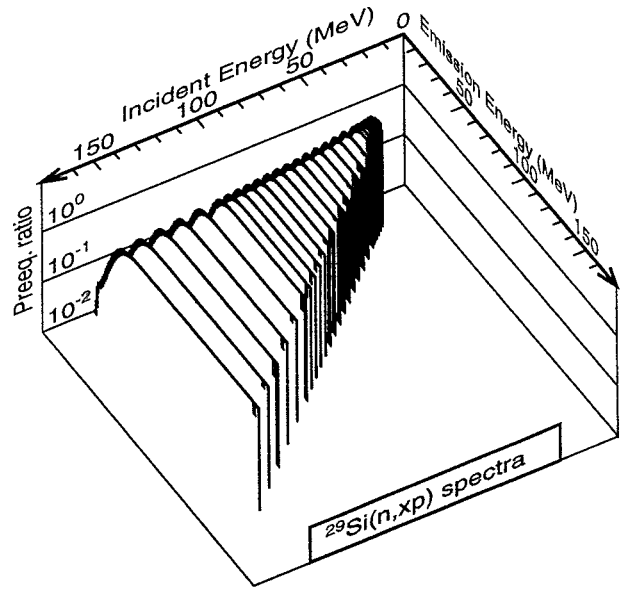


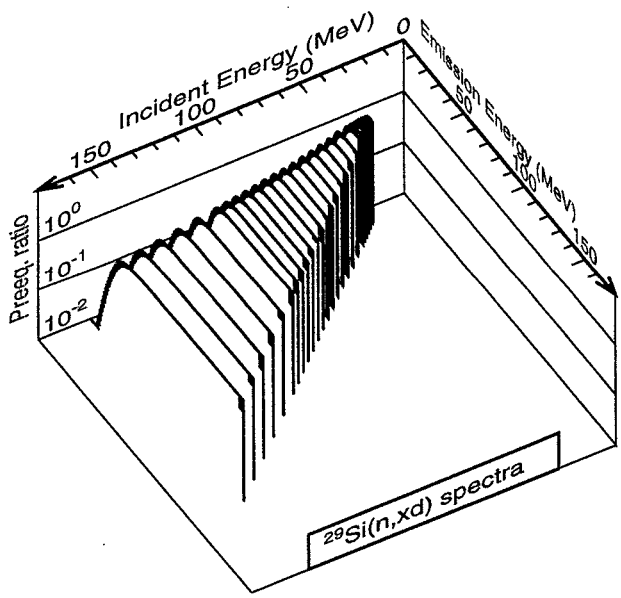


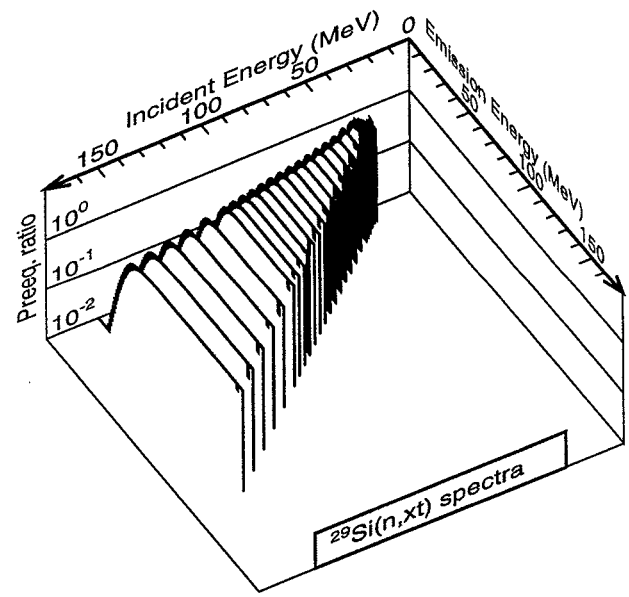


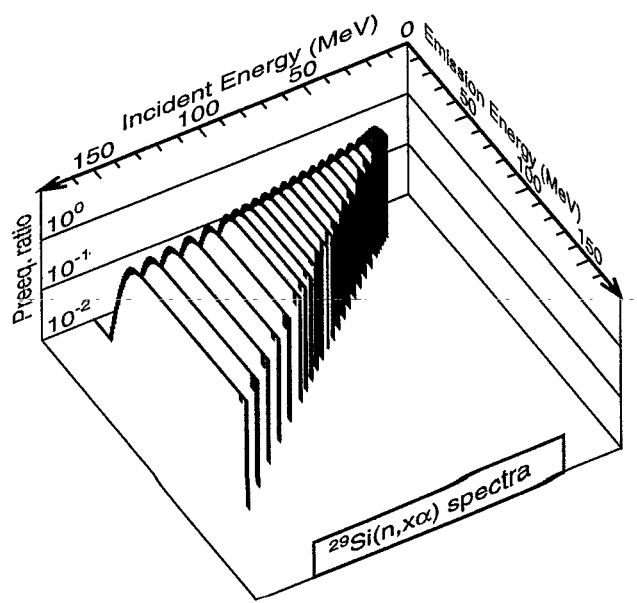
n + ^{29}Si Kalbach preequilibrium ratios

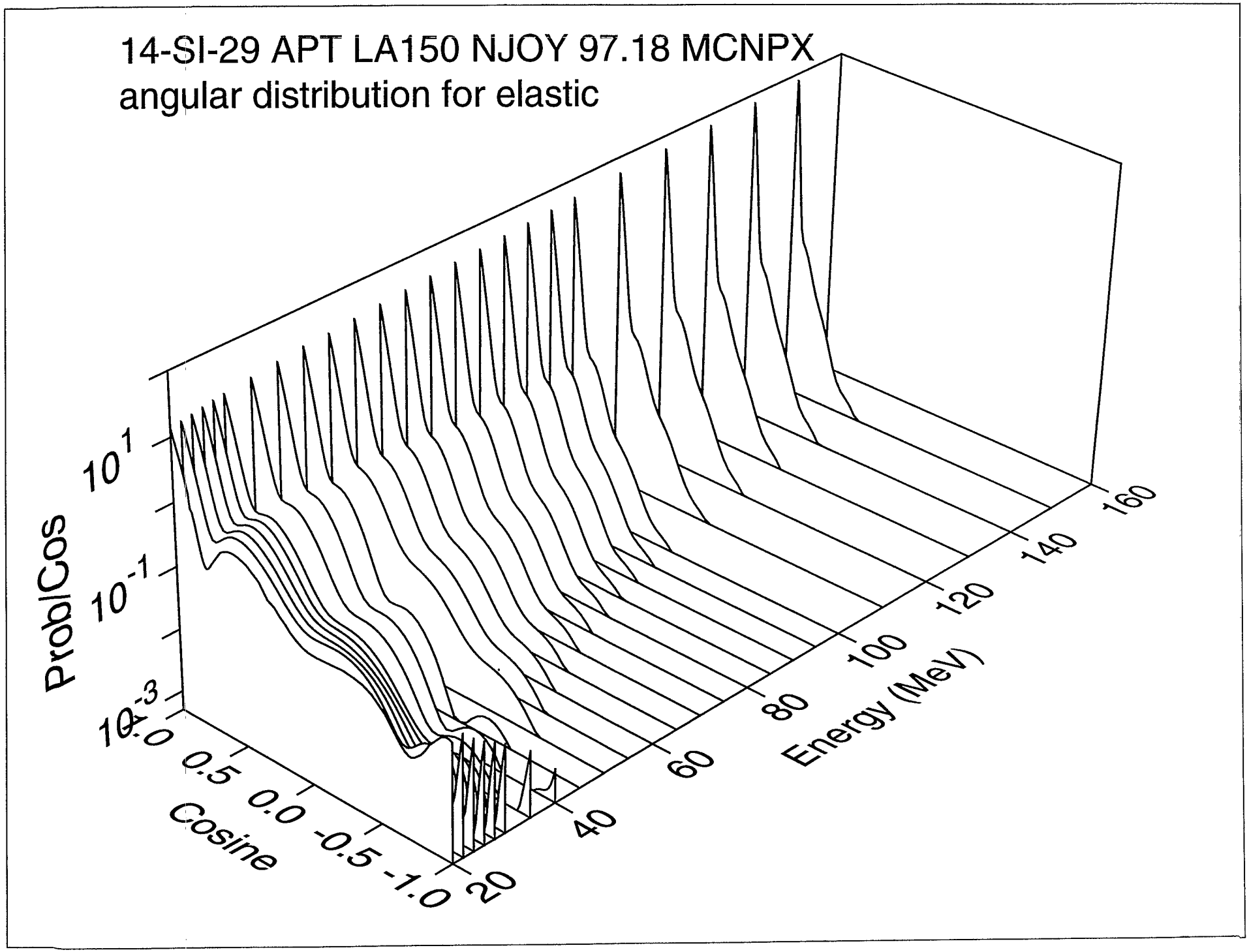


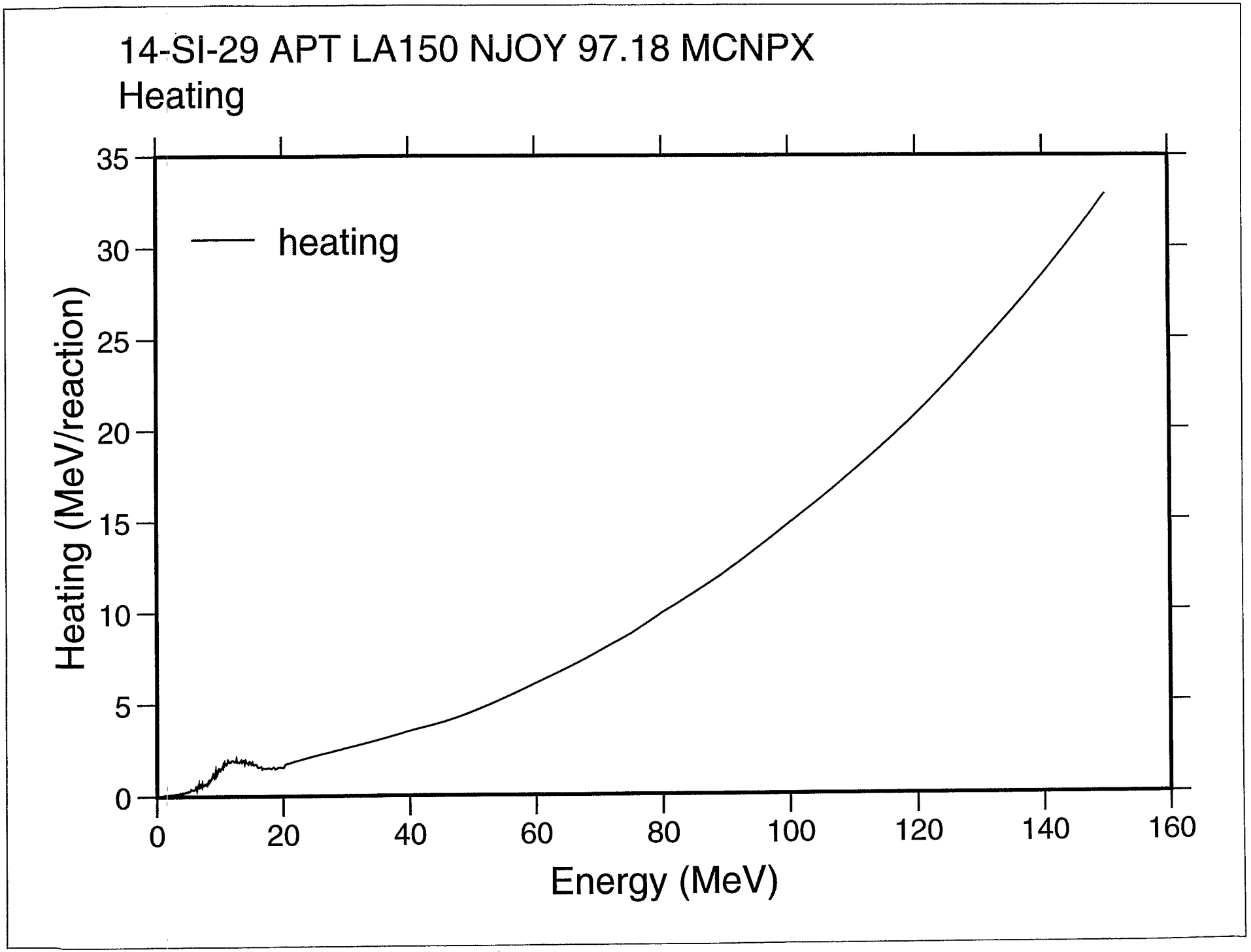


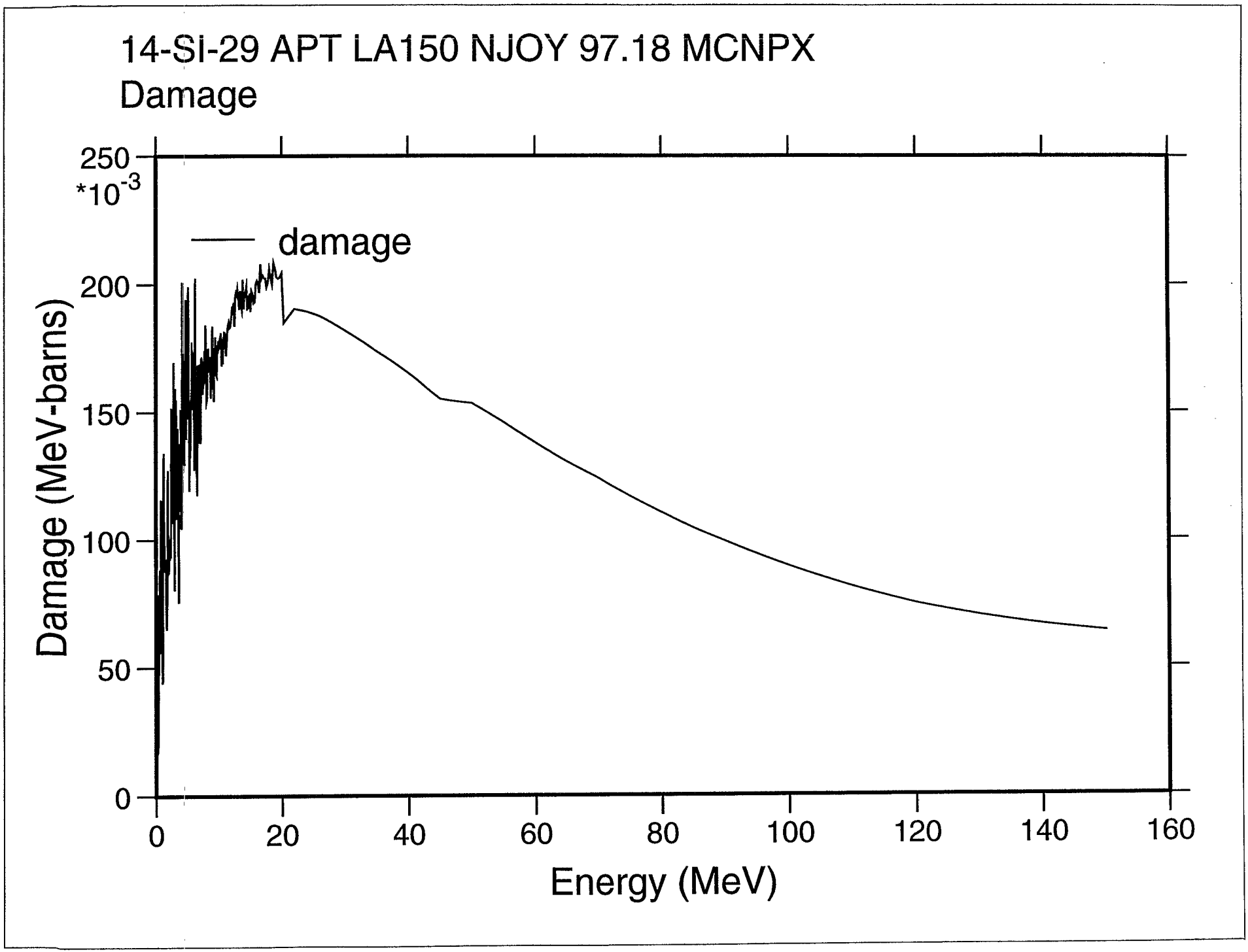







14-SI-29 APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic
Prob/Cos
10^{1}
10^{-1}
10^{-3}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
20
40
60
80
100
120
140
160


14-SI-29 APT LA150 NJOY 97.18 MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
5
10
15
20
25
30
35
0
20
40
60
80
100
120
140
160


14-Si-29 APT LA150 NJOY 97.18 MCNPX
Damage
damage
Damage (MeV-barns)
*10^-3
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF n + 30Si CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

M. B. Chadwick and P. G. Young
1 July 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI.5 (Release 5) evaluation by D. Hetrick, N. Larson, D. Larson, L. Leal, and S. Epperson.

INCIDENT NEUTRON ENERGIES > 20 MeV

The ENDF/B-VI Release 5 evaluation extends to 20 MeV and includes cross sections and energy-angle data for all significant reactions. The present evauation utilizes a more compact composite reaction spectrum representation above 20 MeV in order to reduce the length of the file. No essential data for applications is lost with this representation.

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT= 1	Total Cross Section
	MT= 2	Elastic Scattering Cross Section
	MT= 3	Nonelastic Cross Section
	MT= 5	Sum of Binary (n,n') and (n,x) Reactions
MF=4	MT= 2	Elastic Angular Distributions
MF=6	MT= 5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, Tritons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Si28 and p + Si28 reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

DETAILS OF THE n + SI-30 ANALYSIS

The neutron total cross section above 20 MeV was obtained by evaluating the nat-Si experimental data, with a particular emphasis on the high-accuracy Los Alamos measurements by Finlay (Fi93). The Si-28 total cross section, based on nat-Si data, was scaled by 1.047 (an A**2/3 factor) for Si-30.

The Madland global medium-energy optical potential (Ma88) was used for neutrons above 46 MeV, and the Wilmore-Hodgson potential was used for lower neutron energies. The Madland global medium-energy optical potential was used for protons above 28 MeV, and the Beccheti-Greenlees potential was used for lower proton energies. In both cases the transition region to the Madland potential was chosen to approximately give continuity in the reaction cross section. For deuterons, the Perey global potential was used; for alpha particles the Moyen potential was used; and for tritons the Beccheti-Greenlees potential was used.

While the above optical potentials did describe the experimental proton nonelastic cross section data fairly well, we modified the theoretical predictions slightly to better agree with the measurements, and renormalized the transmission coefficients accordingly. In addition to using Si nonelastic proton cross section measurements, we also were guided by p+Al nonelastic data, scaled by A**2/3. The Si-30 nonelastic cross section was taken by scaling the evaluated Si-28 value by 1.047 (an A**2/3 factor).

Inelastic scattering to the 2+ (2.24 MeV) and 4+ (5.95 MeV) states in 30-Si was determined using a coupled-channel ECIS calculation. To produce continuity in the calculated inelastic cross sections up to 150 MeV, we performed an oblate rotational band (0+, 2+, 4+) coupled channel calculation using the Madland medium energy potential (with its imaginary potential reduced by 20%, to approximately account for the coupling). Deformation parameters were chosen to reproduce the JENDL-3 evaluation at 20 MeV (H.KITAZAWA et al.). The resulting deformation parameters (beta_2=-0.33, beta_4=0.20) were close to those used for Si-28.

The same preequilibrium input parameters were used as for Si-28, which was benchmarked against (n,xz) data from the Louvain group at 63 MeV, and against unpublished (n,xp) data by Haight et al. for neutrons up to 50 MeV. See our ENDF file-1 for n+28Si

for more details.

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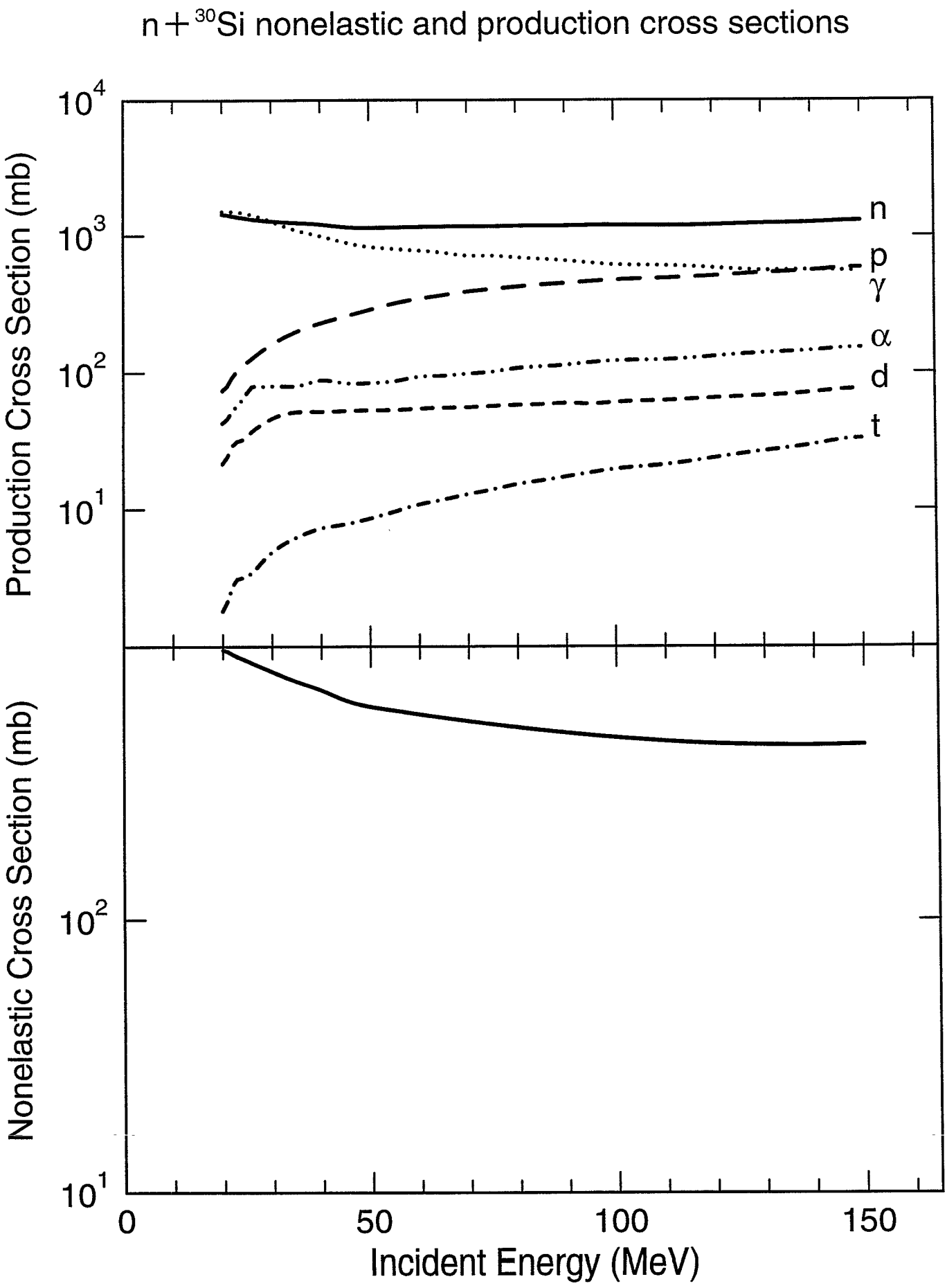
14030 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

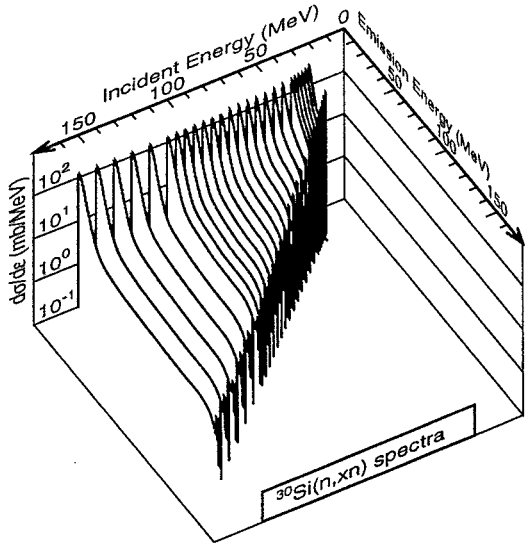
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	9.712E-01	9.555E-01	1.431E+00	7.360E-02	2.140E-02	1.812E-03	0.000E+00	4.257E-02	1.499E+00
2.200E+01	9.353E-01	1.033E+00	1.392E+00	9.227E-02	2.902E-02	2.762E-03	0.000E+00	5.206E-02	1.496E+00
2.400E+01	9.017E-01	1.094E+00	1.356E+00	1.110E-01	3.213E-02	3.174E-03	0.000E+00	6.293E-02	1.469E+00
2.600E+01	8.695E-01	1.146E+00	1.319E+00	1.264E-01	3.700E-02	3.467E-03	0.000E+00	7.857E-02	1.420E+00
2.800E+01	8.387E-01	1.186E+00	1.295E+00	1.439E-01	4.168E-02	4.155E-03	0.000E+00	7.899E-02	1.353E+00
3.000E+01	8.096E-01	1.219E+00	1.276E+00	1.604E-01	4.596E-02	4.874E-03	0.000E+00	7.960E-02	1.273E+00
3.500E+01	7.448E-01	1.274E+00	1.243E+00	1.986E-01	5.143E-02	6.250E-03	0.000E+00	7.953E-02	1.096E+00
4.000E+01	6.903E-01	1.290E+00	1.209E+00	2.301E-01	5.178E-02	7.270E-03	0.000E+00	8.771E-02	9.926E-01
4.500E+01	6.331E-01	1.286E+00	1.154E+00	2.579E-01	5.241E-02	7.806E-03	0.000E+00	8.364E-02	8.919E-01
5.000E+01	6.007E-01	1.247E+00	1.140E+00	2.880E-01	5.292E-02	8.593E-03	0.000E+00	8.373E-02	8.269E-01
5.500E+01	5.819E-01	1.183E+00	1.148E+00	3.208E-01	5.310E-02	9.612E-03	0.000E+00	8.619E-02	7.991E-01
6.000E+01	5.635E-01	1.112E+00	1.157E+00	3.460E-01	5.424E-02	1.084E-02	0.000E+00	9.301E-02	7.762E-01
6.500E+01	5.467E-01	1.043E+00	1.165E+00	3.680E-01	5.505E-02	1.178E-02	0.000E+00	9.457E-02	7.493E-01
7.000E+01	5.313E-01	9.786E-01	1.170E+00	3.911E-01	5.551E-02	1.285E-02	0.000E+00	9.796E-02	7.124E-01
7.500E+01	5.173E-01	9.088E-01	1.169E+00	4.073E-01	5.659E-02	1.389E-02	0.000E+00	1.010E-01	7.103E-01
8.000E+01	5.044E-01	8.453E-01	1.177E+00	4.234E-01	5.756E-02	1.518E-02	0.000E+00	1.070E-01	6.900E-01
8.500E+01	4.925E-01	7.817E-01	1.182E+00	4.379E-01	5.822E-02	1.615E-02	0.000E+00	1.100E-01	6.735E-01
9.000E+01	4.819E-01	7.295E-01	1.183E+00	4.493E-01	5.944E-02	1.725E-02	0.000E+00	1.129E-01	6.561E-01
9.500E+01	4.723E-01	6.774E-01	1.193E+00	4.628E-01	5.878E-02	1.848E-02	0.000E+00	1.175E-01	6.317E-01
1.000E+02	4.637E-01	6.305E-01	1.195E+00	4.743E-01	6.028E-02	1.961E-02	0.000E+00	1.210E-01	6.129E-01
1.100E+02	4.498E-01	5.512E-01	1.188E+00	4.881E-01	6.218E-02	2.105E-02	0.000E+00	1.231E-01	6.026E-01
1.200E+02	4.402E-01	4.822E-01	1.200E+00	5.077E-01	6.481E-02	2.359E-02	0.000E+00	1.299E-01	5.807E-01
1.300E+02	4.356E-01	4.220E-01	1.231E+00	5.337E-01	6.711E-02	2.648E-02	0.000E+00	1.376E-01	5.567E-01
1.400E+02	4.346E-01	3.696E-01	1.252E+00	5.574E-01	7.094E-02	2.951E-02	0.000E+00	1.437E-01	5.615E-01
1.500E+02	4.374E-01	3.249E-01	1.289E+00	5.850E-01	7.512E-02	3.283E-02	0.000E+00	1.505E-01	5.542E-01

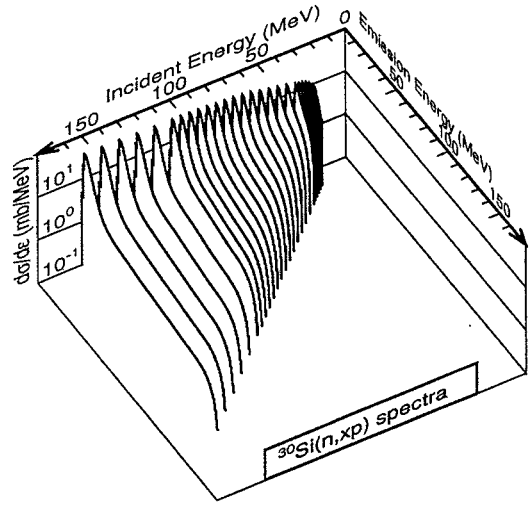
14030 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

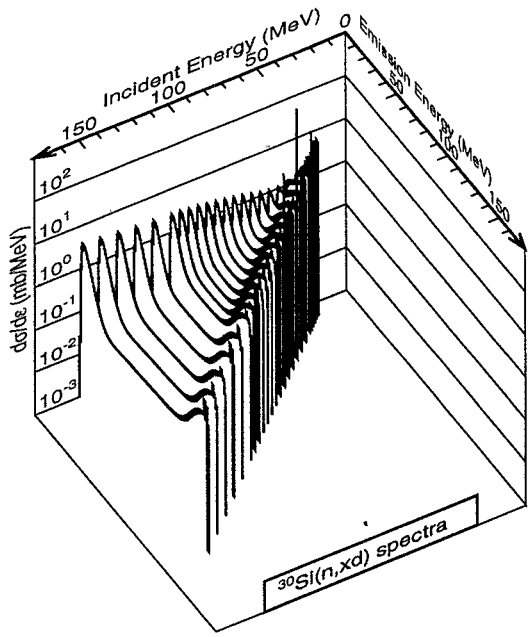
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	1.341E-01	3.664E-02	1.968E-03	0.000E+00	8.574E-02	2.367E-01	7.215E-02	5.673E-01
2.200E+01	1.814E-01	6.101E-02	3.640E-03	0.000E+00	1.065E-01	2.488E-01	8.611E-02	6.874E-01
2.400E+01	2.325E-01	7.927E-02	4.917E-03	0.000E+00	1.323E-01	2.601E-01	8.571E-02	7.947E-01
2.600E+01	2.857E-01	1.058E-01	6.132E-03	0.000E+00	1.700E-01	2.686E-01	8.442E-02	9.207E-01
2.800E+01	3.496E-01	1.349E-01	8.100E-03	0.000E+00	1.809E-01	2.745E-01	8.237E-02	1.030E+00
3.000E+01	4.165E-01	1.666E-01	1.032E-02	0.000E+00	1.896E-01	2.791E-01	8.000E-02	1.142E+00
3.500E+01	5.951E-01	2.351E-01	1.592E-02	0.000E+00	1.994E-01	2.868E-01	7.372E-02	1.406E+00
4.000E+01	7.657E-01	2.874E-01	2.112E-02	0.000E+00	2.276E-01	2.948E-01	6.712E-02	1.664E+00
4.500E+01	9.280E-01	3.468E-01	2.536E-02	0.000E+00	2.228E-01	2.954E-01	6.134E-02	1.880E+00
5.000E+01	1.111E+00	4.005E-01	2.960E-02	0.000E+00	2.264E-01	3.018E-01	6.988E-02	2.139E+00
5.500E+01	1.320E+00	4.457E-01	3.415E-02	0.000E+00	2.354E-01	3.107E-01	6.277E-02	2.409E+00
6.000E+01	1.506E+00	5.012E-01	3.886E-02	0.000E+00	2.577E-01	3.205E-01	5.652E-02	2.681E+00
6.500E+01	1.701E+00	5.501E-01	4.295E-02	0.000E+00	2.643E-01	3.268E-01	5.128E-02	2.936E+00
7.000E+01	1.890E+00	5.893E-01	4.737E-02	0.000E+00	2.750E-01	3.325E-01	4.689E-02	3.181E+00
7.500E+01	2.070E+00	6.382E-01	5.143E-02	0.000E+00	2.862E-01	3.373E-01	4.266E-02	3.426E+00
8.000E+01	2.241E+00	6.821E-01	5.586E-02	0.000E+00	3.068E-01	3.428E-01	3.903E-02	3.668E+00
8.500E+01	2.423E+00	7.178E-01	5.956E-02	0.000E+00	3.167E-01	3.457E-01	3.563E-02	3.898E+00
9.000E+01	2.599E+00	7.673E-01	6.320E-02	0.000E+00	3.262E-01	3.481E-01	3.290E-02	4.137E+00
9.500E+01	2.792E+00	7.636E-01	6.718E-02	0.000E+00	3.410E-01	3.473E-01	3.029E-02	4.341E+00
1.000E+02	2.966E+00	8.136E-01	7.069E-02	0.000E+00	3.517E-01	3.493E-01	2.799E-02	4.579E+00
1.100E+02	3.341E+00	9.093E-01	7.533E-02	0.000E+00	3.598E-01	3.498E-01	2.421E-02	5.060E+00
1.200E+02	3.724E+00	9.936E-01	8.292E-02	0.000E+00	3.833E-01	3.551E-01	2.101E-02	5.559E+00
1.300E+02	4.158E+00	1.043E+00	9.155E-02	0.000E+00	4.118E-01	3.671E-01	1.826E-02	6.089E+00
1.400E+02	4.599E+00	1.142E+00	1.005E-01	0.000E+00	4.366E-01	3.924E-01	1.589E-02	6.687E+00
1.500E+02	5.095E+00	1.240E+00	1.107E-01	0.000E+00	4.625E-01	4.195E-01	1.386E-02	7.342E+00

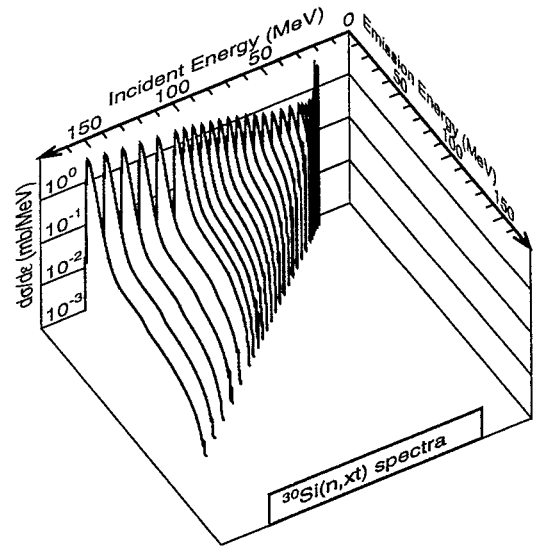

n + 30Si nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
n
p
γ
α
d
t
Nonelastic Cross Section (mb)
10^2
10^1
0
50
100
150
Incident Energy (MeV)

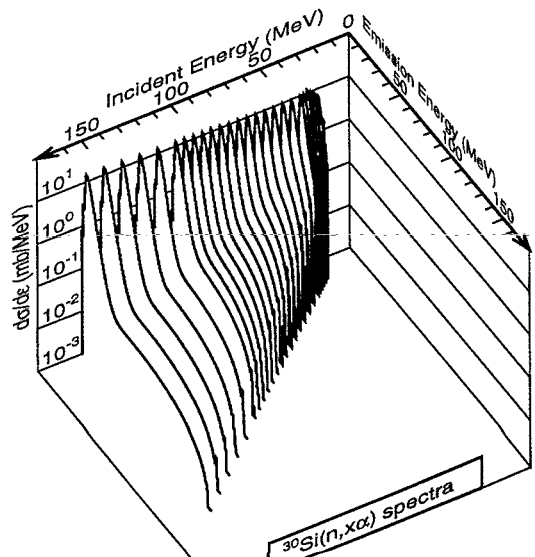
n + ^{30}Si angle-integrated emission spectra

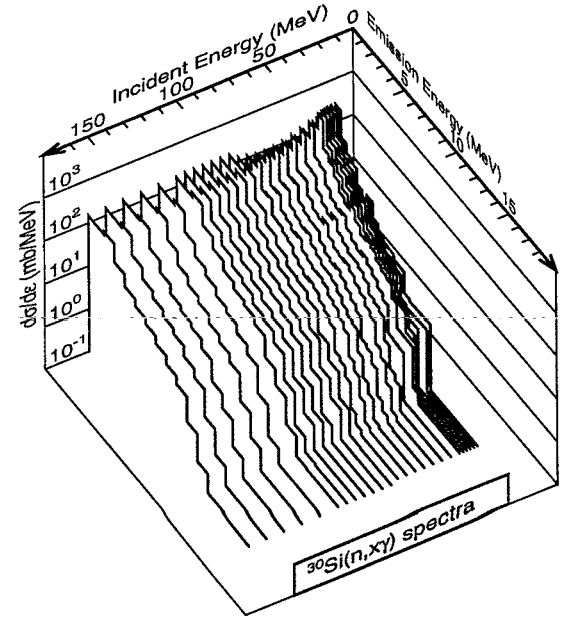




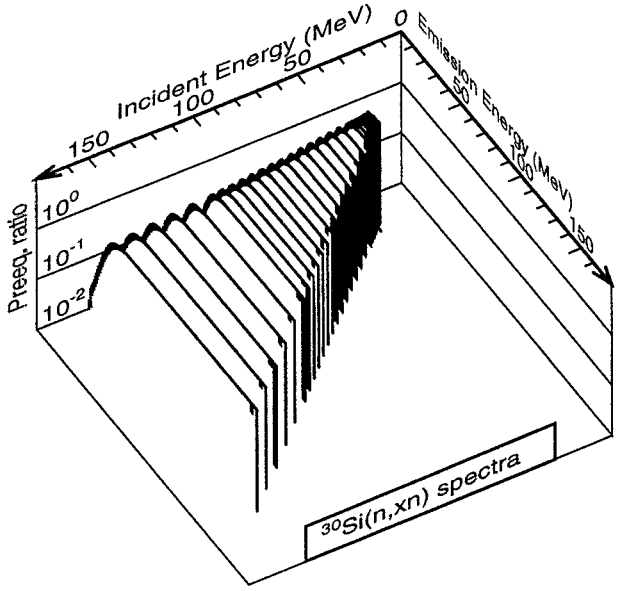


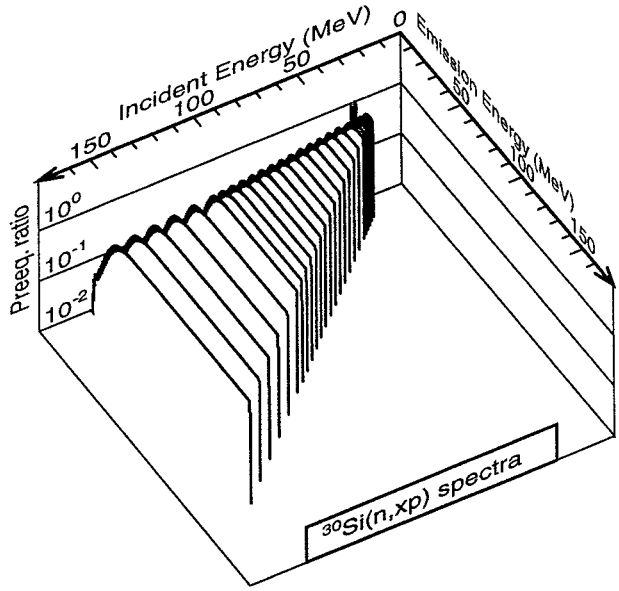


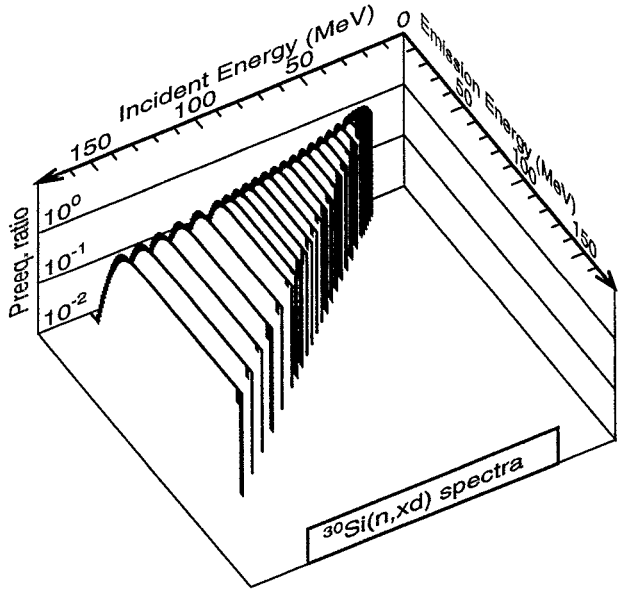


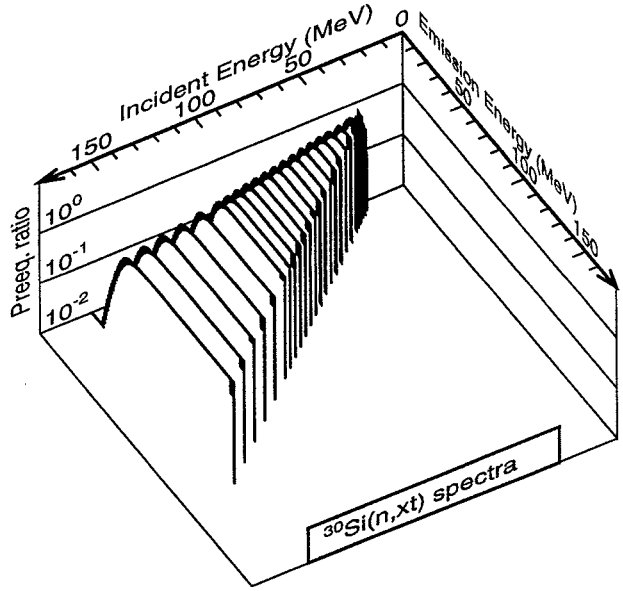


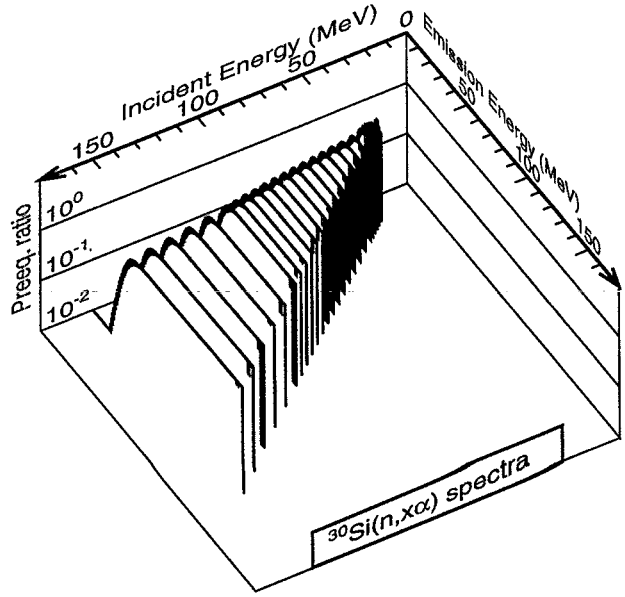
n + ^{30}Si Kalbach preequilibrium ratios

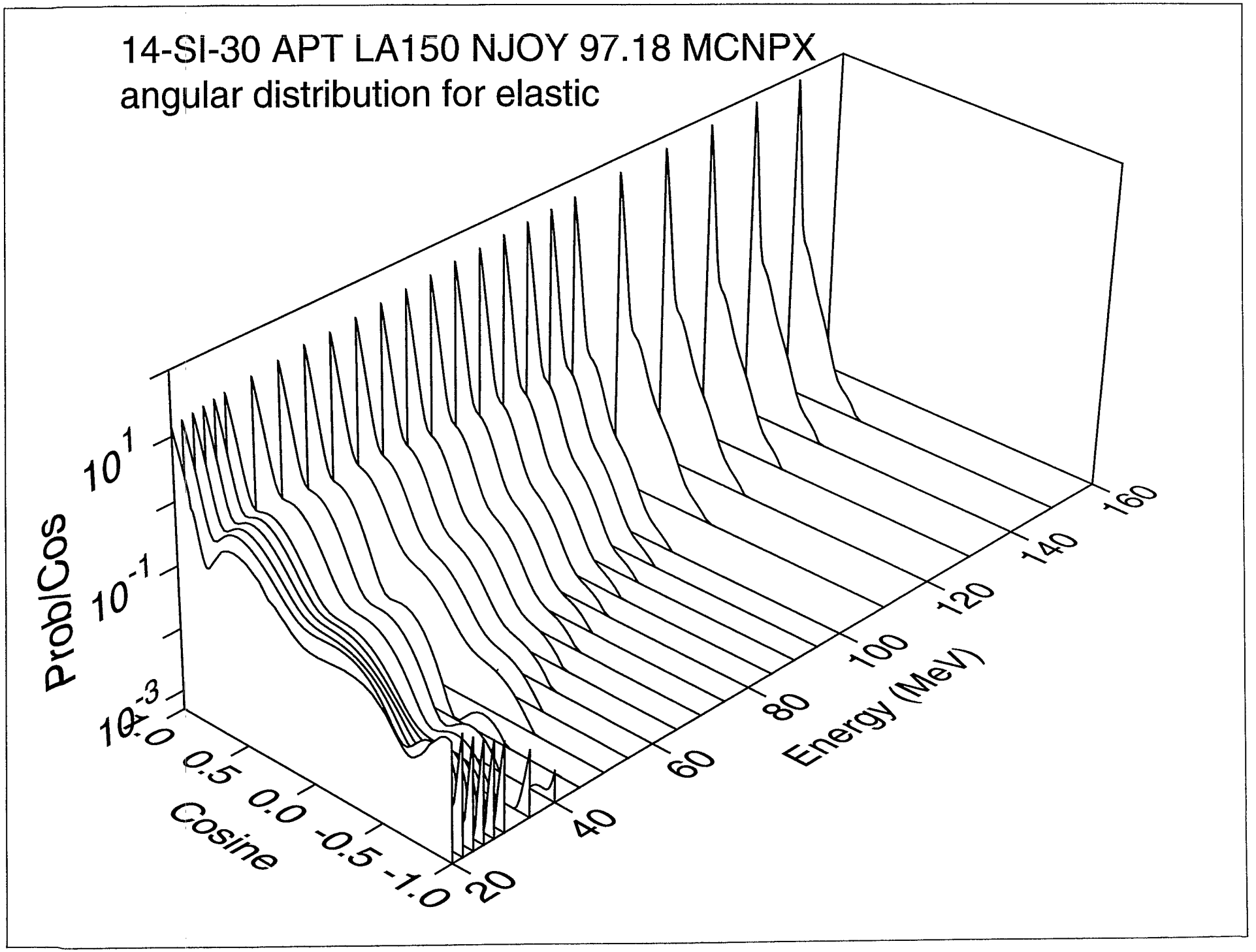


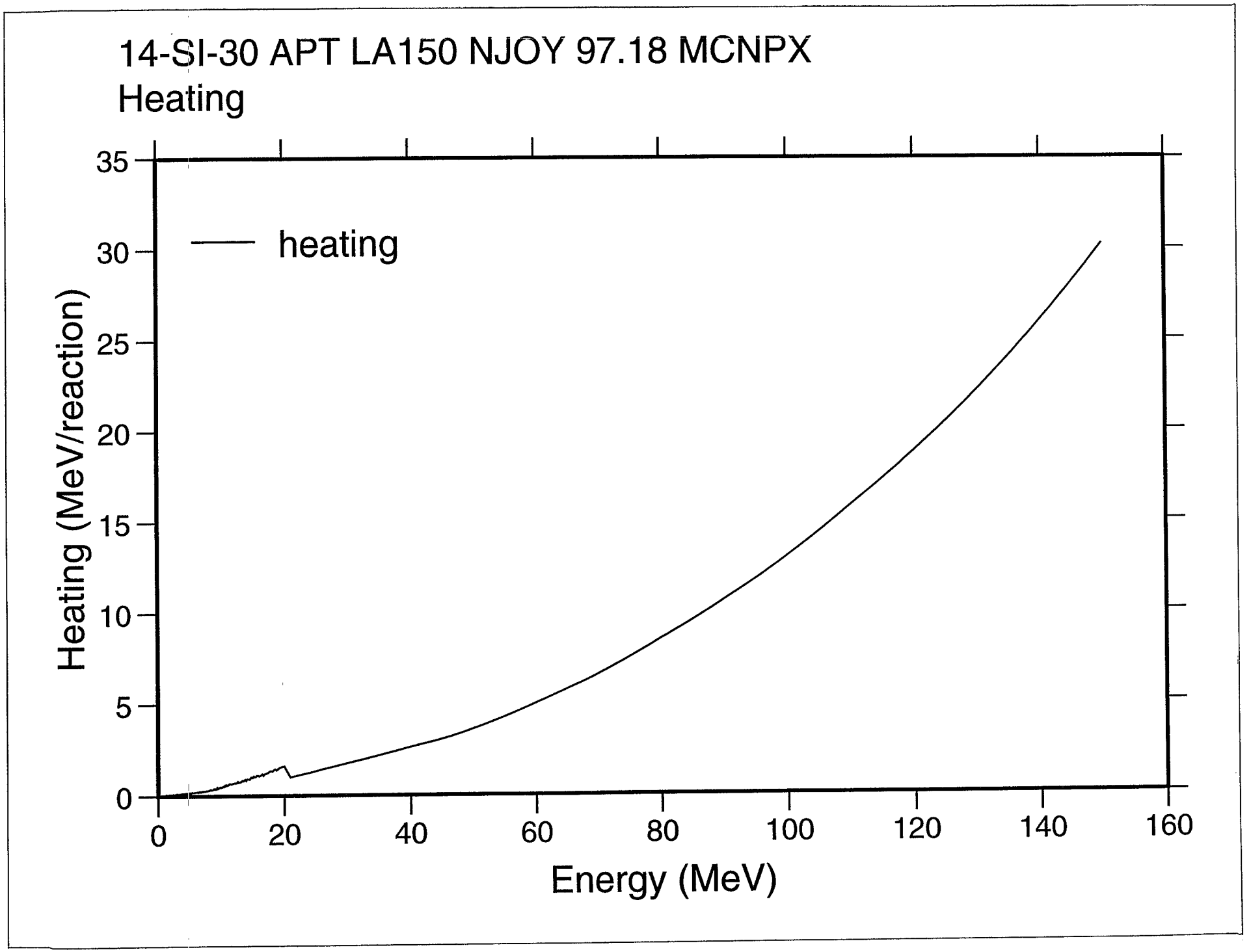


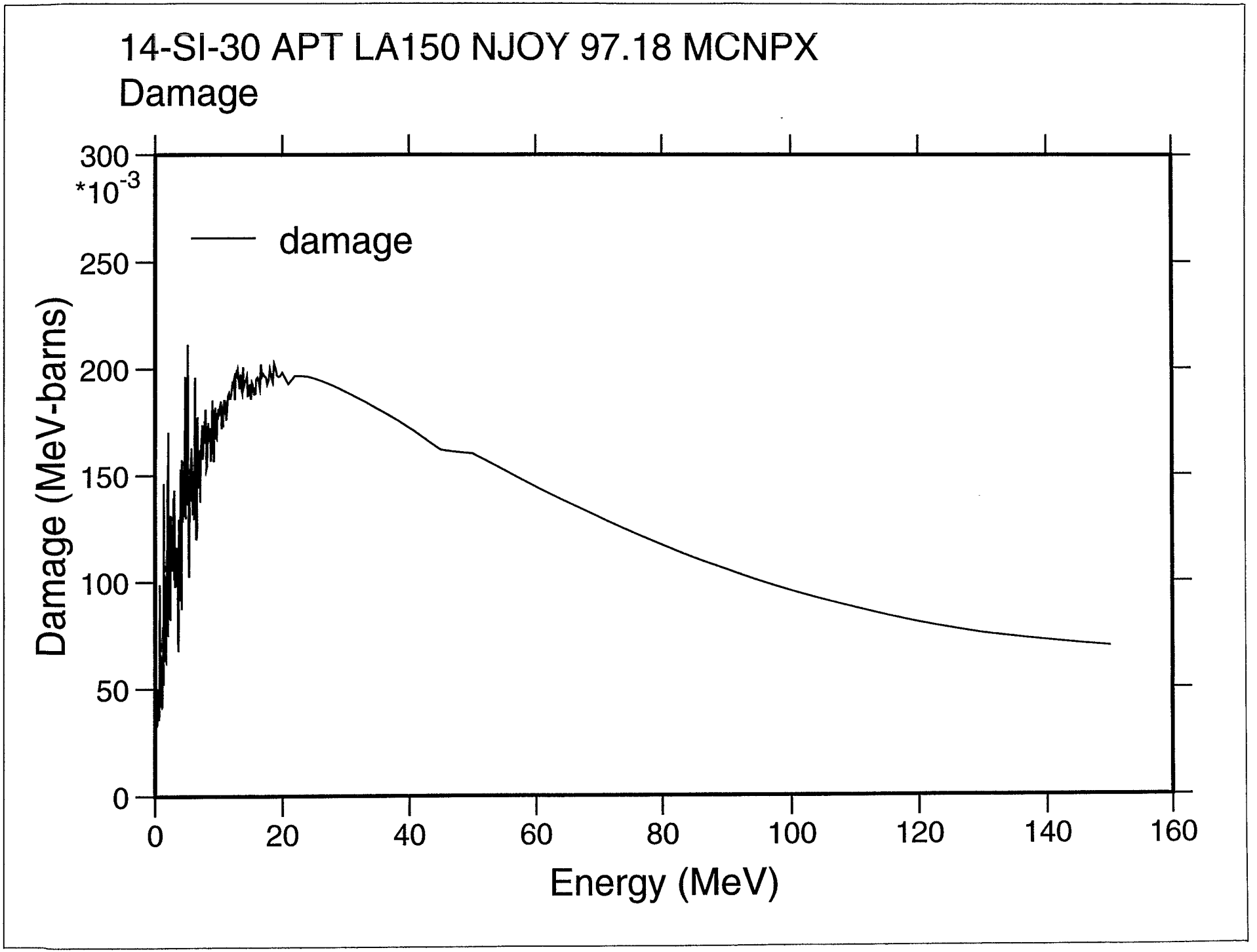







14-SI-30 APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic
Prob/Cos
10^{1}
10^{-1}
10^{-3}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
20
40
60
80
100
120
140
160


14-SI-30 APT LA150 NJOY 97.18 MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
5
10
15
20
25
30
35
0
20
40
60
80
100
120
140
160


14-SI-30 APT LA150 NJOY 97.18 MCNPX
Damage
damage
Damage (MeV-barns)
*10^-3
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF n + 31P CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

M. B. Chadwick, and P. G. Young
15 December 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI (Release 1) evaluation by R. Howerton (1977).

INCIDENT NEUTRON ENERGIES > 20 MeV

The ENDF/B-VI Release 2 evaluation extends to 20 MeV and includes cross sections and energy-angle data for all significant reactions. The present evaluation utilizes a more compact composite reaction spectrum representation above 20 MeV in order to reduce the length of the file. No essential data for applications is lost with this representation.

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT= 1	Total Cross Section
	MT= 2	Elastic Scattering Cross Section
	MT= 3	Nonelastic Cross Section
	MT= 5	Sum of Binary (n,n') and (n,x) Reactions
MF=4	MT= 2	Elastic Angular Distributions
MF=6	MT= 5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, Tritons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + P31 and p + P31 reactions (Ch98). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of

all recoil nuclei in the GNASH calculations (Ch96a). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk et al. (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged- particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

SPECIFIC INFORMATION CONCERNING THE P-31 EVALUATION

For incident neutrons the Wilmore-Hodgson [Wi64] optical potential was used below 20 MeV and the Madland medium [Ma88] energy potential was used at higher energies. Above 130 MeV the reaction cross section, and corresponding transmission coefficients, were renormalized to agree with the evaluated reaction cross section of [Ch96b]. For incident protons the Becchetti-Greenlees [Be69] potential was used below 20 MeV, and the Madland potential at higher energies. Above 6 MeV the reaction cross section (and trans. coeff.) was renormalized to values predicted by the systematics of Wellisch [We96]. The potential of Lohr (Lo74) was used for deuterons, and Mcfadden-Satchler (Mc66) for alpha particles. We followed ref. [Ch96b] in ignoring He-3 emission.

The total cross section was evaluated in the following way. The only measurement above 20 MeV is that of Deconninck et al. (Di61), who measure 2030 +/- 60 mb at 28.4 MeV. We took the evaluated total cross section data from our high-energy n+Si28 evaluation (based primarily on Finlay's 1993 (Fi93) total cross section data), and scaled the values to agree with the Deconninck measurement (a 5% increase). Note that this scaling is approximately consistent with an A**{2/3} dependence in the total cross section (which would give a 7% difference). Our evaluated total cross section at 20 MeV now exceeds the ENDF/B-VI value at 20 MeV by 15%; however, as explained above, arguments exist for our larger value.

We also note that our evaluated nonelastic cross section, which results from optical model calculations, is approximately 20% higher than the ENDF/B-VI value at 20 MeV. No experimental data are available to constrain the evaluation in this energy range. We do note, however, that systematics embodied in the neutron nonelastic cross section parameterization from NASA (Tr97) also supports our higher value, giving a prediction of 959 mb at 20 MeV, a value approximately 3% higher than our evaluated result.

Nuclear level densities were obtained using the Ignatyuk model (Ig75), and low-lying levels were obtained after first determining the upper limit for which the experimental level information is complete.

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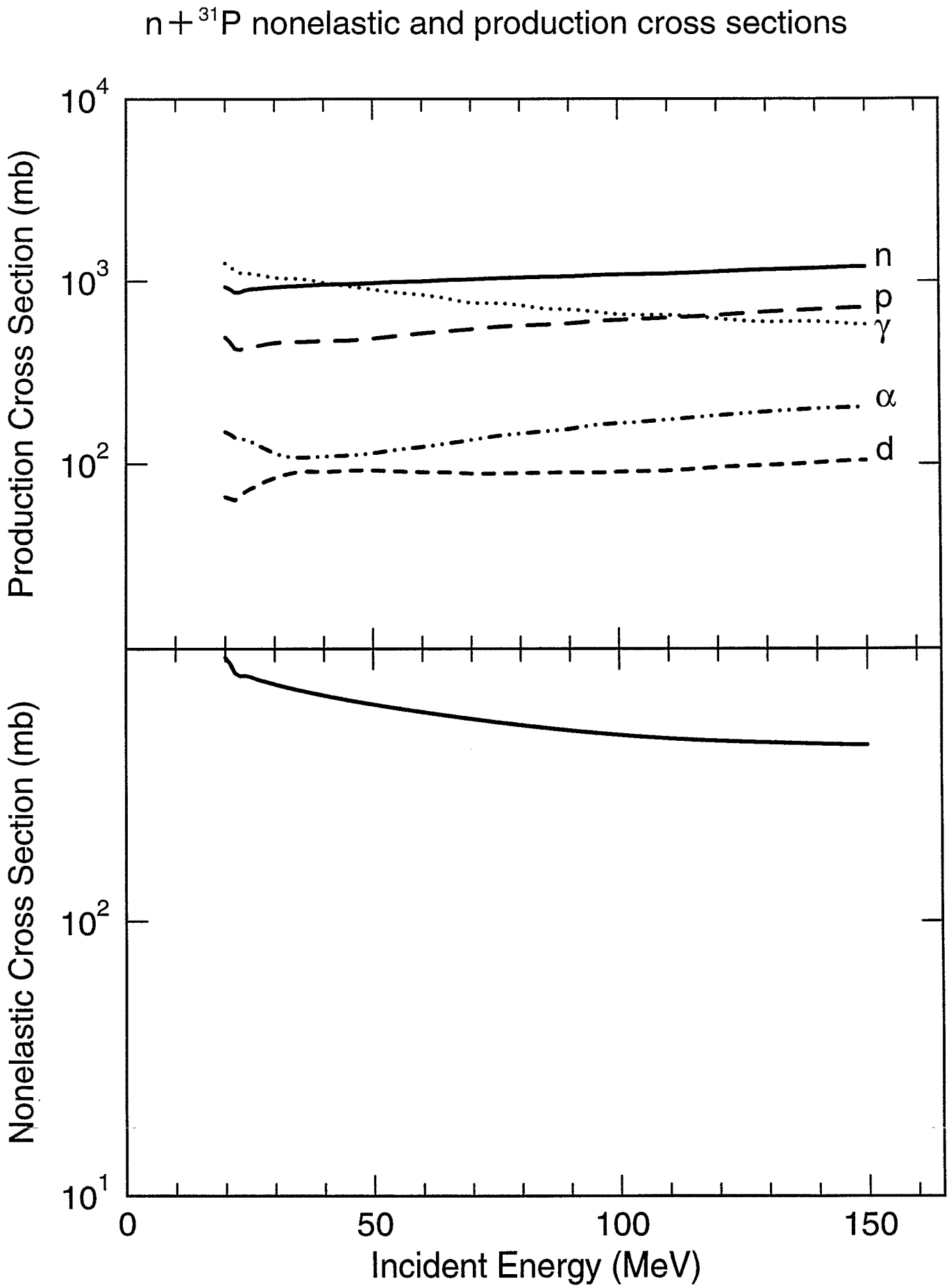
15031 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

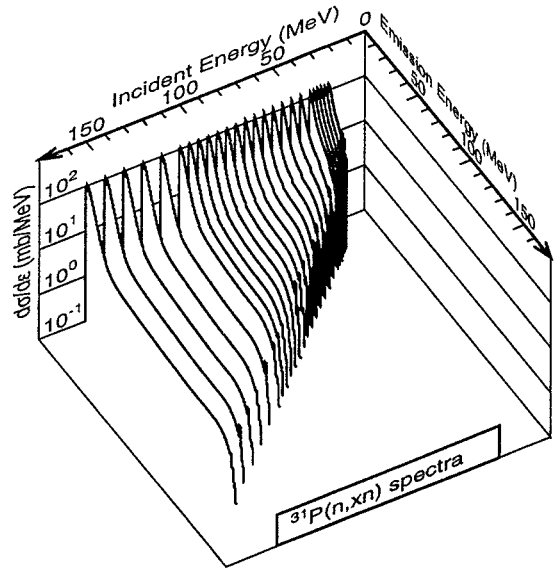
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	9.308E-01	9.995E-01	9.314E-01	4.931E-01	6.590E-02	0.000E+00	0.000E+00	1.498E-01	1.253E+00
2.200E+01	8.150E-01	1.157E+00	8.671E-01	4.267E-01	6.341E-02	0.000E+00	0.000E+00	1.391E-01	1.138E+00
2.400E+01	7.954E-01	1.204E+00	8.912E-01	4.334E-01	7.014E-02	0.000E+00	0.000E+00	1.360E-01	1.107E+00
2.600E+01	7.753E-01	1.244E+00	9.078E-01	4.413E-01	7.480E-02	0.000E+00	0.000E+00	1.290E-01	1.091E+00
2.800E+01	7.557E-01	1.273E+00	9.184E-01	4.513E-01	7.978E-02	0.000E+00	0.000E+00	1.214E-01	1.069E+00
3.000E+01	7.378E-01	1.294E+00	9.283E-01	4.603E-01	8.364E-02	0.000E+00	0.000E+00	1.145E-01	1.044E+00
3.500E+01	7.006E-01	1.322E+00	9.425E-01	4.661E-01	9.036E-02	0.000E+00	0.000E+00	1.083E-01	1.029E+00
4.000E+01	6.701E-01	1.314E+00	9.591E-01	4.717E-01	9.063E-02	0.000E+00	0.000E+00	1.099E-01	9.814E-01
4.500E+01	6.439E-01	1.279E+00	9.649E-01	4.751E-01	9.188E-02	0.000E+00	0.000E+00	1.114E-01	9.401E-01
5.000E+01	6.210E-01	1.231E+00	9.767E-01	4.863E-01	9.207E-02	0.000E+00	0.000E+00	1.145E-01	9.011E-01
5.500E+01	6.004E-01	1.168E+00	9.894E-01	5.023E-01	9.087E-02	0.000E+00	0.000E+00	1.195E-01	8.654E-01
6.000E+01	5.818E-01	1.097E+00	9.973E-01	5.186E-01	9.009E-02	0.000E+00	0.000E+00	1.237E-01	8.417E-01
6.500E+01	5.648E-01	1.028E+00	1.013E+00	5.324E-01	8.976E-02	0.000E+00	0.000E+00	1.290E-01	8.041E-01
7.000E+01	5.492E-01	9.636E-01	1.024E+00	5.465E-01	8.841E-02	0.000E+00	0.000E+00	1.349E-01	7.613E-01
7.500E+01	5.349E-01	8.940E-01	1.037E+00	5.618E-01	8.841E-02	0.000E+00	0.000E+00	1.418E-01	7.564E-01
8.000E+01	5.217E-01	8.305E-01	1.046E+00	5.708E-01	8.898E-02	0.000E+00	0.000E+00	1.464E-01	7.373E-01
8.500E+01	5.098E-01	7.670E-01	1.056E+00	5.778E-01	8.926E-02	0.000E+00	0.000E+00	1.506E-01	7.070E-01
9.000E+01	4.989E-01	7.149E-01	1.062E+00	5.865E-01	8.980E-02	0.000E+00	0.000E+00	1.550E-01	6.984E-01
9.500E+01	4.891E-01	6.628E-01	1.078E+00	6.020E-01	8.944E-02	0.000E+00	0.000E+00	1.626E-01	6.795E-01
1.000E+02	4.804E-01	6.159E-01	1.087E+00	6.126E-01	9.050E-02	0.000E+00	0.000E+00	1.665E-01	6.570E-01
1.100E+02	4.662E-01	5.368E-01	1.100E+00	6.297E-01	9.194E-02	0.000E+00	0.000E+00	1.744E-01	6.523E-01
1.200E+02	4.565E-01	4.678E-01	1.128E+00	6.507E-01	9.575E-02	0.000E+00	0.000E+00	1.840E-01	6.234E-01
1.300E+02	4.503E-01	4.089E-01	1.157E+00	6.785E-01	9.837E-02	0.000E+00	0.000E+00	1.929E-01	5.979E-01
1.400E+02	4.449E-01	3.608E-01	1.178E+00	6.987E-01	1.015E-01	0.000E+00	0.000E+00	2.007E-01	5.997E-01
1.500E+02	4.416E-01	3.222E-01	1.199E+00	7.142E-01	1.044E-01	0.000E+00	0.000E+00	2.041E-01	5.781E-01

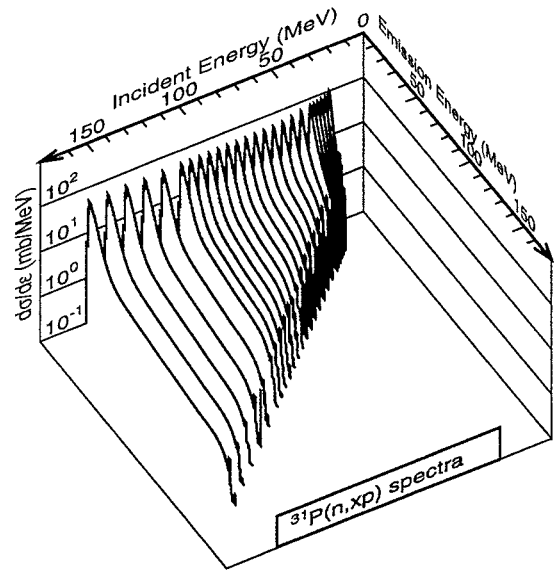
15031 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

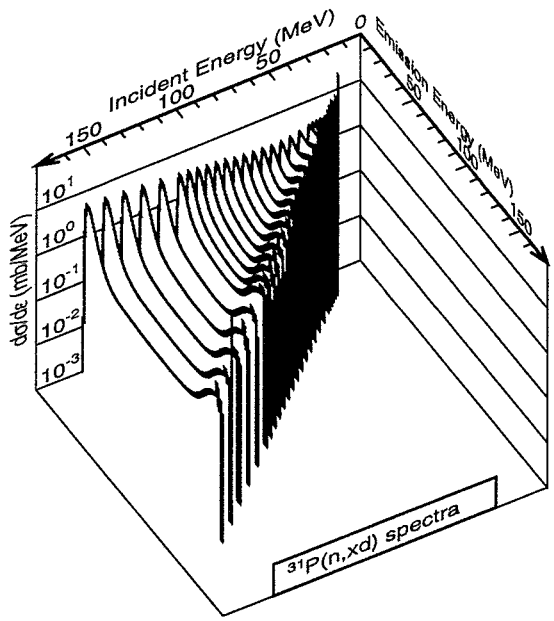
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	6.708E-01	1.709E-01	0.000E+00	0.000E+00	2.873E-01	2.450E-01	1.260E-01	1.500E+00
2.200E+01	6.375E-01	1.854E-01	0.000E+00	0.000E+00	2.837E-01	2.311E-01	1.358E-01	1.474E+00
2.400E+01	6.980E-01	2.270E-01	0.000E+00	0.000E+00	2.919E-01	2.403E-01	1.295E-01	1.587E+00
2.600E+01	7.651E-01	2.635E-01	0.000E+00	0.000E+00	2.898E-01	2.475E-01	1.224E-01	1.688E+00
2.800E+01	8.335E-01	3.068E-01	0.000E+00	0.000E+00	2.826E-01	2.526E-01	1.151E-01	1.791E+00
3.000E+01	9.091E-01	3.473E-01	0.000E+00	0.000E+00	2.750E-01	2.568E-01	1.083E-01	1.896E+00
3.500E+01	1.098E+00	4.578E-01	0.000E+00	0.000E+00	2.700E-01	2.683E-01	9.385E-02	2.188E+00
4.000E+01	1.303E+00	5.381E-01	0.000E+00	0.000E+00	2.826E-01	2.811E-01	8.208E-02	2.487E+00
4.500E+01	1.502E+00	6.328E-01	0.000E+00	0.000E+00	2.946E-01	2.929E-01	7.248E-02	2.795E+00
5.000E+01	1.706E+00	7.144E-01	0.000E+00	0.000E+00	3.085E-01	3.033E-01	6.471E-02	3.096E+00
5.500E+01	1.911E+00	7.679E-01	0.000E+00	0.000E+00	3.271E-01	3.096E-01	5.799E-02	3.373E+00
6.000E+01	2.115E+00	8.270E-01	0.000E+00	0.000E+00	3.432E-01	3.175E-01	5.204E-02	3.655E+00
6.500E+01	2.309E+00	8.847E-01	0.000E+00	0.000E+00	3.619E-01	3.249E-01	4.707E-02	3.928E+00
7.000E+01	2.504E+00	9.189E-01	0.000E+00	0.000E+00	3.807E-01	3.313E-01	4.292E-02	4.178E+00
7.500E+01	2.685E+00	9.544E-01	0.000E+00	0.000E+00	4.033E-01	3.386E-01	3.895E-02	4.420E+00
8.000E+01	2.870E+00	1.012E+00	0.000E+00	0.000E+00	4.207E-01	3.419E-01	3.554E-02	4.680E+00
8.500E+01	3.043E+00	1.063E+00	0.000E+00	0.000E+00	4.374E-01	3.455E-01	3.235E-02	4.921E+00
9.000E+01	3.216E+00	1.114E+00	0.000E+00	0.000E+00	4.526E-01	3.486E-01	2.981E-02	5.160E+00
9.500E+01	3.387E+00	1.114E+00	0.000E+00	0.000E+00	4.778E-01	3.510E-01	2.737E-02	5.357E+00
1.000E+02	3.565E+00	1.166E+00	0.000E+00	0.000E+00	4.929E-01	3.543E-01	2.522E-02	5.603E+00
1.100E+02	3.923E+00	1.235E+00	0.000E+00	0.000E+00	5.246E-01	3.611E-01	2.171E-02	6.065E+00
1.200E+02	4.288E+00	1.339E+00	0.000E+00	0.000E+00	5.637E-01	3.699E-01	1.873E-02	6.579E+00
1.300E+02	4.688E+00	1.397E+00	0.000E+00	0.000E+00	6.003E-01	3.860E-01	1.624E-02	7.088E+00
1.400E+02	5.085E+00	1.465E+00	0.000E+00	0.000E+00	6.337E-01	4.096E-01	1.421E-02	7.607E+00
1.500E+02	5.512E+00	1.575E+00	0.000E+00	0.000E+00	6.551E-01	4.285E-01	1.258E-02	8.183E+00

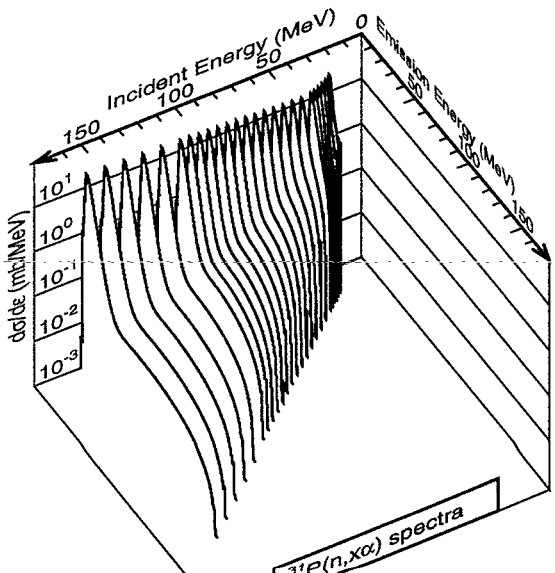

n + 31P nonelastic and production cross sections
Production Cross Section (mb)
Nonelastic Cross Section (mb)
Incident Energy (MeV)
n
p
γ
α
d
10^4
10^3
10^2
10^2
10^1
0
50
100
150

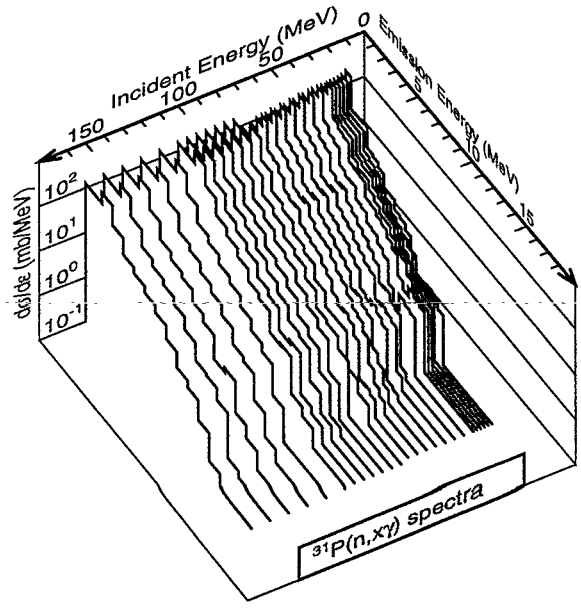
n + ^{31}P angle-integrated emission spectra



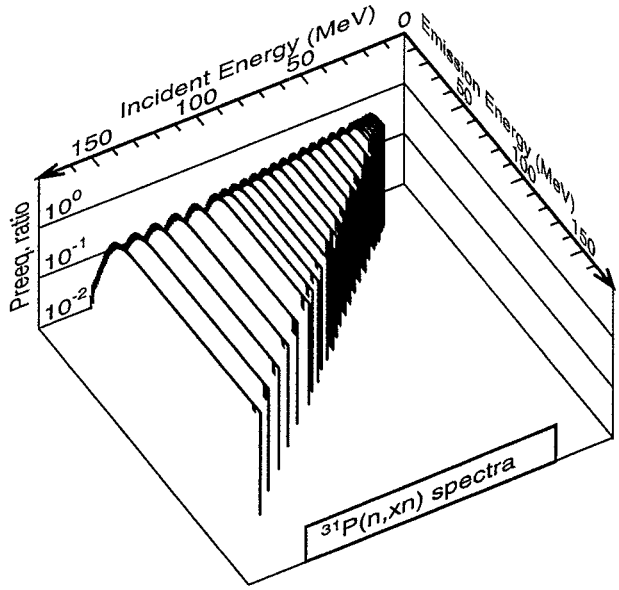


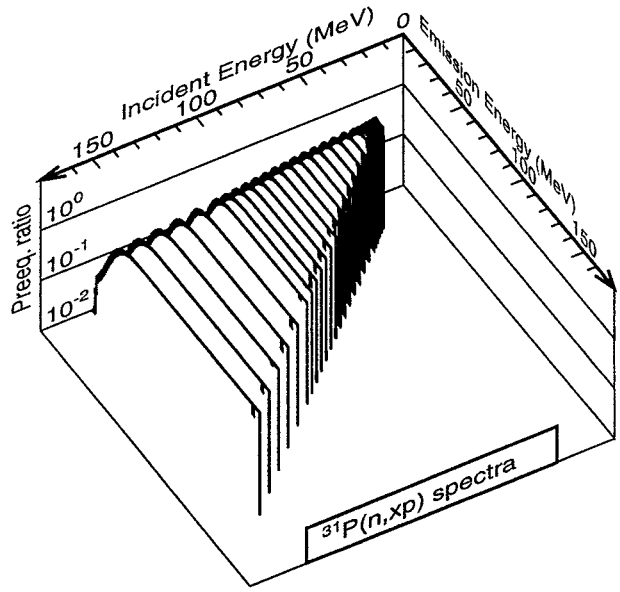


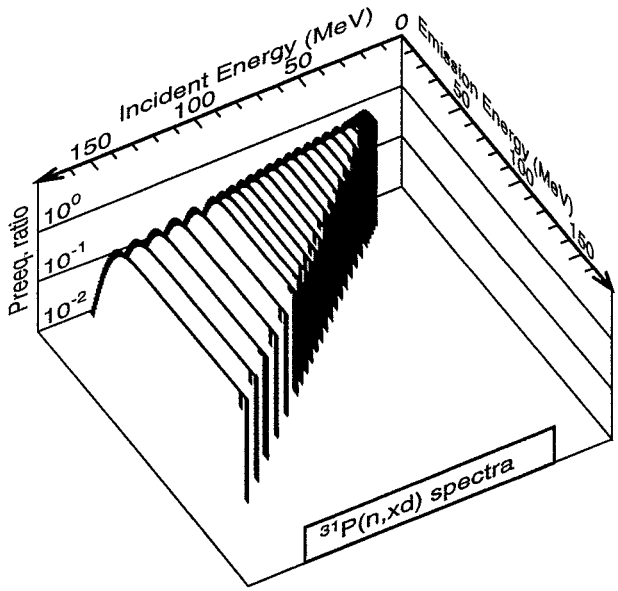


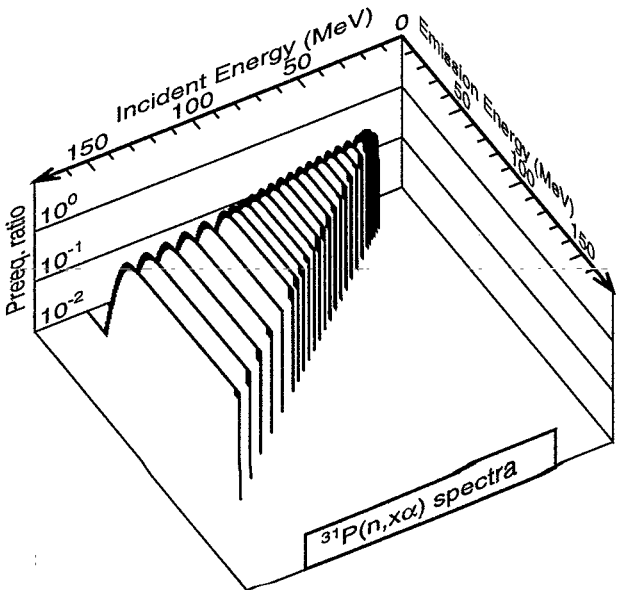


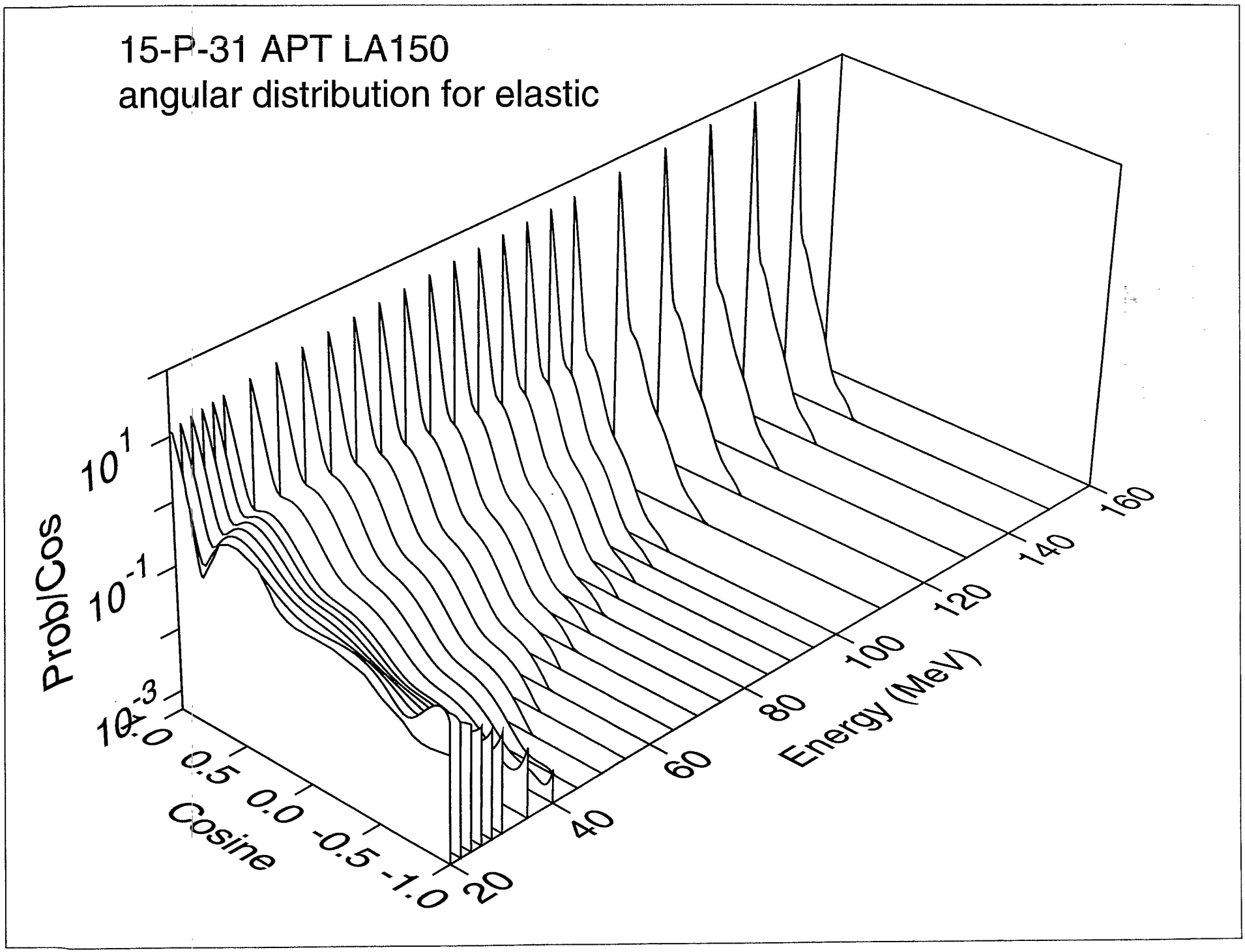
n + ^{31}P Kalbach preequilibrium ratios

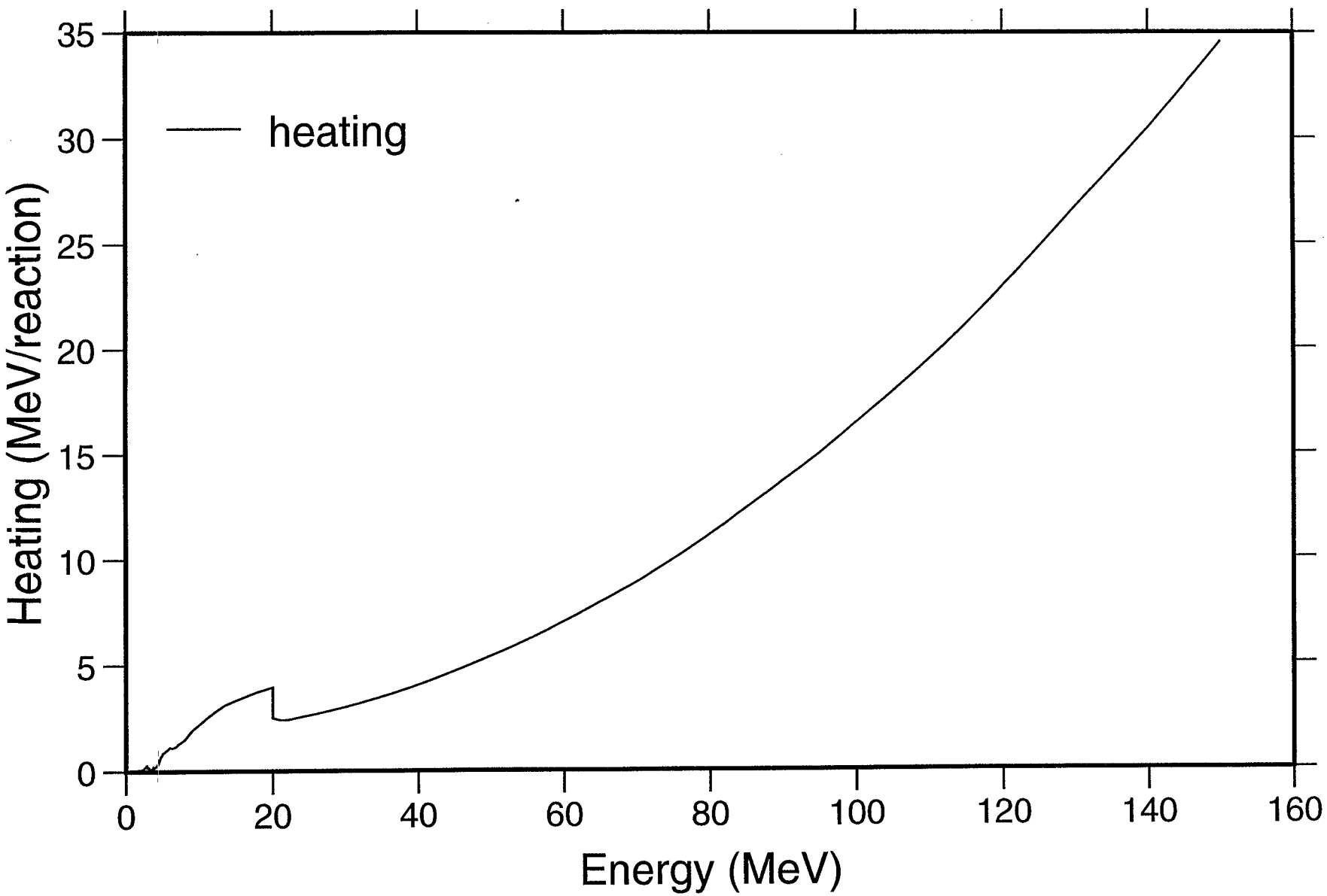


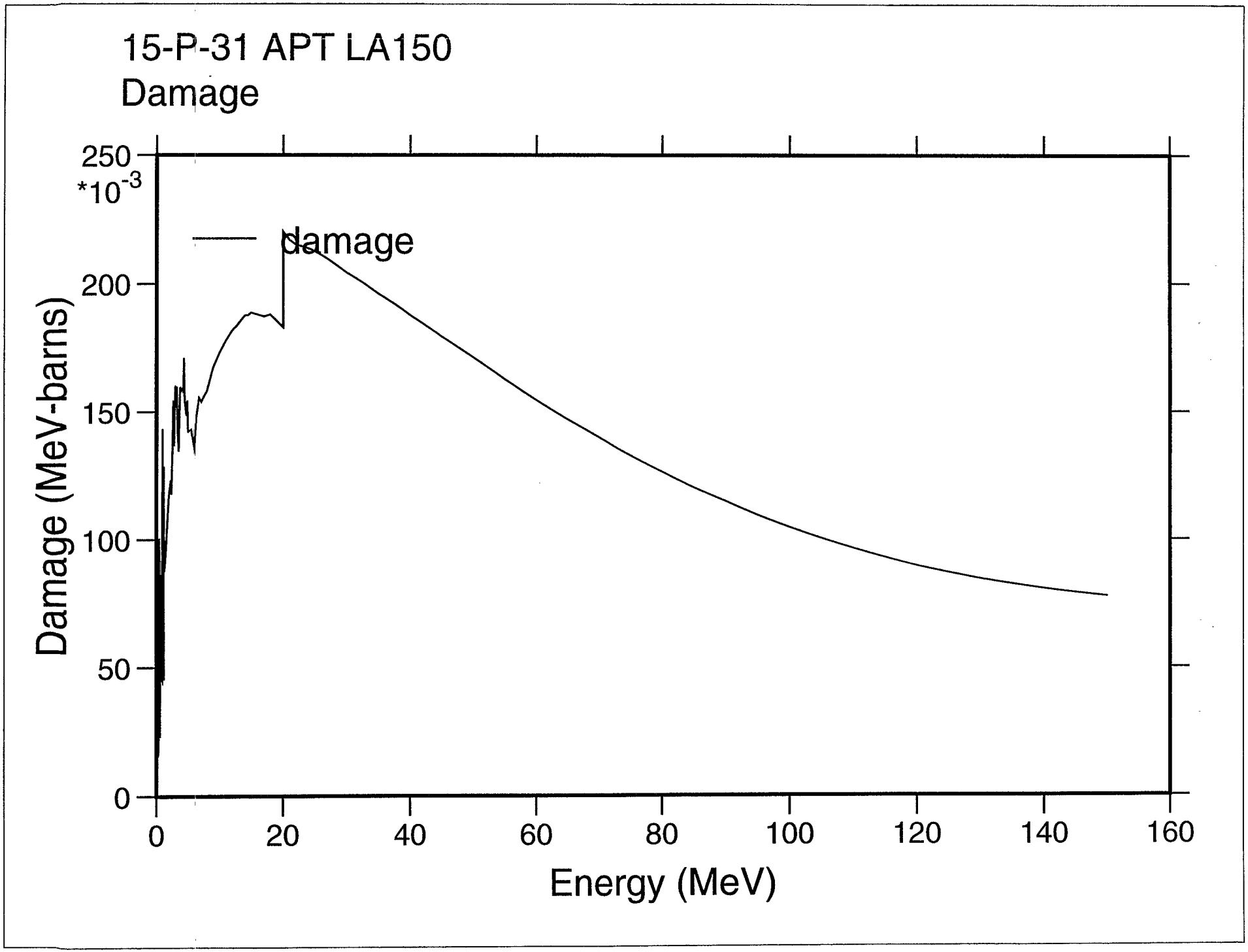







15-P-31 APT LA150
angular distribution for elastic
Prob/Cos
10^{1}
10^{-1}
10^{-3}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
20
40
60
80
100
120
140
160


15-P-31 APT LA150
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
5
10
15
20
25
30
35
0
20
40
60
80
100
120
140
160


15-P-31 APT LA150
Damage
damage
Damage (MeV-barns)
*10^-3
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF n + Ca CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

M. B. Chadwick and P. G. Young
29 March 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI.1 (Release 0) evaluation by C.Y.Fu AND D.M.Hetrick (Fu91).

INCIDENT NEUTRON ENERGIES > 20 MeV (40Ca calcs)

The ENDF/B-VI Release 3 evaluation extends to 40 MeV and includes cross sections and energy-angle data for all significant reactions. The present evauation utilizes a more compact composite reaction spectrum representation above 20 MeV in order to reduce the length of the file. No essential data for applications is lost with this representation. Additionally, we have modified the neutron reaction cross sections slightly to improve agreement with data above 20 MeV.

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT= 1	Total Cross Section
	MT= 2	Elastic Scattering Cross Section
	MT= 3	Nonelastic Cross Section
	MT= 5	Sum of Binary (n,n') and (n,x) Reactions
MF=4	MT= 2	Elastic Angular Distributions
MF=6	MT= 5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data. We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96a). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting..

The starting point for this evaluation was the previous Livermore (1995) evaluation by Chadwick and Young for neutrons up to 100 MeV [Ch95], and protons up to 250 MeV [Ch96b]. The main additions in the current work were: (1) Extension of the neutron calculations to higher energies; (2) Inclusion of direct inelastic scattering to low-lying collective states using ECIS; (3) inclusion of a renormalization of the calculated results to circumvent a numerical inaccuracy at higher incident energies (>150 MeV) which ensure the individual reactions sum to the evaluated nonelastic cross section; (4) inclusion of A>4 nuclide production and nuclide energy spectra; (5) inclusion of triton emission; and (6) utilization of ENDF-6 format.

The neutron total cross section was evaluated from available experimental data. The evaluation was based primarily on Finlay's 1993 high-accuracy measurements [Fi93].

The optical potential of Islam [Is88] specially developed for n+Ca elastic scattering, was used for 20-60 MeV neutrons, and above this energy the Madland global potential was used [Ma88]. The Wilmore-Hodgson potential was used below 20 MeV [Wi64]. For incident protons, the Islam neutron potential was modified to account for proton scattering from 20 to 60 MeV, and again the Madland global potential was used at higher energies. The Becchetti-Greenlees potential was used for protons below 20 MeV [Be69]. For deuterons, tritons and alphas the method of Watanabe, which uses a modified Perey potential [Pe63], was applied at all energies [Ma88].

Direct inelastic scattering to the low-lying collective states was calculated with the ECIS code. Deformation lengths were taken from the works of Alarcon and Rapaport [8] and Honore et al. [Ho86], giving: 3- (Ex= 3.736 MeV, delta=1.340), 2+ (Ex=3.904, delta=0.360), and 5- (Ex=4.492, delta=0.930).

While the above optical potentials did describe the experimental neutron and proton nonelastic cross section data fairly well, we modified these theoretical predictions slightly to better agree with the measurements, and renormalized the transmission coefficients accordingly. The calculated neutron elastic scattering distributions agree well with experimental data.

Nuclear level densities were taken from the Ignatyuk model [Ig75], which includes a washing out of shell effects with increasing excitation energy, and gamma-ray strength functions were obtained from the model of Kopecky and Uhl [Ko90].

The existing ENDF/B-VI evaluation below 20 MeV was performed at Oak Ridge, for natural Calcium. Since 40Ca makes up approximately 97% of natural calcium, we have combined the natural evaluation below 20 MeV with our new 40Ca evaluation above 20 MeV. The combined evaluation up to 150 MeV can be treated as a natural evaluation to a good approximation. Using our 40Ca for natural Ca above 20 MeV is a very good approximation for transport and heating applications; although our evaluation above 20 MeV does omit the production of radionuclides with A>40 (the practical consequences of this are expected to be small).

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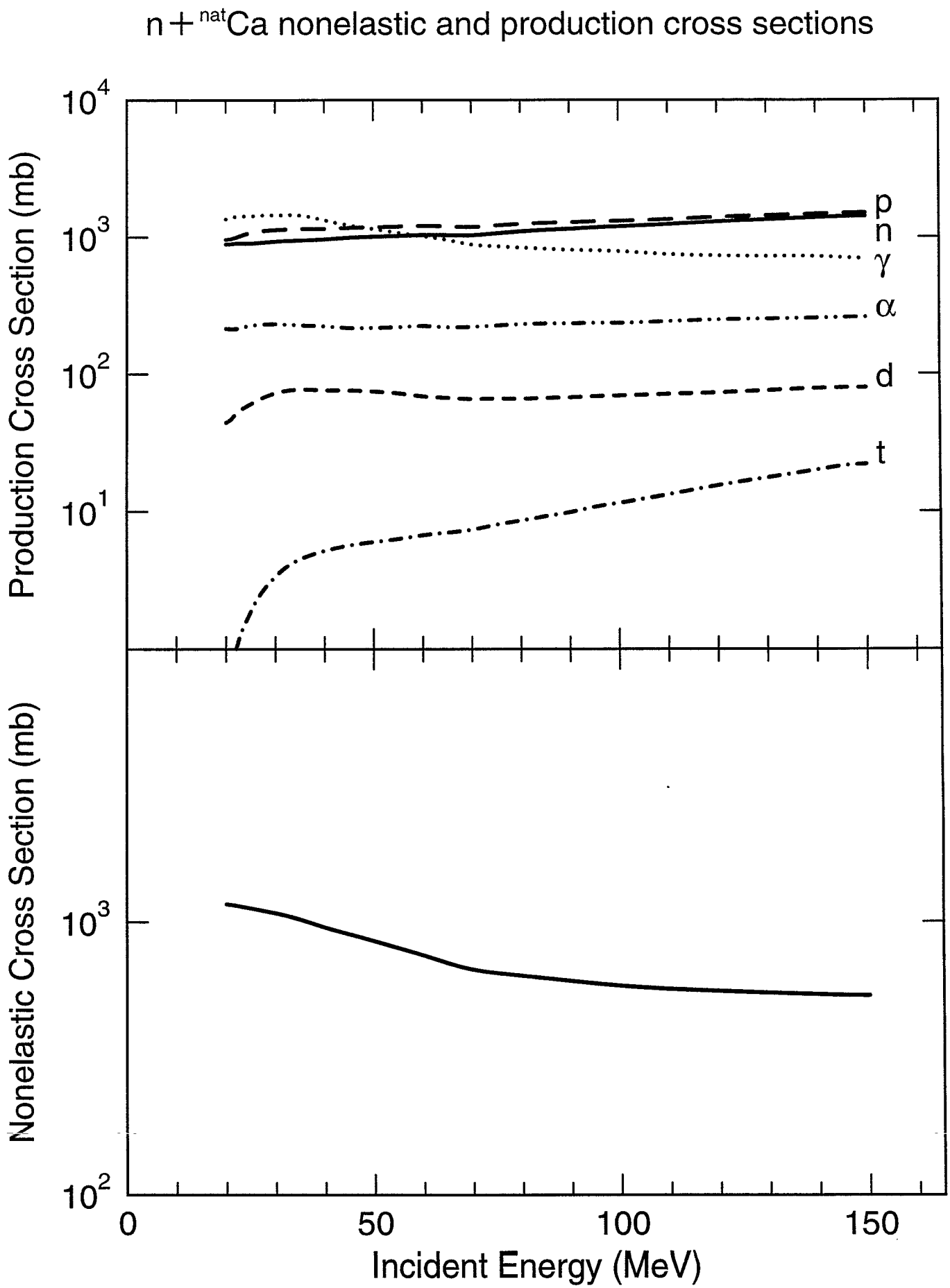
20000 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

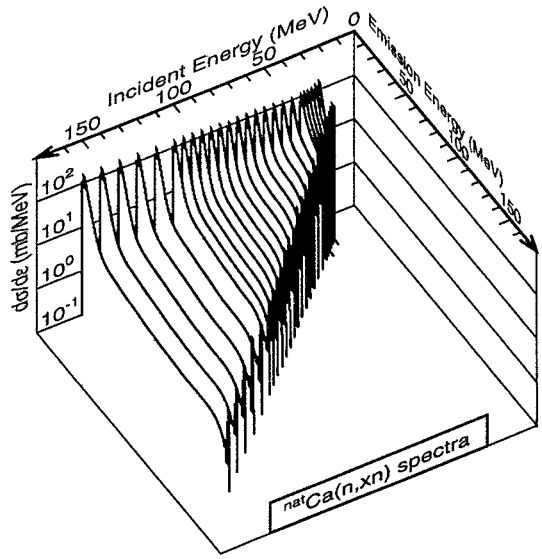
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	1.162E+00	9.540E-01	8.871E-01	9.586E-01	4.428E-02	4.781E-04	0.000E+00	2.140E-01	1.355E+00
2.200E+01	1.148E+00	9.677E-01	8.982E-01	9.931E-01	5.158E-02	9.757E-04	0.000E+00	2.132E-01	1.416E+00
2.400E+01	1.131E+00	9.972E-01	8.979E-01	1.052E+00	5.787E-02	1.564E-03	0.000E+00	2.223E-01	1.423E+00
2.600E+01	1.112E+00	1.041E+00	9.041E-01	1.090E+00	6.338E-02	2.200E-03	0.000E+00	2.277E-01	1.434E+00
2.800E+01	1.094E+00	1.089E+00	9.170E-01	1.115E+00	6.861E-02	2.804E-03	0.000E+00	2.308E-01	1.451E+00
3.000E+01	1.075E+00	1.133E+00	9.298E-01	1.128E+00	7.270E-02	3.371E-03	0.000E+00	2.315E-01	1.451E+00
3.500E+01	1.019E+00	1.227E+00	9.479E-01	1.146E+00	7.723E-02	4.493E-03	0.000E+00	2.269E-01	1.446E+00
4.000E+01	9.530E-01	1.323E+00	9.658E-01	1.148E+00	7.622E-02	5.164E-03	0.000E+00	2.233E-01	1.332E+00
4.500E+01	8.995E-01	1.363E+00	9.941E-01	1.170E+00	7.596E-02	5.652E-03	0.000E+00	2.168E-01	1.220E+00
5.000E+01	8.490E-01	1.363E+00	1.011E+00	1.181E+00	7.453E-02	5.984E-03	0.000E+00	2.174E-01	1.146E+00
5.500E+01	8.000E-01	1.340E+00	1.024E+00	1.196E+00	7.233E-02	6.307E-03	0.000E+00	2.200E-01	1.077E+00
6.000E+01	7.520E-01	1.312E+00	1.037E+00	1.208E+00	6.874E-02	6.714E-03	0.000E+00	2.242E-01	1.017E+00
6.500E+01	7.043E-01	1.289E+00	1.035E+00	1.198E+00	6.694E-02	7.018E-03	0.000E+00	2.196E-01	9.567E-01
7.000E+01	6.680E-01	1.248E+00	1.034E+00	1.184E+00	6.557E-02	7.359E-03	0.000E+00	2.206E-01	8.826E-01
7.500E+01	6.483E-01	1.177E+00	1.066E+00	1.216E+00	6.613E-02	8.001E-03	0.000E+00	2.252E-01	8.560E-01
8.000E+01	6.340E-01	1.099E+00	1.098E+00	1.246E+00	6.583E-02	8.573E-03	0.000E+00	2.304E-01	8.365E-01
8.500E+01	6.198E-01	1.036E+00	1.127E+00	1.269E+00	6.667E-02	9.193E-03	0.000E+00	2.327E-01	8.192E-01
9.000E+01	6.060E-01	9.750E-01	1.148E+00	1.282E+00	6.729E-02	9.845E-03	0.000E+00	2.332E-01	8.056E-01
9.500E+01	5.930E-01	9.030E-01	1.174E+00	1.302E+00	6.854E-02	1.076E-02	0.000E+00	2.350E-01	7.977E-01
1.000E+02	5.820E-01	8.430E-01	1.195E+00	1.314E+00	6.935E-02	1.152E-02	0.000E+00	2.352E-01	7.862E-01
1.100E+02	5.669E-01	7.431E-01	1.242E+00	1.350E+00	7.123E-02	1.325E-02	0.000E+00	2.417E-01	7.495E-01
1.200E+02	5.570E-01	6.470E-01	1.297E+00	1.402E+00	7.292E-02	1.544E-02	0.000E+00	2.486E-01	7.320E-01
1.300E+02	5.487E-01	5.703E-01	1.344E+00	1.439E+00	7.555E-02	1.759E-02	0.000E+00	2.523E-01	7.244E-01
1.400E+02	5.420E-01	5.110E-01	1.392E+00	1.477E+00	7.840E-02	2.004E-02	0.000E+00	2.564E-01	7.233E-01
1.500E+02	5.372E-01	4.628E-01	1.425E+00	1.504E+00	7.946E-02	2.199E-02	0.000E+00	2.603E-01	6.994E-01

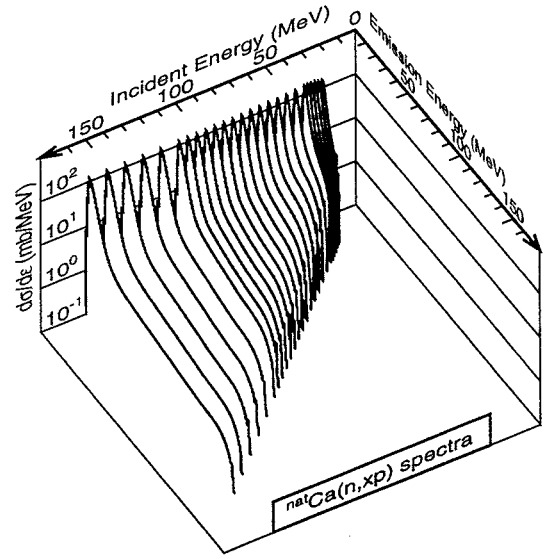
20000 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

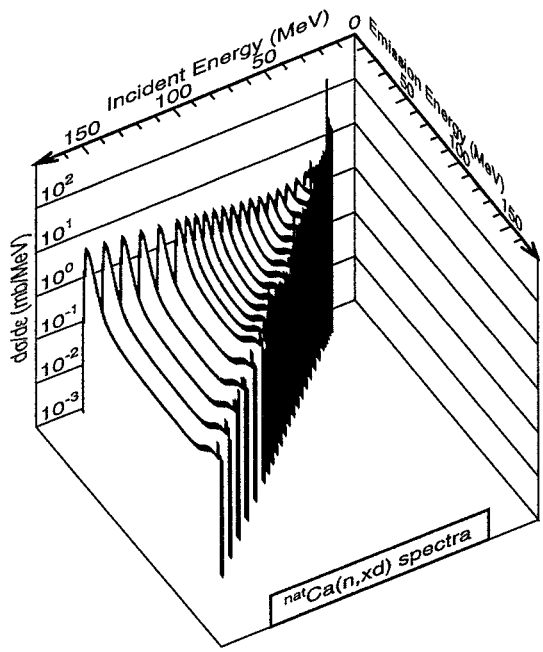
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	1.163E+00	9.359E-02	5.499E-04	0.000E+00	4.235E-01	1.996E-01	5.635E-02	1.936E+00
2.200E+01	1.251E+00	1.227E-01	1.307E-03	0.000E+00	4.299E-01	2.101E-01	4.706E-02	2.062E+00
2.400E+01	1.376E+00	1.521E-01	2.405E-03	0.000E+00	4.531E-01	2.216E-01	4.631E-02	2.251E+00
2.600E+01	1.475E+00	1.817E-01	3.833E-03	0.000E+00	4.698E-01	2.305E-01	4.585E-02	2.407E+00
2.800E+01	1.573E+00	2.142E-01	5.460E-03	0.000E+00	4.841E-01	2.373E-01	4.543E-02	2.559E+00
3.000E+01	1.678E+00	2.461E-01	7.234E-03	0.000E+00	4.925E-01	2.436E-01	4.480E-02	2.712E+00
3.500E+01	1.914E+00	3.125E-01	1.178E-02	0.000E+00	4.990E-01	2.572E-01	4.309E-02	3.038E+00
4.000E+01	2.114E+00	3.584E-01	1.576E-02	0.000E+00	5.024E-01	2.623E-01	4.229E-02	3.295E+00
4.500E+01	2.331E+00	4.104E-01	1.968E-02	0.000E+00	5.003E-01	2.674E-01	4.056E-02	3.569E+00
5.000E+01	2.519E+00	4.505E-01	2.321E-02	0.000E+00	5.120E-01	2.714E-01	3.844E-02	3.814E+00
5.500E+01	2.690E+00	4.778E-01	2.637E-02	0.000E+00	5.265E-01	2.742E-01	3.640E-02	4.031E+00
6.000E+01	2.830E+00	4.756E-01	2.907E-02	0.000E+00	5.422E-01	2.754E-01	3.476E-02	4.187E+00
6.500E+01	2.936E+00	4.943E-01	3.166E-02	0.000E+00	5.406E-01	2.726E-01	3.305E-02	4.309E+00
7.000E+01	3.053E+00	5.111E-01	3.424E-02	0.000E+00	5.495E-01	2.719E-01	3.093E-02	4.451E+00
7.500E+01	3.244E+00	5.334E-01	3.701E-02	0.000E+00	5.669E-01	2.772E-01	2.837E-02	4.687E+00
8.000E+01	3.454E+00	5.427E-01	3.972E-02	0.000E+00	5.848E-01	2.819E-01	2.593E-02	4.929E+00
8.500E+01	3.655E+00	5.691E-01	4.238E-02	0.000E+00	5.997E-01	2.850E-01	2.402E-02	5.175E+00
9.000E+01	3.840E+00	5.921E-01	4.485E-02	0.000E+00	6.079E-01	2.874E-01	2.227E-02	5.394E+00
9.500E+01	4.027E+00	6.115E-01	4.780E-02	0.000E+00	6.221E-01	2.909E-01	2.039E-02	5.620E+00
1.000E+02	4.206E+00	6.323E-01	5.050E-02	0.000E+00	6.314E-01	2.926E-01	1.884E-02	5.831E+00
1.100E+02	4.612E+00	6.664E-01	5.607E-02	0.000E+00	6.602E-01	2.990E-01	1.636E-02	6.310E+00
1.200E+02	5.056E+00	6.627E-01	6.253E-02	0.000E+00	6.912E-01	3.061E-01	1.408E-02	6.793E+00
1.300E+02	5.490E+00	6.860E-01	6.870E-02	0.000E+00	7.163E-01	3.213E-01	1.230E-02	7.295E+00
1.400E+02	5.922E+00	6.969E-01	7.542E-02	0.000E+00	7.434E-01	3.380E-01	1.092E-02	7.786E+00
1.500E+02	6.378E+00	6.856E-01	8.122E-02	0.000E+00	7.654E-01	3.508E-01	9.812E-03	8.271E+00

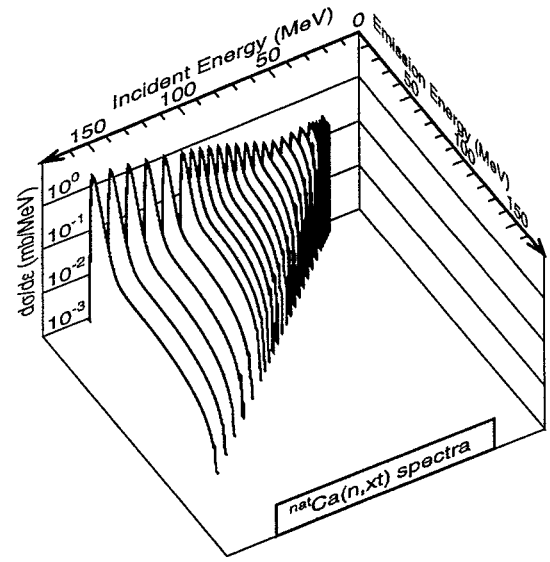

n + natCa nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
p
n
γ
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
0
50
100
150
Incident Energy (MeV)

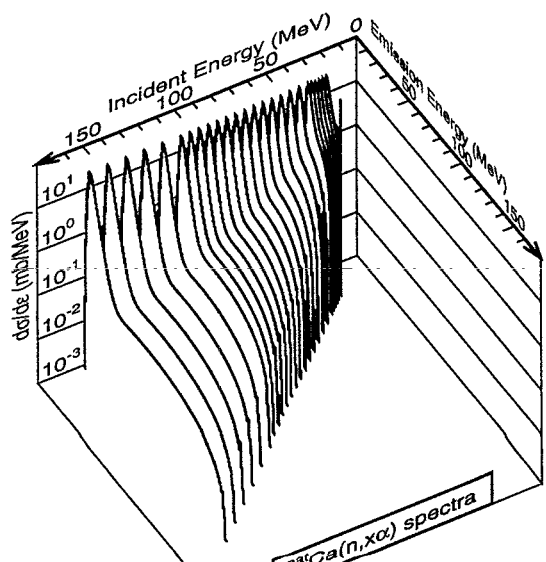
n + ^{nat}Ca angle-integrated emission spectra

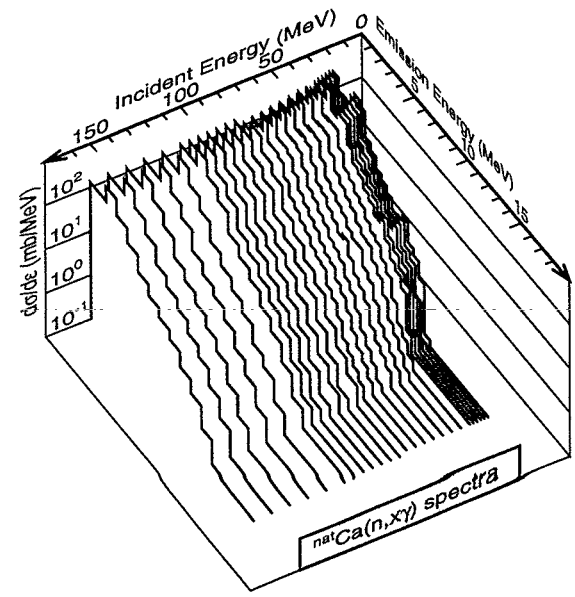




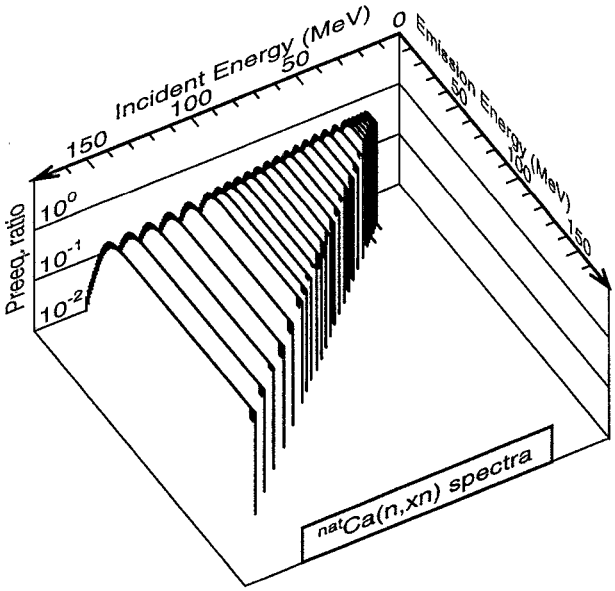


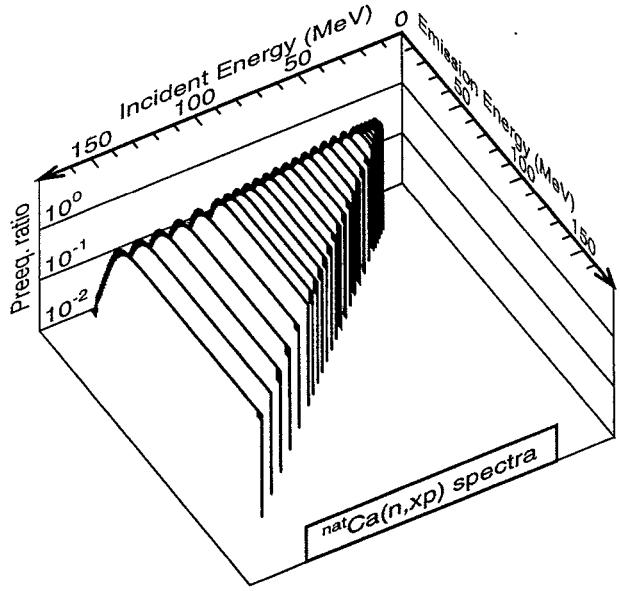


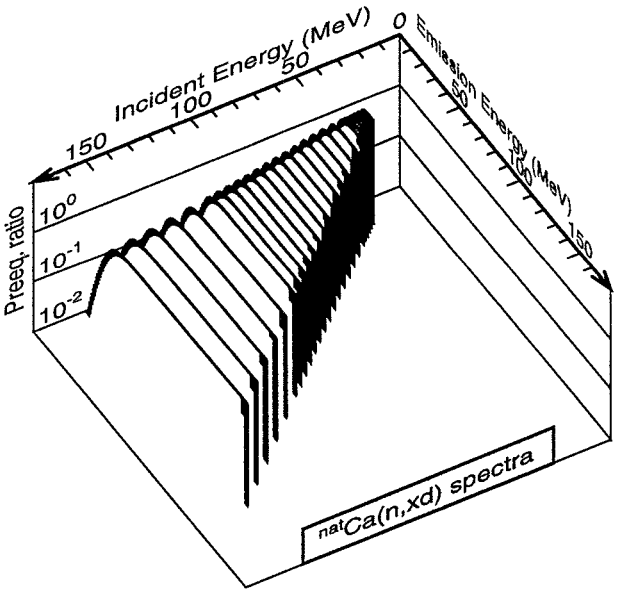


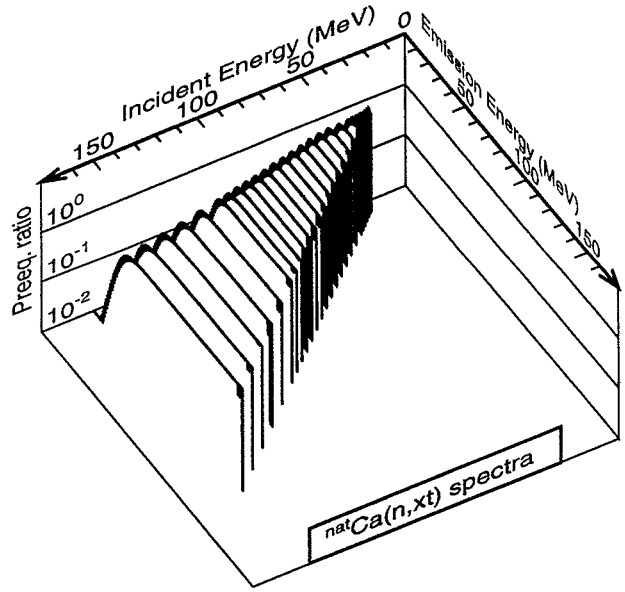


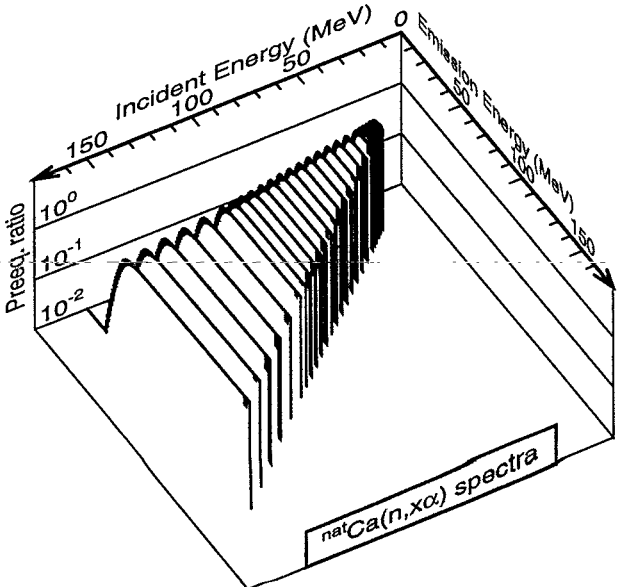
n + ^{nat}Ca Kalbach preequilibrium ratios

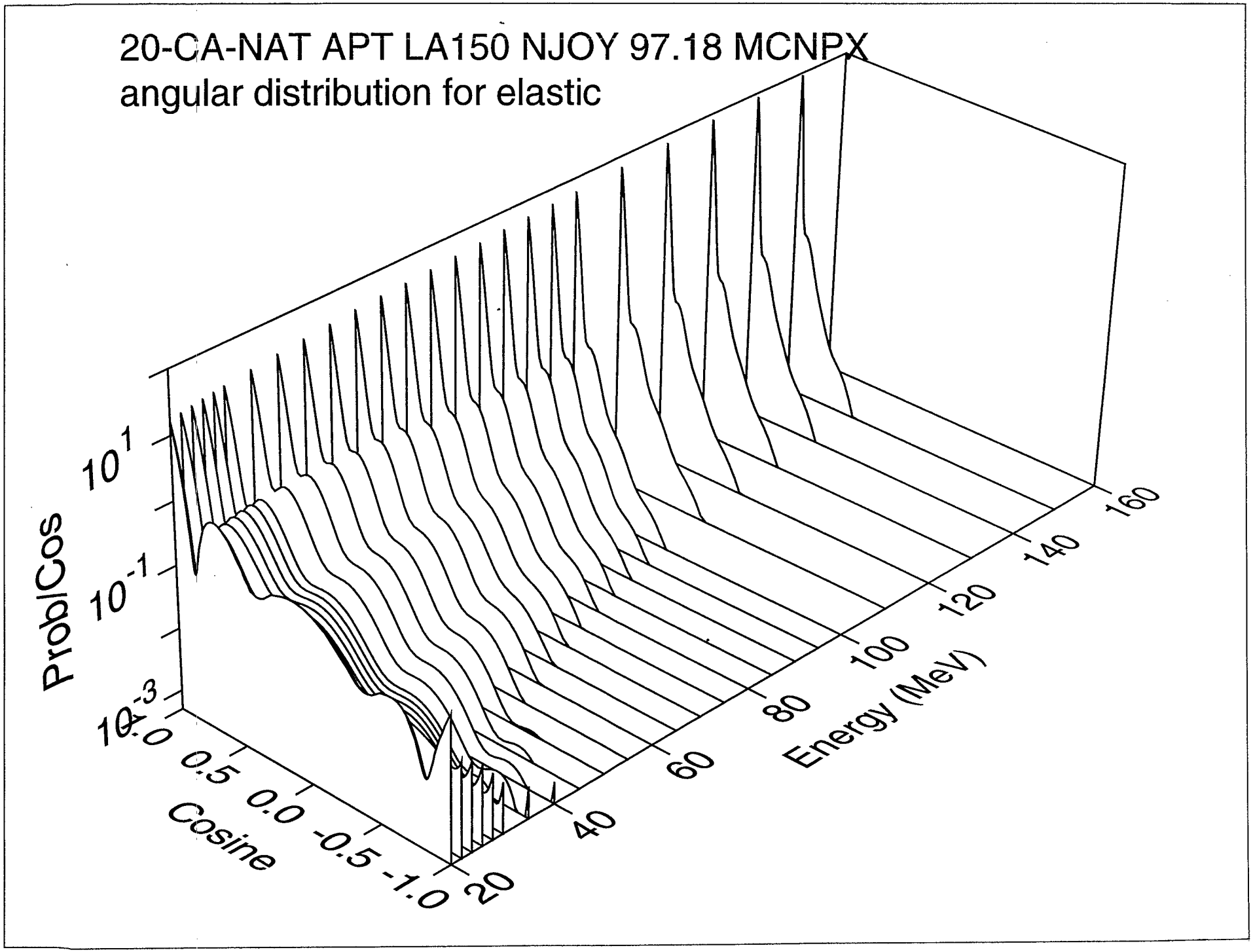


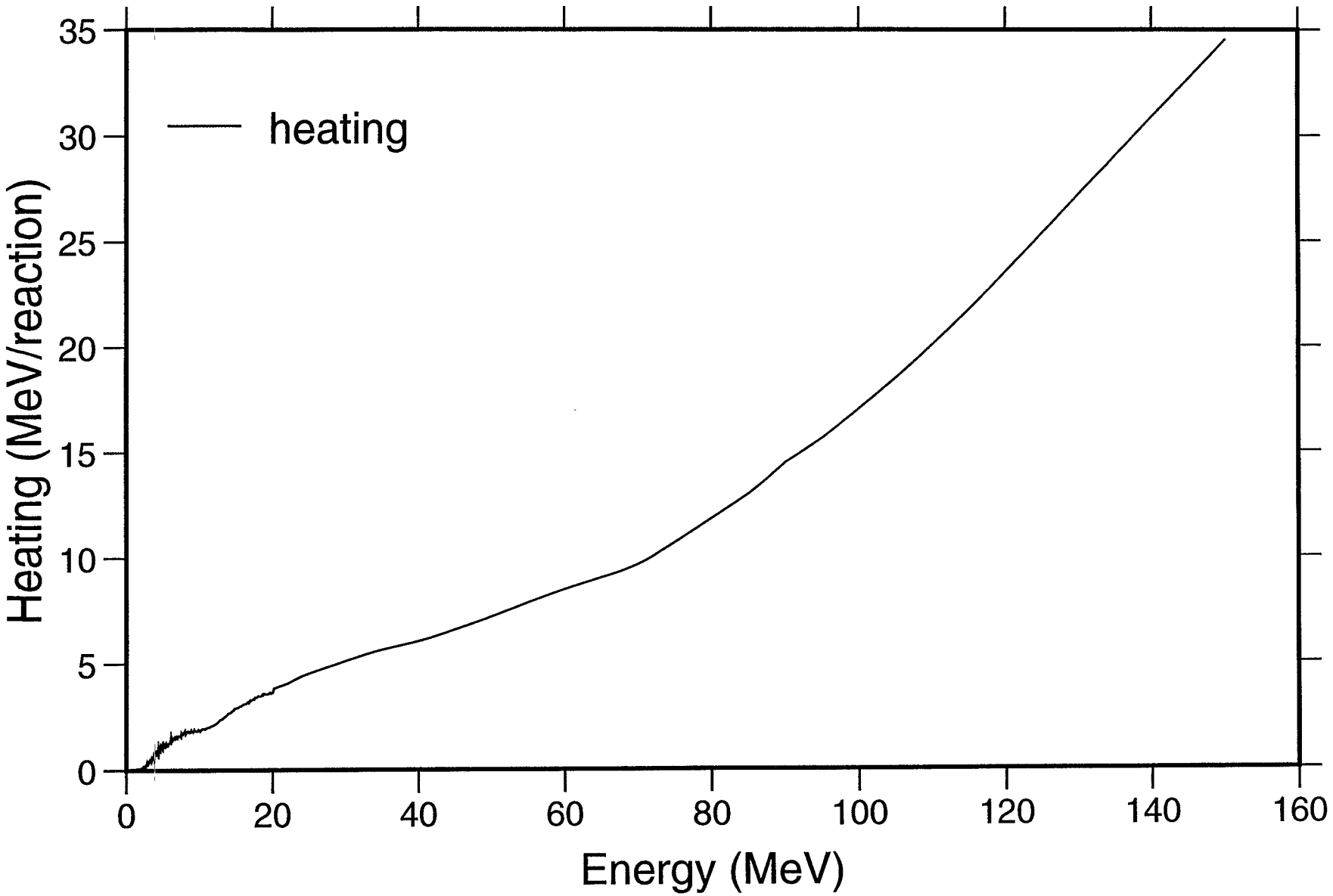


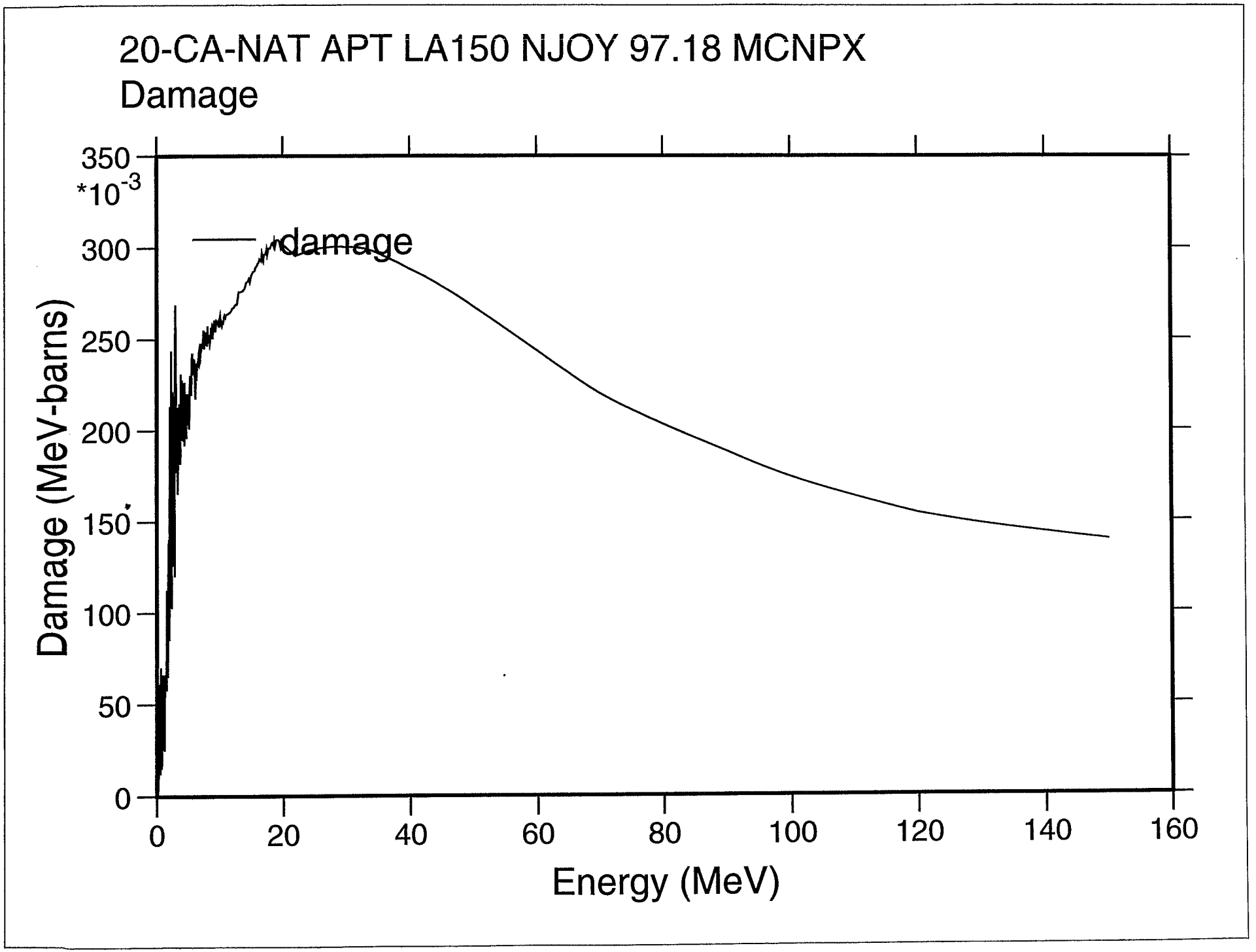







20-CA-NAT APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic
Prob/Cos
10^{1}
10^{-1}
10^{-3}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
20
40
60
80
100
120
140
160


20-CA-NAT APT LA150 NJOY 97.18 MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
5
10
15
20
25
30
35
0
20
40
60
80
100
120
140
160


20-CA-NAT APT LA150 NJOY 97.18 MCNPX
Damage
damage
Damage (MeV-barns)
*10^-3
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF n + 50Cr CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

S. Chiba, M. B. Chadwick, and P. G. Young
22 Oct. 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI.5 (Release 2) evaluation by D. Hetrick, D. Larson, N. Larson, and C. Y. Fu.

INCIDENT NEUTRON ENERGIES > 20 MeV

The ENDF/B-VI Release 2 evaluation extends to 20 MeV and includes cross sections and energy-angle data for all significant reactions. The present evaluation utilizes a more compact composite reaction spectrum representation above 20 MeV in order to reduce the length of the file. No essential data for applications is lost with this representation.

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT= 1	Total Cross Section
	MT= 2	Elastic Scattering Cross Section
	MT= 3	Nonelastic Cross Section
	MT= 5	Sum of Binary (n,n') and (n,x) Reactions
MF=4	MT= 2	Elastic Angular Distributions
MF=6	MT= 5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, Tritons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Cr52 and p + Cr52 reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of

all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk et al. (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged- particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

SOME Cr-SPECIFIC INFORMATION CONCERNING THE EVAL.

The neutron total cross section was evaluated at energy grid points by using the least-squares code GMA (Po81) taking account of the new data measured by Dietrich et al. for natural Cr(Di97). The results were transformed to the Cr-50 cross section according to the A*(2/3) law, i.e., by multiplying by a factor of 0.973515.

The neutron optical model potential derived for n + Cr-52 was used for calculation of DWBA cross sections.

The transmission coefficients calculated for the n + Cr-52 evaluation were employed for all the n + Cr-50 evaluation channels, by multiplying by a factor of 0.974192, i.e., a ratio of A**(2/3) between Cr-50 and Cr-52.

The Cr-52 transmission coefficients were calculated by using the following potentials:

For the neutron channel, the newly-searched potential for n + Cr-52, as described in File 1 of the n + Cr-52 evaluation, was used.

For the proton channel, a combination of 2 potentials was used :

below 40 MeV : Becchetti-Greenlees (Be69)
above 40 MeV : Madland medium energy potential (Ma88)

The proton reaction cross section and transmission coefficients below 40 MeV were multiplied by a factor of 0.845 to make the agreement with the measured proton reaction cross section (Ca96) better, and also to make the connection to higher energy values smoothly.

For deuterons, the Lohr-Haeberli (Lo74) global potential was used; for alpha particles the McFadden-Satchler (Mc66) potential was used; and for tritons the Becchetti-Greenlees (Be71) potential was used. The He-3 channel was ignored.

The direct collective inelastic scattering to the following levels in Cr-50 was considered by the DWBA-mode calculation of ECIS95 (Ra96):

Jpi	Ex(MeV)	Deformation length
2+	0.786	1.063
2+	2.922	0.479
2+	3.156	0.591
4+	3.317	0.4
4+	3.621	0.565
4+	3.692	0.447
4+	3.898	0.214
3-	4.045	0.692
2+	4.188	0.648
5-	4.363	0.565
3-	4.543	0.223
2+	4.676	0.316
2+	4.772	0.316
4+	4.924	0.4
4+	5.233	0.469
3-	6.45	0.264
3-	6.65	0.360
3-	6.79	0.244
3-	7.86	0.2

These data were retrieved from the literature (Bu95).

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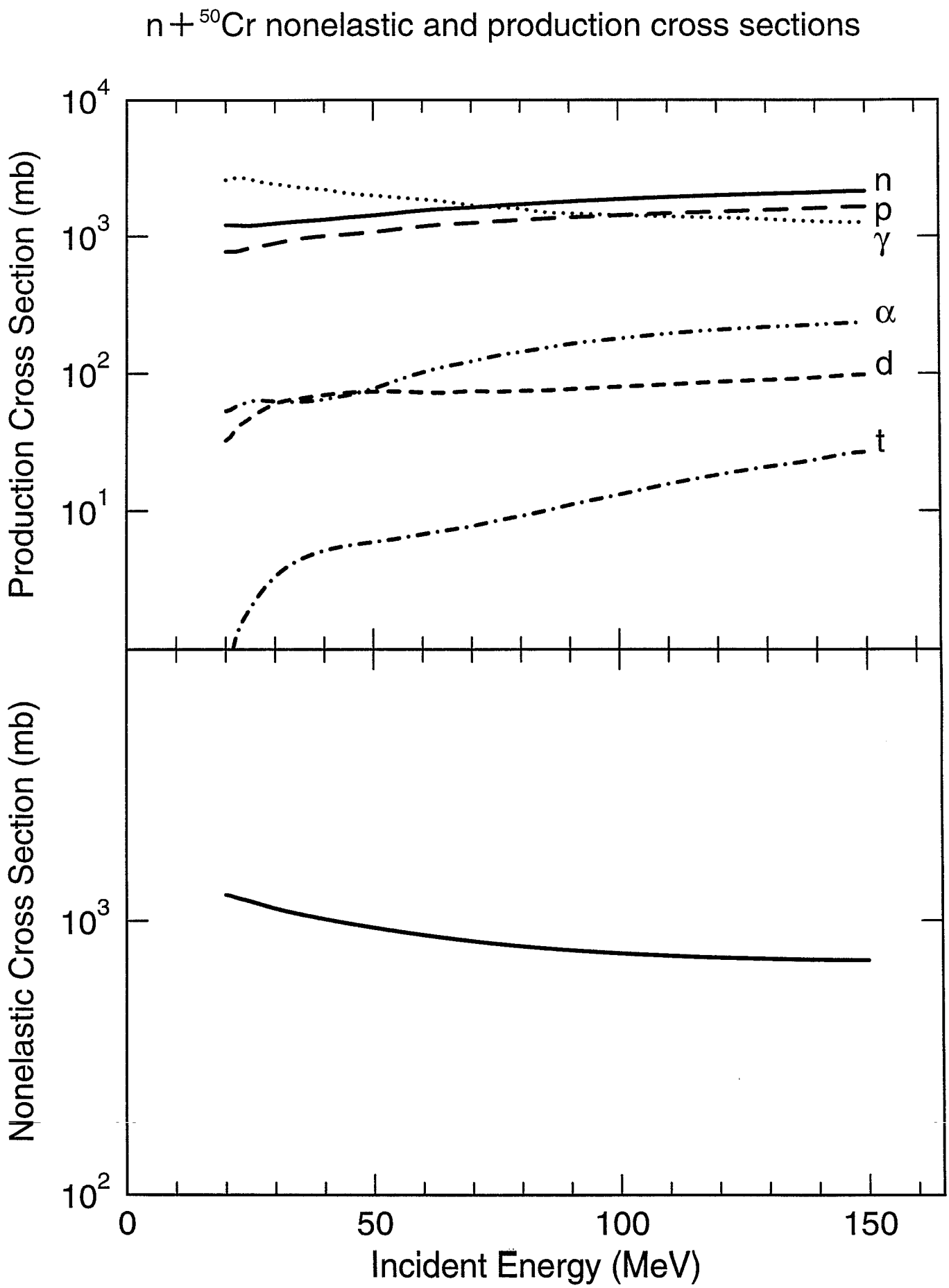
24050 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

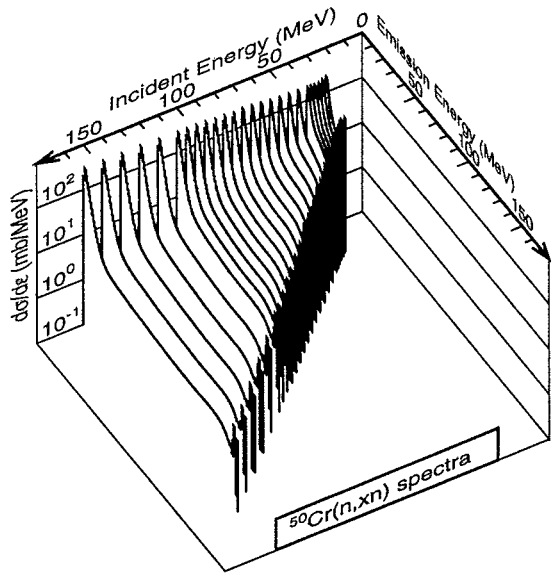
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	1.246E+00	8.926E-01	1.204E+00	7.738E-01	3.252E-02	6.981E-04	0.000E+00	5.324E-02	2.582E+00
2.200E+01	1.218E+00	9.109E-01	1.202E+00	7.755E-01	3.908E-02	1.195E-03	0.000E+00	5.729E-02	2.672E+00
2.400E+01	1.191E+00	9.659E-01	1.193E+00	8.067E-01	4.496E-02	1.747E-03	0.000E+00	6.130E-02	2.660E+00
2.600E+01	1.163E+00	1.015E+00	1.201E+00	8.370E-01	5.044E-02	2.270E-03	0.000E+00	6.368E-02	2.558E+00
2.800E+01	1.135E+00	1.080E+00	1.220E+00	8.591E-01	5.562E-02	2.826E-03	0.000E+00	6.351E-02	2.457E+00
3.000E+01	1.108E+00	1.140E+00	1.240E+00	8.876E-01	6.031E-02	3.363E-03	0.000E+00	6.279E-02	2.405E+00
3.500E+01	1.056E+00	1.279E+00	1.285E+00	9.595E-01	6.616E-02	4.461E-03	0.000E+00	6.235E-02	2.271E+00
4.000E+01	1.014E+00	1.380E+00	1.322E+00	1.004E+00	6.997E-02	5.188E-03	0.000E+00	6.507E-02	2.192E+00
4.500E+01	9.765E-01	1.439E+00	1.375E+00	1.036E+00	7.288E-02	5.658E-03	0.000E+00	7.026E-02	2.057E+00
5.000E+01	9.435E-01	1.461E+00	1.421E+00	1.075E+00	7.398E-02	5.983E-03	0.000E+00	7.776E-02	1.985E+00
5.500E+01	9.140E-01	1.454E+00	1.480E+00	1.127E+00	7.420E-02	6.355E-03	0.000E+00	8.980E-02	1.921E+00
6.000E+01	8.874E-01	1.424E+00	1.542E+00	1.181E+00	7.306E-02	6.809E-03	0.000E+00	1.020E-01	1.859E+00
6.500E+01	8.637E-01	1.376E+00	1.590E+00	1.224E+00	7.289E-02	7.276E-03	0.000E+00	1.130E-01	1.787E+00
7.000E+01	8.426E-01	1.317E+00	1.623E+00	1.250E+00	7.448E-02	7.782E-03	0.000E+00	1.222E-01	1.684E+00
7.500E+01	8.239E-01	1.257E+00	1.673E+00	1.285E+00	7.393E-02	8.519E-03	0.000E+00	1.342E-01	1.629E+00
8.000E+01	8.075E-01	1.188E+00	1.714E+00	1.312E+00	7.487E-02	9.222E-03	0.000E+00	1.434E-01	1.587E+00
8.500E+01	7.931E-01	1.115E+00	1.755E+00	1.346E+00	7.540E-02	1.003E-02	0.000E+00	1.530E-01	1.496E+00
9.000E+01	7.805E-01	1.049E+00	1.797E+00	1.375E+00	7.704E-02	1.108E-02	0.000E+00	1.632E-01	1.471E+00
9.500E+01	7.696E-01	9.763E-01	1.833E+00	1.395E+00	7.853E-02	1.207E-02	0.000E+00	1.715E-01	1.447E+00
1.000E+02	7.601E-01	9.143E-01	1.867E+00	1.420E+00	8.012E-02	1.314E-02	0.000E+00	1.787E-01	1.425E+00
1.100E+02	7.450E-01	7.931E-01	1.936E+00	1.471E+00	8.313E-02	1.570E-02	0.000E+00	1.939E-01	1.392E+00
1.200E+02	7.338E-01	6.863E-01	1.990E+00	1.509E+00	8.681E-02	1.835E-02	0.000E+00	2.066E-01	1.367E+00
1.300E+02	7.260E-01	5.936E-01	2.041E+00	1.553E+00	8.971E-02	2.099E-02	0.000E+00	2.165E-01	1.328E+00
1.400E+02	7.207E-01	5.196E-01	2.088E+00	1.600E+00	9.327E-02	2.370E-02	0.000E+00	2.251E-01	1.278E+00
1.500E+02	7.183E-01	4.534E-01	2.138E+00	1.645E+00	9.788E-02	2.682E-02	0.000E+00	2.326E-01	1.261E+00

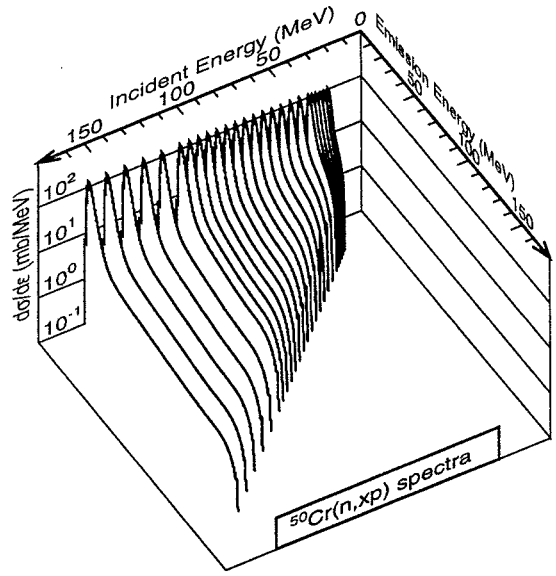
24050 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

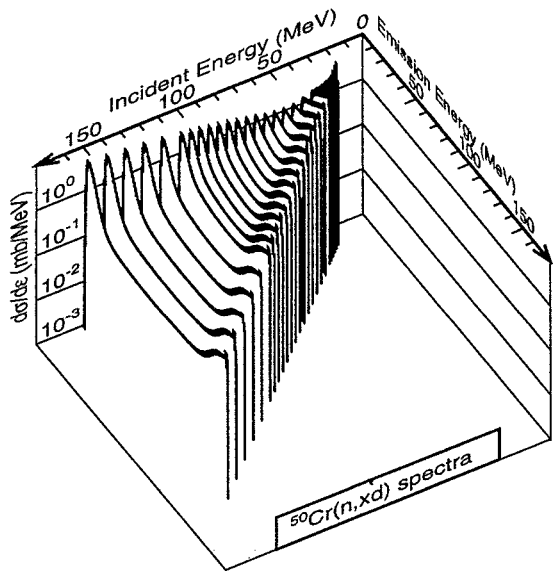
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	8.542E-01	5.344E-02	6.475E-04	0.000E+00	9.895E-02	1.209E-01	2.792E-02	1.156E+00
2.200E+01	9.055E-01	7.327E-02	1.324E-03	0.000E+00	1.094E-01	1.277E-01	2.937E-02	1.247E+00
2.400E+01	9.696E-01	9.436E-02	2.239E-03	0.000E+00	1.201E-01	1.339E-01	3.095E-02	1.351E+00
2.600E+01	1.029E+00	1.168E-01	3.270E-03	0.000E+00	1.285E-01	1.384E-01	3.157E-02	1.448E+00
2.800E+01	1.093E+00	1.408E-01	4.556E-03	0.000E+00	1.322E-01	1.419E-01	3.219E-02	1.545E+00
3.000E+01	1.168E+00	1.662E-01	5.982E-03	0.000E+00	1.350E-01	1.441E-01	3.241E-02	1.651E+00
3.500E+01	1.375E+00	2.175E-01	9.693E-03	0.000E+00	1.418E-01	1.537E-01	3.219E-02	1.930E+00
4.000E+01	1.595E+00	2.723E-01	1.329E-02	0.000E+00	1.525E-01	1.612E-01	3.099E-02	2.225E+00
4.500E+01	1.793E+00	3.290E-01	1.659E-02	0.000E+00	1.666E-01	1.686E-01	2.928E-02	2.504E+00
5.000E+01	1.998E+00	3.764E-01	1.952E-02	0.000E+00	1.844E-01	1.763E-01	2.730E-02	2.782E+00
5.500E+01	2.203E+00	4.151E-01	2.219E-02	0.000E+00	2.097E-01	1.841E-01	2.524E-02	3.059E+00
6.000E+01	2.401E+00	4.356E-01	2.467E-02	0.000E+00	2.358E-01	1.916E-01	2.319E-02	3.312E+00
6.500E+01	2.603E+00	4.626E-01	2.710E-02	0.000E+00	2.602E-01	1.960E-01	2.118E-02	3.570E+00
7.000E+01	2.788E+00	5.067E-01	2.932E-02	0.000E+00	2.815E-01	2.032E-01	1.928E-02	3.828E+00
7.500E+01	2.983E+00	5.196E-01	3.170E-02	0.000E+00	3.083E-01	2.065E-01	1.760E-02	4.067E+00
8.000E+01	3.174E+00	5.508E-01	3.394E-02	0.000E+00	3.307E-01	2.106E-01	1.597E-02	4.316E+00
8.500E+01	3.376E+00	5.732E-01	3.621E-02	0.000E+00	3.537E-01	2.148E-01	1.446E-02	4.568E+00
9.000E+01	3.569E+00	6.044E-01	3.863E-02	0.000E+00	3.781E-01	2.195E-01	1.316E-02	4.823E+00
9.500E+01	3.762E+00	6.366E-01	4.097E-02	0.000E+00	3.994E-01	2.229E-01	1.190E-02	5.074E+00
1.000E+02	3.963E+00	6.684E-01	4.327E-02	0.000E+00	4.187E-01	2.260E-01	1.086E-02	5.331E+00
1.100E+02	4.375E+00	7.158E-01	4.820E-02	0.000E+00	4.596E-01	2.312E-01	9.010E-03	5.839E+00
1.200E+02	4.798E+00	7.755E-01	5.262E-02	0.000E+00	4.962E-01	2.340E-01	7.528E-03	6.364E+00
1.300E+02	5.233E+00	8.179E-01	5.620E-02	0.000E+00	5.283E-01	2.416E-01	6.338E-03	6.883E+00
1.400E+02	5.686E+00	8.712E-01	5.936E-02	0.000E+00	5.575E-01	2.513E-01	5.437E-03	7.431E+00
1.500E+02	6.148E+00	9.332E-01	6.311E-02	0.000E+00	5.856E-01	2.600E-01	4.679E-03	7.995E+00

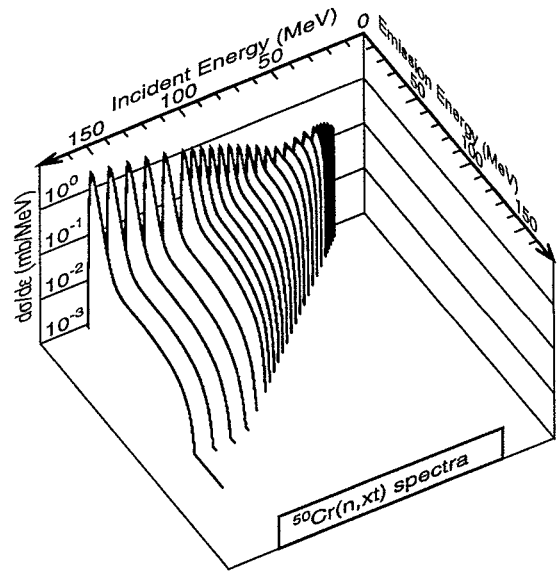

n + 50Cr nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
n
p
γ
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
0
50
100
150
Incident Energy (MeV)

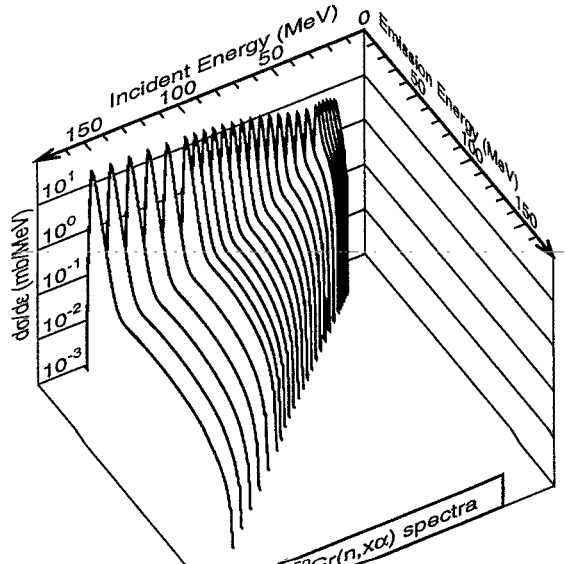
n + ^{50}Cr angle-integrated emission spectra

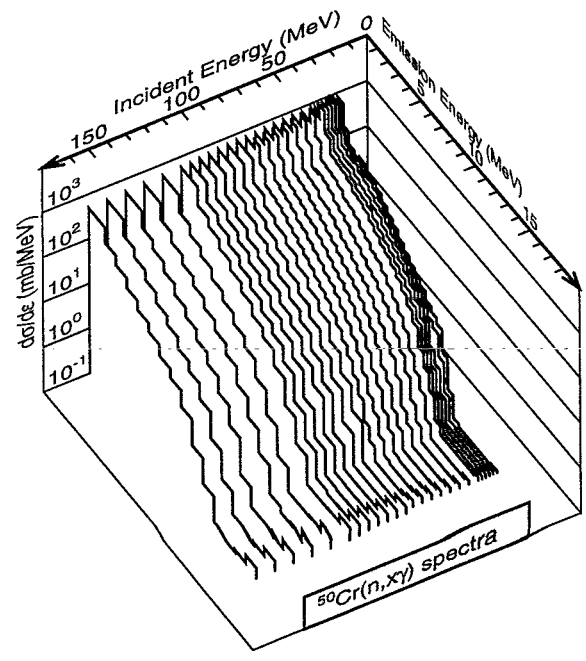




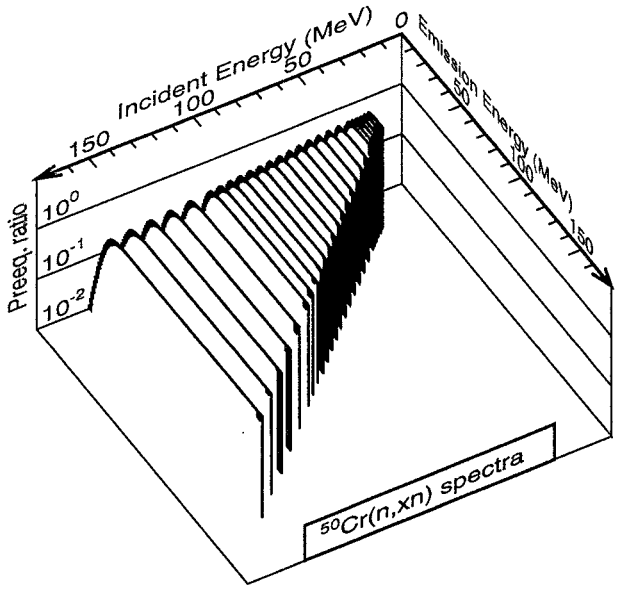


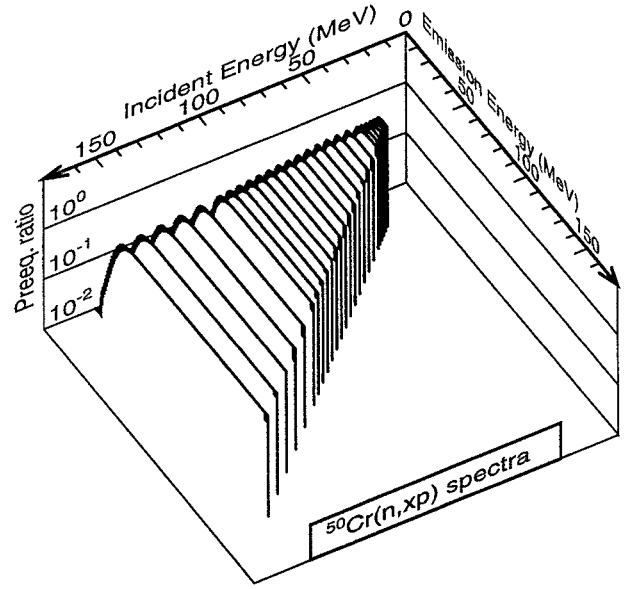


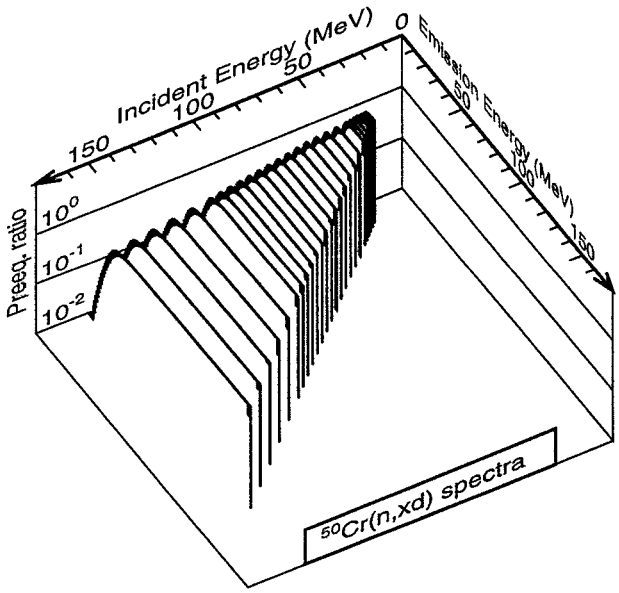


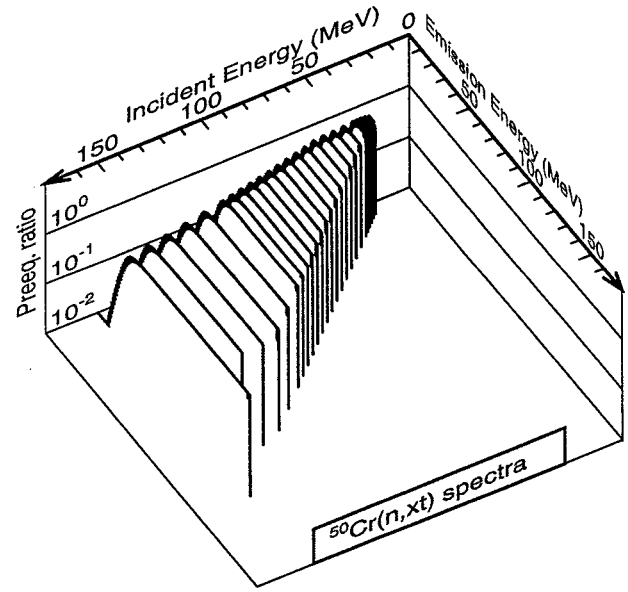


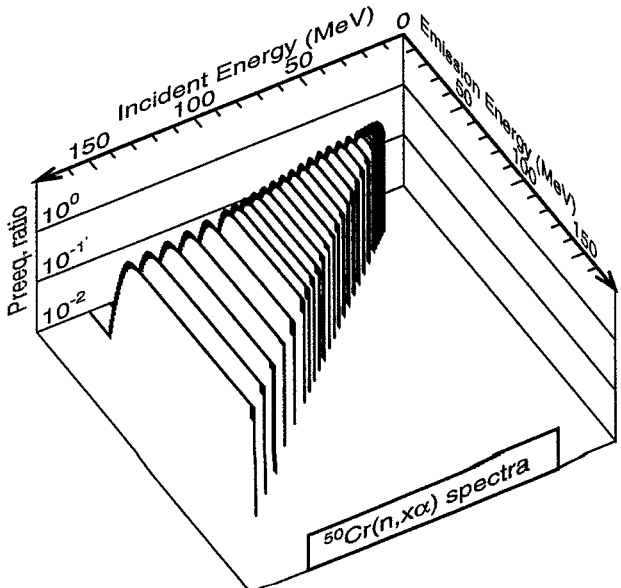
n + ^{50}Cr Kalbach preequilibrium ratios

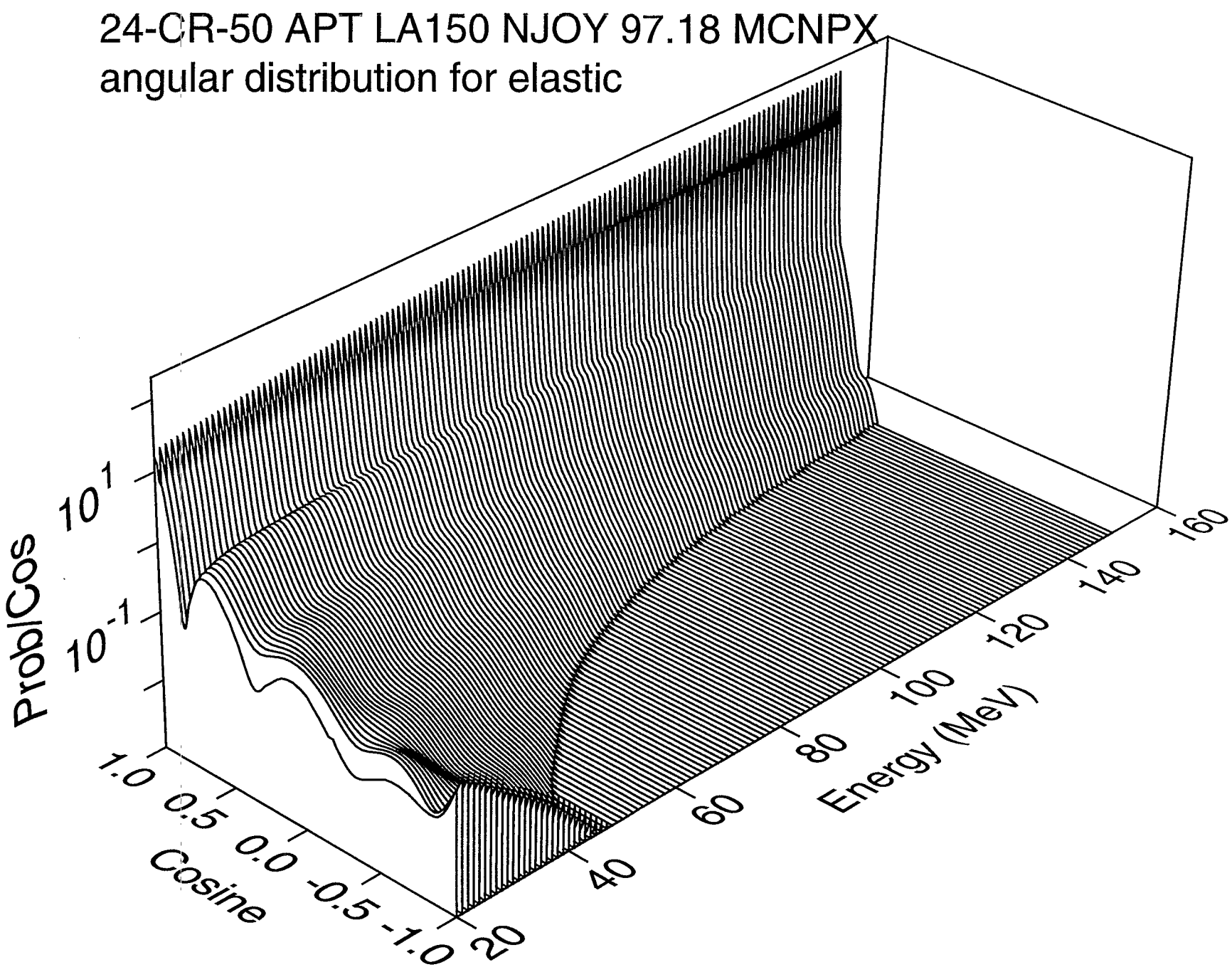


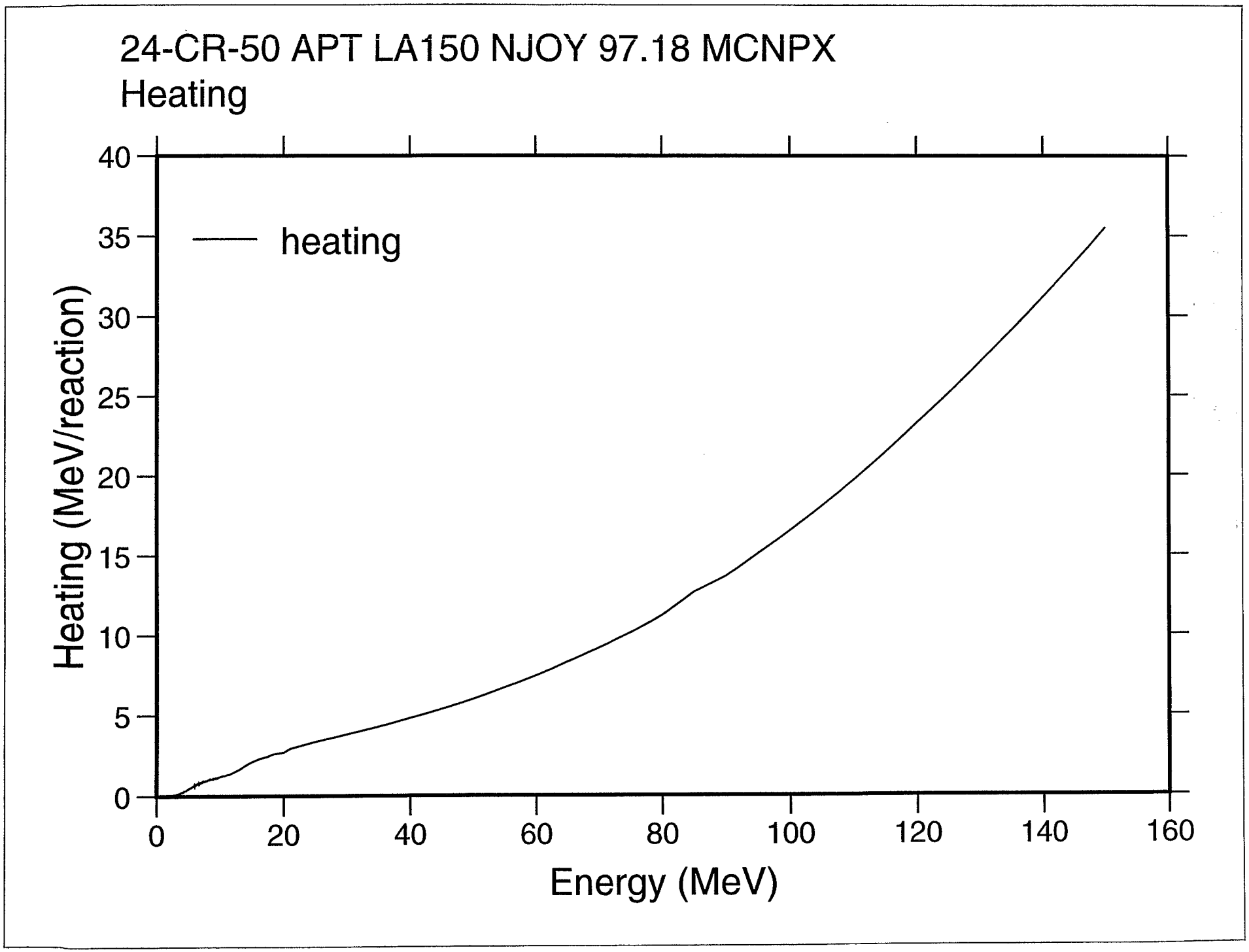


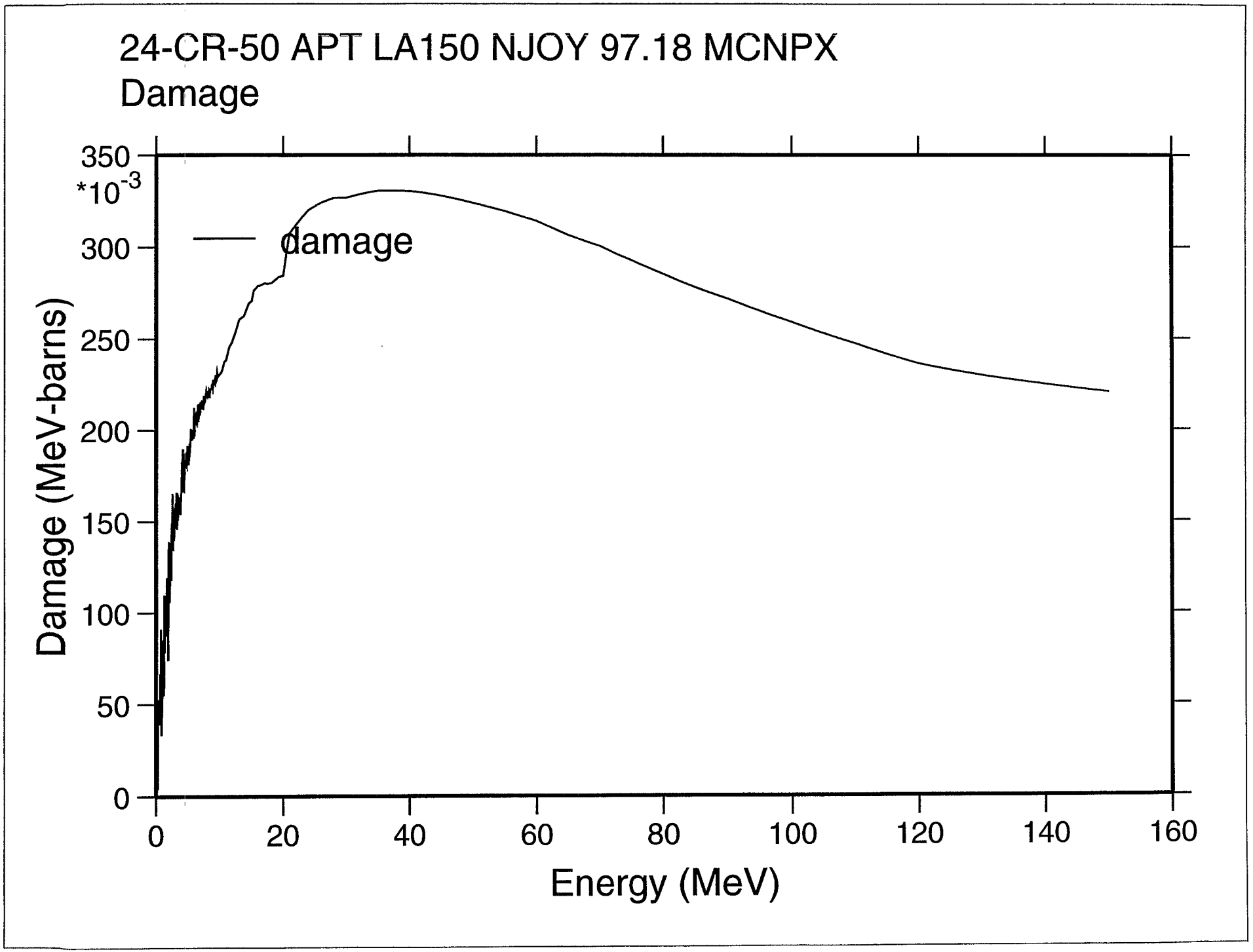







24-CR-50 APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic
Prob/Cos
10^{1}
10^{-1}
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


24-CR-50 APT LA150 NJOY 97.18 MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
5
10
15
20
25
30
35
40
0
20
40
60
80
100
120
140
160


24-CR-50 APT LA150 NJOY 97.18 MCNPX
Damage
damage
Damage (MeV-barns)
*10^-3
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF n + 52Cr CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

S. Chiba, M. B. Chadwick, and P. G. Young
22 Oct. 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI (Revision 1) evaluation by D. Hetrick, D. Larson, N. Larson, and C. Y. Fu.

INCIDENT NEUTRON ENERGIES > 20 MeV

The ENDF/B-VI Release 2 evaluation extends to 20 MeV and includes cross sections and energy-angle data for all significant reactions. The present evaluation utilizes a more compact composite reaction spectrum representation above 20 MeV in order to reduce the length of the file. No essential data for applications is lost with this representation.

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT= 1	Total Cross Section
	MT= 2	Elastic Scattering Cross Section
	MT= 3	Nonelastic Cross Section
	MT= 5	Sum of Binary (n,n') and (n,x) Reactions
MF=4	MT= 2	Elastic Angular Distributions
MF=6	MT= 5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, Tritons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Cr52 and p + Cr52 reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of

all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk et al. (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged- particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

SOME Cr-SPECIFIC INFORMATION CONCERNING THE EVAL.

The neutron total cross section was evaluated at grid energy points by using the least-squares code GMA (Po81) taking account of the new data measured by Dietrich et al. for natural Cr(Di97). The results were transformed to the Cr-52 cross section according to A*(2/3) law, i.e., by multiplying a factor of 0.999305.

The evaluated total cross section data (present result from 20 to 250 MeV, and ENDF/B-VI value below 20 MeV), s-wave strength function(Mu81), and elastic scattering angular distribution data (Ki74, Ol87) were used to obtain the neutron optical potential parameters. The parameter estimation was carried out based on Bayesian approach (Sm91), where ECIS95 code was used for the optical model calculation. We have employed the energy dependence of the optical potential similar to Delaroche's work(De89). Total of 18 parameters concerning the central potential were estimated.
Presently obtained potential was used for the calculation of neutron transmission coefficients and DWBA cross sections in the entire energy region.

For proton channel, a combination of 2 potentials were used :
below 40 MeV : Becchetti-Greenlees
above 40 MeV : Madland medium energy potential

The proton reaction cross section and transmission coefficients below 40 MeV were multiplied by a factor of 0.845 to make the agreement with the measured proton reaction cross section (Ca96) better, and also to make the connection to higher energy values smoothly.
For deuterons, the Lohr-Haeberli global potential was used; for alpha particles the Moyen potential (MacFadden-Satchler) was used; and for tritons the Becchetti-Greenlees potential was used.
The He-3 channelwas ignored.
The direct collective inelastic scattering to the following levels in Cr-52 was considered by the DWBA-mode calculation of ECIS95:

Jpi	Ex(MeV)	Deformation length
2+	1.434	0.87
4+	2.369	0.33

0+	2.647	0.095
4+	2.768	0.30
2+	2.965	0.08
6+	3.114	0.35
2+	3.162	0.27
4+	3.415	0.13
2+	3.772	0.28
4+	4.040	0.16
3-	4.563	0.61
4+	4.630	0.36
0+	4.738	0.145
4+	4.951	0.20
4+	5.095	0.15
4+	5.425	0.32
4+	5.541	0.074
2+	5.661	0.095
3-	5.873	0.082
3-	5.996	0.087
2+	6.055	0.13
2+	6.143	0.07
2+	6.175	0.21
2+	6.493	0.21
3-	6.580	0.34
3-	6.786	0.26
2+	6.810	0.22
5-	6.871	0.16
3-	6.993	0.18
3-	7.080	0.34
4+	7.140	0.14
2+	7.217	0.10
4+	7.278	0.13
2+	7.344	0.074
5-	7.376	0.11
3-	7.409	0.091
3-	7.482	0.13
3-	7.585	0.074
3-	7.738	0.26
3-	7.823	0.12
4+	7.848	0.11
4+	7.893	0.12
3-	7.967	0.095
2+	8.022	0.10
3-	8.089	0.091
3-	8.281	0.15
3-	8.457	0.13
3-	8.505	0.10
3-	8.679	0.10
3-	8.782	0.10
3-	8.778	0.13
3-	9.440	0.095

These data were retrieved from the literature (Ju94).

****

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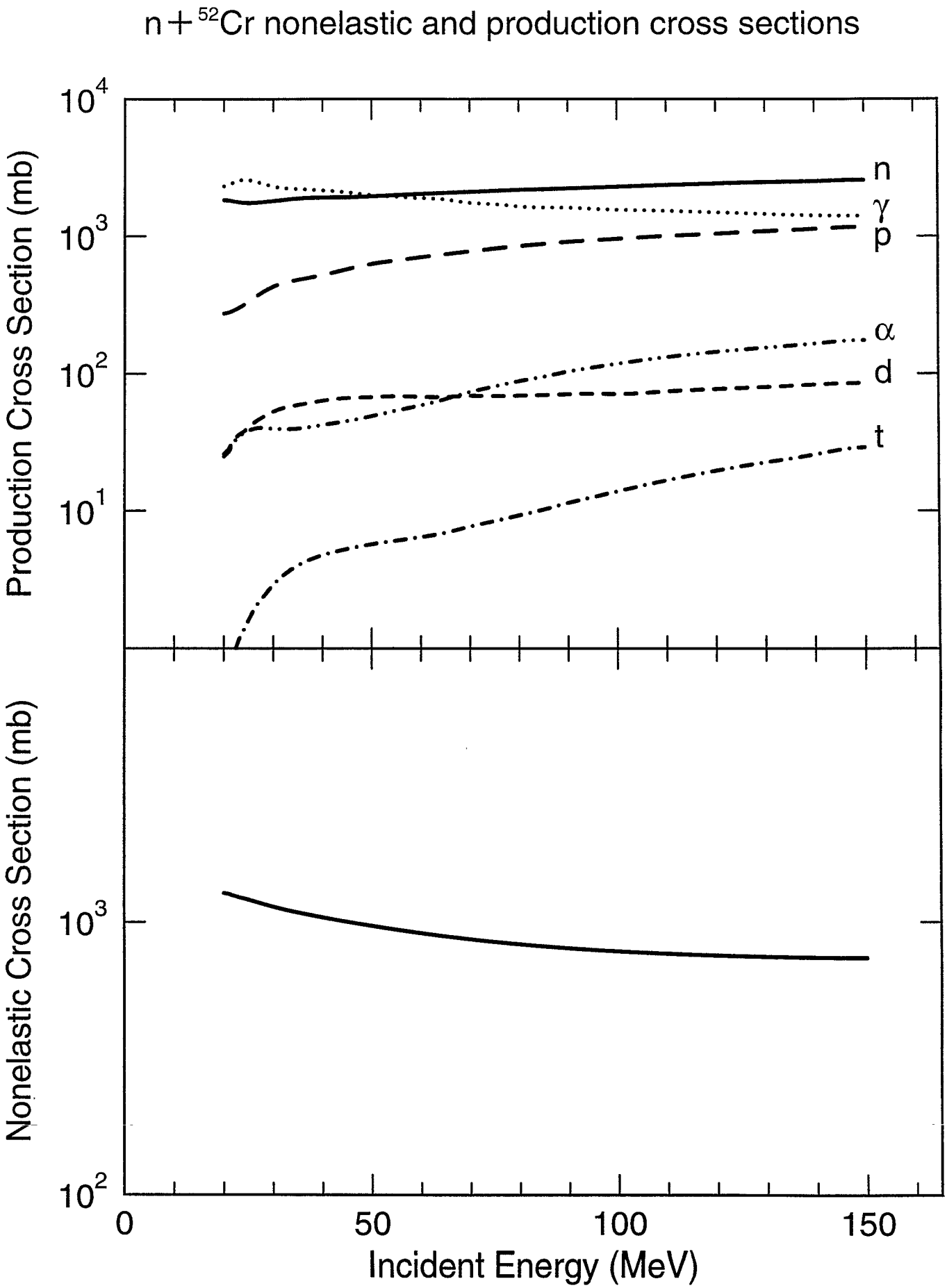
24052 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

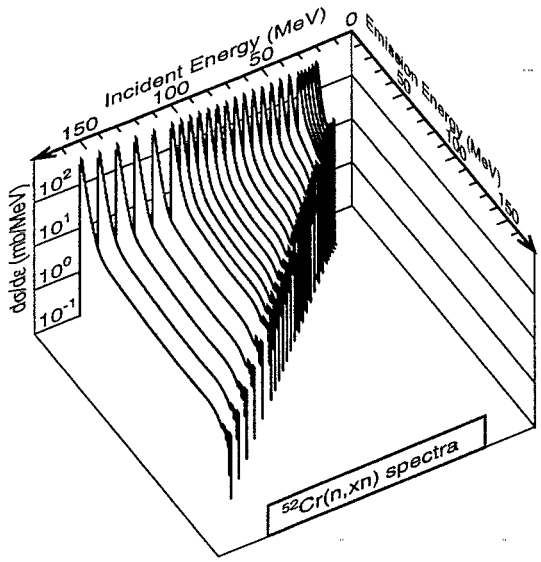
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	1.279E+00	9.163E-01	1.835E+00	2.751E-01	2.588E-02	4.586E-04	0.000E+00	2.480E-02	2.315E+00
2.200E+01	1.250E+00	9.350E-01	1.798E+00	2.901E-01	3.265E-02	8.735E-04	0.000E+00	3.146E-02	2.470E+00
2.400E+01	1.222E+00	9.915E-01	1.754E+00	3.174E-01	3.775E-02	1.353E-03	0.000E+00	3.679E-02	2.587E+00
2.600E+01	1.194E+00	1.042E+00	1.752E+00	3.553E-01	4.347E-02	1.890E-03	0.000E+00	3.968E-02	2.527E+00
2.800E+01	1.165E+00	1.109E+00	1.782E+00	3.967E-01	4.847E-02	2.382E-03	0.000E+00	4.025E-02	2.412E+00
3.000E+01	1.138E+00	1.171E+00	1.809E+00	4.328E-01	5.292E-02	2.905E-03	0.000E+00	3.971E-02	2.306E+00
3.500E+01	1.084E+00	1.312E+00	1.886E+00	4.846E-01	5.915E-02	4.013E-03	0.000E+00	3.980E-02	2.210E+00
4.000E+01	1.041E+00	1.416E+00	1.920E+00	5.247E-01	6.365E-02	4.764E-03	0.000E+00	4.233E-02	2.159E+00
4.500E+01	1.002E+00	1.477E+00	1.929E+00	5.794E-01	6.665E-02	5.287E-03	0.000E+00	4.508E-02	2.089E+00
5.000E+01	9.685E-01	1.499E+00	1.959E+00	6.318E-01	6.761E-02	5.722E-03	0.000E+00	4.910E-02	1.990E+00
5.500E+01	9.382E-01	1.492E+00	2.000E+00	6.703E-01	6.867E-02	6.081E-03	0.000E+00	5.383E-02	1.947E+00
6.000E+01	9.110E-01	1.462E+00	2.036E+00	7.069E-01	6.787E-02	6.446E-03	0.000E+00	5.880E-02	1.902E+00
6.500E+01	8.866E-01	1.413E+00	2.075E+00	7.436E-01	6.773E-02	6.934E-03	0.000E+00	6.532E-02	1.860E+00
7.000E+01	8.649E-01	1.352E+00	2.110E+00	7.803E-01	6.905E-02	7.695E-03	0.000E+00	7.353E-02	1.756E+00
7.500E+01	8.458E-01	1.291E+00	2.148E+00	8.159E-01	6.864E-02	8.435E-03	0.000E+00	8.059E-02	1.717E+00
8.000E+01	8.289E-01	1.219E+00	2.182E+00	8.497E-01	6.915E-02	9.260E-03	0.000E+00	8.813E-02	1.651E+00
8.500E+01	8.141E-01	1.145E+00	2.205E+00	8.800E-01	6.977E-02	1.019E-02	0.000E+00	9.503E-02	1.622E+00
9.000E+01	8.012E-01	1.076E+00	2.236E+00	9.100E-01	7.082E-02	1.139E-02	0.000E+00	1.035E-01	1.620E+00
9.500E+01	7.900E-01	1.002E+00	2.269E+00	9.347E-01	7.137E-02	1.253E-02	0.000E+00	1.105E-01	1.585E+00
1.000E+02	7.803E-01	9.385E-01	2.303E+00	9.584E-01	7.111E-02	1.377E-02	0.000E+00	1.177E-01	1.564E+00
1.100E+02	7.647E-01	8.141E-01	2.370E+00	1.005E+00	7.413E-02	1.662E-02	0.000E+00	1.318E-01	1.532E+00
1.200E+02	7.533E-01	7.045E-01	2.428E+00	1.043E+00	7.716E-02	1.954E-02	0.000E+00	1.439E-01	1.493E+00
1.300E+02	7.452E-01	6.093E-01	2.480E+00	1.087E+00	7.964E-02	2.245E-02	0.000E+00	1.544E-01	1.446E+00
1.400E+02	7.398E-01	5.334E-01	2.524E+00	1.130E+00	8.313E-02	2.576E-02	0.000E+00	1.654E-01	1.414E+00
1.500E+02	7.373E-01	4.654E-01	2.579E+00	1.167E+00	8.527E-02	2.899E-02	0.000E+00	1.746E-01	1.404E+00

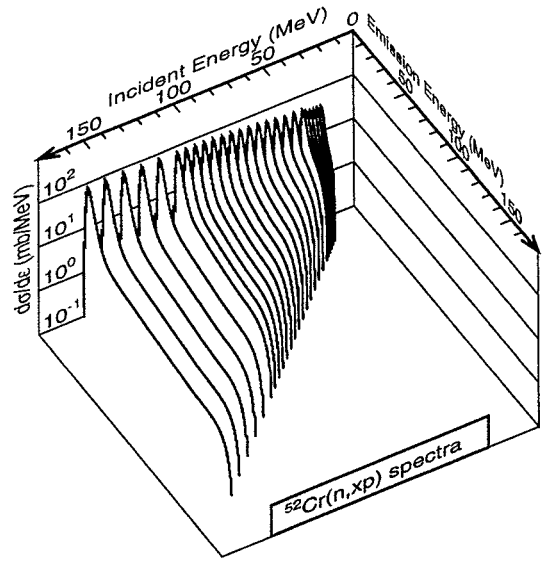
24052 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

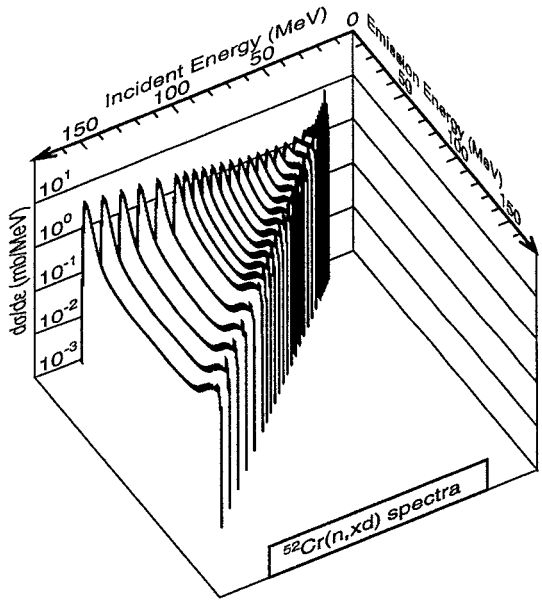
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	2.987E-01	3.823E-02	3.929E-04	0.000E+00	4.111E-02	1.082E-01	2.651E-02	5.132E-01
2.200E+01	3.445E-01	5.551E-02	8.998E-04	0.000E+00	5.290E-02	1.152E-01	2.835E-02	5.973E-01
2.400E+01	3.975E-01	7.170E-02	1.600E-03	0.000E+00	6.329E-02	1.212E-01	3.017E-02	6.855E-01
2.600E+01	4.600E-01	9.184E-02	2.524E-03	0.000E+00	7.086E-02	1.260E-01	3.096E-02	7.821E-01
2.800E+01	5.299E-01	1.125E-01	3.485E-03	0.000E+00	7.473E-02	1.298E-01	3.168E-02	8.822E-01
3.000E+01	6.049E-01	1.338E-01	4.662E-03	0.000E+00	7.644E-02	1.333E-01	3.195E-02	9.851E-01
3.500E+01	7.924E-01	1.800E-01	7.805E-03	0.000E+00	8.145E-02	1.424E-01	3.162E-02	1.236E+00
4.000E+01	9.748E-01	2.296E-01	1.082E-02	0.000E+00	8.980E-02	1.508E-01	3.024E-02	1.486E+00
4.500E+01	1.165E+00	2.788E-01	1.362E-02	0.000E+00	9.817E-02	1.575E-01	2.840E-02	1.742E+00
5.000E+01	1.359E+00	3.175E-01	1.622E-02	0.000E+00	1.081E-01	1.637E-01	2.634E-02	1.991E+00
5.500E+01	1.548E+00	3.569E-01	1.857E-02	0.000E+00	1.194E-01	1.689E-01	2.425E-02	2.236E+00
6.000E+01	1.737E+00	3.812E-01	2.082E-02	0.000E+00	1.312E-01	1.730E-01	2.220E-02	2.465E+00
6.500E+01	1.923E+00	4.076E-01	2.296E-02	0.000E+00	1.456E-01	1.778E-01	2.021E-02	2.697E+00
7.000E+01	2.101E+00	4.446E-01	2.518E-02	0.000E+00	1.632E-01	1.835E-01	1.835E-02	2.935E+00
7.500E+01	2.287E+00	4.628E-01	2.733E-02	0.000E+00	1.789E-01	1.879E-01	1.671E-02	3.161E+00
8.000E+01	2.474E+00	4.894E-01	2.948E-02	0.000E+00	1.954E-01	1.913E-01	1.513E-02	3.394E+00
8.500E+01	2.658E+00	5.154E-01	3.168E-02	0.000E+00	2.112E-01	1.945E-01	1.368E-02	3.625E+00
9.000E+01	2.844E+00	5.399E-01	3.412E-02	0.000E+00	2.297E-01	1.983E-01	1.243E-02	3.858E+00
9.500E+01	3.037E+00	5.591E-01	3.643E-02	0.000E+00	2.460E-01	2.012E-01	1.122E-02	4.091E+00
1.000E+02	3.235E+00	5.628E-01	3.887E-02	0.000E+00	2.628E-01	2.030E-01	1.022E-02	4.313E+00
1.100E+02	3.623E+00	6.151E-01	4.396E-02	0.000E+00	2.964E-01	2.086E-01	8.465E-03	4.795E+00
1.200E+02	4.022E+00	6.675E-01	4.868E-02	0.000E+00	3.268E-01	2.132E-01	7.060E-03	5.285E+00
1.300E+02	4.440E+00	7.087E-01	5.273E-02	0.000E+00	3.544E-01	2.245E-01	5.935E-03	5.787E+00
1.400E+02	4.859E+00	7.575E-01	5.699E-02	0.000E+00	3.832E-01	2.384E-01	5.084E-03	6.301E+00
1.500E+02	5.316E+00	7.773E-01	6.121E-02	0.000E+00	4.092E-01	2.498E-01	4.371E-03	6.818E+00

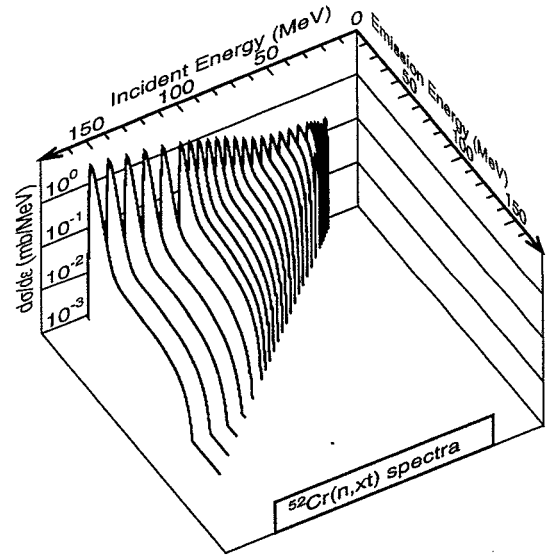

n + 52Cr nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
n
γ
p
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
0
50
100
150
Incident Energy (MeV)

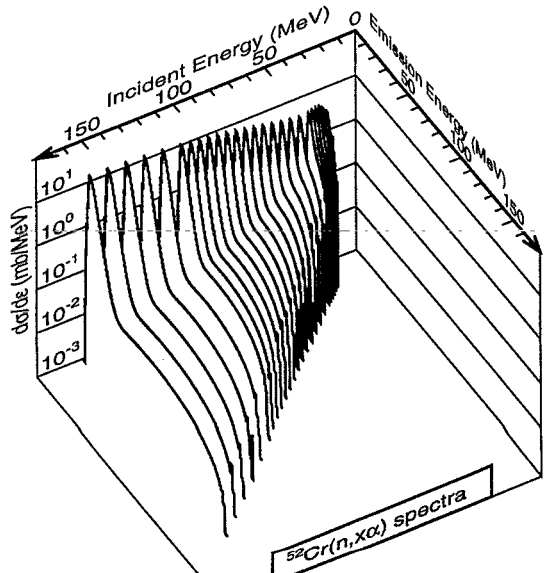
n + ^{52}Cr angle-integrated emission spectra

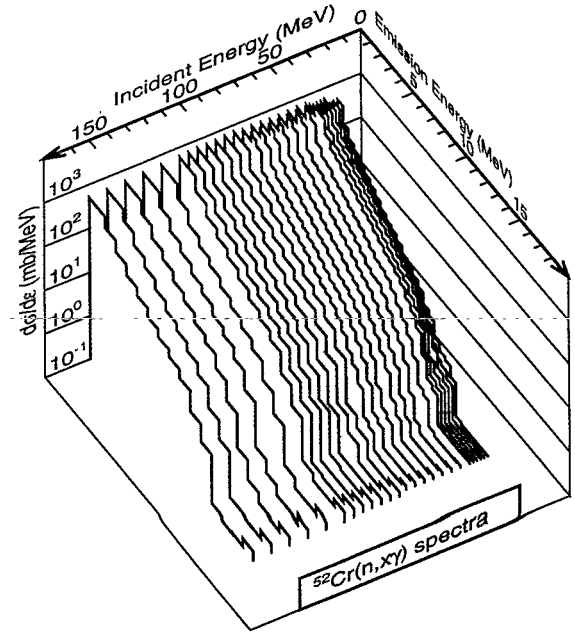




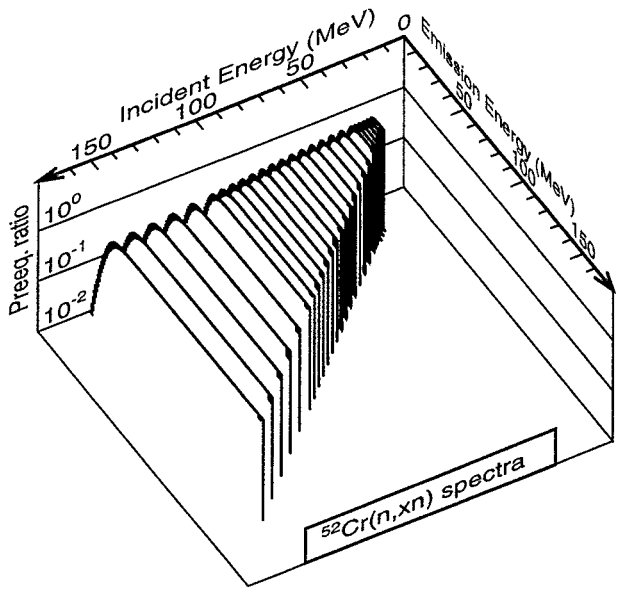


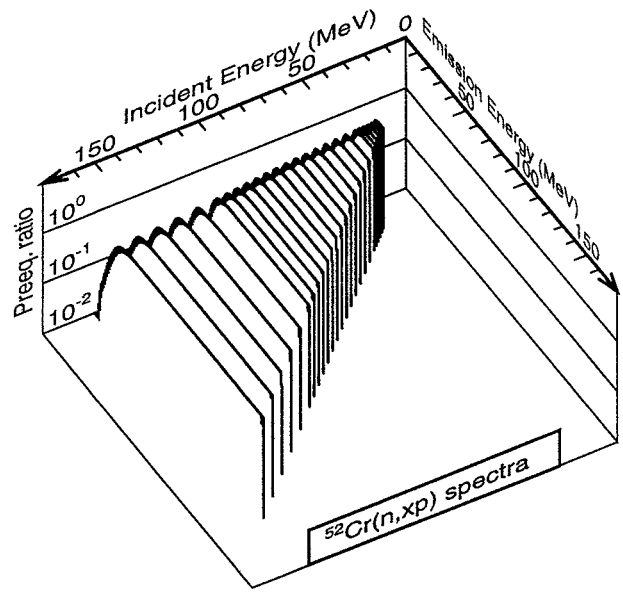


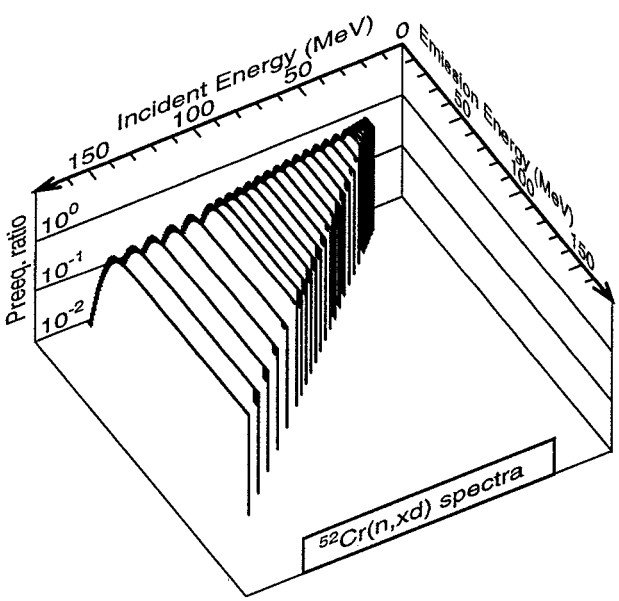


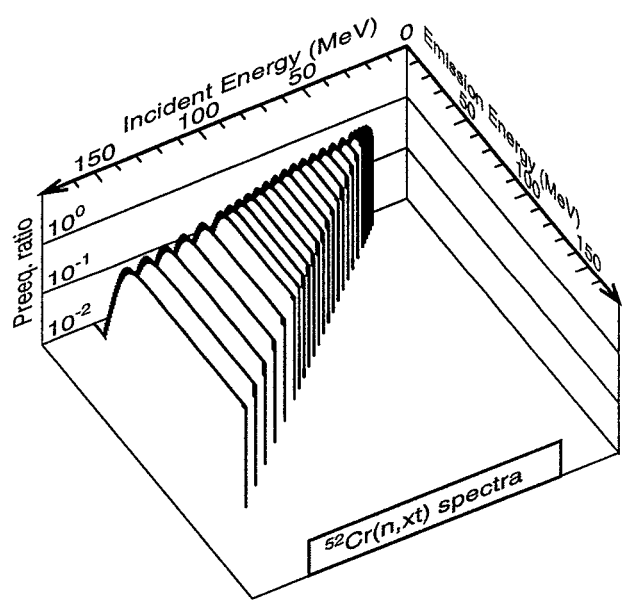


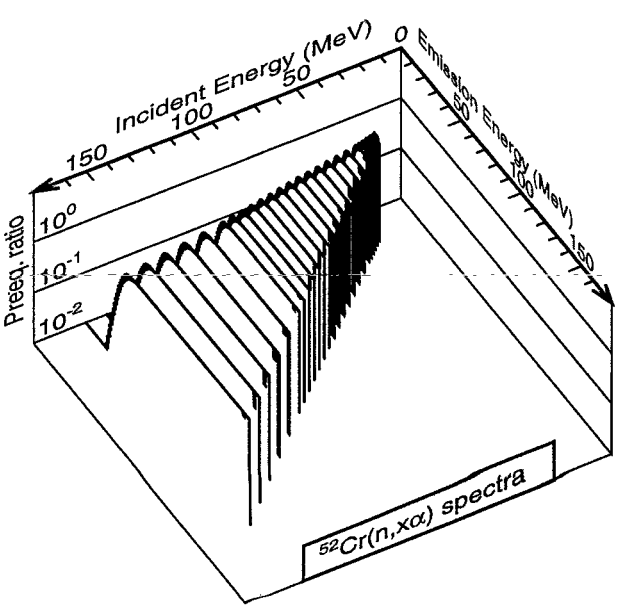
n + ^{52}Cr Kalbach preequilibrium ratios

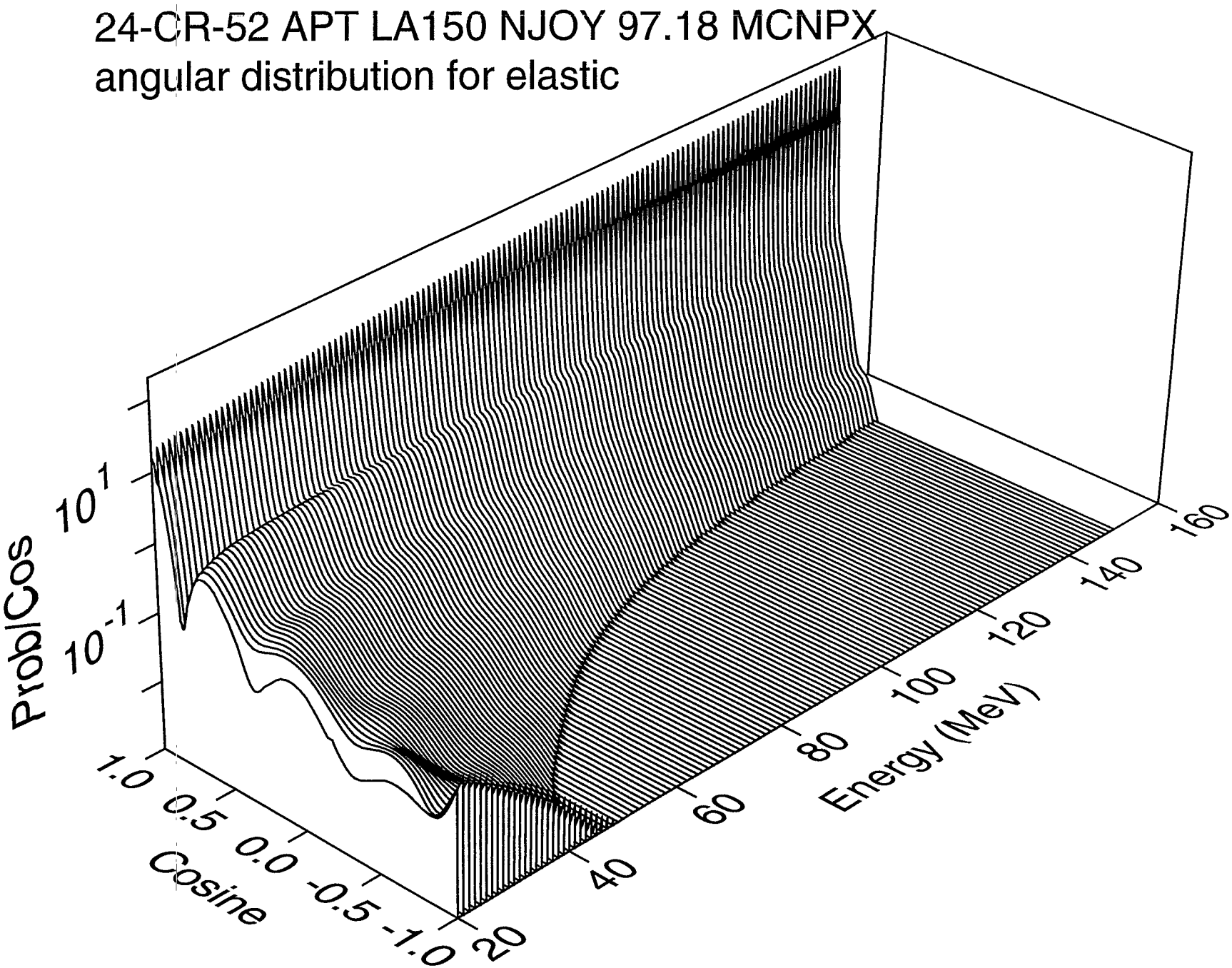


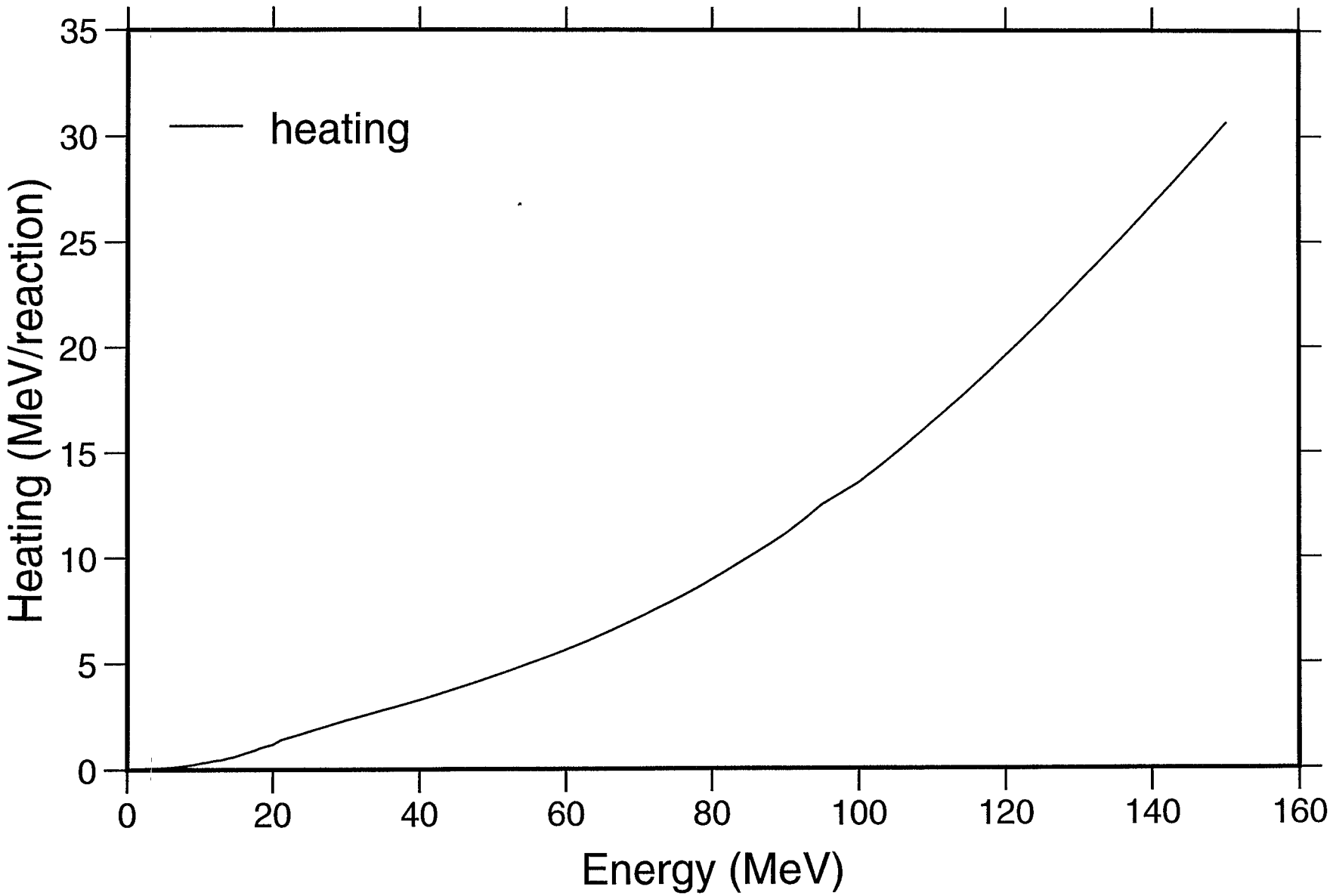


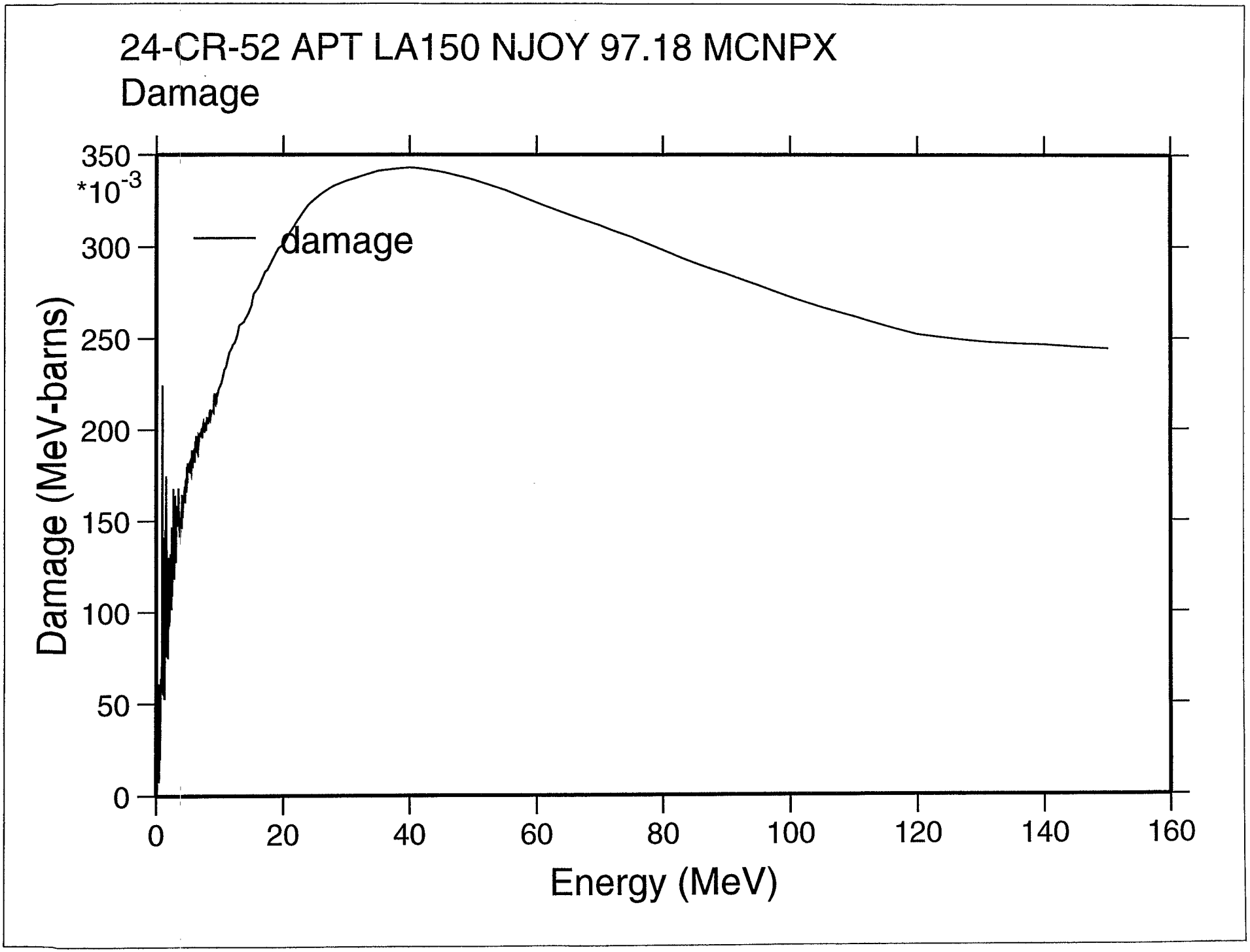







24-CR-52 APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic
Prob/Cos
10^{1}
10^{-1}
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


24-CR-52 APT LA150 NJOY 97.18 MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
5
10
15
20
25
30
35
0
20
40
60
80
100
120
140
160


24-CR-52 APT LA150 NJOY 97.18 MCNPX
Damage
damage
Damage (MeV-barns)
*10^-3
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF n + 53Cr CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

S. Chiba, M. B. Chadwick, and P. G. Young
22 Oct. 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI.5 (Release 2) evaluation by D. Hetrick, D. Larson, N. Larson, and C. Y. Fu.

INCIDENT NEUTRON ENERGIES > 20 MeV

The ENDF/B-VI Release 2 evaluation extends to 20 MeV and includes cross sections and energy-angle data for all significant reactions. The present evaluation utilizes a more compact composite reaction spectrum representation above 20 MeV in order to reduce the length of the file. No essential data for applications is lost with this representation.

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT= 1	Total Cross Section
	MT= 2	Elastic Scattering Cross Section
	MT= 3	Nonelastic Cross Section
	MT= 5	Sum of Binary (n,n') and (n,x) Reactions
MF=4	MT= 2	Elastic Angular Distributions
MF=6	MT= 5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, Tritons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Cr52 and p + Cr52 reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of

all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk et al. (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged- particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

SOME Cr-SPECIFIC INFORMATION CONCERNING THE EVAL.

The neutron total cross section was evaluated at energy grid points by using the least-squares code GMA (Po81) taking account of the new data measured by Dietrich et al. for natural Cr(Di97). The results were transformed to the Cr-53 cross section according to the A*(2/3) law, i.e., by multiplying by a factor of 1.012076.

The neutron optical model potential derived for n + Cr-52 was used for calculation of DWBA cross sections.

The transmission coefficients calculated for the n + Cr-52 evaluation were employed for all the n + Cr-50 evaluation channels, by multiplying by a factor of 1.01278, i.e., a ratio of A**(2/3) between Cr-53 and Cr-52.

The Cr-52 transmission coefficients were calculated by using the following potentials:

For the neutron channel, the newly-searched potential for n + Cr-52, as described in File 1 of the n + Cr-52 evaluation, was used.

For the proton channel, a combination of 2 potentials was used :

below 40 MeV : Becchetti-Greenlees (Be69)
above 40 MeV : Madland medium energy potential (Ma88)

The proton reaction cross section and transmission coefficients below 40 MeV were multiplied by a factor of 0.845 to make the agreement with the measured proton reaction cross section (Ca96) better, and also to make the connection to higher energy values smoothly.

For deuterons, the Lohr-Haeberli (Lo74) global potential was used; for alpha particles the McFadden-Satchler (Mc66) potential was used; and for tritons the Becchetti-Greenlees (Be71) potential was used. The He-3 channel was ignored.

No direct collective inelastic scattering was considered.

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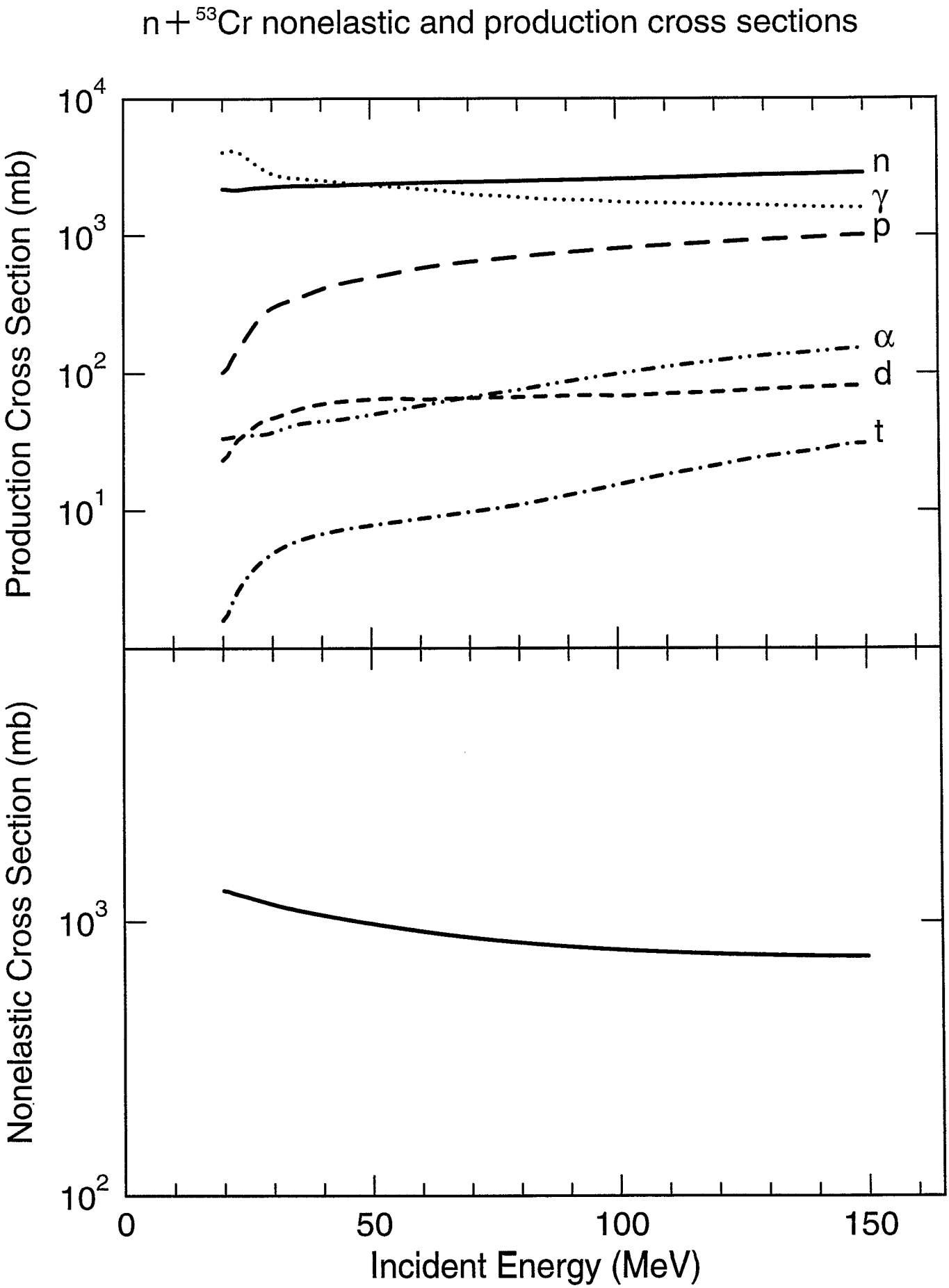
[Yo92]. P. G. Young, E. D. Arthur, and M. B. Chadwick, "Comprehensive Nuclear Model Calculations: Introduction to the Theory and Use of the GNASH Code," LA-12343-MS (1992).

24053 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

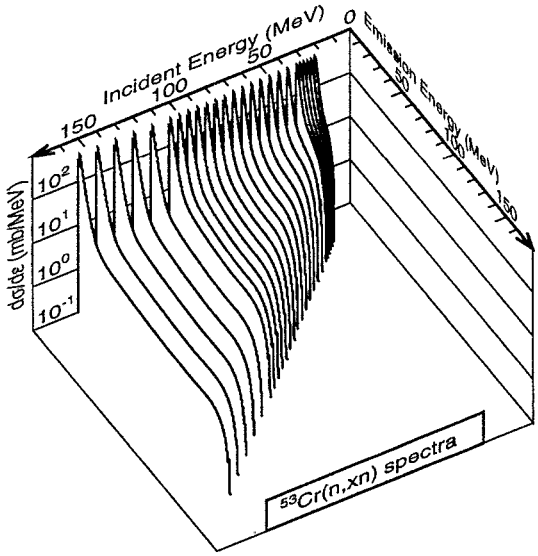
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	1.295E+00	9.285E-01	2.173E+00	1.012E-01	2.313E-02	1.592E-03	0.000E+00	3.350E-02	4.040E+00
2.200E+01	1.266E+00	9.474E-01	2.134E+00	1.285E-01	2.926E-02	2.192E-03	0.000E+00	3.440E-02	4.150E+00
2.400E+01	1.238E+00	1.005E+00	2.157E+00	1.654E-01	3.484E-02	2.948E-03	0.000E+00	3.486E-02	3.898E+00
2.600E+01	1.208E+00	1.056E+00	2.204E+00	2.128E-01	3.994E-02	3.660E-03	0.000E+00	3.547E-02	3.435E+00
2.800E+01	1.179E+00	1.123E+00	2.227E+00	2.629E-01	4.473E-02	4.298E-03	0.000E+00	3.581E-02	3.066E+00
3.000E+01	1.152E+00	1.186E+00	2.252E+00	2.976E-01	4.712E-02	4.862E-03	0.000E+00	3.715E-02	2.807E+00
3.500E+01	1.098E+00	1.329E+00	2.293E+00	3.491E-01	5.424E-02	5.977E-03	0.000E+00	4.242E-02	2.602E+00
4.000E+01	1.054E+00	1.435E+00	2.299E+00	4.071E-01	5.965E-02	6.726E-03	0.000E+00	4.461E-02	2.503E+00
4.500E+01	1.015E+00	1.496E+00	2.322E+00	4.546E-01	6.266E-02	7.316E-03	0.000E+00	4.674E-02	2.397E+00
5.000E+01	9.808E-01	1.519E+00	2.358E+00	4.925E-01	6.443E-02	7.782E-03	0.000E+00	4.989E-02	2.300E+00
5.500E+01	9.501E-01	1.511E+00	2.384E+00	5.332E-01	6.552E-02	8.235E-03	0.000E+00	5.360E-02	2.251E+00
6.000E+01	9.225E-01	1.480E+00	2.413E+00	5.770E-01	6.439E-02	8.706E-03	0.000E+00	5.789E-02	2.172E+00
6.500E+01	8.978E-01	1.431E+00	2.438E+00	6.128E-01	6.516E-02	9.201E-03	0.000E+00	6.226E-02	2.108E+00
7.000E+01	8.759E-01	1.369E+00	2.449E+00	6.433E-01	6.593E-02	9.735E-03	0.000E+00	6.684E-02	1.993E+00
7.500E+01	8.565E-01	1.307E+00	2.470E+00	6.703E-01	6.644E-02	1.031E-02	0.000E+00	7.117E-02	1.951E+00
8.000E+01	8.394E-01	1.235E+00	2.489E+00	6.975E-01	6.689E-02	1.096E-02	0.000E+00	7.548E-02	1.902E+00
8.500E+01	8.244E-01	1.159E+00	2.512E+00	7.258E-01	6.757E-02	1.183E-02	0.000E+00	8.098E-02	1.843E+00
9.000E+01	8.114E-01	1.090E+00	2.532E+00	7.531E-01	6.834E-02	1.288E-02	0.000E+00	8.670E-02	1.817E+00
9.500E+01	8.000E-01	1.015E+00	2.554E+00	7.793E-01	6.902E-02	1.403E-02	0.000E+00	9.258E-02	1.804E+00
1.000E+02	7.902E-01	9.505E-01	2.580E+00	8.053E-01	6.837E-02	1.528E-02	0.000E+00	9.850E-02	1.756E+00
1.100E+02	7.745E-01	8.245E-01	2.636E+00	8.518E-01	7.081E-02	1.825E-02	0.000E+00	1.111E-01	1.723E+00
1.200E+02	7.629E-01	7.135E-01	2.692E+00	8.913E-01	7.280E-02	2.123E-02	0.000E+00	1.225E-01	1.684E+00
1.300E+02	7.547E-01	6.172E-01	2.754E+00	9.324E-01	7.616E-02	2.469E-02	0.000E+00	1.338E-01	1.655E+00
1.400E+02	7.492E-01	5.402E-01	2.798E+00	9.657E-01	7.872E-02	2.756E-02	0.000E+00	1.424E-01	1.606E+00
1.500E+02	7.467E-01	4.714E-01	2.842E+00	1.006E+00	8.066E-02	3.082E-02	0.000E+00	1.513E-01	1.592E+00

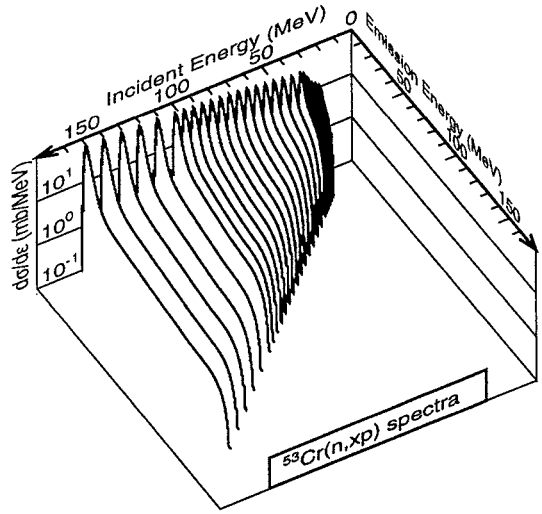
24053 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

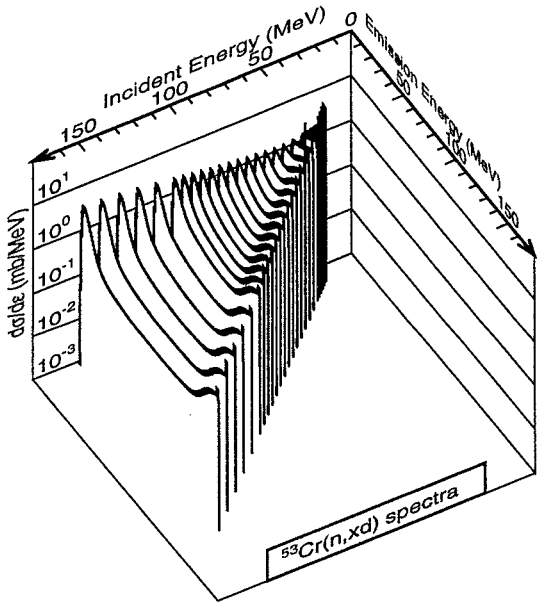
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	1.322E-01	3.384E-02	1.751E-03	0.000E+00	6.307E-02	1.069E-01	2.578E-02	3.636E-01
2.200E+01	1.751E-01	4.894E-02	2.717E-03	0.000E+00	6.747E-02	1.133E-01	2.794E-02	4.354E-01
2.400E+01	2.264E-01	6.545E-02	4.076E-03	0.000E+00	7.070E-02	1.190E-01	3.003E-02	5.156E-01
2.600E+01	2.898E-01	8.312E-02	5.549E-03	0.000E+00	7.371E-02	1.242E-01	3.102E-02	6.074E-01
2.800E+01	3.608E-01	1.022E-01	7.081E-03	0.000E+00	7.599E-02	1.287E-01	3.188E-02	7.067E-01
3.000E+01	4.329E-01	1.151E-01	8.612E-03	0.000E+00	7.960E-02	1.325E-01	3.222E-02	8.010E-01
3.500E+01	6.031E-01	1.599E-01	1.234E-02	0.000E+00	9.071E-02	1.423E-01	3.182E-02	1.040E+00
4.000E+01	7.875E-01	2.095E-01	1.564E-02	0.000E+00	9.804E-02	1.506E-01	3.028E-02	1.292E+00
4.500E+01	9.714E-01	2.540E-01	1.865E-02	0.000E+00	1.048E-01	1.577E-01	2.829E-02	1.535E+00
5.000E+01	1.150E+00	2.935E-01	2.118E-02	0.000E+00	1.127E-01	1.642E-01	2.612E-02	1.768E+00
5.500E+01	1.330E+00	3.282E-01	2.364E-02	0.000E+00	1.215E-01	1.695E-01	2.396E-02	1.997E+00
6.000E+01	1.519E+00	3.436E-01	2.591E-02	0.000E+00	1.311E-01	1.736E-01	2.187E-02	2.215E+00
6.500E+01	1.703E+00	3.747E-01	2.801E-02	0.000E+00	1.410E-01	1.776E-01	1.987E-02	2.444E+00
7.000E+01	1.890E+00	4.040E-01	2.992E-02	0.000E+00	1.515E-01	1.815E-01	1.800E-02	2.675E+00
7.500E+01	2.075E+00	4.322E-01	3.179E-02	0.000E+00	1.612E-01	1.841E-01	1.636E-02	2.901E+00
8.000E+01	2.262E+00	4.590E-01	3.360E-02	0.000E+00	1.713E-01	1.864E-01	1.480E-02	3.127E+00
8.500E+01	2.449E+00	4.842E-01	3.558E-02	0.000E+00	1.835E-01	1.888E-01	1.336E-02	3.354E+00
9.000E+01	2.631E+00	5.098E-01	3.767E-02	0.000E+00	1.964E-01	1.916E-01	1.212E-02	3.579E+00
9.500E+01	2.818E+00	5.321E-01	3.979E-02	0.000E+00	2.096E-01	1.942E-01	1.093E-02	3.805E+00
1.000E+02	3.014E+00	5.310E-01	4.205E-02	0.000E+00	2.232E-01	1.955E-01	9.952E-03	4.015E+00
1.100E+02	3.395E+00	5.746E-01	4.686E-02	0.000E+00	2.519E-01	2.005E-01	8.225E-03	4.477E+00
1.200E+02	3.792E+00	6.086E-01	5.114E-02	0.000E+00	2.789E-01	2.046E-01	6.849E-03	4.942E+00
1.300E+02	4.189E+00	6.553E-01	5.561E-02	0.000E+00	3.062E-01	2.155E-01	5.749E-03	5.427E+00
1.400E+02	4.609E+00	7.039E-01	5.891E-02	0.000E+00	3.284E-01	2.278E-01	4.920E-03	5.933E+00
1.500E+02	5.052E+00	7.239E-01	6.304E-02	0.000E+00	3.518E-01	2.395E-01	4.226E-03	6.435E+00

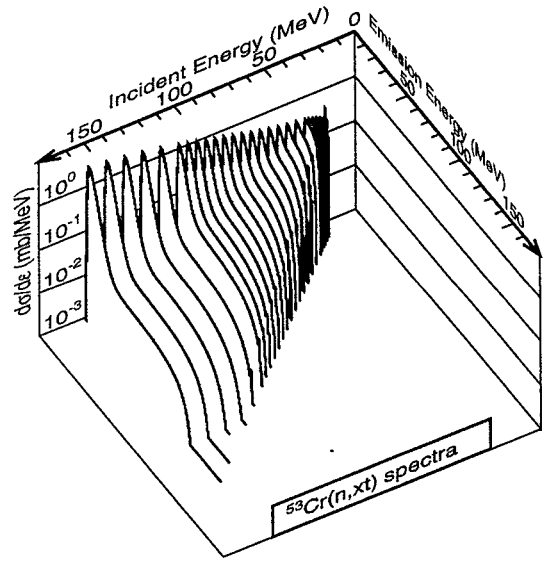

n + 53Cr nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
n
γ
p
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
0
50
100
150
Incident Energy (MeV)

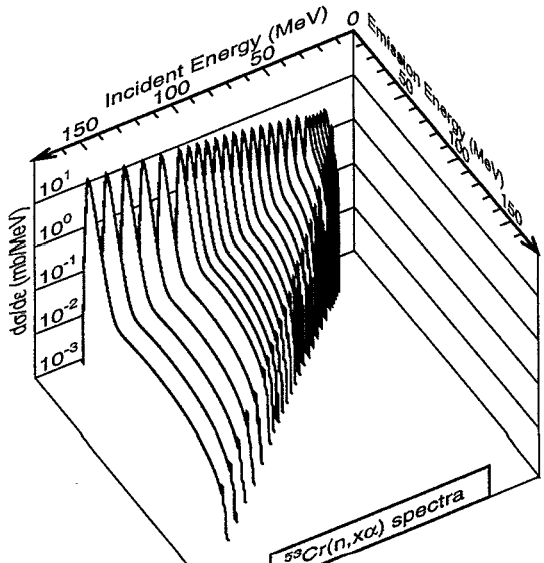
n + ^{53}Cr angle-integrated emission spectra

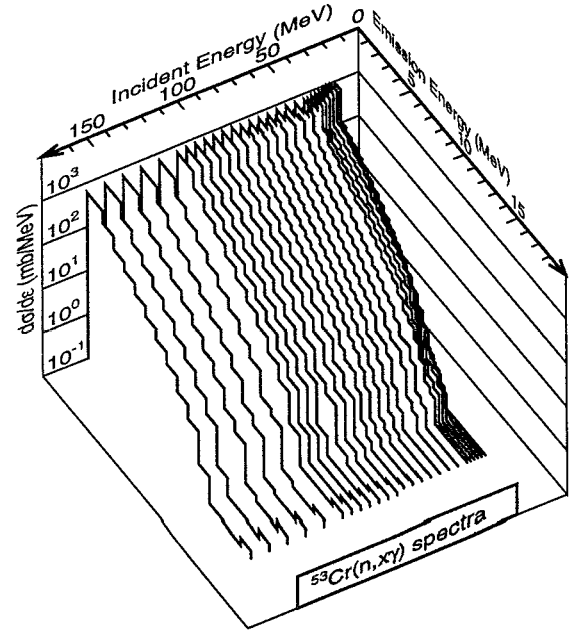




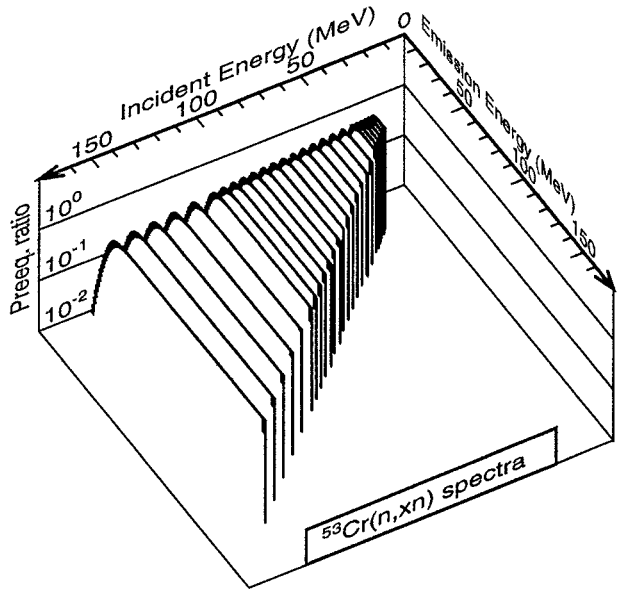


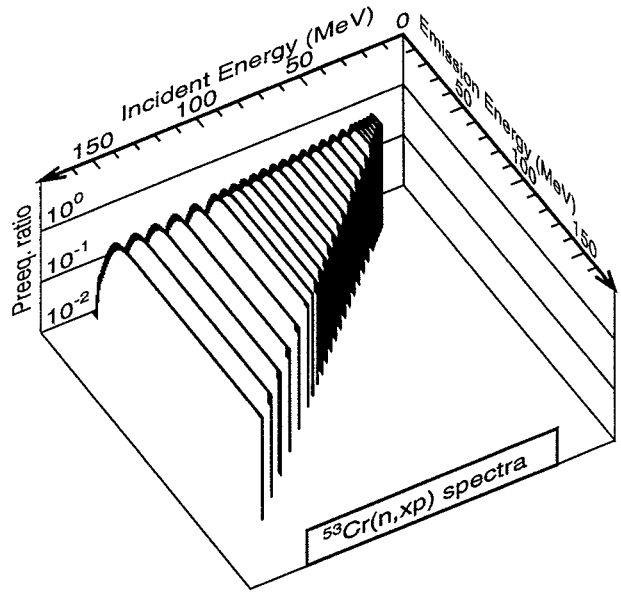


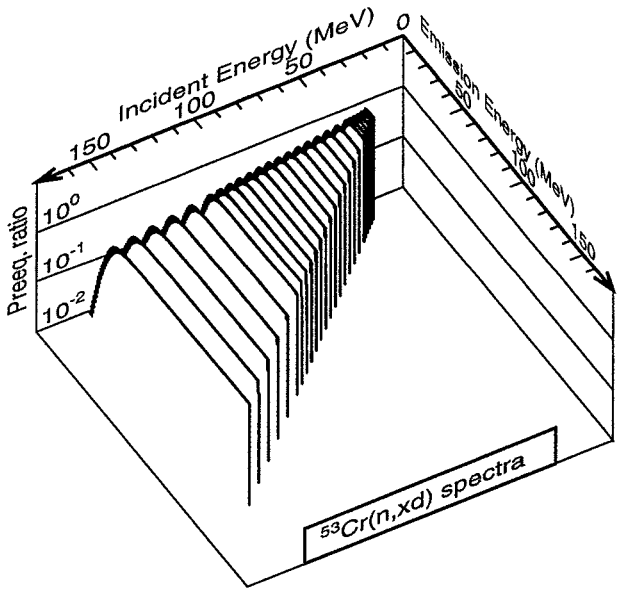


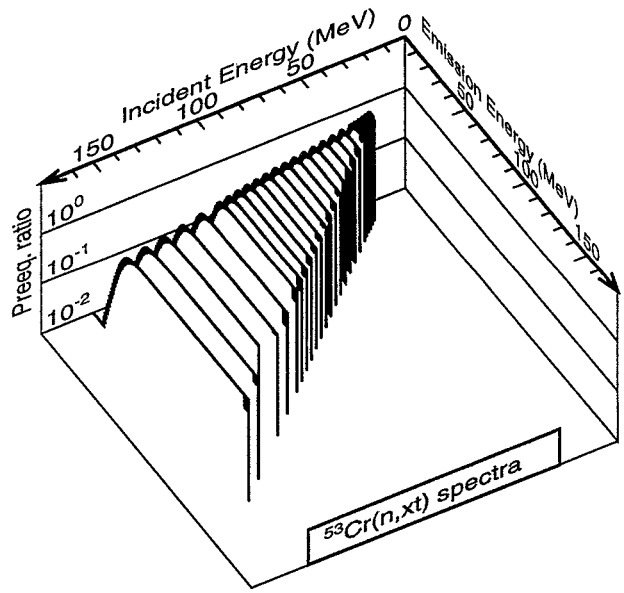


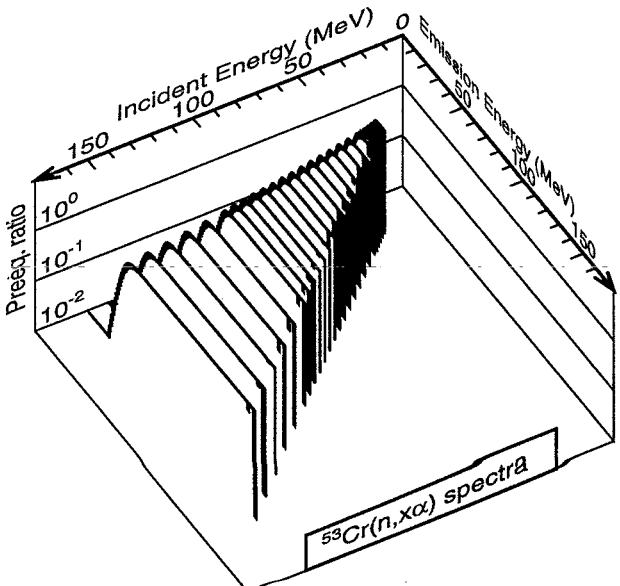
n + ^{53}Cr Kalbach preequilibrium ratios

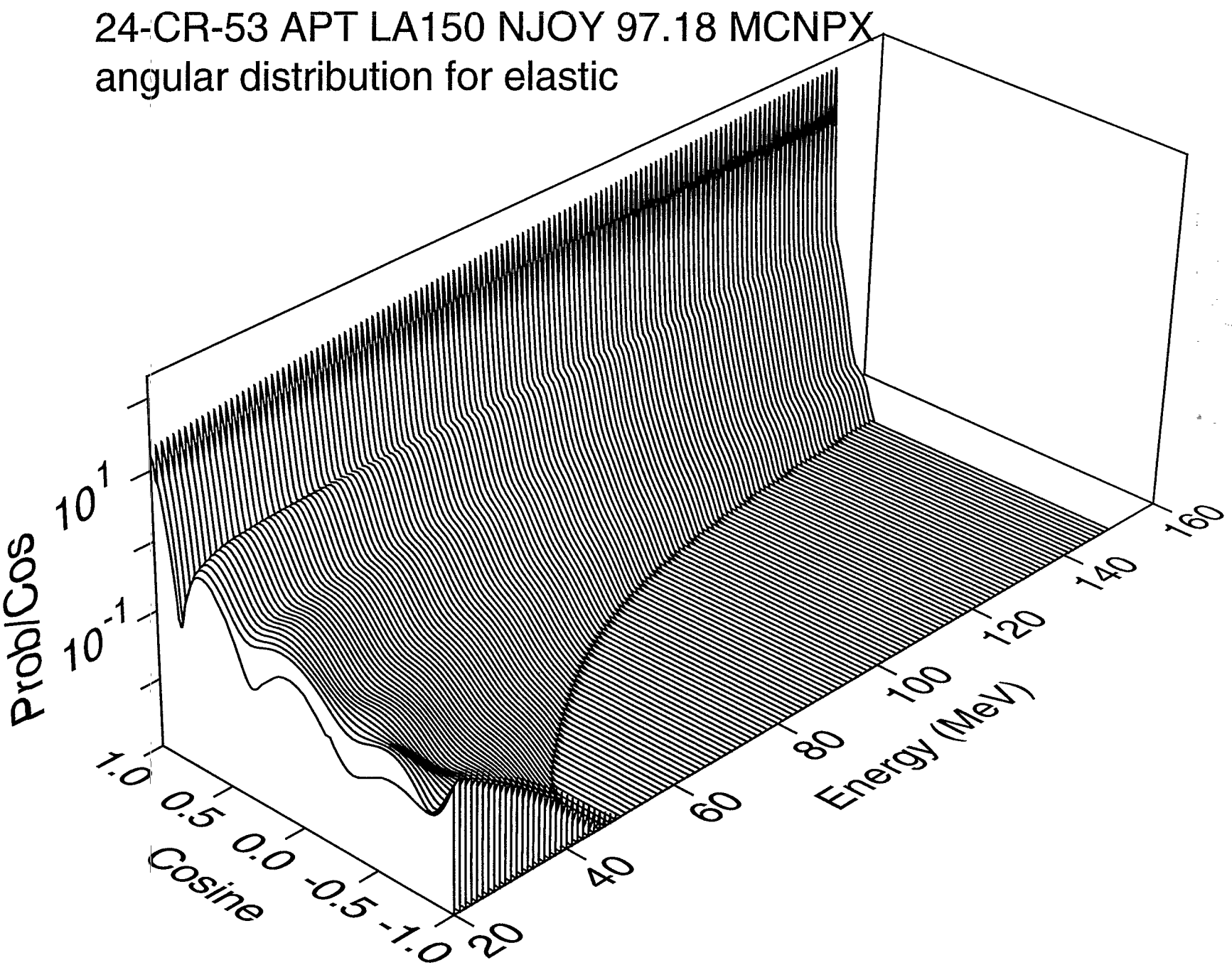


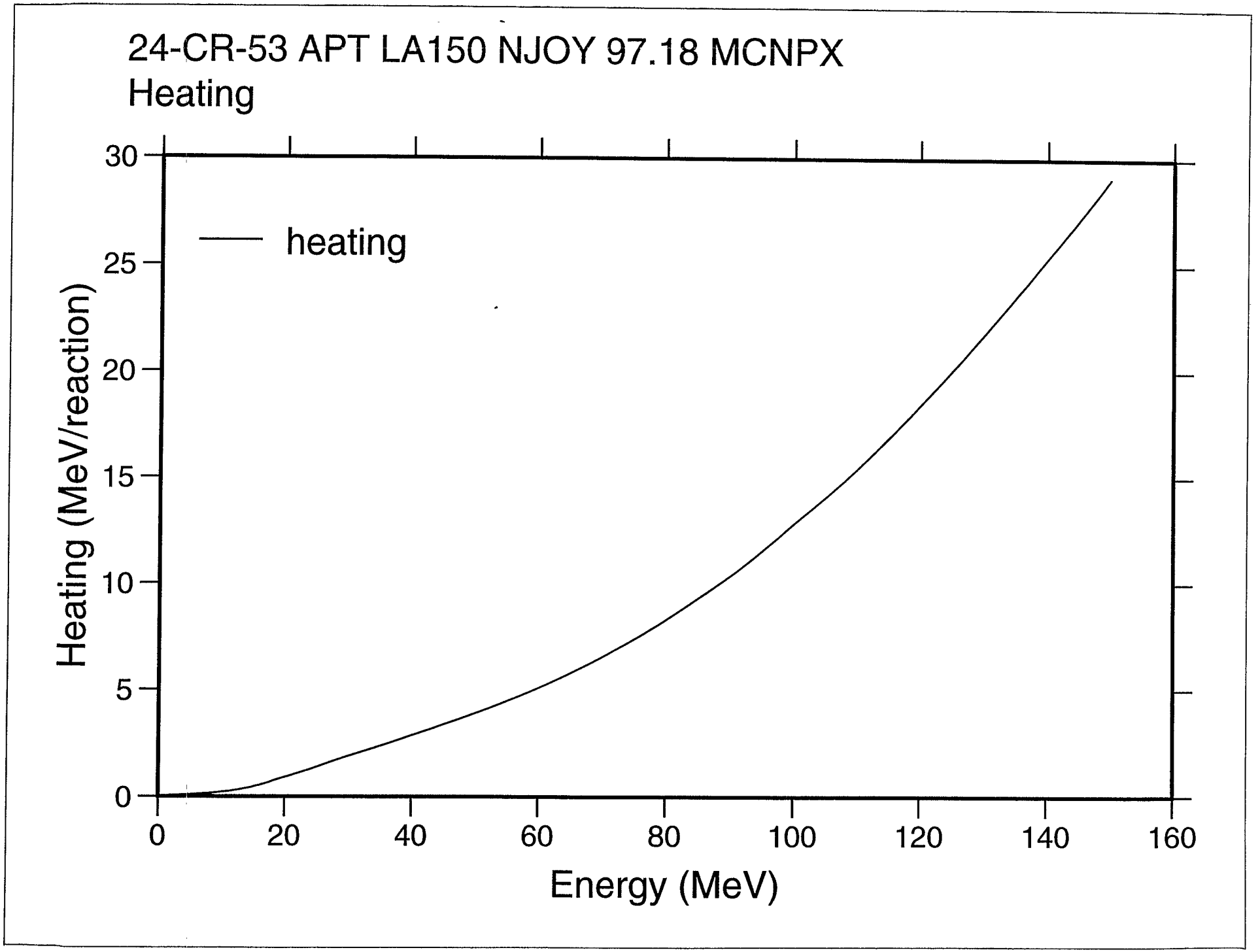


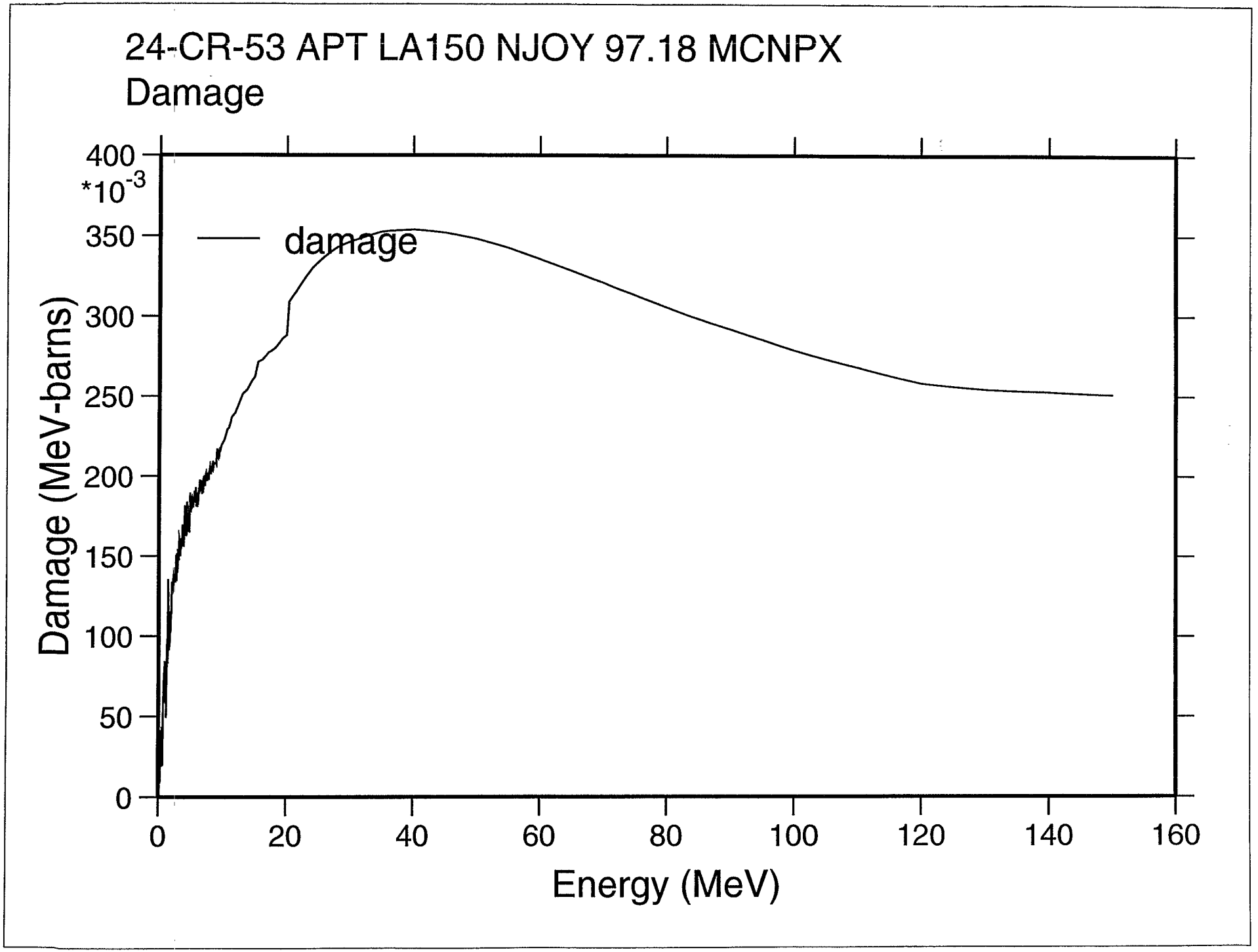







24-CR-53 APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic
Prob/Cos
10^{1}
10^{-1}
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


24-CR-53 APT LA150 NJOY 97.18 MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
5
10
15
20
25
30
0
20
40
60
80
100
120
140
160


24-CR-53 APT LA150 NJOY 97.18 MCNPX
Damage
damage
Damage (MeV-barns)
*10^-3
400
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF n + 54Cr CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

S. Chiba, M. B. Chadwick, and P. G. Young
22 Oct. 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI.5 (Release 2) evaluation by D. Hetrick, D. Larson, N. Larson, and C. Y. Fu.

INCIDENT NEUTRON ENERGIES > 20 MeV

The ENDF/B-VI Release 2 evaluation extends to 20 MeV and includes cross sections and energy-angle data for all significant reactions. The present evaluation utilizes a more compact composite reaction spectrum representation above 20 MeV in order to reduce the length of the file. No essential data for applications is lost with this representation.

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT= 1	Total Cross Section
	MT= 2	Elastic Scattering Cross Section
	MT= 3	Nonelastic Cross Section
	MT= 5	Sum of Binary (n,n') and (n,x) Reactions
MF=4	MT= 2	Elastic Angular Distributions
MF=6	MT= 5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, Tritons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Cr52 and p + Cr52 reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of

all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk et al. (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged- particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

SOME Cr-SPECIFIC INFORMATION CONCERNING THE EVAL.

The neutron total cross section was evaluated at energy grid points by using the least-squares code GMA (Po81) taking account of the new data measured by Dietrich et al. for natural Cr(Di97). The results were transformed to the Cr-54 cross section according to the A*(2/3) law, i.e., by multiplying by a factor of 1.024767.

The neutron optical model potential derived for n + Cr-52 was used for calculation of DWBA cross sections.

The transmission coefficients calculated for the n + Cr-52 evaluation were employed for all the n + Cr-54 evaluation channels, by multiplying by a factor of 1.025479, i.e., a ratio of A**(2/3) between Cr-54 and Cr-52.

The Cr-52 transmission coefficients were calculated by using the following potentials:

For the neutron channel, the newly-searched potential for n + Cr-52, as described in File 1 of the n + Cr-52 evaluation, was used.

For the proton channel, a combination of 2 potentials was used :

below 40 MeV : Becchetti-Greenlees (Be69)
above 40 MeV : Madland medium energy potential (Ma88)

The proton reaction cross section and transmission coefficients below 40 MeV were multiplied by a factor of 0.845 to make the agreement with the measured proton reaction cross section (Ca96) better, and also to make the connection to higher energy values smoothly.

For deuterons, the Lohr-Haeberli (Lo74) global potential was used; for alpha particles the McFadden-Satchler (Mc66) potential was used; and for tritons the Becchetti-Greenlees (Be71) potential was used. The He-3 channel was ignored.

The direct collective inelastic scattering to the following levels in Cr-54 was considered by the DWBA-mode calculation of ECIS95:

Jpi	Ex(MeV)	Deformation Parameter
2+	0.835	0.250

The data was retrieved from the literature (Ra87).

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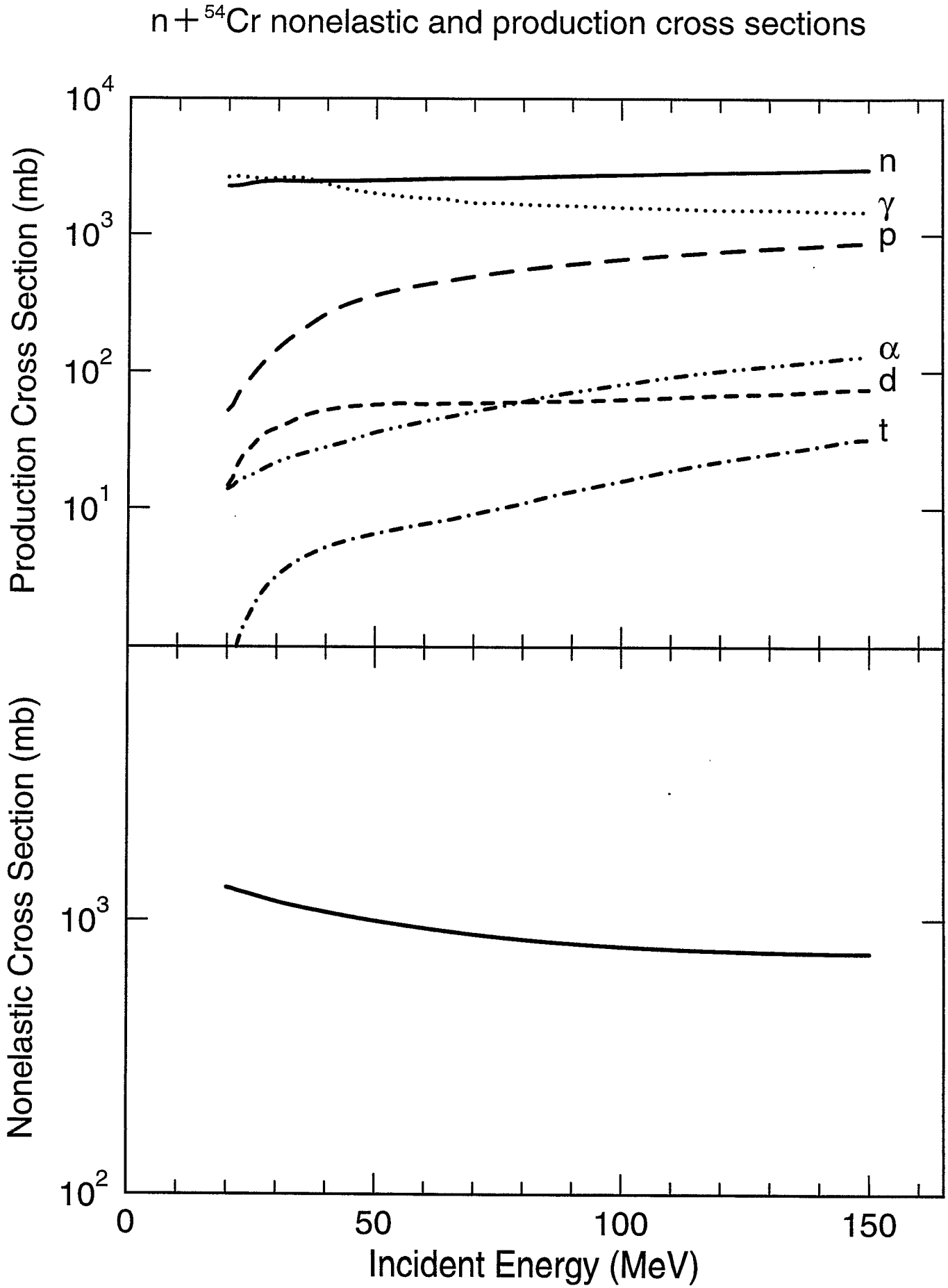
24054 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

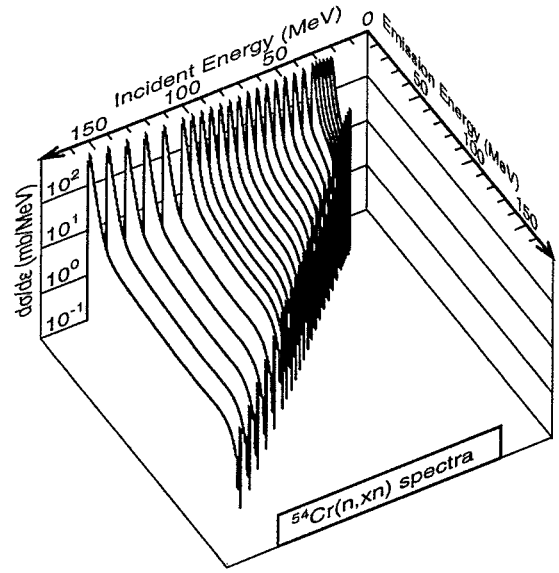
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	1.311E+00	9.396E-01	2.271E+00	5.200E-02	1.463E-02	5.760E-04	0.000E+00	1.381E-02	2.638E+00
2.200E+01	1.282E+00	9.589E-01	2.288E+00	6.740E-02	2.069E-02	1.041E-03	0.000E+00	1.571E-02	2.671E+00
2.400E+01	1.254E+00	1.017E+00	2.361E+00	8.465E-02	2.623E-02	1.587E-03	0.000E+00	1.690E-02	2.628E+00
2.600E+01	1.224E+00	1.069E+00	2.434E+00	1.037E-01	3.135E-02	2.179E-03	0.000E+00	1.834E-02	2.588E+00
2.800E+01	1.194E+00	1.137E+00	2.473E+00	1.245E-01	3.609E-02	2.748E-03	0.000E+00	2.006E-02	2.568E+00
3.000E+01	1.167E+00	1.200E+00	2.488E+00	1.460E-01	3.867E-02	3.257E-03	0.000E+00	2.163E-02	2.594E+00
3.500E+01	1.112E+00	1.346E+00	2.471E+00	2.012E-01	4.676E-02	4.360E-03	0.000E+00	2.499E-02	2.604E+00
4.000E+01	1.067E+00	1.452E+00	2.478E+00	2.630E-01	5.243E-02	5.275E-03	0.000E+00	2.805E-02	2.352E+00
4.500E+01	1.028E+00	1.515E+00	2.483E+00	3.187E-01	5.582E-02	5.979E-03	0.000E+00	3.156E-02	2.129E+00
5.000E+01	9.932E-01	1.538E+00	2.507E+00	3.594E-01	5.744E-02	6.594E-03	0.000E+00	3.602E-02	2.004E+00
5.500E+01	9.621E-01	1.530E+00	2.534E+00	3.980E-01	5.886E-02	7.174E-03	0.000E+00	3.970E-02	1.914E+00
6.000E+01	9.342E-01	1.499E+00	2.566E+00	4.318E-01	5.813E-02	7.755E-03	0.000E+00	4.339E-02	1.857E+00
6.500E+01	9.092E-01	1.449E+00	2.591E+00	4.617E-01	5.890E-02	8.340E-03	0.000E+00	4.696E-02	1.816E+00
7.000E+01	8.870E-01	1.386E+00	2.600E+00	4.944E-01	5.899E-02	9.140E-03	0.000E+00	5.134E-02	1.717E+00
7.500E+01	8.673E-01	1.324E+00	2.615E+00	5.253E-01	5.958E-02	9.983E-03	0.000E+00	5.574E-02	1.719E+00
8.000E+01	8.500E-01	1.250E+00	2.644E+00	5.546E-01	6.013E-02	1.092E-02	0.000E+00	6.044E-02	1.678E+00
8.500E+01	8.349E-01	1.174E+00	2.682E+00	5.821E-01	6.087E-02	1.220E-02	0.000E+00	6.620E-02	1.659E+00
9.000E+01	8.216E-01	1.104E+00	2.711E+00	6.077E-01	6.103E-02	1.335E-02	0.000E+00	7.095E-02	1.642E+00
9.500E+01	8.101E-01	1.028E+00	2.741E+00	6.331E-01	6.194E-02	1.458E-02	0.000E+00	7.575E-02	1.620E+00
1.000E+02	8.001E-01	9.624E-01	2.768E+00	6.591E-01	6.286E-02	1.589E-02	0.000E+00	8.073E-02	1.595E+00
1.100E+02	7.842E-01	8.348E-01	2.827E+00	7.088E-01	6.492E-02	1.899E-02	0.000E+00	9.156E-02	1.568E+00
1.200E+02	7.725E-01	7.224E-01	2.878E+00	7.538E-01	6.750E-02	2.211E-02	0.000E+00	1.015E-01	1.528E+00
1.300E+02	7.642E-01	6.249E-01	2.919E+00	7.952E-01	6.897E-02	2.519E-02	0.000E+00	1.106E-01	1.528E+00
1.400E+02	7.587E-01	5.470E-01	2.981E+00	8.320E-01	7.209E-02	2.874E-02	0.000E+00	1.205E-01	1.501E+00
1.500E+02	7.561E-01	4.773E-01	3.039E+00	8.687E-01	7.458E-02	3.210E-02	0.000E+00	1.288E-01	1.483E+00

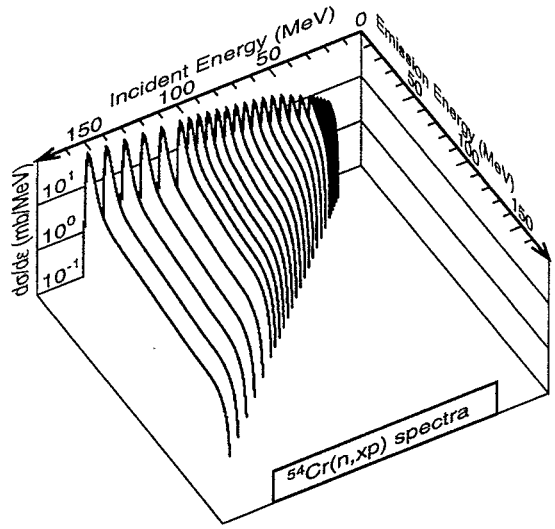
24054 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

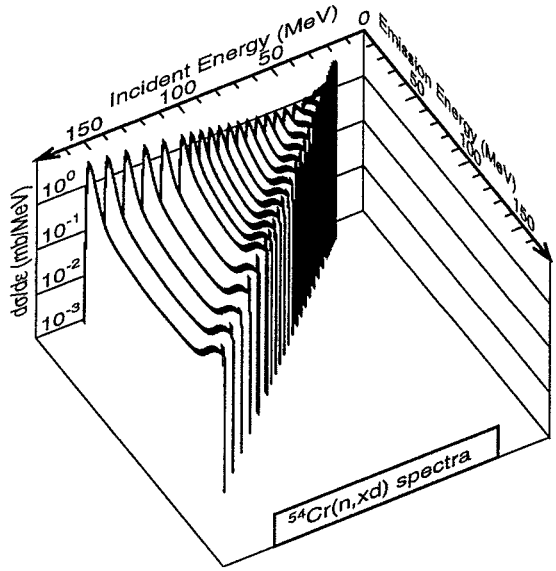
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	6.629E-02	1.801E-02	5.172E-04	0.000E+00	2.211E-02	1.019E-01	2.493E-02	2.337E-01
2.200E+01	9.371E-02	3.010E-02	1.087E-03	0.000E+00	2.641E-02	1.080E-01	2.733E-02	2.866E-01
2.400E+01	1.268E-01	4.392E-02	1.872E-03	0.000E+00	2.967E-02	1.135E-01	2.964E-02	3.454E-01
2.600E+01	1.657E-01	5.914E-02	2.842E-03	0.000E+00	3.296E-02	1.184E-01	3.084E-02	4.099E-01
2.800E+01	2.108E-01	7.563E-02	3.925E-03	0.000E+00	3.681E-02	1.226E-01	3.184E-02	4.816E-01
3.000E+01	2.614E-01	8.785E-02	5.061E-03	0.000E+00	4.048E-02	1.260E-01	3.225E-02	5.530E-01
3.500E+01	4.082E-01	1.301E-01	7.972E-03	0.000E+00	4.898E-02	1.346E-01	3.182E-02	7.616E-01
4.000E+01	5.745E-01	1.747E-01	1.091E-02	0.000E+00	5.673E-02	1.432E-01	3.016E-02	9.902E-01
4.500E+01	7.492E-01	2.169E-01	1.361E-02	0.000E+00	6.469E-02	1.503E-01	2.807E-02	1.223E+00
5.000E+01	9.184E-01	2.519E-01	1.614E-02	0.000E+00	7.418E-02	1.567E-01	2.582E-02	1.443E+00
5.500E+01	1.089E+00	2.868E-01	1.850E-02	0.000E+00	8.262E-02	1.615E-01	2.362E-02	1.662E+00
6.000E+01	1.263E+00	3.047E-01	2.072E-02	0.000E+00	9.113E-02	1.654E-01	2.151E-02	1.866E+00
6.500E+01	1.436E+00	3.341E-01	2.279E-02	0.000E+00	9.931E-02	1.691E-01	1.950E-02	2.081E+00
7.000E+01	1.610E+00	3.548E-01	2.498E-02	0.000E+00	1.089E-01	1.731E-01	1.763E-02	2.289E+00
7.500E+01	1.783E+00	3.803E-01	2.703E-02	0.000E+00	1.186E-01	1.762E-01	1.601E-02	2.501E+00
8.000E+01	1.960E+00	4.040E-01	2.913E-02	0.000E+00	1.289E-01	1.792E-01	1.445E-02	2.716E+00
8.500E+01	2.133E+00	4.258E-01	3.157E-02	0.000E+00	1.413E-01	1.823E-01	1.303E-02	2.927E+00
9.000E+01	2.316E+00	4.402E-01	3.381E-02	0.000E+00	1.519E-01	1.849E-01	1.182E-02	3.138E+00
9.500E+01	2.500E+00	4.628E-01	3.614E-02	0.000E+00	1.627E-01	1.870E-01	1.065E-02	3.359E+00
1.000E+02	2.686E+00	4.846E-01	3.848E-02	0.000E+00	1.739E-01	1.892E-01	9.685E-03	3.582E+00
1.100E+02	3.062E+00	5.221E-01	4.363E-02	0.000E+00	1.983E-01	1.940E-01	7.992E-03	4.028E+00
1.200E+02	3.452E+00	5.672E-01	4.847E-02	0.000E+00	2.214E-01	1.980E-01	6.647E-03	4.493E+00
1.300E+02	3.860E+00	5.902E-01	5.267E-02	0.000E+00	2.430E-01	2.063E-01	5.574E-03	4.957E+00
1.400E+02	4.266E+00	6.328E-01	5.737E-02	0.000E+00	2.665E-01	2.196E-01	4.766E-03	5.447E+00
1.500E+02	4.701E+00	6.660E-01	6.180E-02	0.000E+00	2.873E-01	2.316E-01	4.089E-03	5.952E+00

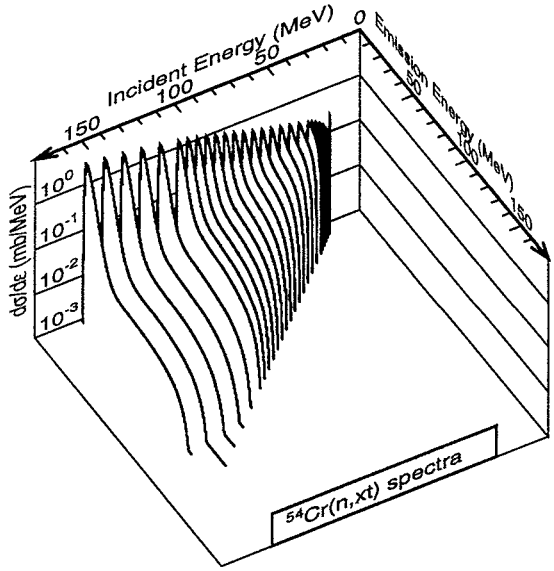

n + 54Cr nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
n
γ
p
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
0
50
100
150
Incident Energy (MeV)

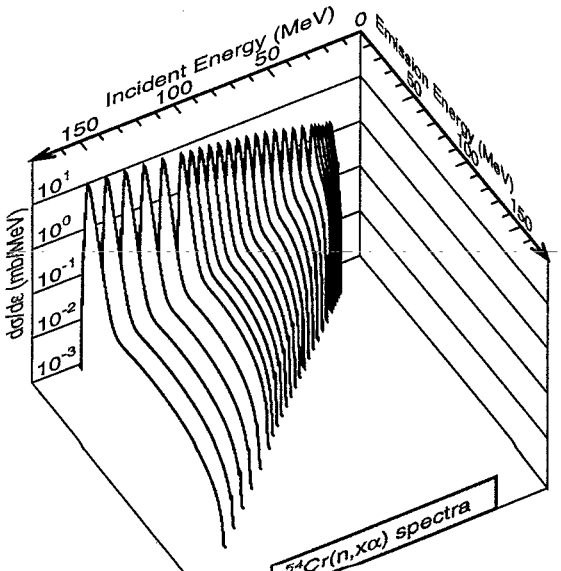
n + ^{54}Cr angle-integrated emission spectra

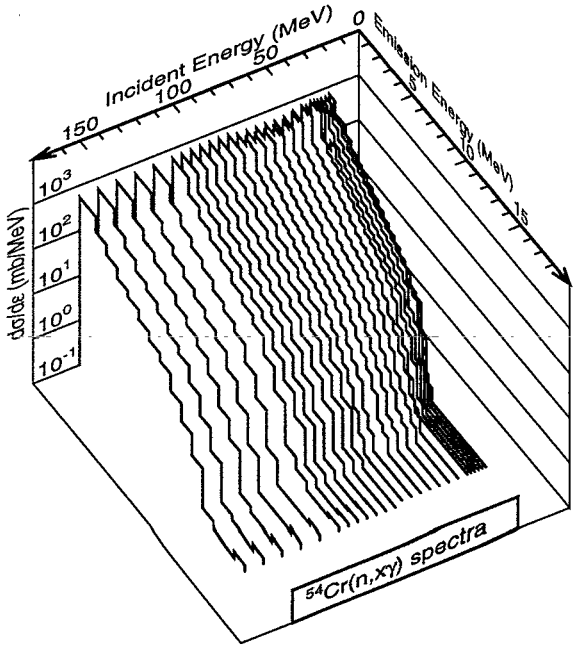




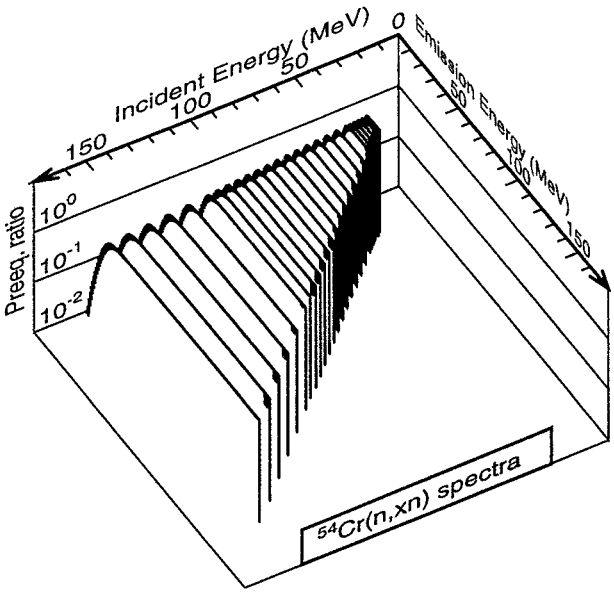


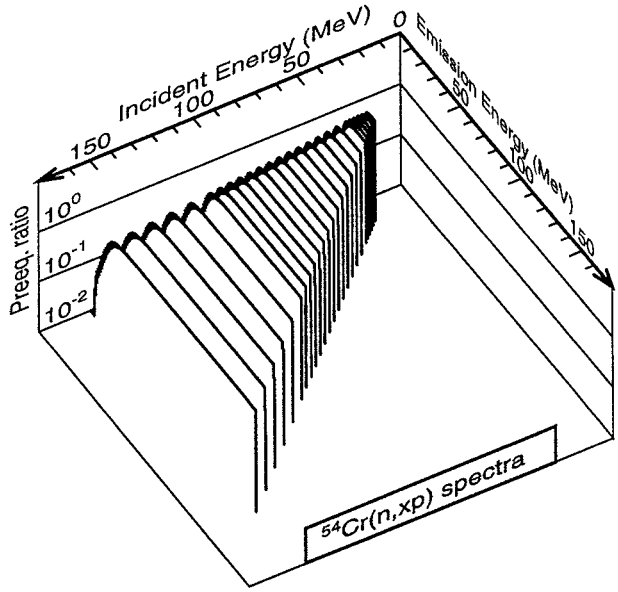


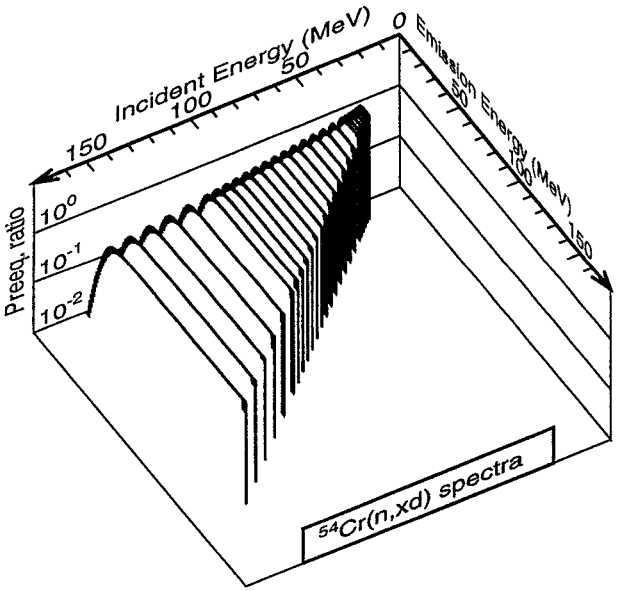


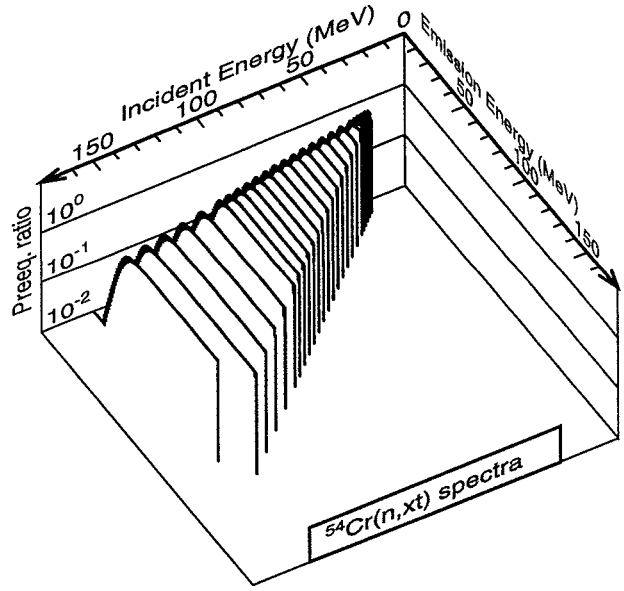


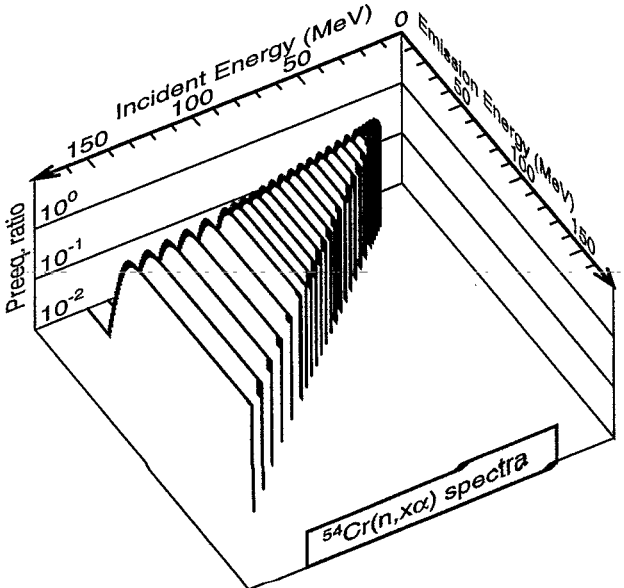
n + ^{54}Cr Kalbach preequilibrium ratios

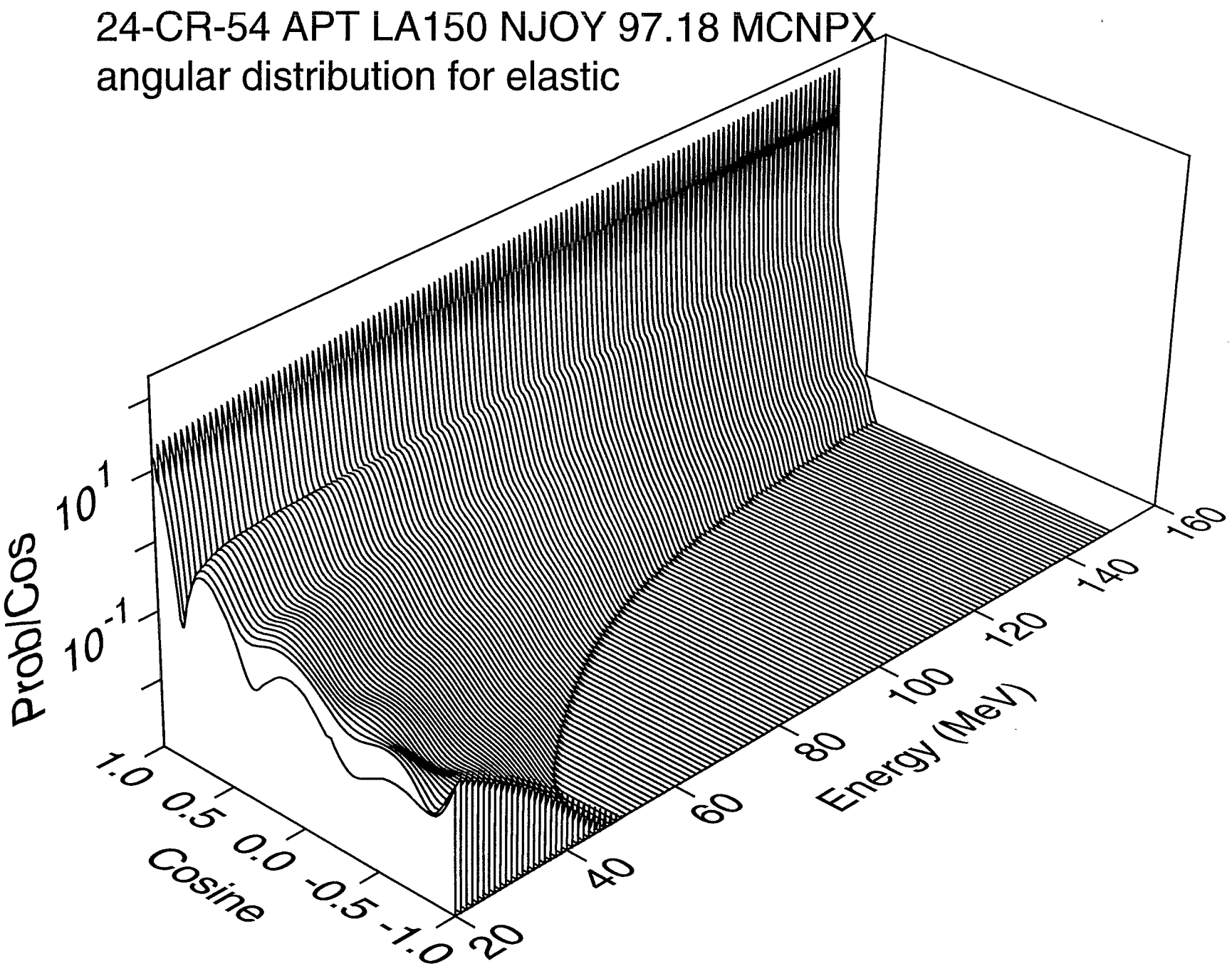


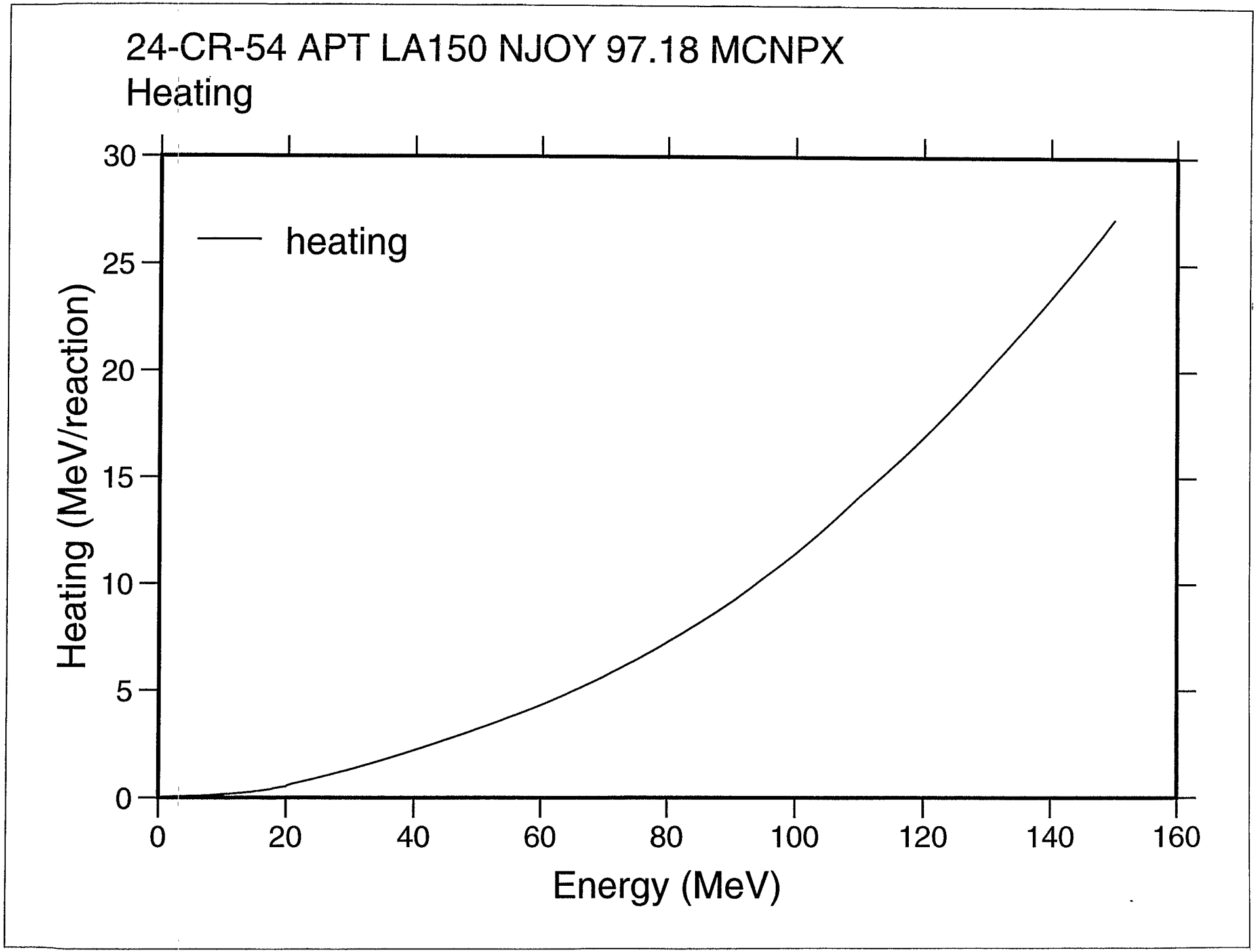


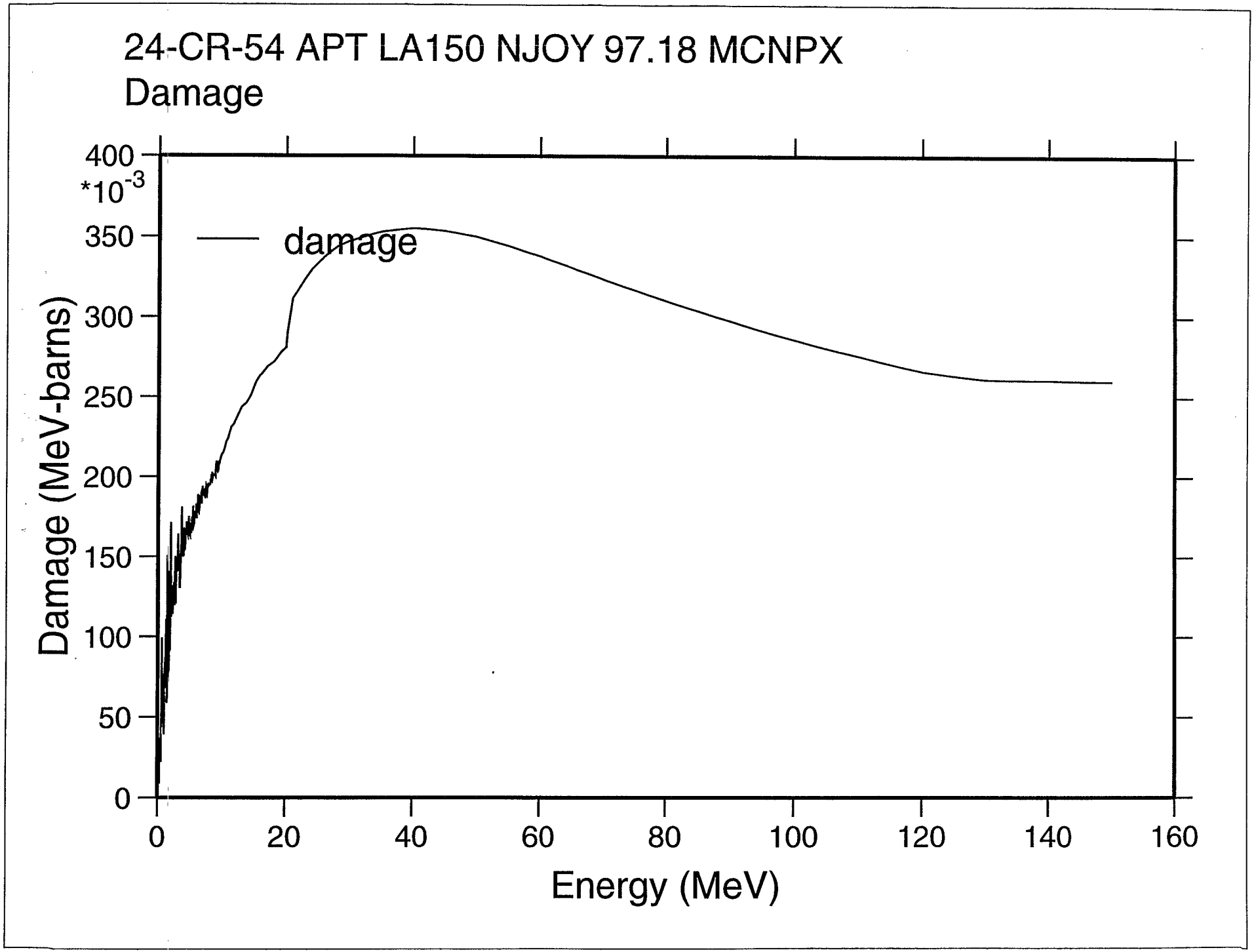







24-CR-54 APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic
Prob/Cos
10^{1}
10^{-1}
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


24-CR-54 APT LA150 NJOY 97.18 MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
5
10
15
20
25
30
0
20
40
60
80
100
120
140
160


24-CR-54 APT LA150 NJOY 97.18 MCNPX
Damage
damage
Damage (MeV-barns)
*10^-3
400
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF n + 54Fe CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

M. B. Chadwick, P. G. Young, and A. J. Koning
6 September 1996

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI.1 (Release 1) evaluation by He91 (see also Fu86). The following modifications were made to the ENDF/B-VI.1 evaluation:

1. The covariance files (MF=33) were removed from the file.

2. The derived MF=3 files for MT=203,205,207 were removed.

INCIDENT NEUTRON ENERGIES > 20 MeV

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT= 1	Total Cross Section
	MT= 2	Elastic Scattering Cross Section
	MT= 3	Nonelastic Cross Section
	MT= 5	Sum of Binary (n,n') and (n,x) Reactions
MF=4	MT= 2	Elastic Angular Distributions
MF=6	MT= 5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Fe56 and p + Fe56 reactions (Ch96a). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of

all recoil nuclei in the GNASH calculations (Ch96b). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. Note that all other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation requires a modification of the original ENDF-6 format.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

The neutron optical model potential of Arthur et al. (Ar80) was used to calculate transmission coefficients and cross sections with the SCAT2 code (Be92) up to a neutron energy of 26 MeV. Between 26 and 52 MeV, the imaginary volume component of Arthur's potential was modified to better account for nonelastic cross section measurements, and above 52 MeV the Semmering potential of Madland (Ma88) was used. For protons, the Beccetti-Greenlees potential (Be69) was utilized below 28 MeV, and the Madland potential (Ma88) was used at higher energies. The global spherical potential of Perey (Pe63) was utilized for deuterons, and the potential of Beccetti-Greenlees (Be) was adopted for tritons. Finally, the alpha potential of Lemos (Le72), as adapted by Arthur et al. (Ar80), was used for alpha particles.

Direct reaction cross sections to discrete states were calculated with the ECIS95 code [Re95] using deformation parameters compiled in Nuclear Data Sheets.

We used the same values for the total, elastic, and nonelastic cross sections (MF=3, MT=1,2,3) above 20 MeV as were used in the n + 56Fe evaluation.

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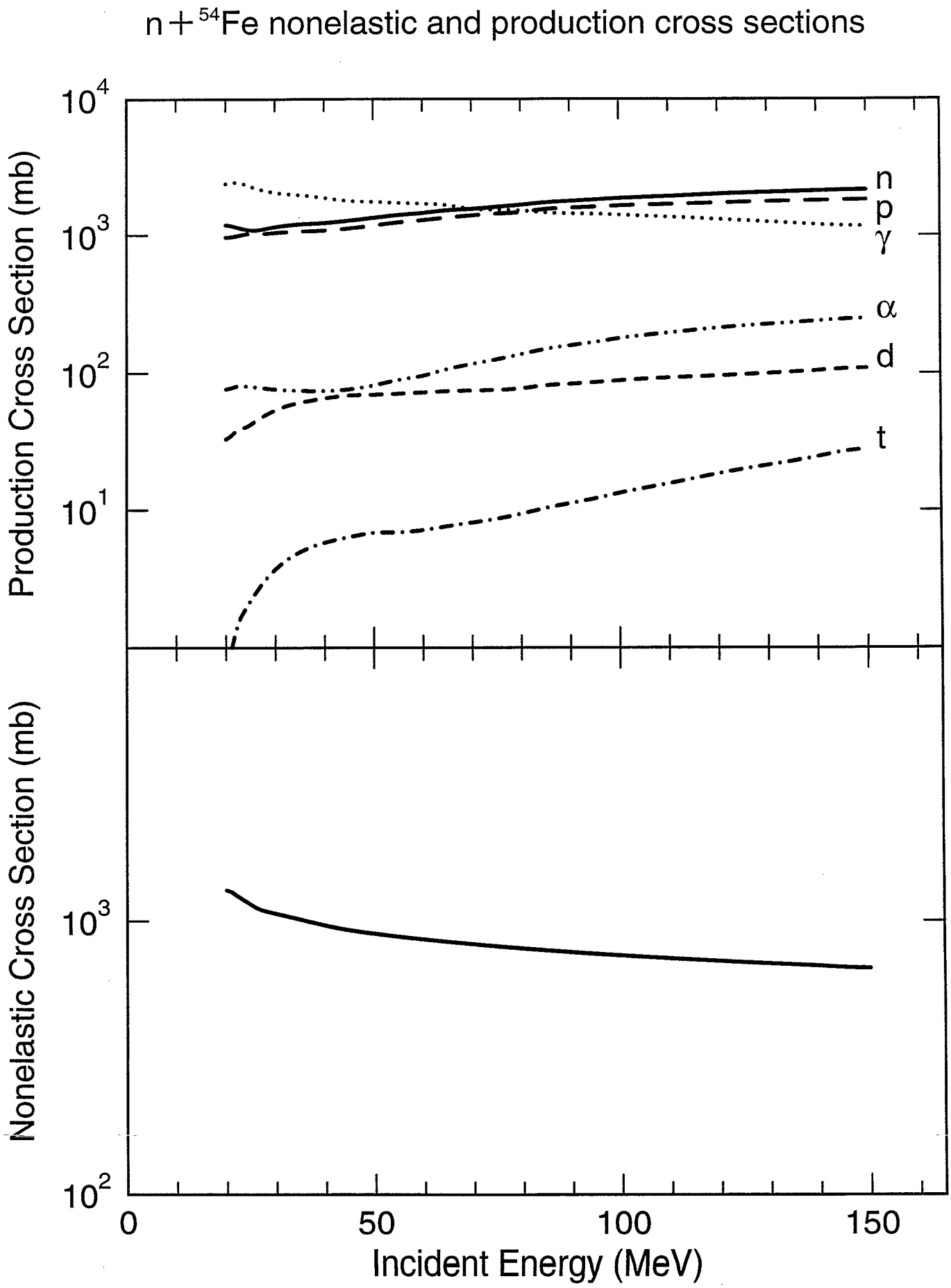
26054 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

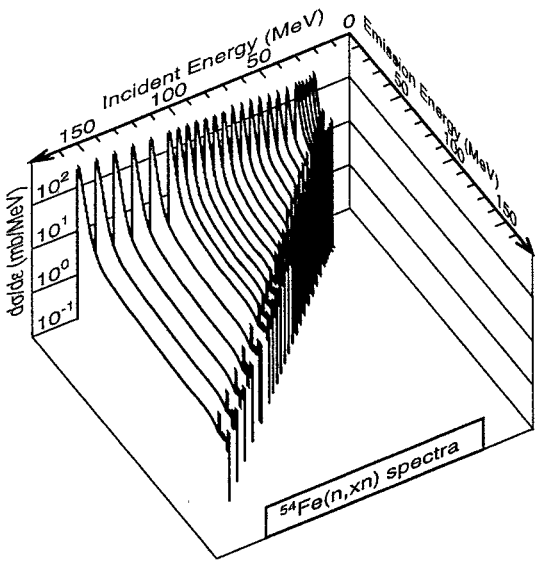
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	1.296E+00	9.424E-01	1.188E+00	9.654E-01	3.292E-02	7.686E-04	0.000E+00	7.651E-02	2.380E+00
2.200E+01	1.240E+00	9.979E-01	1.149E+00	9.822E-01	3.755E-02	1.319E-03	0.000E+00	8.006E-02	2.434E+00
2.400E+01	1.177E+00	1.053E+00	1.102E+00	1.018E+00	4.024E-02	1.927E-03	0.000E+00	8.035E-02	2.351E+00
2.600E+01	1.117E+00	1.135E+00	1.086E+00	1.027E+00	4.459E-02	2.507E-03	0.000E+00	7.915E-02	2.209E+00
2.800E+01	1.084E+00	1.206E+00	1.116E+00	1.029E+00	4.928E-02	3.137E-03	0.000E+00	7.756E-02	2.119E+00
3.000E+01	1.063E+00	1.267E+00	1.151E+00	1.043E+00	5.366E-02	3.740E-03	0.000E+00	7.630E-02	2.051E+00
3.500E+01	1.012E+00	1.422E+00	1.206E+00	1.070E+00	6.087E-02	4.987E-03	0.000E+00	7.461E-02	1.973E+00
4.000E+01	9.637E-01	1.536E+00	1.234E+00	1.086E+00	6.562E-02	5.827E-03	0.000E+00	7.441E-02	1.880E+00
4.500E+01	9.265E-01	1.593E+00	1.283E+00	1.125E+00	6.886E-02	6.403E-03	0.000E+00	7.656E-02	1.787E+00
5.000E+01	9.004E-01	1.600E+00	1.343E+00	1.180E+00	6.977E-02	6.852E-03	0.000E+00	8.161E-02	1.756E+00
5.500E+01	8.778E-01	1.587E+00	1.407E+00	1.244E+00	7.093E-02	6.916E-03	0.000E+00	8.923E-02	1.725E+00
6.000E+01	8.578E-01	1.547E+00	1.458E+00	1.291E+00	7.235E-02	7.178E-03	0.000E+00	9.573E-02	1.699E+00
6.500E+01	8.399E-01	1.488E+00	1.522E+00	1.347E+00	7.394E-02	7.645E-03	0.000E+00	1.071E-01	1.659E+00
7.000E+01	8.236E-01	1.428E+00	1.556E+00	1.396E+00	7.461E-02	8.117E-03	0.000E+00	1.164E-01	1.556E+00
7.500E+01	8.087E-01	1.352E+00	1.609E+00	1.436E+00	7.538E-02	8.647E-03	0.000E+00	1.258E-01	1.535E+00
8.000E+01	7.949E-01	1.279E+00	1.667E+00	1.477E+00	7.735E-02	9.377E-03	0.000E+00	1.370E-01	1.512E+00
8.500E+01	7.823E-01	1.218E+00	1.737E+00	1.550E+00	8.124E-02	1.033E-02	0.000E+00	1.492E-01	1.466E+00
9.000E+01	7.705E-01	1.159E+00	1.780E+00	1.584E+00	8.331E-02	1.117E-02	0.000E+00	1.587E-01	1.441E+00
9.500E+01	7.596E-01	1.090E+00	1.823E+00	1.611E+00	8.550E-02	1.210E-02	0.000E+00	1.680E-01	1.429E+00
1.000E+02	7.494E-01	1.037E+00	1.865E+00	1.643E+00	8.800E-02	1.329E-02	0.000E+00	1.788E-01	1.405E+00
1.100E+02	7.307E-01	9.113E-01	1.930E+00	1.683E+00	9.232E-02	1.555E-02	0.000E+00	1.959E-01	1.359E+00
1.200E+02	7.141E-01	8.009E-01	2.004E+00	1.723E+00	9.541E-02	1.839E-02	0.000E+00	2.124E-01	1.306E+00
1.300E+02	6.992E-01	7.028E-01	2.059E+00	1.764E+00	9.944E-02	2.125E-02	0.000E+00	2.263E-01	1.252E+00
1.400E+02	6.857E-01	6.243E-01	2.114E+00	1.798E+00	1.043E-01	2.452E-02	0.000E+00	2.396E-01	1.198E+00
1.500E+02	6.734E-01	5.896E-01	2.150E+00	1.823E+00	1.085E-01	2.771E-02	0.000E+00	2.498E-01	1.168E+00

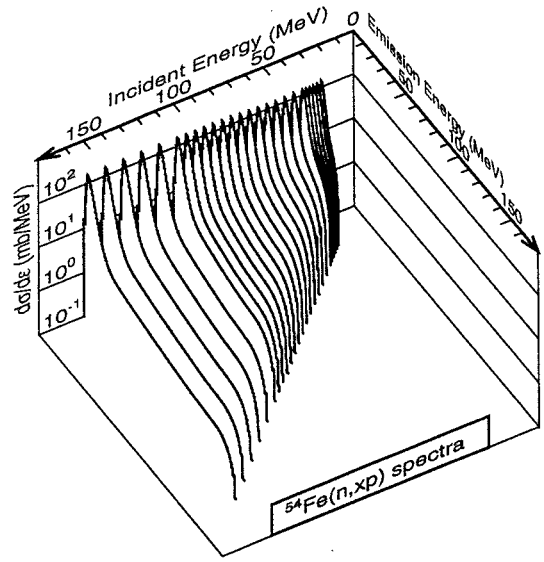
26054 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

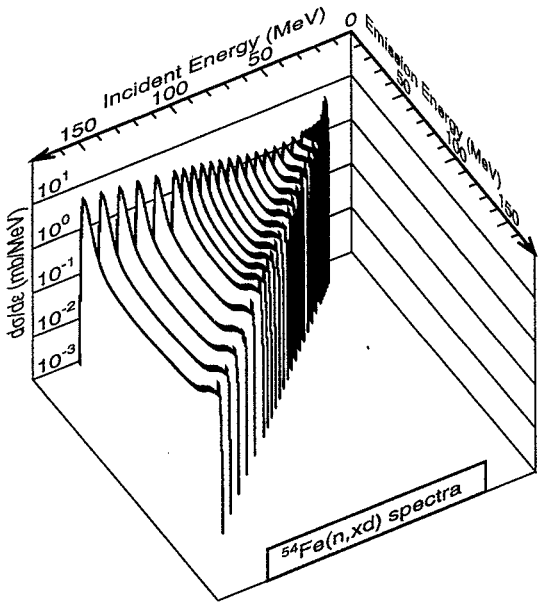
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	9.635E-01	5.320E-02	6.899E-04	0.000E+00	1.345E-01	1.137E-01	2.039E-02	1.286E+00
2.200E+01	1.002E+00	6.796E-02	1.406E-03	0.000E+00	1.454E-01	1.177E-01	3.311E-02	1.367E+00
2.400E+01	1.050E+00	8.009E-02	2.370E-03	0.000E+00	1.514E-01	1.195E-01	3.564E-02	1.439E+00
2.600E+01	1.081E+00	9.754E-02	3.467E-03	0.000E+00	1.543E-01	1.200E-01	3.862E-02	1.495E+00
2.800E+01	1.124E+00	1.174E-01	4.846E-03	0.000E+00	1.564E-01	1.220E-01	3.929E-02	1.564E+00
3.000E+01	1.181E+00	1.387E-01	6.362E-03	0.000E+00	1.585E-01	1.245E-01	3.889E-02	1.648E+00
3.500E+01	1.341E+00	1.887E-01	1.033E-02	0.000E+00	1.637E-01	1.320E-01	3.667E-02	1.872E+00
4.000E+01	1.504E+00	2.401E-01	1.422E-02	0.000E+00	1.696E-01	1.375E-01	3.370E-02	2.099E+00
4.500E+01	1.678E+00	2.889E-01	1.788E-02	0.000E+00	1.786E-01	1.435E-01	3.064E-02	2.338E+00
5.000E+01	1.878E+00	3.226E-01	2.138E-02	0.000E+00	1.923E-01	1.494E-01	2.764E-02	2.591E+00
5.500E+01	2.101E+00	3.589E-01	2.322E-02	0.000E+00	2.090E-01	1.565E-01	2.289E-02	2.872E+00
6.000E+01	2.304E+00	3.958E-01	2.581E-02	0.000E+00	2.250E-01	1.617E-01	2.093E-02	3.133E+00
6.500E+01	2.492E+00	4.303E-01	2.829E-02	0.000E+00	2.493E-01	1.685E-01	1.915E-02	3.388E+00
7.000E+01	2.685E+00	4.570E-01	3.070E-02	0.000E+00	2.702E-01	1.745E-01	1.767E-02	3.635E+00
7.500E+01	2.864E+00	4.817E-01	3.301E-02	0.000E+00	2.914E-01	1.796E-01	1.621E-02	3.866E+00
8.000E+01	3.038E+00	5.148E-01	3.532E-02	0.000E+00	3.160E-01	1.852E-01	1.496E-02	4.104E+00
8.500E+01	3.296E+00	5.646E-01	3.858E-02	0.000E+00	3.448E-01	1.919E-01	1.396E-02	4.450E+00
9.000E+01	3.475E+00	6.012E-01	4.097E-02	0.000E+00	3.670E-01	1.961E-01	1.309E-02	4.693E+00
9.500E+01	3.655E+00	6.386E-01	4.340E-02	0.000E+00	3.890E-01	1.994E-01	1.215E-02	4.938E+00
1.000E+02	3.827E+00	6.731E-01	4.592E-02	0.000E+00	4.139E-01	2.036E-01	1.144E-02	5.175E+00
1.100E+02	4.169E+00	7.452E-01	5.069E-02	0.000E+00	4.556E-01	2.094E-01	9.904E-03	5.639E+00
1.200E+02	4.512E+00	7.785E-01	5.605E-02	0.000E+00	4.974E-01	2.134E-01	8.615E-03	6.066E+00
1.300E+02	4.854E+00	8.331E-01	6.117E-02	0.000E+00	5.338E-01	2.241E-01	7.503E-03	6.514E+00
1.400E+02	5.176E+00	8.947E-01	6.673E-02	0.000E+00	5.689E-01	2.342E-01	6.624E-03	6.947E+00
1.500E+02	5.504E+00	9.511E-01	7.213E-02	0.000E+00	5.975E-01	2.411E-01	6.220E-03	7.372E+00

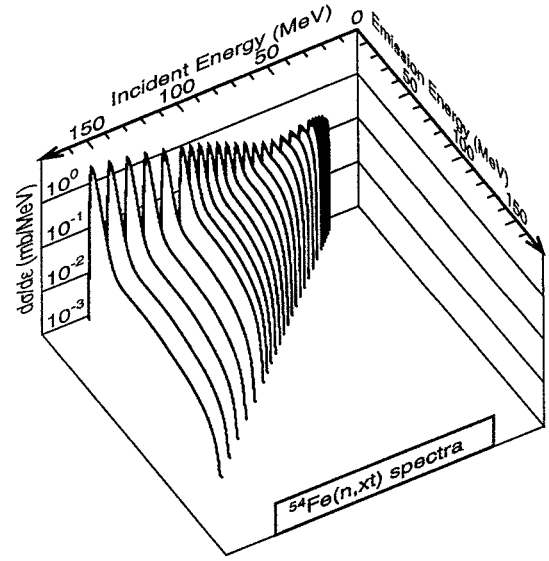

n + 54Fe nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
n
p
γ
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
0
50
100
150
Incident Energy (MeV)

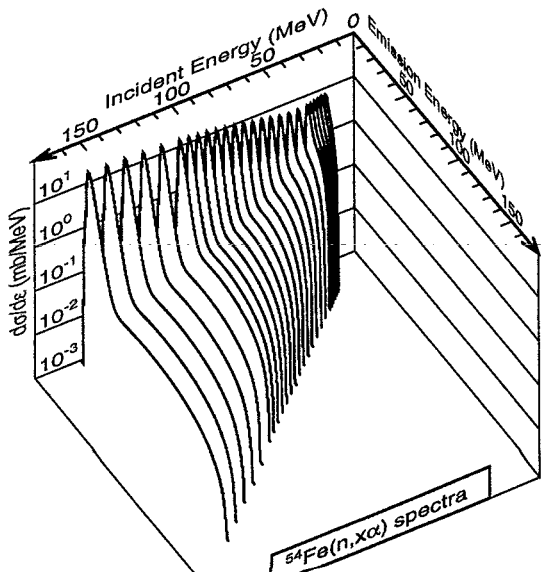
n + ^{54}Fe angle-integrated emission spectra

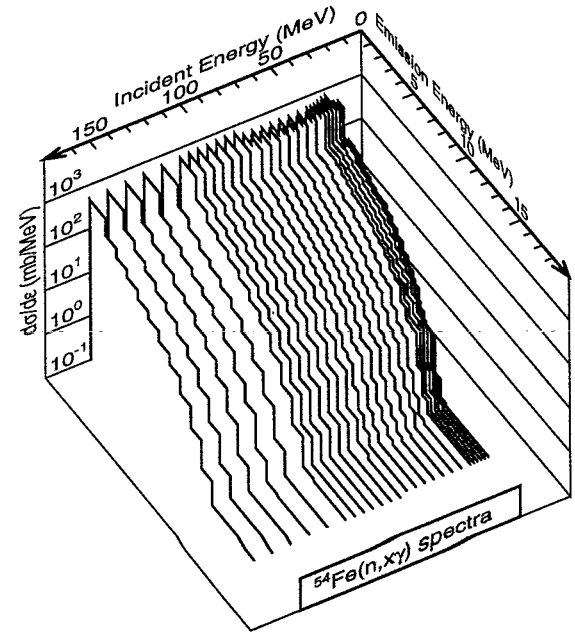




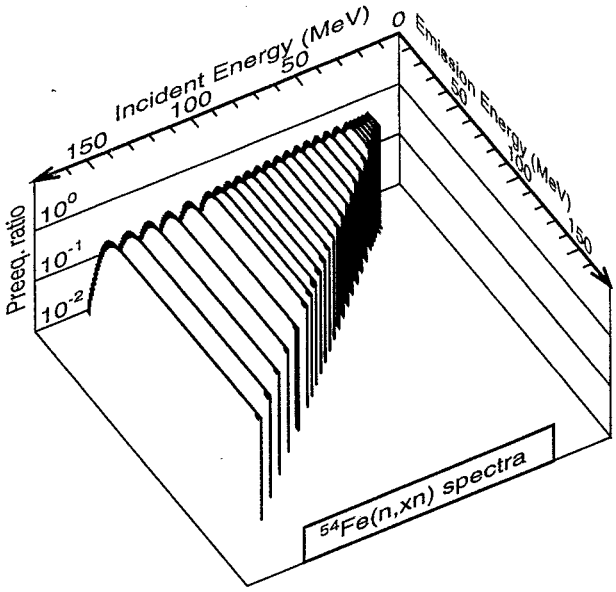


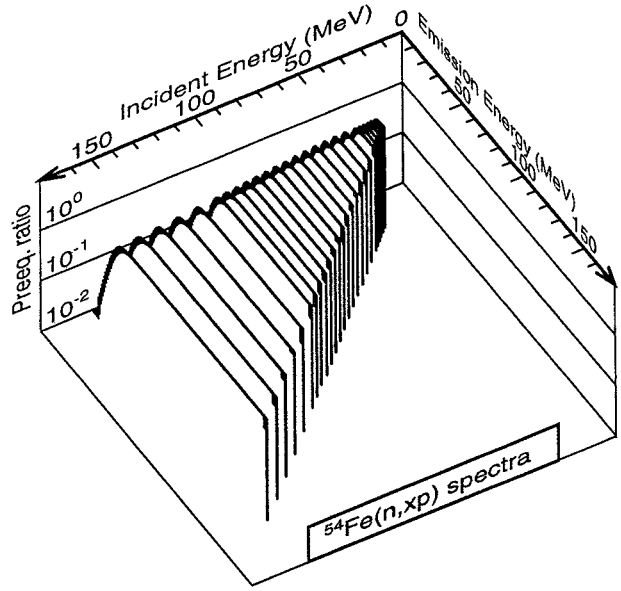


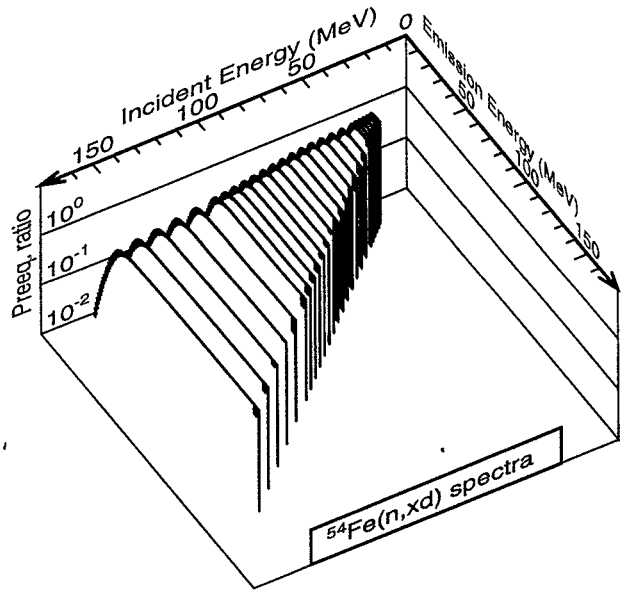


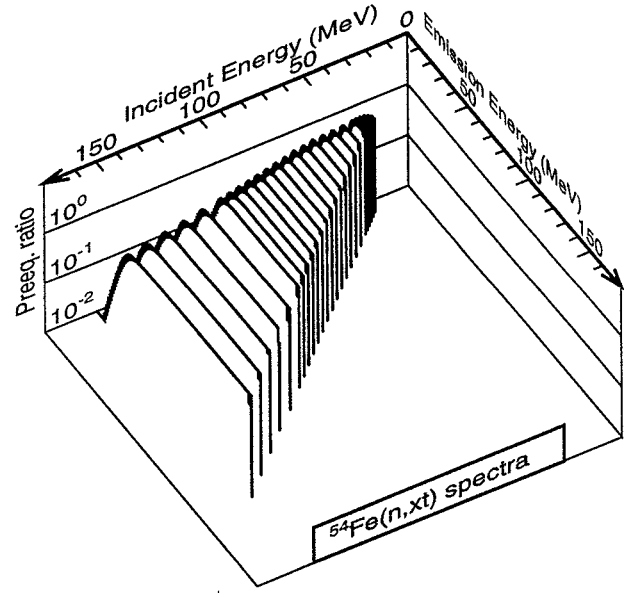


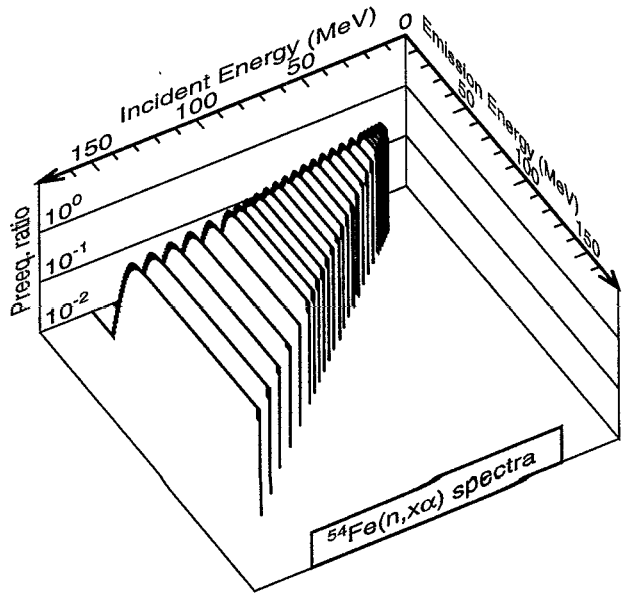
n + ^{54}Fe Kalbach preequilibrium ratios

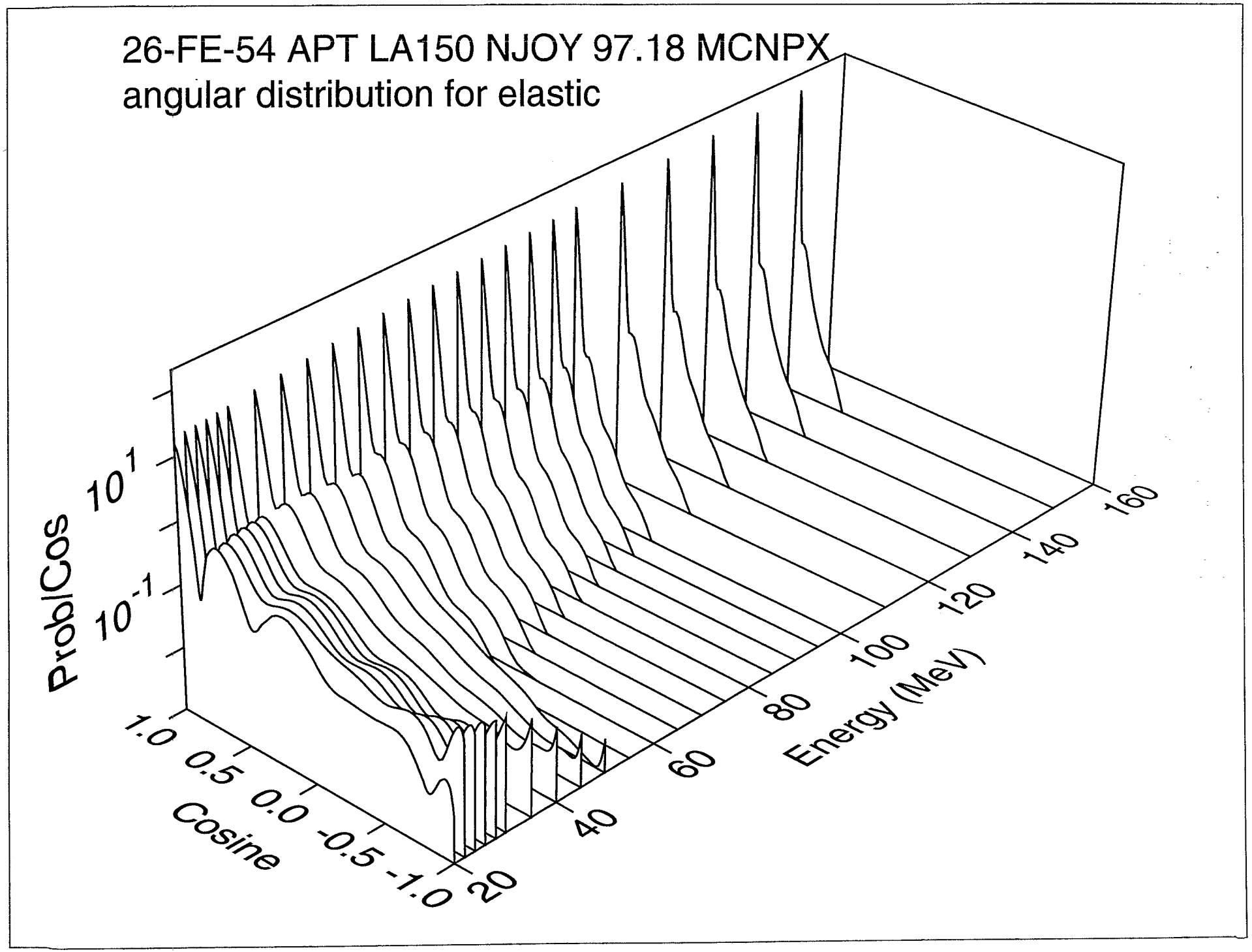


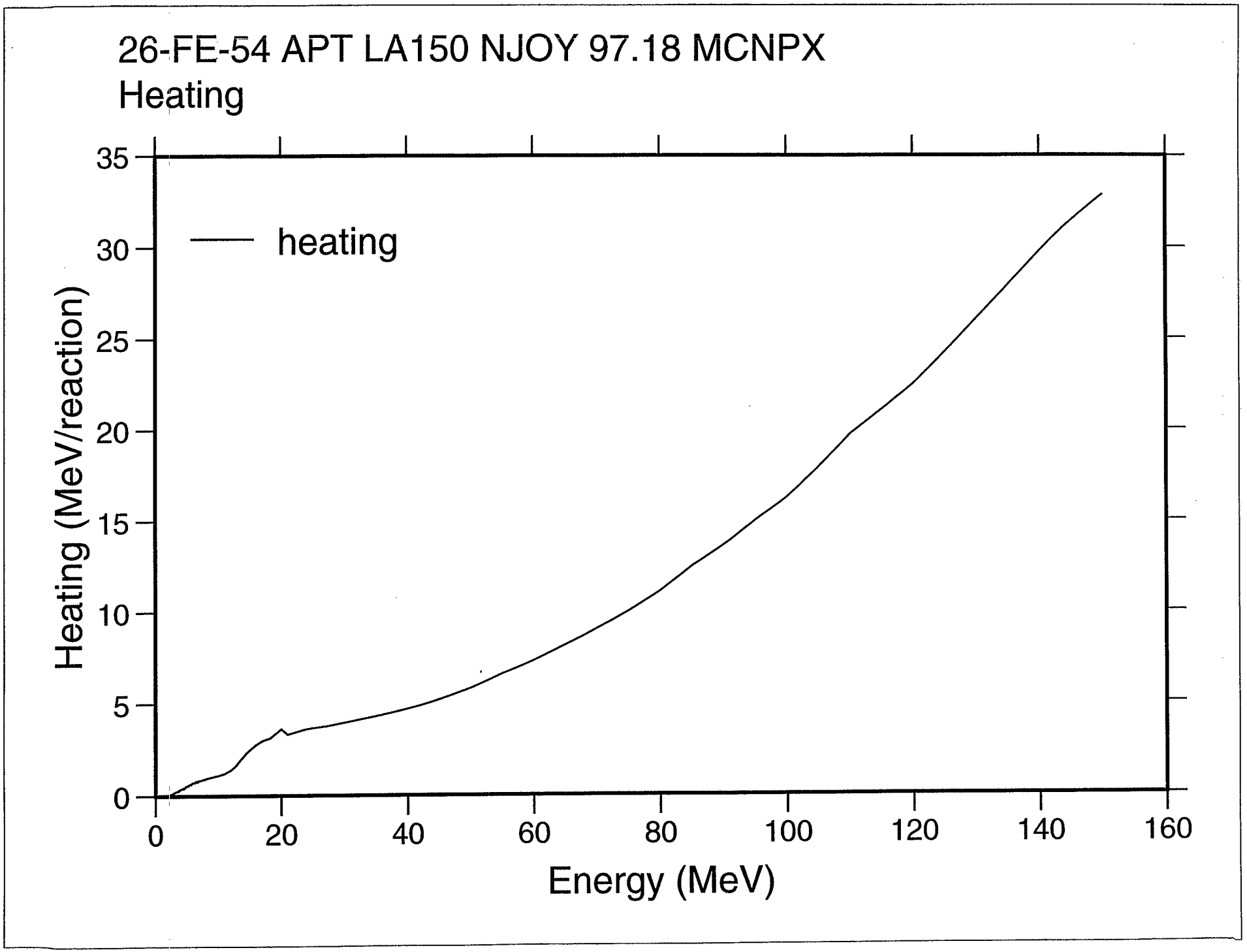


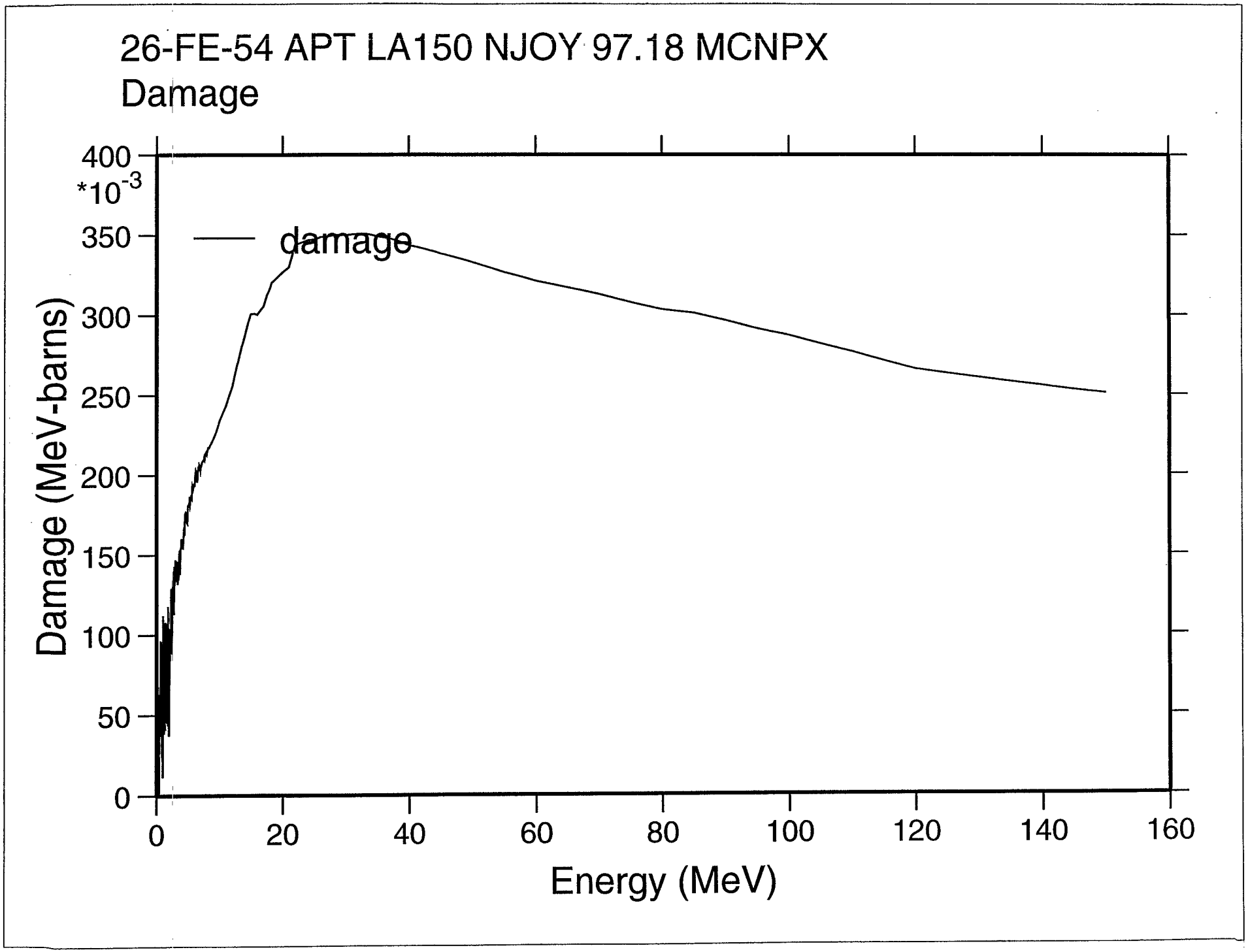







26-FE-54 APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic
Prob/Cos
10^1
10^{-1}
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


26-FE-54 APT LA150 NJOY 97.18 MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
5
10
15
20
25
30
35
0
20
40
60
80
100
120
140
160


26-FE-54 APT LA150 NJOY 97.18 MCNPX
Damage
damage
Damage (MeV-barns)
*10^-3
400
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF n + 56Fe CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

M. B. Chadwick, P. G. Young, and A. J. Koning
6 September 1996

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI.1 (Release 1) evaluation by Fu91 (see also Fu86). The following modifications were made to the ENDF/B-VI.1 evaluation:

1. The covariance files (MF=33) were removed from the file.

2. The derived MF=3 files for MT=203,205,207 were removed.

INCIDENT NEUTRON ENERGIES > 20 MeV

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT= 1	Total Cross Section
	MT= 2	Elastic Scattering Cross Section
	MT= 3	Nonelastic Cross Section
	MT= 5	Sum of Binary (n,n') and (n,x) Reactions
MF=4	MT= 2	Elastic Angular Distributions
MF=6	MT= 5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Fe56 and p + Fe56 reactions (Ch96a). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of

all recoil nuclei in the GNASH calculations (Ch96b). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. Note that all other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation requires a modification of the original ENDF-6 format.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

The neutron optical model potential of Arthur et al. (Ar80) was used to calculate transmission coefficients and cross sections with the SCAT2 code (Be92) up to a neutron energy of 26 MeV. Between 26 and 52 MeV, the imaginary volume component of Arthur's potential was modified to better account for nonelastic cross section measurements, and above 52 MeV the Semmering potential of Madland (Ma88) was used. For protons, the Beccetti-Greenlees potential (Be69) was utilized below 28 MeV, and the Madland potential (Ma88) was used at higher energies. The global spherical potential of Perey (Pe63) was utilized for deuterons, and the potential of Beccetti-Greenlees (Be) was adopted for tritons. Finally, the alpha potential of Lemos (Le72), as adapted by Arthur et al. (Ar80), was used for alpha particles.

Direct reaction cross sections to discrete states were calculated with the ECIS95 code [Re95] using deformation parameters compiled in Nuclear Data Sheets.

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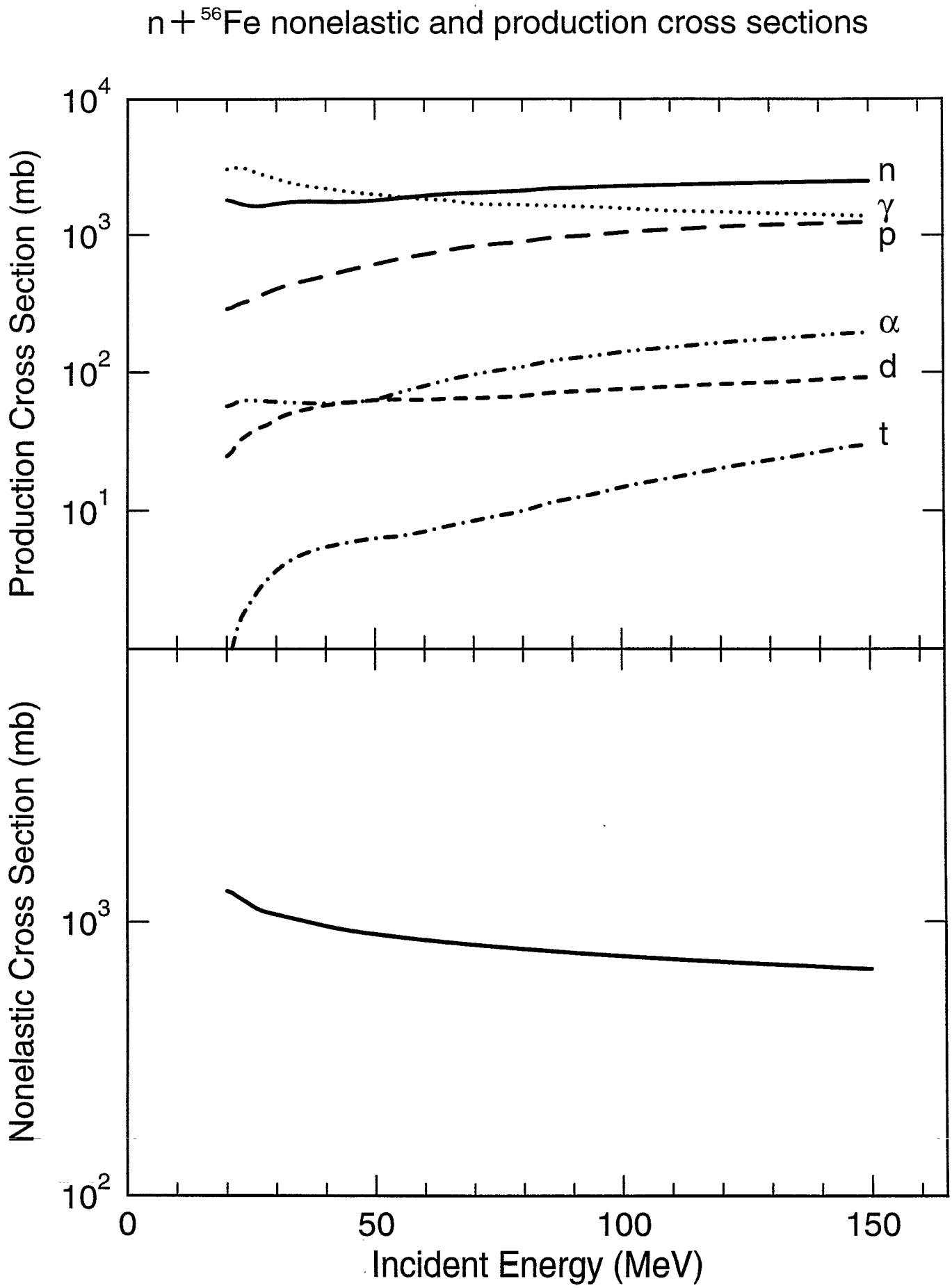
26056 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

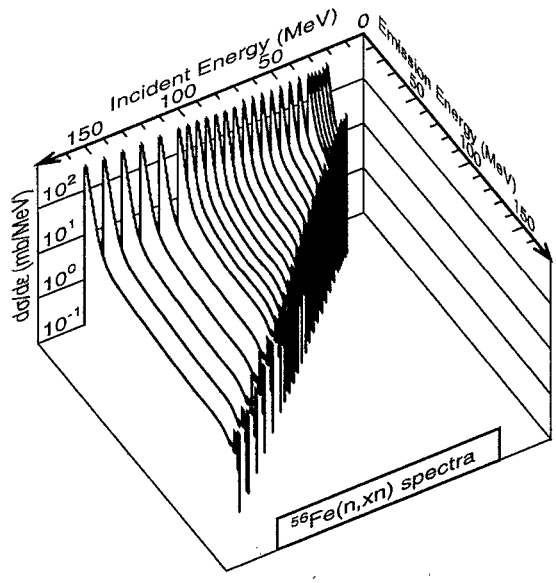
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	1.296E+00	9.424E-01	1.808E+00	2.876E-01	2.485E-02	8.216E-04	0.000E+00	5.695E-02	3.055E+00
2.200E+01	1.240E+00	9.979E-01	1.726E+00	3.084E-01	3.037E-02	1.365E-03	0.000E+00	6.090E-02	3.141E+00
2.400E+01	1.177E+00	1.053E+00	1.653E+00	3.264E-01	3.499E-02	1.952E-03	0.000E+00	6.299E-02	3.079E+00
2.600E+01	1.117E+00	1.135E+00	1.625E+00	3.501E-01	3.902E-02	2.538E-03	0.000E+00	6.255E-02	2.880E+00
2.800E+01	1.084E+00	1.206E+00	1.653E+00	3.762E-01	4.154E-02	3.134E-03	0.000E+00	6.194E-02	2.732E+00
3.000E+01	1.063E+00	1.267E+00	1.696E+00	4.023E-01	4.577E-02	3.693E-03	0.000E+00	6.126E-02	2.599E+00
3.500E+01	1.012E+00	1.422E+00	1.765E+00	4.536E-01	5.285E-02	4.785E-03	0.000E+00	6.009E-02	2.326E+00
4.000E+01	9.637E-01	1.536E+00	1.757E+00	5.017E-01	5.781E-02	5.479E-03	0.000E+00	5.977E-02	2.193E+00
4.500E+01	9.265E-01	1.593E+00	1.758E+00	5.569E-01	6.064E-02	5.952E-03	0.000E+00	6.091E-02	2.063E+00
5.000E+01	9.004E-01	1.600E+00	1.795E+00	6.090E-01	6.308E-02	6.329E-03	0.000E+00	6.380E-02	1.980E+00
5.500E+01	8.778E-01	1.587E+00	1.869E+00	6.696E-01	6.379E-02	6.575E-03	0.000E+00	7.151E-02	1.902E+00
6.000E+01	8.578E-01	1.547E+00	1.939E+00	7.204E-01	6.336E-02	7.086E-03	0.000E+00	7.969E-02	1.837E+00
6.500E+01	8.399E-01	1.488E+00	2.000E+00	7.758E-01	6.472E-02	7.807E-03	0.000E+00	8.883E-02	1.792E+00
7.000E+01	8.236E-01	1.428E+00	2.034E+00	8.274E-01	6.500E-02	8.481E-03	0.000E+00	9.631E-02	1.694E+00
7.500E+01	8.087E-01	1.352E+00	2.075E+00	8.612E-01	6.627E-02	9.204E-03	0.000E+00	1.033E-01	1.676E+00
8.000E+01	7.949E-01	1.279E+00	2.113E+00	8.926E-01	6.755E-02	1.000E-02	0.000E+00	1.098E-01	1.666E+00
8.500E+01	7.823E-01	1.218E+00	2.185E+00	9.469E-01	7.078E-02	1.132E-02	0.000E+00	1.198E-01	1.639E+00
9.000E+01	7.705E-01	1.159E+00	2.221E+00	9.773E-01	7.244E-02	1.234E-02	0.000E+00	1.264E-01	1.619E+00
9.500E+01	7.596E-01	1.090E+00	2.252E+00	1.006E+00	7.400E-02	1.342E-02	0.000E+00	1.326E-01	1.602E+00
1.000E+02	7.494E-01	1.037E+00	2.287E+00	1.044E+00	7.544E-02	1.483E-02	0.000E+00	1.402E-01	1.570E+00
1.100E+02	7.307E-01	9.113E-01	2.336E+00	1.096E+00	7.875E-02	1.734E-02	0.000E+00	1.519E-01	1.505E+00
1.200E+02	7.141E-01	8.009E-01	2.383E+00	1.149E+00	8.216E-02	2.036E-02	0.000E+00	1.640E-01	1.474E+00
1.300E+02	6.992E-01	7.028E-01	2.425E+00	1.187E+00	8.458E-02	2.335E-02	0.000E+00	1.745E-01	1.440E+00
1.400E+02	6.857E-01	6.243E-01	2.467E+00	1.215E+00	8.834E-02	2.668E-02	0.000E+00	1.852E-01	1.415E+00
1.500E+02	6.734E-01	5.896E-01	2.496E+00	1.239E+00	9.159E-02	2.989E-02	0.000E+00	1.939E-01	1.379E+00

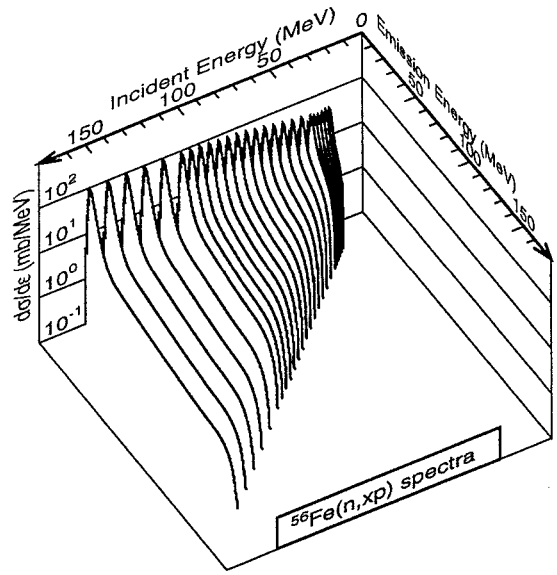
26056 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

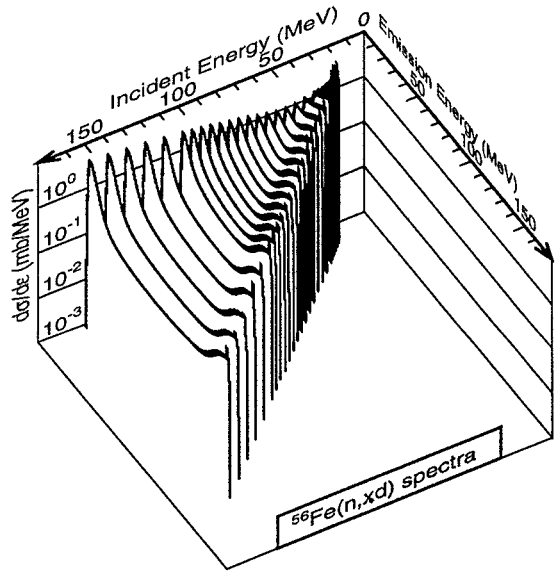
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	3.018E-01	3.548E-02	7.378E-04	0.000E+00	8.950E-02	9.794E-02	1.898E-02	5.445E-01
2.200E+01	3.482E-01	4.966E-02	1.426E-03	0.000E+00	9.912E-02	1.021E-01	3.030E-02	6.308E-01
2.400E+01	3.873E-01	6.405E-02	2.328E-03	0.000E+00	1.059E-01	1.039E-01	3.300E-02	6.965E-01
2.600E+01	4.262E-01	7.890E-02	3.388E-03	0.000E+00	1.085E-01	1.047E-01	3.609E-02	7.578E-01
2.800E+01	4.753E-01	9.069E-02	4.616E-03	0.000E+00	1.106E-01	1.067E-01	3.688E-02	8.247E-01
3.000E+01	5.360E-01	1.087E-01	5.938E-03	0.000E+00	1.121E-01	1.094E-01	3.647E-02	9.085E-01
3.500E+01	6.945E-01	1.513E-01	9.256E-03	0.000E+00	1.155E-01	1.164E-01	3.418E-02	1.121E+00
4.000E+01	8.529E-01	1.965E-01	1.237E-02	0.000E+00	1.193E-01	1.214E-01	3.138E-02	1.334E+00
4.500E+01	1.022E+00	2.371E-01	1.525E-02	0.000E+00	1.247E-01	1.262E-01	2.843E-02	1.554E+00
5.000E+01	1.200E+00	2.776E-01	1.791E-02	0.000E+00	1.329E-01	1.317E-01	2.556E-02	1.785E+00
5.500E+01	1.387E+00	3.073E-01	1.948E-02	0.000E+00	1.482E-01	1.384E-01	2.087E-02	2.021E+00
6.000E+01	1.564E+00	3.252E-01	2.169E-02	0.000E+00	1.651E-01	1.442E-01	1.909E-02	2.239E+00
6.500E+01	1.735E+00	3.544E-01	2.399E-02	0.000E+00	1.839E-01	1.500E-01	1.747E-02	2.465E+00
7.000E+01	1.908E+00	3.737E-01	2.618E-02	0.000E+00	2.000E-01	1.557E-01	1.614E-02	2.679E+00
7.500E+01	2.070E+00	4.026E-01	2.832E-02	0.000E+00	2.153E-01	1.597E-01	1.482E-02	2.891E+00
8.000E+01	2.233E+00	4.311E-01	3.045E-02	0.000E+00	2.300E-01	1.632E-01	1.368E-02	3.101E+00
8.500E+01	2.456E+00	4.696E-01	3.357E-02	0.000E+00	2.521E-01	1.690E-01	1.279E-02	3.394E+00
9.000E+01	2.628E+00	5.005E-01	3.591E-02	0.000E+00	2.674E-01	1.722E-01	1.199E-02	3.617E+00
9.500E+01	2.795E+00	5.298E-01	3.822E-02	0.000E+00	2.821E-01	1.749E-01	1.115E-02	3.831E+00
1.000E+02	2.961E+00	5.497E-01	4.083E-02	0.000E+00	2.994E-01	1.782E-01	1.050E-02	4.040E+00
1.100E+02	3.295E+00	6.069E-01	4.557E-02	0.000E+00	3.277E-01	1.831E-01	9.108E-03	4.467E+00
1.200E+02	3.623E+00	6.549E-01	5.079E-02	0.000E+00	3.572E-01	1.876E-01	7.937E-03	4.882E+00
1.300E+02	3.953E+00	6.868E-01	5.593E-02	0.000E+00	3.833E-01	1.960E-01	6.925E-03	5.282E+00
1.400E+02	4.269E+00	7.364E-01	6.143E-02	0.000E+00	4.097E-01	2.072E-01	6.124E-03	5.690E+00
1.500E+02	4.585E+00	7.822E-01	6.674E-02	0.000E+00	4.322E-01	2.168E-01	5.759E-03	6.089E+00

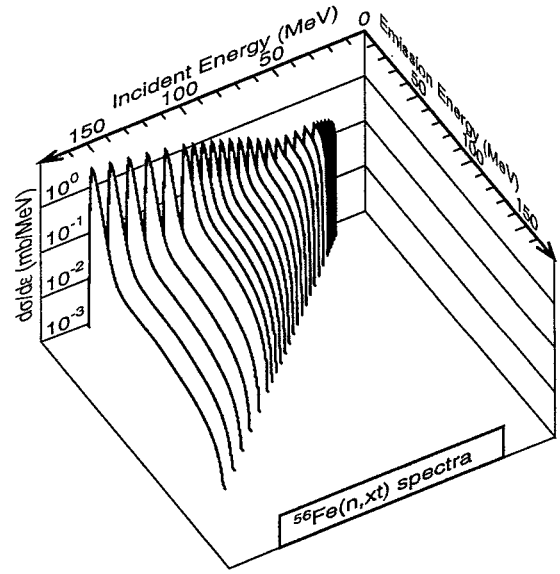

n + 56Fe nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
n
γ
p
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
0
50
100
150
Incident Energy (MeV)

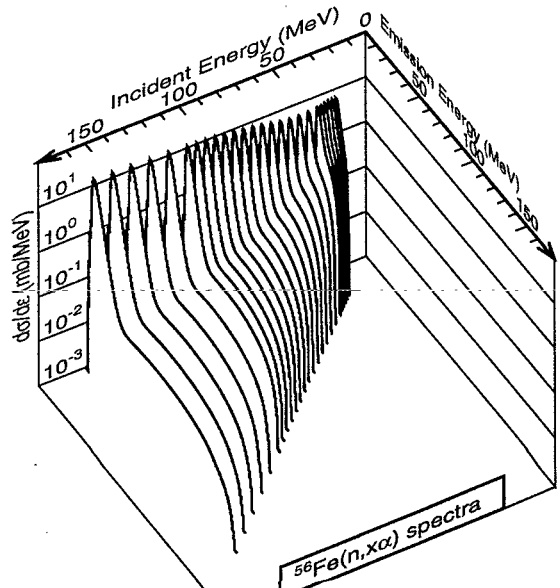
n + ^{56}Fe angle-integrated emission spectra

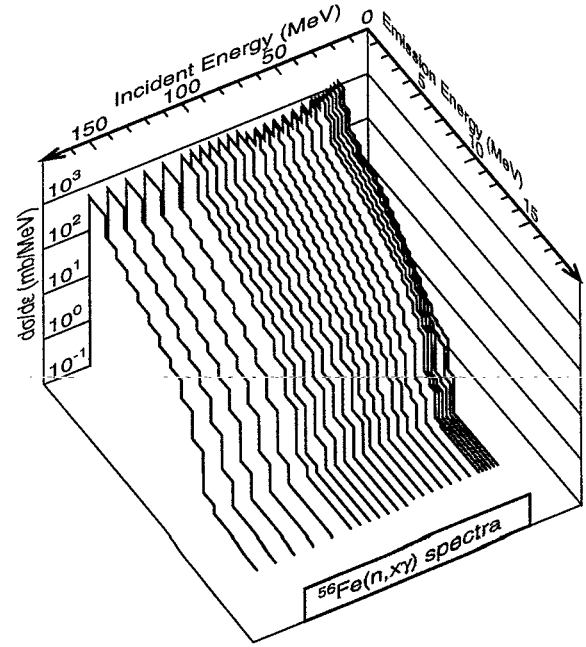




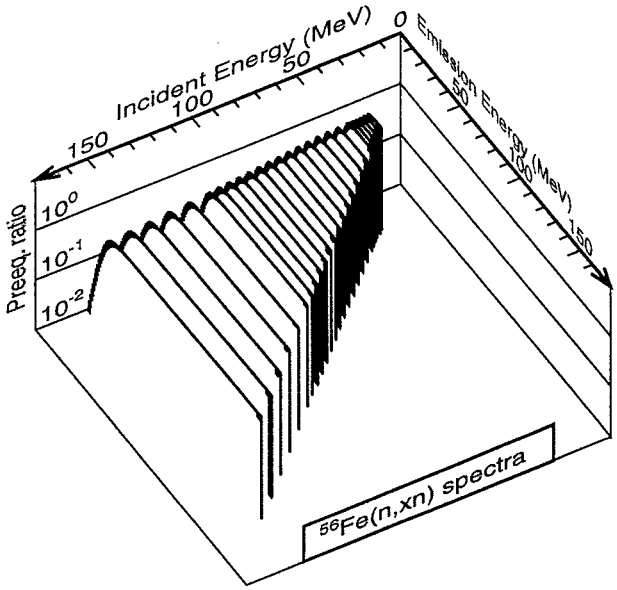


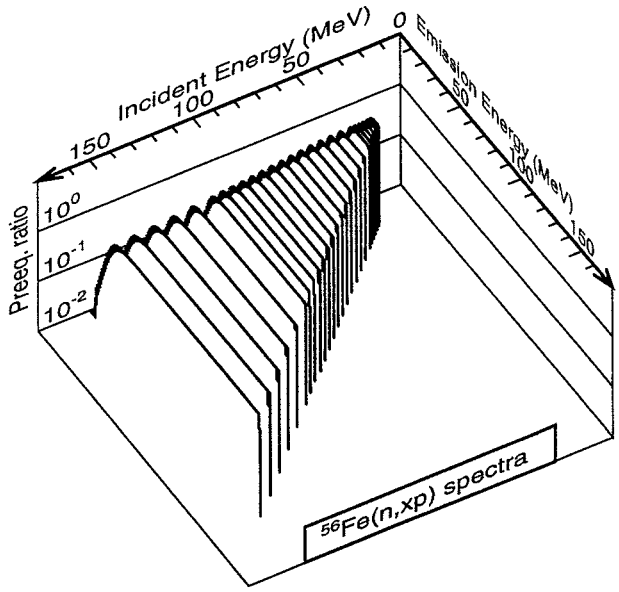


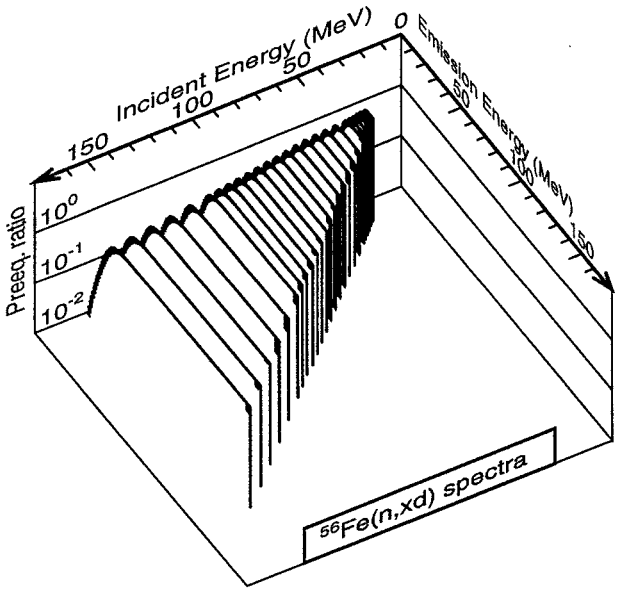


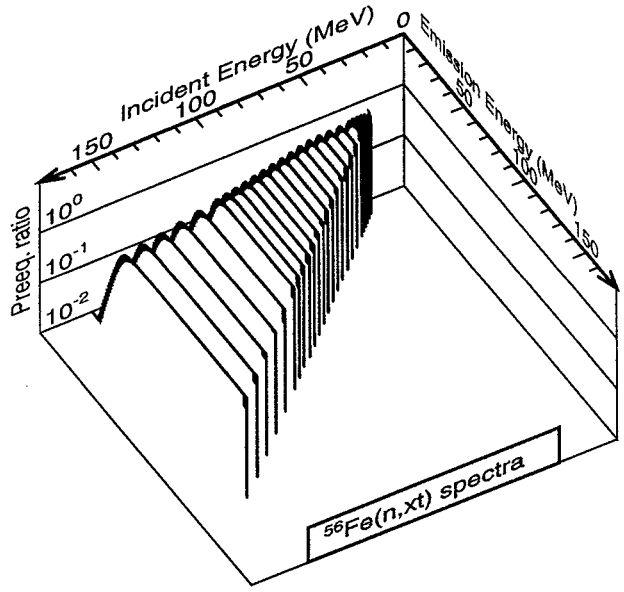


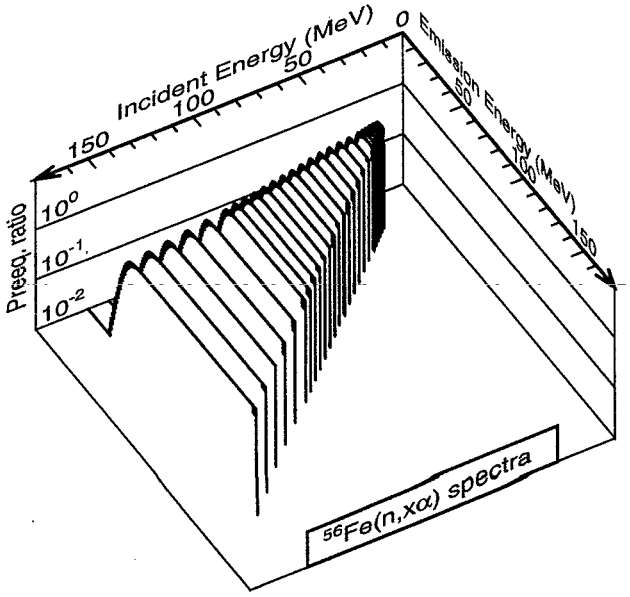
n + ^{56}Fe Kalbach preequilibrium ratios

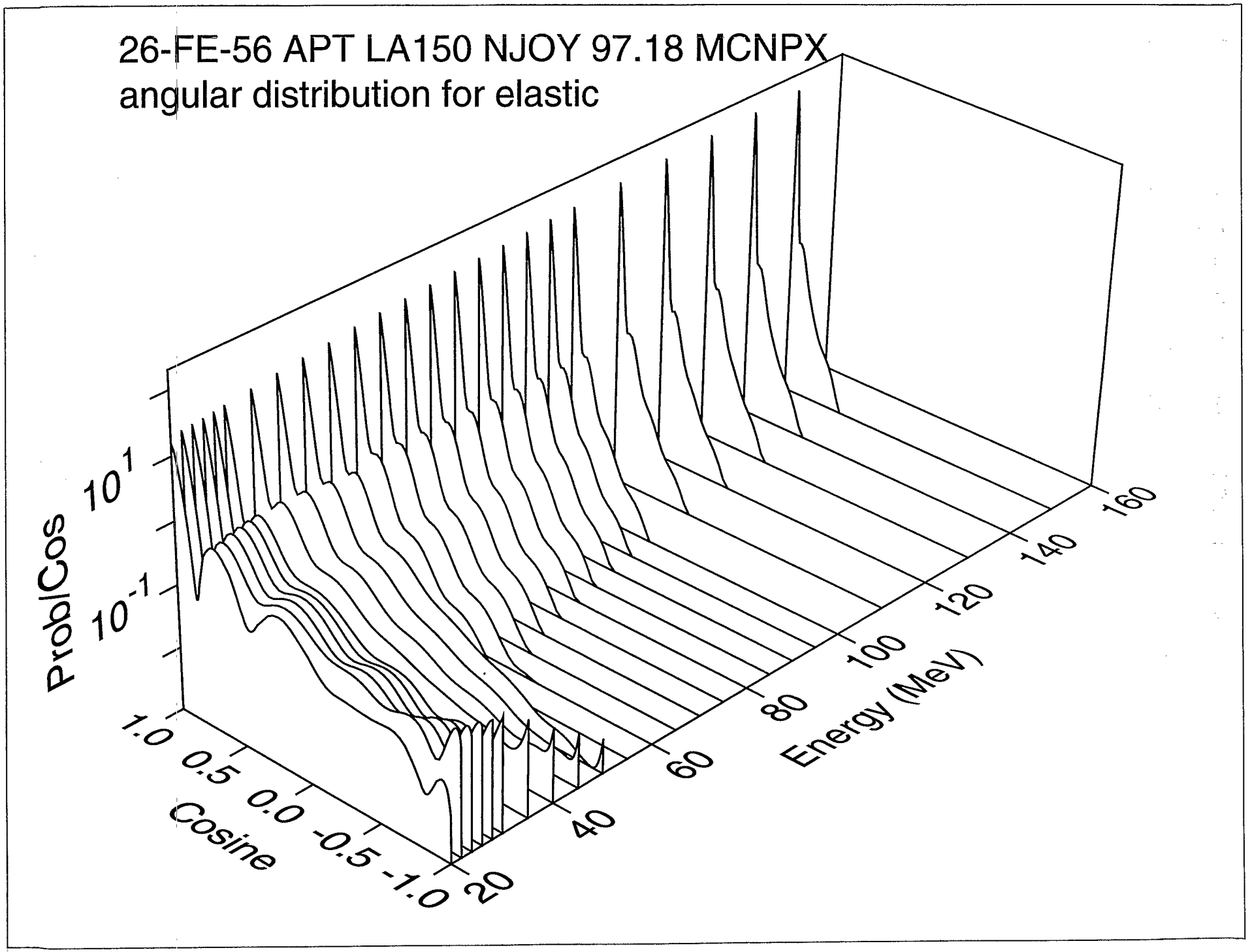


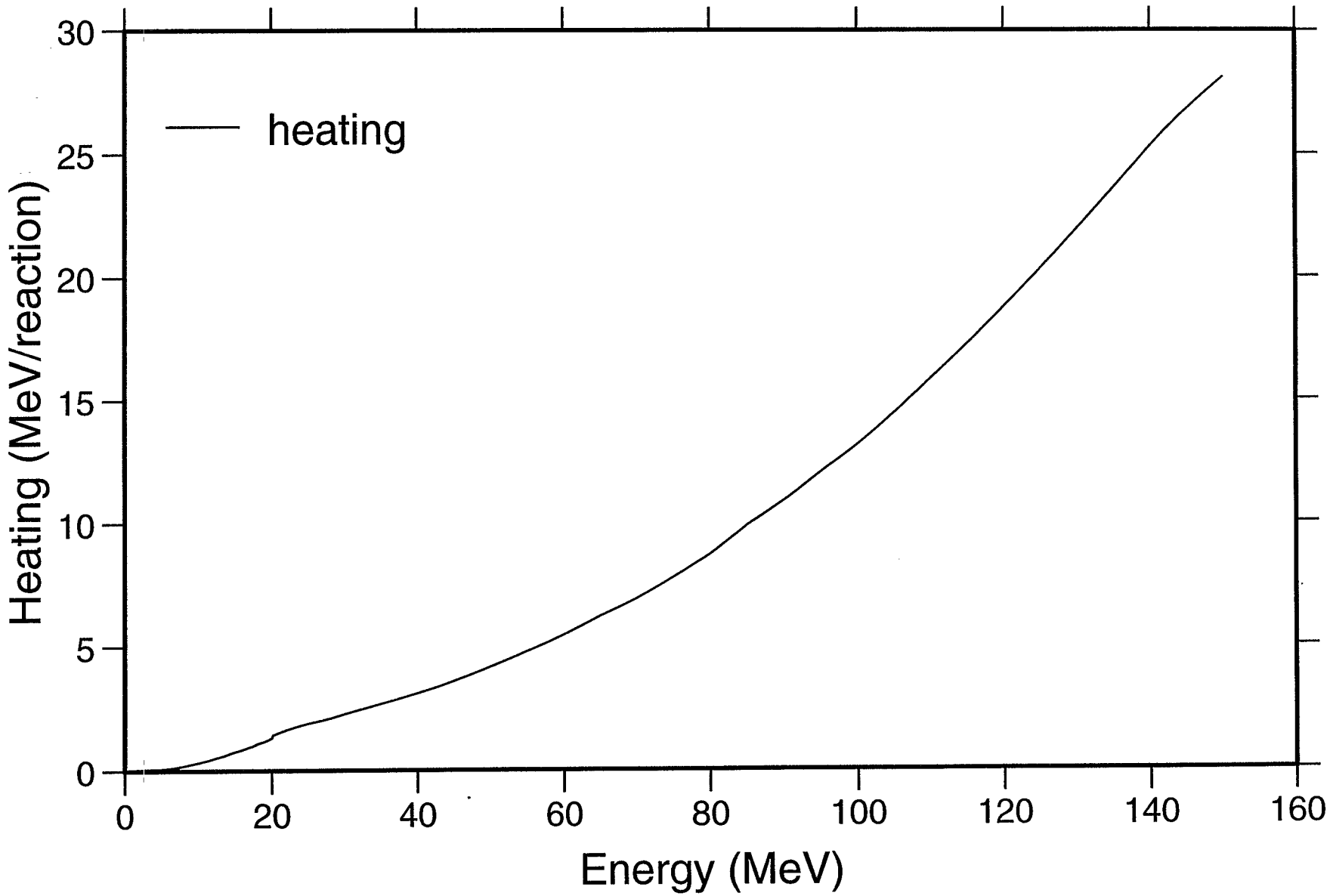


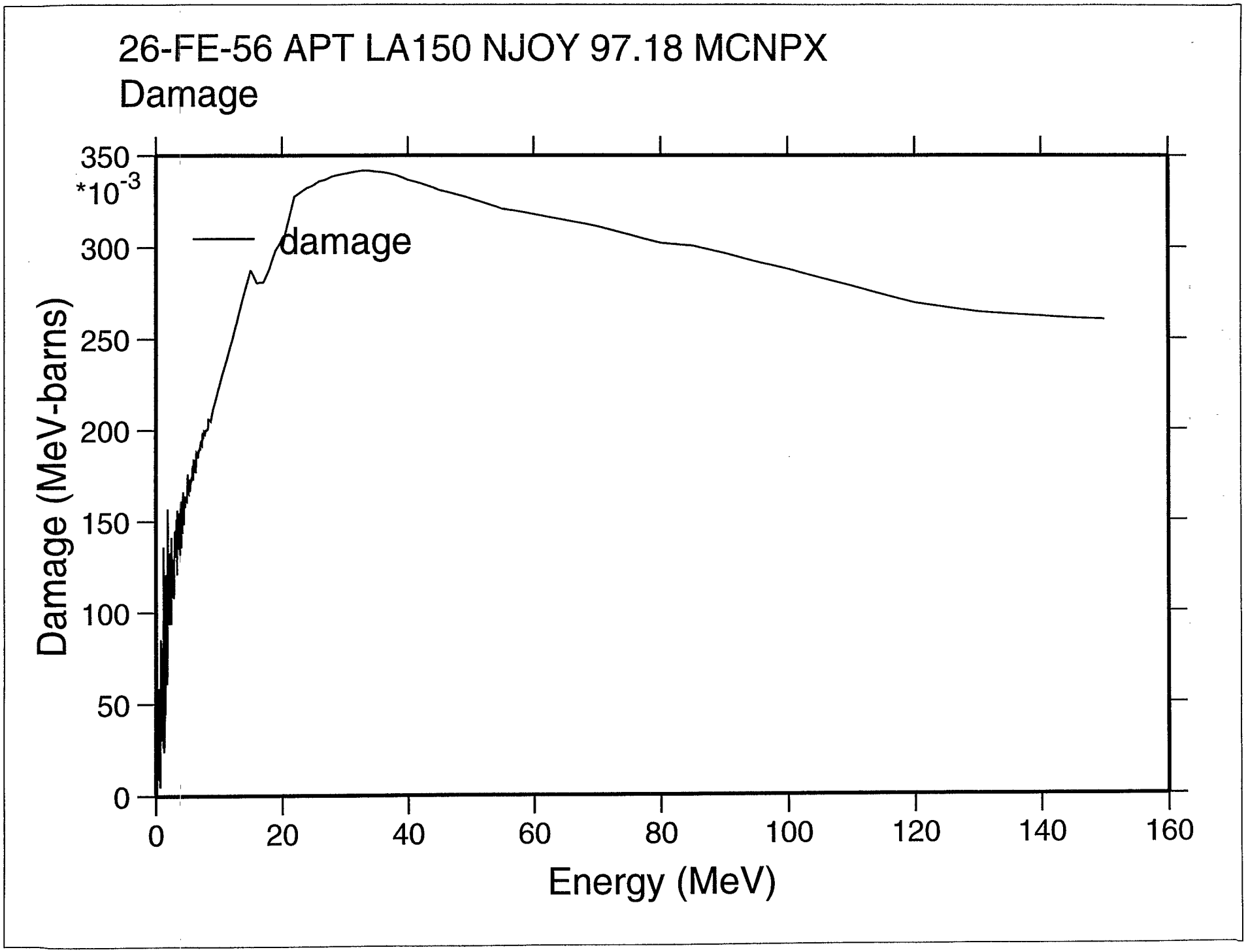







26-FE-56 APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic
Prob/Cos
10^1
10^{-1}
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


26-FE-56 APT LA150 NJOY 97.18 MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
5
10
15
20
25
30
0
20
40
60
80
100
120
140
160


26-FE-56 APT LA150 NJOY 97.18 MCNPX
Damage
damage
Damage (MeV-barns)
*10^-3
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF n + 57Fe CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

M. B. Chadwick, P. G. Young, and A. J. Koning
6 September 1996

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI.1 (Release 1) evaluation by He91 (see also Fu86). The following modifications were made to the ENDF/B-VI.1 evaluation:

1. The covariance files (MF=33) were removed from the file.

2. The derived MF=3 files for MT=203,205,207 were removed.

INCIDENT NEUTRON ENERGIES > 20 MeV

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT=	1	Total Cross Section
	MT=	2	Elastic Scattering Cross Section
	MT=	3	Nonelastic Cross Section
	MT=	5	Sum of Binary (n,n') and (n,x) Reactions
MF=4	MT=	2	Elastic Angular Distributions
MF=6	MT=	5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Fe56 and p + Fe56 reactions (Ch96a). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of

all recoil nuclei in the GNASH calculations (Ch96b). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. Note that all other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation requires a modification of the original ENDF-6 format.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

The neutron optical model potential of Arthur et al. (Ar80) was used to calculate transmission coefficients and cross sections with the SCAT2 code (Be92) up to a neutron energy of 26 MeV. Between 26 and 52 MeV, the imaginary volume component of Arthur's potential was modified to better account for nonelastic cross section measurements, and above 52 MeV the Semmering potential of Madland (Ma88) was used. For protons, the Beccetti-Greenlees potential (Be69) was utilized below 28 MeV, and the Madland potential (Ma88) was used at higher energies. The global spherical potential of Perey (Pe63) was utilized for deuterons, and the potential of Beccetti-Greenlees (Be) was adopted for tritons. Finally, the alpha potential of Lemos (Le72), as adapted by Arthur et al. (Ar80), was used for alpha particles.

Direct reaction cross sections to discrete states were calculated with the ECIS95 code [Re95] using deformation parameters compiled in Nuclear Data Sheets.

We used the same values for the total, elastic, and nonelastic cross sections (MF=3, MT=1,2,3) above 20 MeV as were used in the n + 56Fe evaluation.

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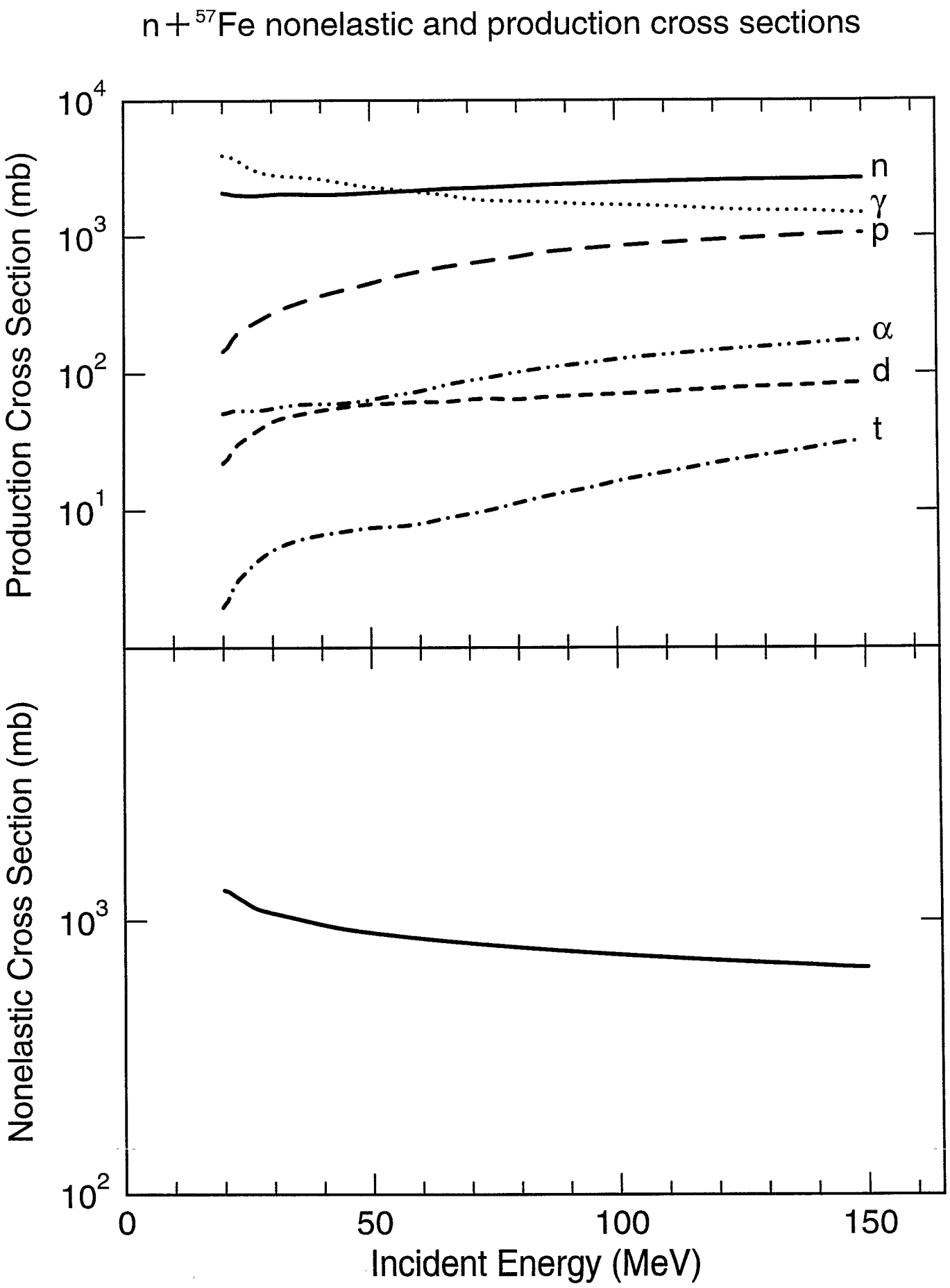
26057 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

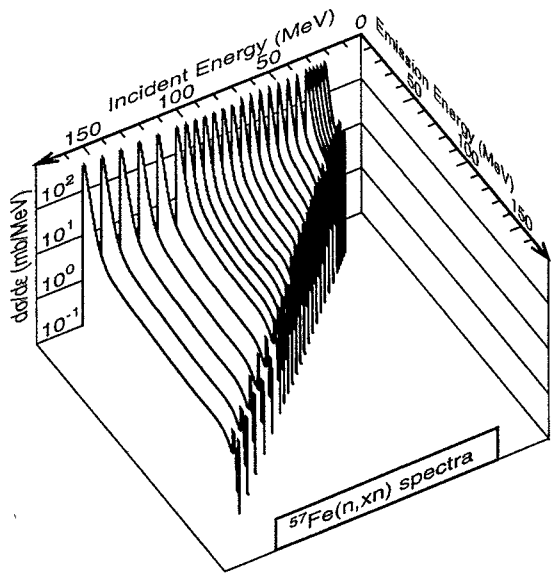
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	1.296E+00	9.424E-01	2.092E+00	1.449E-01	2.209E-02	1.973E-03	0.000E+00	5.093E-02	3.950E+00
2.200E+01	1.240E+00	9.979E-01	2.028E+00	1.786E-01	2.738E-02	2.681E-03	0.000E+00	5.325E-02	3.811E+00
2.400E+01	1.177E+00	1.053E+00	2.003E+00	2.082E-01	3.213E-02	3.359E-03	0.000E+00	5.341E-02	3.452E+00
2.600E+01	1.117E+00	1.135E+00	1.991E+00	2.290E-01	3.600E-02	3.974E-03	0.000E+00	5.330E-02	3.126E+00
2.800E+01	1.084E+00	1.206E+00	2.011E+00	2.513E-01	4.019E-02	4.573E-03	0.000E+00	5.389E-02	2.945E+00
3.000E+01	1.063E+00	1.267E+00	2.037E+00	2.743E-01	4.416E-02	5.099E-03	0.000E+00	5.533E-02	2.838E+00
3.500E+01	1.012E+00	1.422E+00	2.045E+00	3.237E-01	4.965E-02	6.026E-03	0.000E+00	5.893E-02	2.739E+00
4.000E+01	9.637E-01	1.536E+00	2.024E+00	3.692E-01	5.354E-02	6.609E-03	0.000E+00	5.962E-02	2.625E+00
4.500E+01	9.265E-01	1.593E+00	2.045E+00	4.100E-01	5.673E-02	7.043E-03	0.000E+00	6.053E-02	2.445E+00
5.000E+01	9.004E-01	1.600E+00	2.085E+00	4.535E-01	5.927E-02	7.440E-03	0.000E+00	6.391E-02	2.294E+00
5.500E+01	8.778E-01	1.587E+00	2.131E+00	5.067E-01	6.034E-02	7.609E-03	0.000E+00	6.922E-02	2.206E+00
6.000E+01	8.578E-01	1.547E+00	2.168E+00	5.532E-01	6.164E-02	7.967E-03	0.000E+00	7.381E-02	2.103E+00
6.500E+01	8.399E-01	1.488E+00	2.226E+00	5.950E-01	6.155E-02	8.698E-03	0.000E+00	8.139E-02	2.014E+00
7.000E+01	8.236E-01	1.428E+00	2.259E+00	6.308E-01	6.395E-02	9.395E-03	0.000E+00	8.786E-02	1.883E+00
7.500E+01	8.087E-01	1.352E+00	2.295E+00	6.685E-01	6.477E-02	1.018E-02	0.000E+00	9.399E-02	1.825E+00
8.000E+01	7.949E-01	1.279E+00	2.335E+00	7.074E-01	6.416E-02	1.131E-02	0.000E+00	1.015E-01	1.809E+00
8.500E+01	7.823E-01	1.218E+00	2.381E+00	7.571E-01	6.640E-02	1.245E-02	0.000E+00	1.082E-01	1.786E+00
9.000E+01	7.705E-01	1.159E+00	2.415E+00	7.896E-01	6.776E-02	1.354E-02	0.000E+00	1.137E-01	1.749E+00
9.500E+01	7.596E-01	1.090E+00	2.447E+00	8.171E-01	6.906E-02	1.470E-02	0.000E+00	1.191E-01	1.714E+00
1.000E+02	7.494E-01	1.037E+00	2.483E+00	8.449E-01	7.009E-02	1.619E-02	0.000E+00	1.255E-01	1.700E+00
1.100E+02	7.307E-01	9.113E-01	2.533E+00	8.920E-01	7.313E-02	1.882E-02	0.000E+00	1.355E-01	1.655E+00
1.200E+02	7.141E-01	8.009E-01	2.580E+00	9.380E-01	7.650E-02	2.194E-02	0.000E+00	1.460E-01	1.583E+00
1.300E+02	6.992E-01	7.028E-01	2.613E+00	9.769E-01	7.958E-02	2.496E-02	0.000E+00	1.550E-01	1.536E+00
1.400E+02	6.857E-01	6.243E-01	2.636E+00	1.019E+00	8.168E-02	2.839E-02	0.000E+00	1.644E-01	1.526E+00
1.500E+02	6.734E-01	5.896E-01	2.663E+00	1.051E+00	8.442E-02	3.162E-02	0.000E+00	1.719E-01	1.476E+00

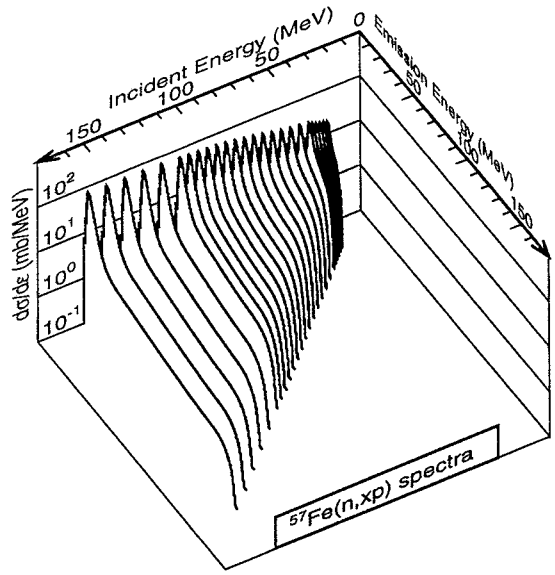
26057 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

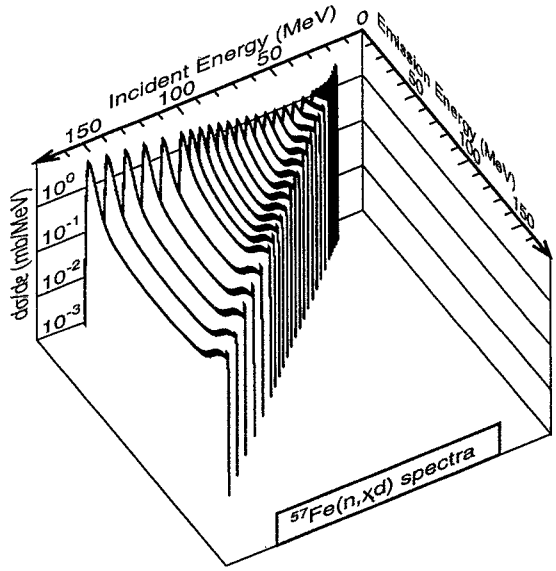
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	1.687E-01	3.101E-02	2.131E-03	0.000E+00	8.734E-02	9.486E-02	1.833E-02	4.024E-01
2.200E+01	2.127E-01	4.384E-02	3.295E-03	0.000E+00	9.351E-02	9.843E-02	2.902E-02	4.808E-01
2.400E+01	2.547E-01	5.780E-02	4.609E-03	0.000E+00	9.608E-02	1.002E-01	3.181E-02	5.451E-01
2.600E+01	2.942E-01	7.146E-02	5.986E-03	0.000E+00	9.746E-02	1.011E-01	3.493E-02	6.052E-01
2.800E+01	3.437E-01	8.726E-02	7.468E-03	0.000E+00	1.003E-01	1.037E-01	3.574E-02	6.782E-01
3.000E+01	3.989E-01	1.043E-01	8.953E-03	0.000E+00	1.042E-01	1.066E-01	3.532E-02	7.582E-01
3.500E+01	5.432E-01	1.395E-01	1.229E-02	0.000E+00	1.136E-01	1.132E-01	3.303E-02	9.549E-01
4.000E+01	6.934E-01	1.770E-01	1.531E-02	0.000E+00	1.183E-01	1.183E-01	3.031E-02	1.153E+00
4.500E+01	8.496E-01	2.163E-01	1.807E-02	0.000E+00	1.227E-01	1.231E-01	2.742E-02	1.357E+00
5.000E+01	1.013E+00	2.537E-01	2.066E-02	0.000E+00	1.309E-01	1.284E-01	2.460E-02	1.571E+00
5.500E+01	1.188E+00	2.838E-01	2.193E-02	0.000E+00	1.413E-01	1.340E-01	1.995E-02	1.789E+00
6.000E+01	1.359E+00	3.148E-01	2.388E-02	0.000E+00	1.514E-01	1.386E-01	1.825E-02	2.006E+00
6.500E+01	1.518E+00	3.312E-01	2.599E-02	0.000E+00	1.666E-01	1.434E-01	1.671E-02	2.202E+00
7.000E+01	1.677E+00	3.717E-01	2.797E-02	0.000E+00	1.798E-01	1.490E-01	1.544E-02	2.421E+00
7.500E+01	1.837E+00	3.971E-01	2.997E-02	0.000E+00	1.929E-01	1.527E-01	1.418E-02	2.624E+00
8.000E+01	1.993E+00	4.004E-01	3.228E-02	0.000E+00	2.087E-01	1.558E-01	1.310E-02	2.804E+00
8.500E+01	2.197E+00	4.329E-01	3.492E-02	0.000E+00	2.237E-01	1.601E-01	1.225E-02	3.061E+00
9.000E+01	2.365E+00	4.591E-01	3.714E-02	0.000E+00	2.365E-01	1.628E-01	1.149E-02	3.272E+00
9.500E+01	2.528E+00	4.845E-01	3.933E-02	0.000E+00	2.489E-01	1.655E-01	1.069E-02	3.477E+00
1.000E+02	2.687E+00	4.987E-01	4.186E-02	0.000E+00	2.633E-01	1.683E-01	1.007E-02	3.669E+00
1.100E+02	3.011E+00	5.518E-01	4.638E-02	0.000E+00	2.870E-01	1.722E-01	8.745E-03	4.077E+00
1.200E+02	3.327E+00	6.020E-01	5.149E-02	0.000E+00	3.118E-01	1.763E-01	7.627E-03	4.476E+00
1.300E+02	3.643E+00	6.515E-01	5.639E-02	0.000E+00	3.335E-01	1.847E-01	6.660E-03	4.876E+00
1.400E+02	3.959E+00	6.702E-01	6.188E-02	0.000E+00	3.564E-01	1.940E-01	5.895E-03	5.247E+00
1.500E+02	4.271E+00	7.078E-01	6.705E-02	0.000E+00	3.754E-01	2.028E-01	5.548E-03	5.629E+00

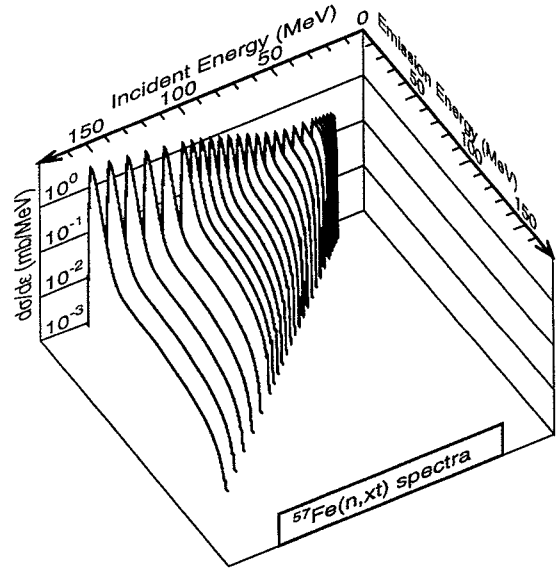

n + 57Fe nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
n
γ
p
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
0
50
100
150
Incident Energy (MeV)

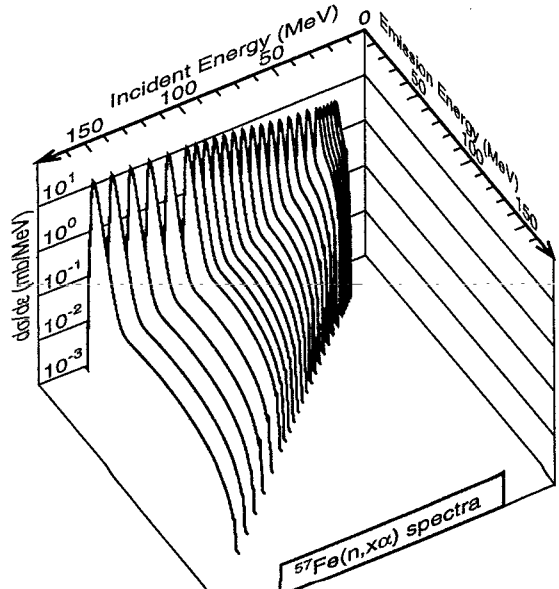
n + ^{57}Fe angle-integrated emission spectra

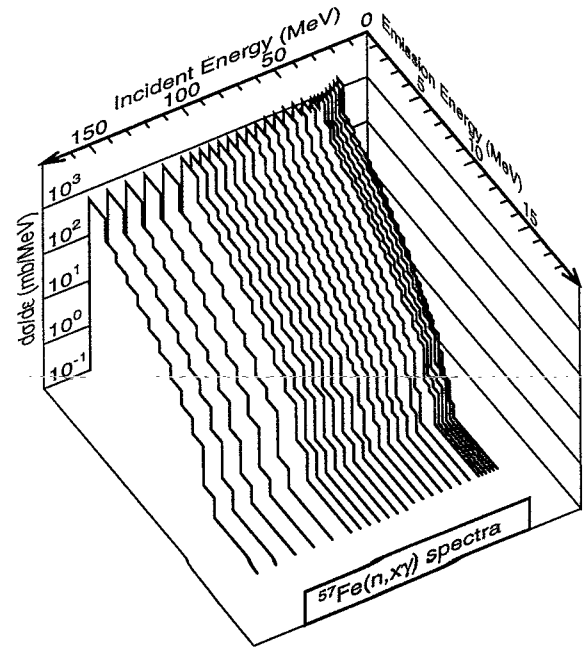




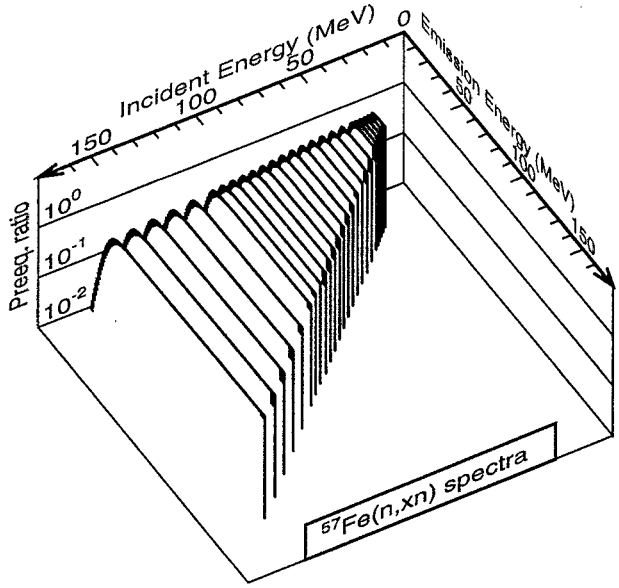


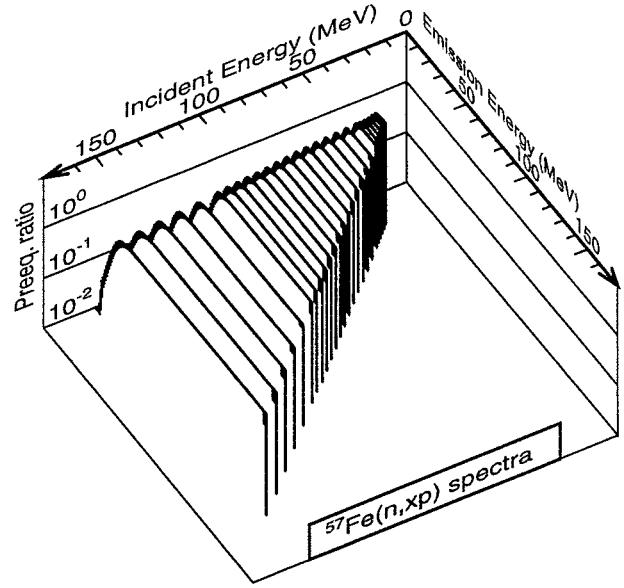


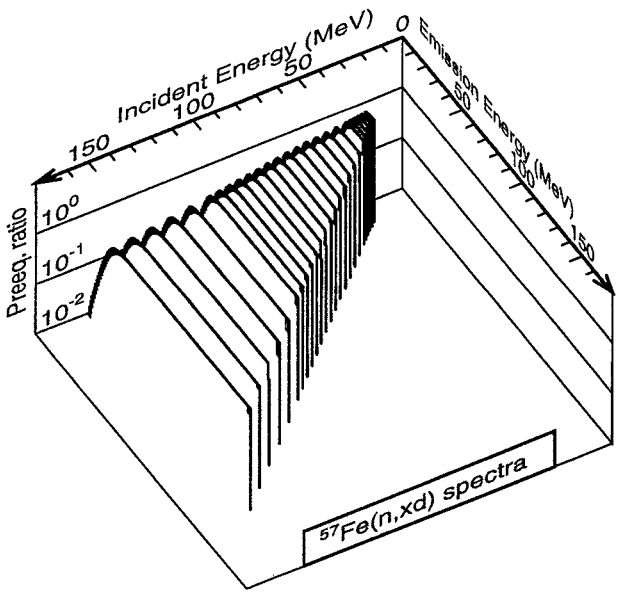


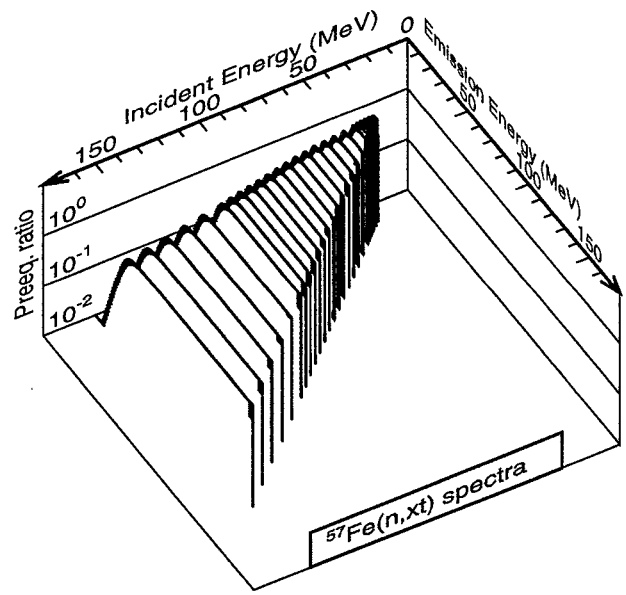


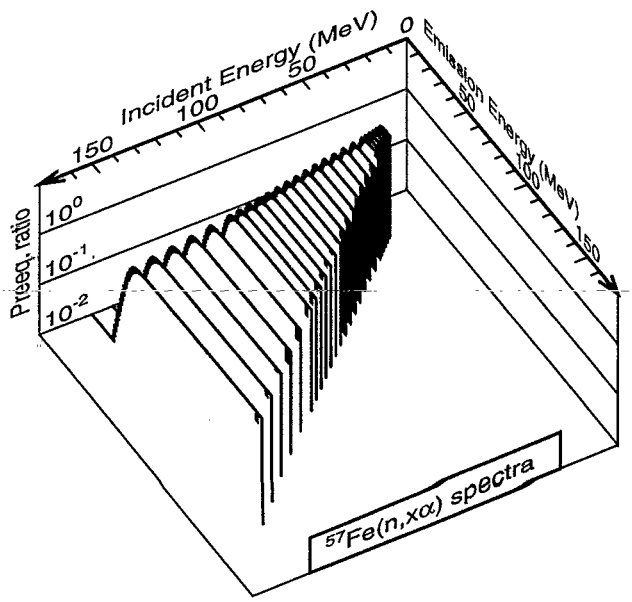
n + ^{57}Fe Kalbach preequilibrium ratios

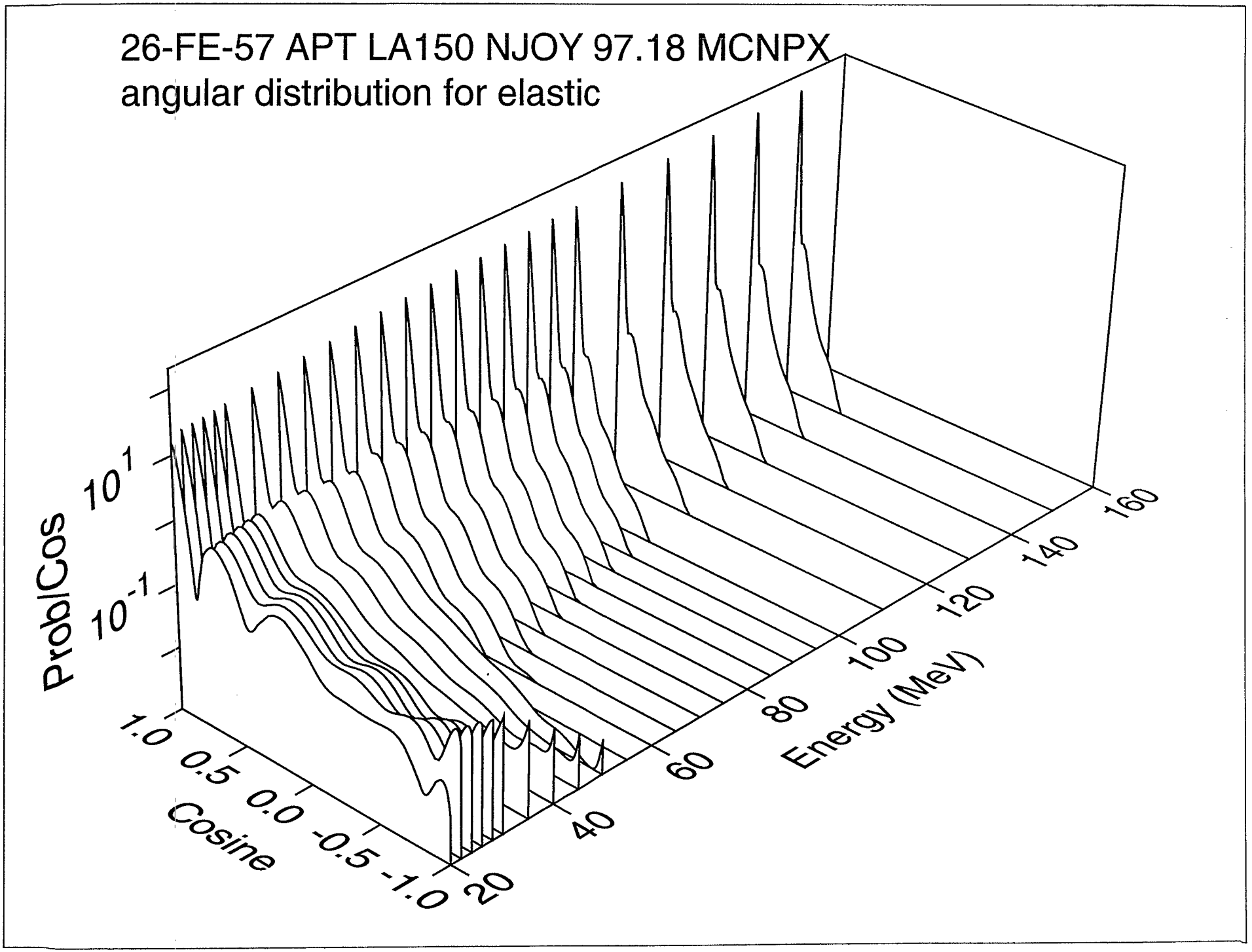


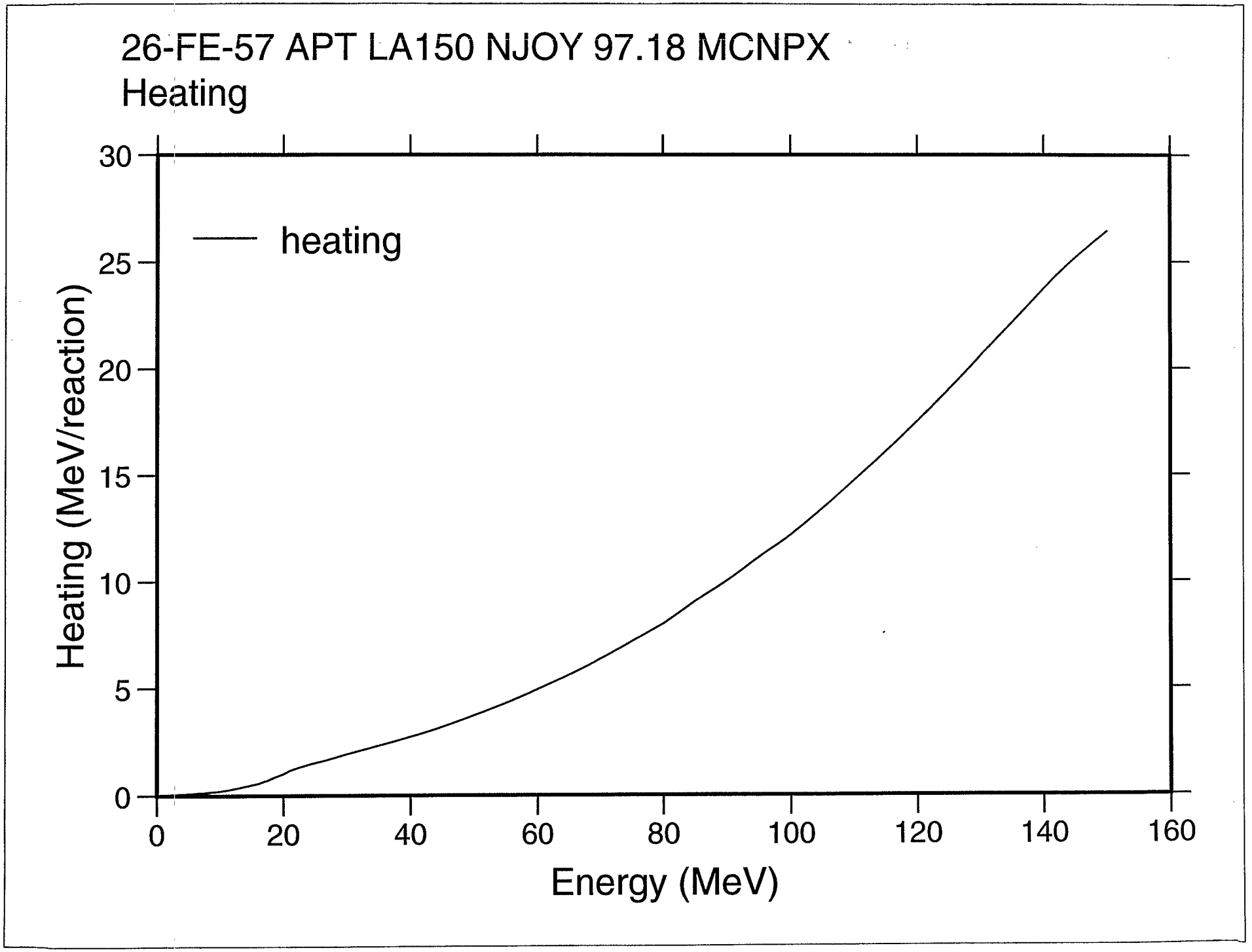


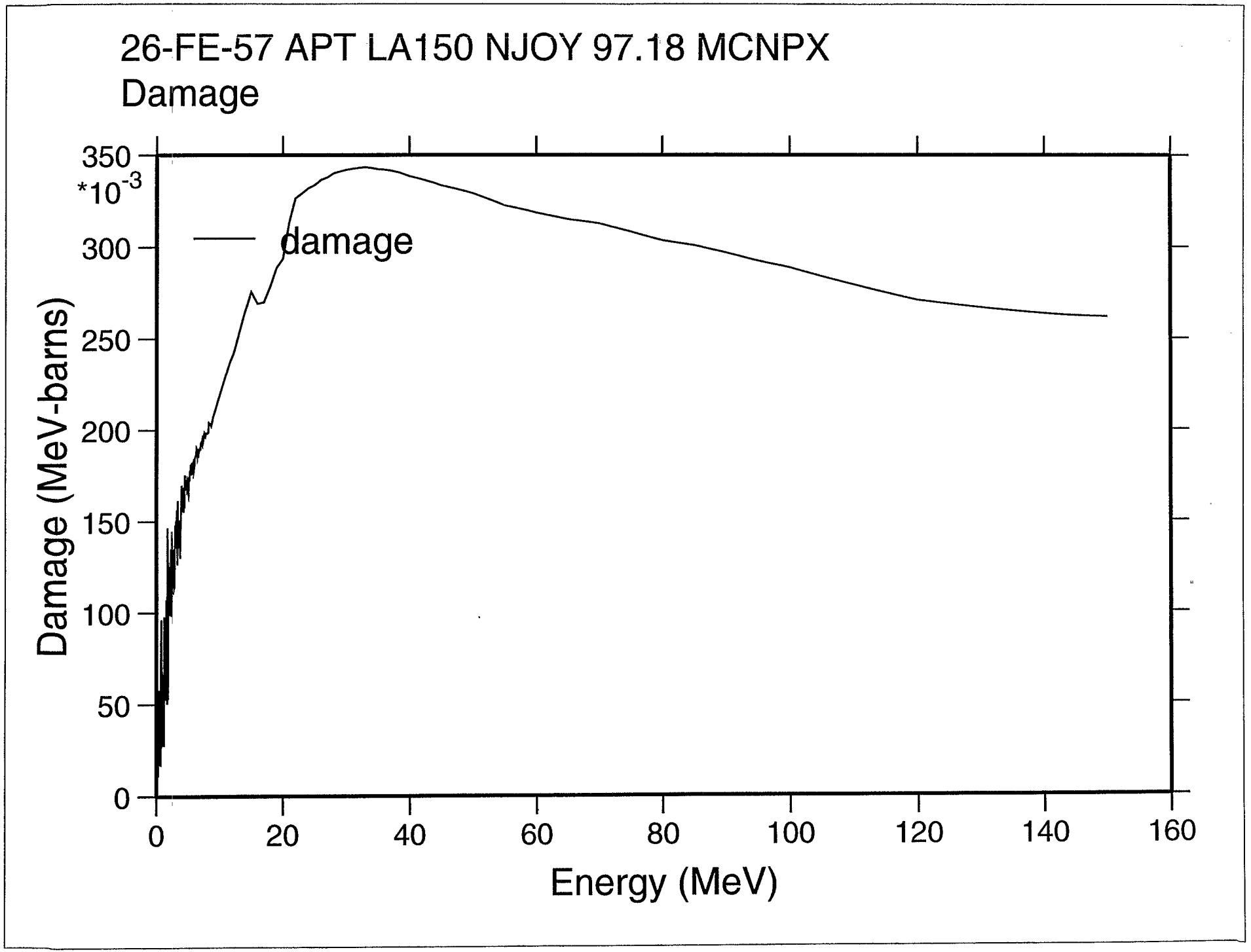







26-FE-57 APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic
Prob/Cos
10^1
10^{-1}
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


26-FE-57 APT LA150 NJOY 97.18 MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
5
10
15
20
25
30
0
20
40
60
80
100
120
140
160


26-FE-57 APT LA150 NJOY 97.18 MCNPX
Damage
damage
Damage (MeV-barns)
*10^-3
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF n + 58Ni CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

S. Chiba, M. B. Chadwick, P. G. Young, and A. J. Koning
22 Sept. 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI.5 (Release 2) evaluation by Larson, C. Perey, Hetrich, and Fu.

INCIDENT NEUTRON ENERGIES > 20 MeV

The ENDF/B-VI Release 2 evaluation extends to 20 MeV and includes cross sections and energy-angle data for all significant reactions. The present evauation utilizes a more compact composite reaction spectrum representation above 20 MeV in order to reduce the length of the file. No essential data for applications is lost with this representation.

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT= 1	Total Cross Section
	MT= 2	Elastic Scattering Cross Section
	MT= 3	Nonelastic Cross Section
	MT= 5	Sum of Binary (n,n') and (n,x) Reactions
MF=4	MT= 2	Elastic Angular Distributions
MF=6	MT= 5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, Tritons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Ni58 and p + Ni58 reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of

all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Gilbert and Cameron (Gi65) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged- particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

SOME Ni-SPECIFIC INFORMATION CONCERNING THE EVAL.

The neutron total cross section was evaluated based on the least-squares method with GMA code system (Po81) taking account of the experimental data(Ci68, Pe73, Sc73, La83, Sm92, Di97). The data for natural Ni was used above 20 MeV because there was no data for Ni-58 at this energy region. The data for natural Ni were transformed to the Ni-58 cross section according to A*(2/3) law. In the GMA analysis, the systematic error was assumed to be 1 % for all the data set. Result of the GMA evaluation was used as the evaluated total cross section data above 20 MeV.

The evaluated total cross section data (1 to 250 MeV), s-wave strength function(Mu81), and elastic scattering angular distribution data (Sm92, Gu85, Tu73, Pe88, Ya79) were used to obtain the neutron optical potential parameters. The parameter estimation was carried out based on Marquart-Bayesian approach (Sm91), where ECIS95 code (Ra96) was used for the optical model calculation. We have employed the energy dependence of the optical potential similar to Delaroche's work(De89). The initial potential parameters were adopted from Koning and Delaroche (Ko97). Total of 17 parameters concerning the central potential were estimated with associated covariance matrix. Presently obtained potential was used for the calculation of neutron transmission coefficients and DWBA cross sections in the entire energy region above 20 MeV. Below 20 MeV, the Harper neutron potential (Ha82) was used.

The proton optical potential was also searched for to obtain a good description of proton-total reaction cross section as predicted by Wellisch-Axen systematic (We96) above 50 MeV. The parameter estimation was carried out by the Marquart-Bayesian approach similar to the neutron OMP, but trying to seek the best parameter to reproduce the reaction cross sections compiled by Carlson (Ca96) and Wellisch values. In this search, the geometrical parameters were fixed to be same as the neutron potential. The present potential gives a good description of the proton total reaction cross section above 10 MeV to 250 MeV. However, after some trial and error to reproduce both the elastic scattering and reaction cross section data, we have employed the following combination of proton potentials:

0 to 5 MeV : Harper potential (Ha82)
5 to 50 MeV : Koning and Delaroche (Ko97)
50 to 260 MeV : Present OMP

For deuterons, the Lohr-Haeberli (Lo74) global potential was used; for alpha particles the McFadden-Satchler potential (Mc66) was used; and for tritons the Beccheti-Greenlees (Be71) potential was used. The He-3 channel was ignored.

The direct collective inelastic scattering to the following levels in Ni-58 was considered by the DWBA-mode calculation of ECIS95 (Ra96):

Jpi	Ex(MeV)	Deformation length
2+	1.454	0.900
4+	2.459	0.350
2+	3.038	0.242
2+	3.263	0.306
4+	3.620	0.246
2+	3.898	0.111
2+	4.108	0.063
4+	4.299	0.127
4+	4.405	0.329
3-	4.475	0.708
4+	4.757	0.403
4+	5.438	0.151
4+	5.472	0.080
2+	5.749	0.048
4+	5.766	0.086
2+	5.906	0.115
3-	6.312	0.128
2+	6.417	0.068
4+	6.460	0.098
2+	6.475	0.065
2+	6.569	0.056
2+	6.752	0.141
3-	6.854	0.296
2+	6.983	0.116
4+	7.051	0.090
4+	7.068	0.086
3-	7.111	0.079
4+	7.141	0.112
3-	7.210	0.323
2+	7.272	0.088
3-	7.300	0.063
3-	7.420	0.048
3-	7.514	0.171
2+	7.580	0.051
4+	7.618	0.083
3-	7.858	0.106
4+	7.860	0.097
3-	8.134	0.142
3-	8.797	0.097
3-	8.841	0.112
4+	8.902	0.072
3-	9.012	0.056
3-	9.304	0.065
3-	9.379	0.106
4+	9.436	0.071

3-	9.458	0.082
4+	9.588	0.052
4+	9.632	0.080
3-	9.672	0.121
3-	9.835	0.083
3-	9.870	0.076
3-	9.929	0.061
3-	9.956	0.071

These data were retrieved from the literature (Nuclear Data Sheets), or were evaluated by Koning [Ko97].

Only 2 measurements exist for neutron-induced emission spectra above 20 MeV for 58Ni: the (n,x alpha) data by Haight et al (Ha97), and (n,xp) data by Ullman et al (Ul83). Some of the level density parameters were adjusted to give a good description of these data. Our starting point was the Gilbert-Cameron analysis of Fu [Fu96], who studied the extreme sensitivity of calculated cross sections on level densities for an IAEA CRP. Fu matched the experimental D-0 value (14.4 keV) in 55Fe, and experimental neutron, alpha, and proton emission data, by modifying the level density a parameters. We modified Fu's 58Ni level density by 5% to a=6.5 to better describe Haight's data at 14 MeV. Above 14 MeV, where (n,na) and (n,pa) become important, we increased the default level density a parameters in 54Fe and 54Mn by 7.5% to obtain an improved agreement of the Haight data in the 40-50 MeV range (no direct experimental information constrains these level densities). See Ref. [Ch97] for benchmark comparisons of the evaluation with measured data.

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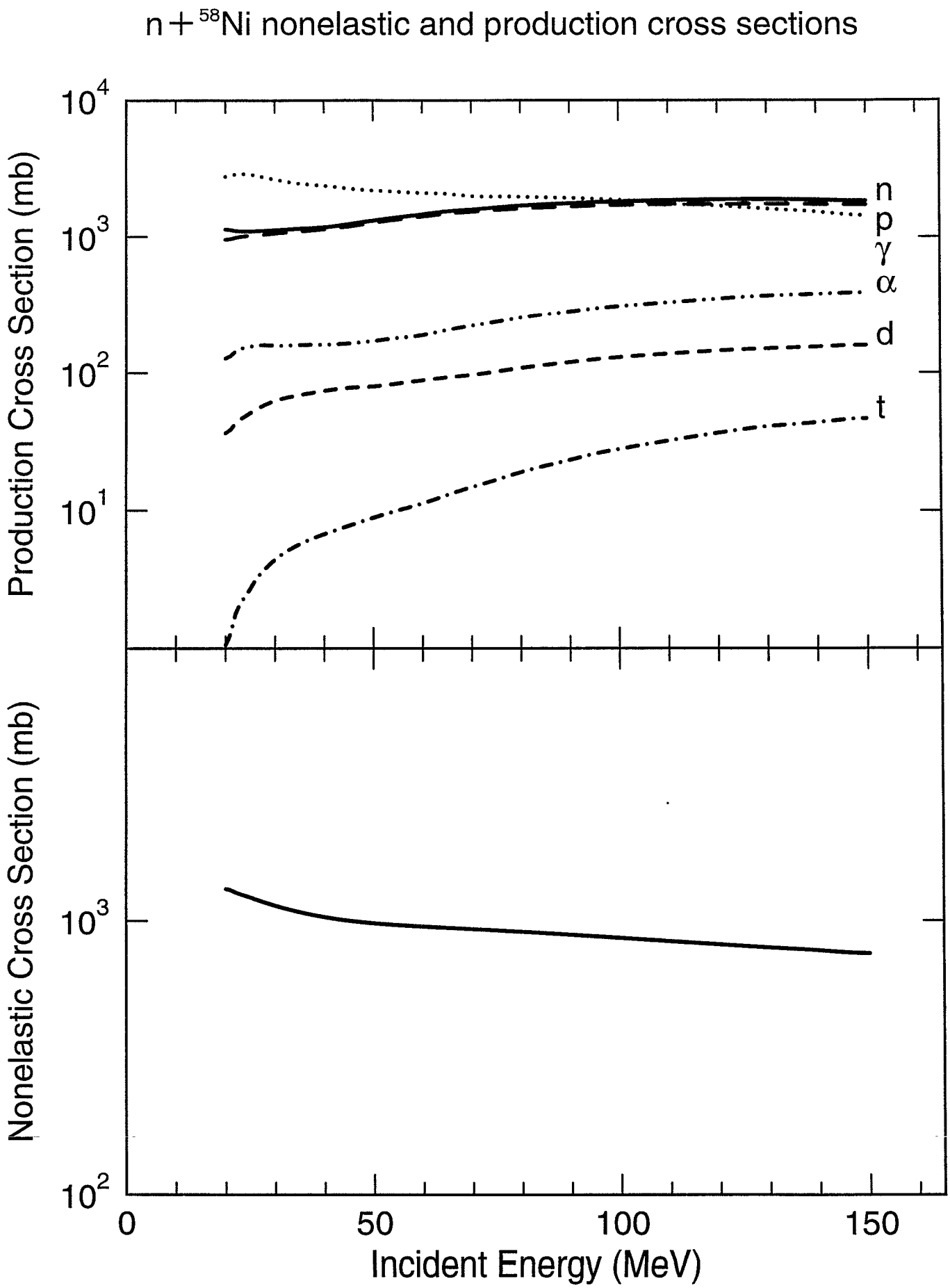
28058 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

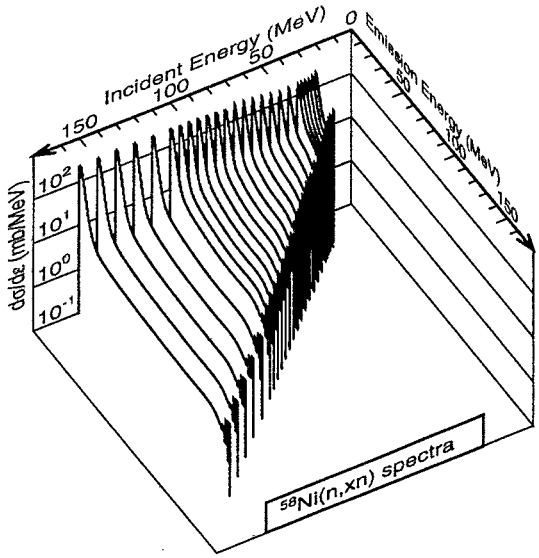
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	1.308E+00	1.020E+00	1.136E+00	9.530E-01	3.667E-02	1.054E-03	0.000E+00	1.275E-01	2.766E+00
2.200E+01	1.270E+00	1.026E+00	1.108E+00	9.844E-01	4.302E-02	1.758E-03	0.000E+00	1.431E-01	2.868E+00
2.400E+01	1.234E+00	1.055E+00	1.096E+00	1.013E+00	4.869E-02	2.370E-03	0.000E+00	1.534E-01	2.882E+00
2.600E+01	1.198E+00	1.088E+00	1.102E+00	1.029E+00	5.386E-02	3.080E-03	0.000E+00	1.584E-01	2.828E+00
2.800E+01	1.165E+00	1.154E+00	1.113E+00	1.042E+00	5.873E-02	3.776E-03	0.000E+00	1.600E-01	2.725E+00
3.000E+01	1.136E+00	1.218E+00	1.121E+00	1.060E+00	6.289E-02	4.409E-03	0.000E+00	1.585E-01	2.633E+00
3.500E+01	1.076E+00	1.369E+00	1.152E+00	1.098E+00	6.926E-02	5.724E-03	0.000E+00	1.602E-01	2.456E+00
4.000E+01	1.032E+00	1.482E+00	1.179E+00	1.141E+00	7.430E-02	6.788E-03	0.000E+00	1.612E-01	2.364E+00
4.500E+01	1.001E+00	1.566E+00	1.243E+00	1.198E+00	7.802E-02	7.802E-03	0.000E+00	1.647E-01	2.257E+00
5.000E+01	9.797E-01	1.600E+00	1.319E+00	1.274E+00	7.981E-02	8.922E-03	0.000E+00	1.715E-01	2.182E+00
5.500E+01	9.647E-01	1.602E+00	1.391E+00	1.346E+00	8.373E-02	1.004E-02	0.000E+00	1.802E-01	2.137E+00
6.000E+01	9.529E-01	1.580E+00	1.462E+00	1.412E+00	8.821E-02	1.128E-02	0.000E+00	1.890E-01	2.091E+00
6.500E+01	9.425E-01	1.517E+00	1.539E+00	1.479E+00	9.273E-02	1.301E-02	0.000E+00	2.060E-01	2.063E+00
7.000E+01	9.322E-01	1.454E+00	1.588E+00	1.528E+00	9.664E-02	1.483E-02	0.000E+00	2.219E-01	1.984E+00
7.500E+01	9.218E-01	1.393E+00	1.644E+00	1.575E+00	1.021E-01	1.676E-02	0.000E+00	2.371E-01	1.972E+00
8.000E+01	9.109E-01	1.325E+00	1.695E+00	1.615E+00	1.082E-01	1.910E-02	0.000E+00	2.540E-01	1.965E+00
8.500E+01	8.996E-01	1.239E+00	1.733E+00	1.646E+00	1.137E-01	2.123E-02	0.000E+00	2.681E-01	1.943E+00
9.000E+01	8.879E-01	1.166E+00	1.763E+00	1.670E+00	1.191E-01	2.340E-02	0.000E+00	2.812E-01	1.925E+00
9.500E+01	8.761E-01	1.094E+00	1.794E+00	1.695E+00	1.248E-01	2.592E-02	0.000E+00	2.960E-01	1.894E+00
1.000E+02	8.643E-01	1.044E+00	1.815E+00	1.711E+00	1.295E-01	2.808E-02	0.000E+00	3.077E-01	1.862E+00
1.100E+02	8.409E-01	8.908E-01	1.851E+00	1.731E+00	1.375E-01	3.231E-02	0.000E+00	3.281E-01	1.751E+00
1.200E+02	8.184E-01	7.884E-01	1.874E+00	1.738E+00	1.449E-01	3.671E-02	0.000E+00	3.494E-01	1.692E+00
1.300E+02	7.972E-01	7.005E-01	1.883E+00	1.743E+00	1.505E-01	4.090E-02	0.000E+00	3.677E-01	1.604E+00
1.400E+02	7.774E-01	6.232E-01	1.864E+00	1.735E+00	1.549E-01	4.379E-02	0.000E+00	3.785E-01	1.526E+00
1.500E+02	7.591E-01	5.672E-01	1.833E+00	1.723E+00	1.588E-01	4.666E-02	0.000E+00	3.879E-01	1.434E+00

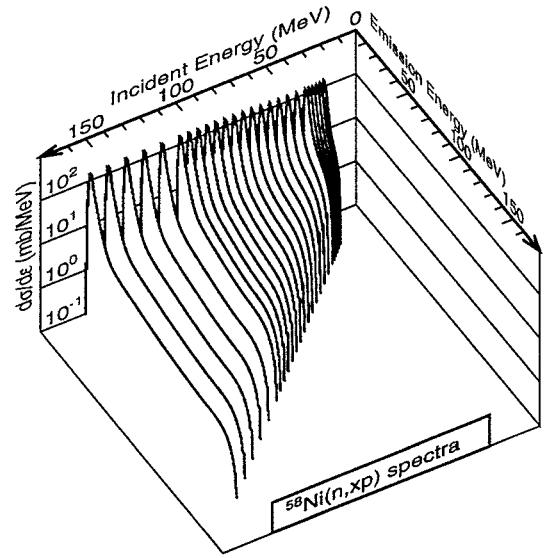
28058 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

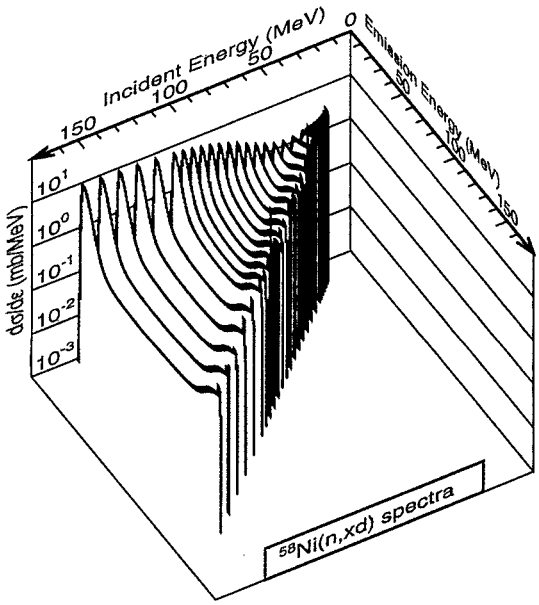
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	9.475E-01	5.870E-02	1.042E-03	0.000E+00	2.076E-01	1.053E-01	2.550E-02	1.346E+00
2.200E+01	1.014E+00	7.719E-02	2.032E-03	0.000E+00	2.363E-01	1.116E-01	2.634E-02	1.468E+00
2.400E+01	1.076E+00	9.632E-02	3.077E-03	0.000E+00	2.578E-01	1.165E-01	2.809E-02	1.577E+00
2.600E+01	1.128E+00	1.163E-01	4.457E-03	0.000E+00	2.714E-01	1.200E-01	2.899E-02	1.669E+00
2.800E+01	1.189E+00	1.377E-01	6.023E-03	0.000E+00	2.790E-01	1.227E-01	3.002E-02	1.765E+00
3.000E+01	1.258E+00	1.592E-01	7.668E-03	0.000E+00	2.810E-01	1.246E-01	3.042E-02	1.861E+00
3.500E+01	1.435E+00	2.077E-01	1.182E-02	0.000E+00	2.930E-01	1.318E-01	2.991E-02	2.109E+00
4.000E+01	1.639E+00	2.606E-01	1.587E-02	0.000E+00	3.040E-01	1.386E-01	2.813E-02	2.386E+00
4.500E+01	1.857E+00	3.106E-01	1.982E-02	0.000E+00	3.185E-01	1.457E-01	2.620E-02	2.678E+00
5.000E+01	2.094E+00	3.440E-01	2.380E-02	0.000E+00	3.383E-01	1.530E-01	2.399E-02	2.977E+00
5.500E+01	2.332E+00	3.882E-01	2.747E-02	0.000E+00	3.617E-01	1.608E-01	2.193E-02	3.292E+00
6.000E+01	2.573E+00	4.319E-01	3.124E-02	0.000E+00	3.852E-01	1.680E-01	2.006E-02	3.610E+00
6.500E+01	2.804E+00	4.664E-01	3.517E-02	0.000E+00	4.235E-01	1.766E-01	1.811E-02	3.924E+00
7.000E+01	3.026E+00	4.929E-01	3.909E-02	0.000E+00	4.602E-01	1.842E-01	1.651E-02	4.219E+00
7.500E+01	3.239E+00	5.310E-01	4.305E-02	0.000E+00	4.960E-01	1.910E-01	1.520E-02	4.515E+00
8.000E+01	3.437E+00	5.669E-01	4.740E-02	0.000E+00	5.355E-01	1.973E-01	1.400E-02	4.798E+00
8.500E+01	3.629E+00	6.027E-01	5.150E-02	0.000E+00	5.695E-01	2.020E-01	1.275E-02	5.067E+00
9.000E+01	3.813E+00	6.372E-01	5.556E-02	0.000E+00	6.020E-01	2.059E-01	1.174E-02	5.325E+00
9.500E+01	3.986E+00	6.707E-01	6.003E-02	0.000E+00	6.382E-01	2.094E-01	1.082E-02	5.575E+00
1.000E+02	4.156E+00	7.022E-01	6.401E-02	0.000E+00	6.683E-01	2.112E-01	1.017E-02	5.812E+00
1.100E+02	4.490E+00	7.532E-01	7.169E-02	0.000E+00	7.234E-01	2.120E-01	8.484E-03	6.259E+00
1.200E+02	4.808E+00	7.996E-01	7.937E-02	0.000E+00	7.806E-01	2.092E-01	7.389E-03	6.684E+00
1.300E+02	5.117E+00	8.295E-01	8.631E-02	0.000E+00	8.326E-01	2.095E-01	6.491E-03	7.081E+00
1.400E+02	5.416E+00	8.798E-01	9.048E-02	0.000E+00	8.687E-01	2.081E-01	5.728E-03	7.469E+00
1.500E+02	5.699E+00	9.286E-01	9.409E-02	0.000E+00	9.026E-01	2.062E-01	5.187E-03	7.836E+00

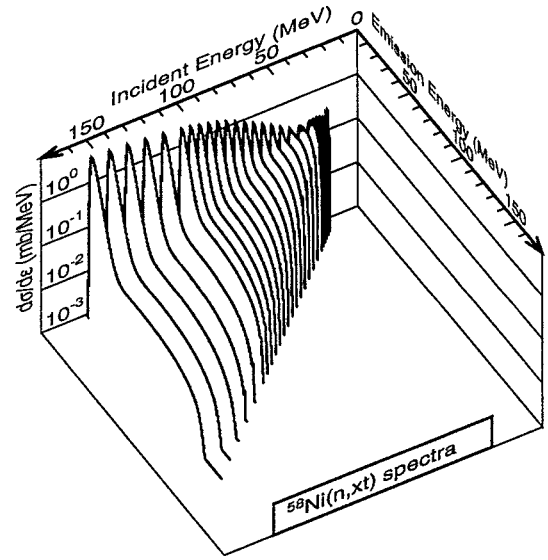

n + 58Ni nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
n
p
γ
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
0
50
100
150
Incident Energy (MeV)

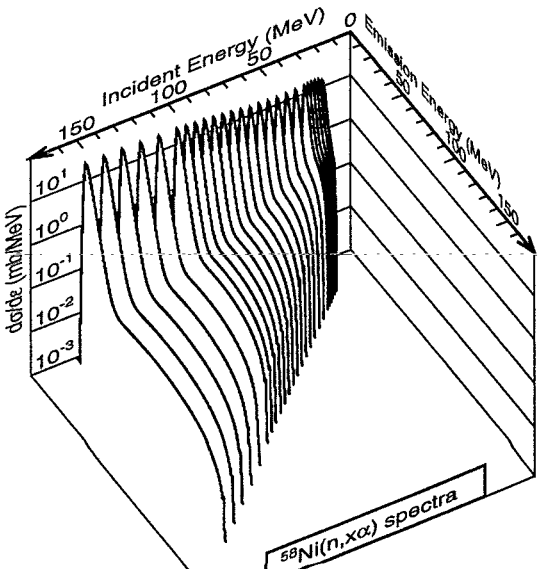
n + ^{58}Ni angle-integrated emission spectra

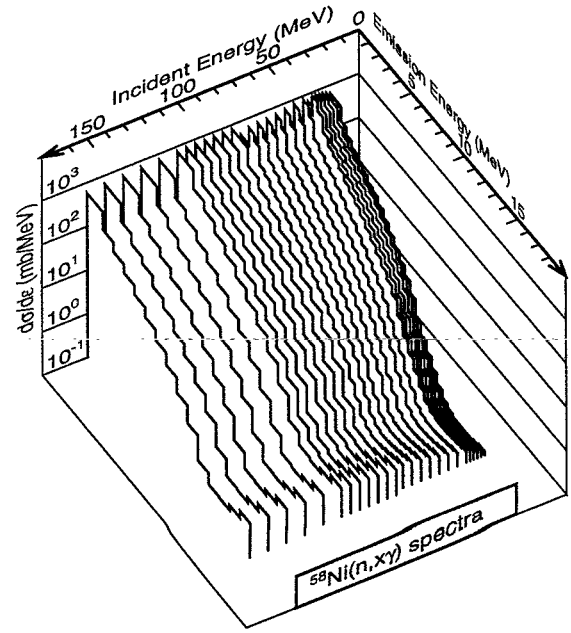




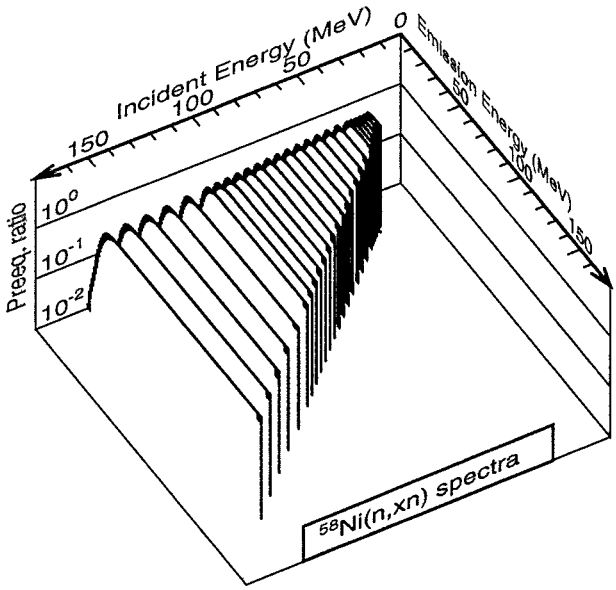


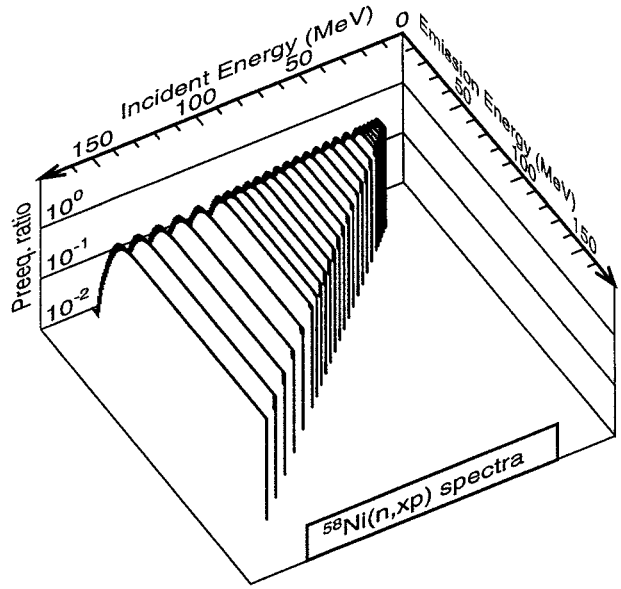


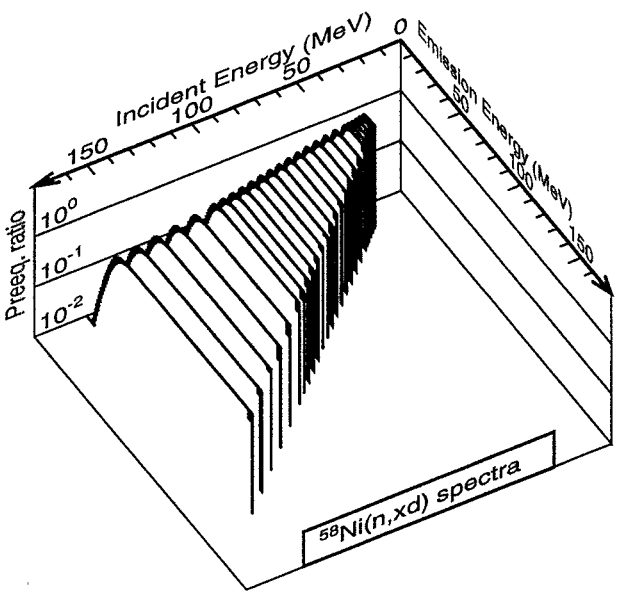


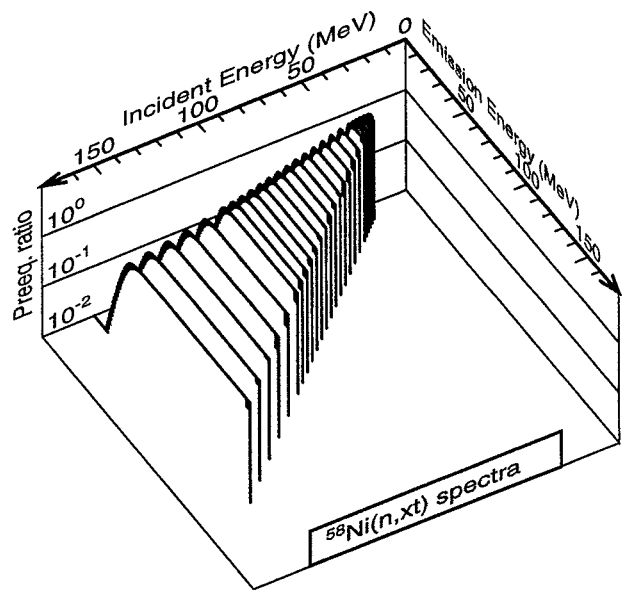


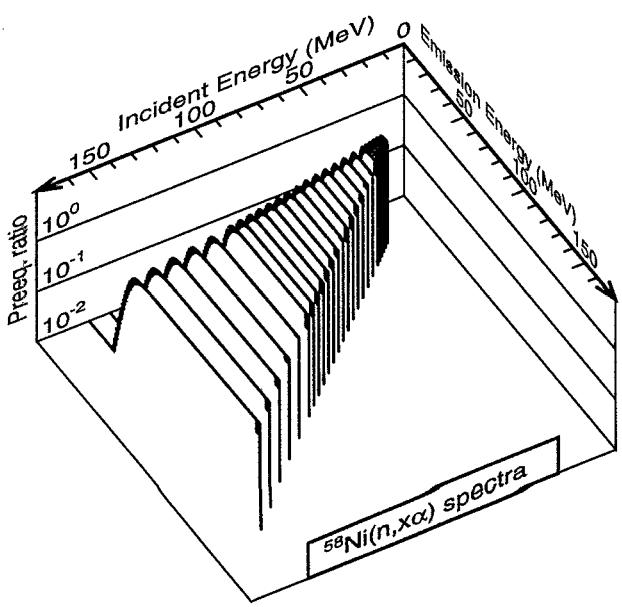
n + ^{58}Ni Kalbach preequilibrium ratios

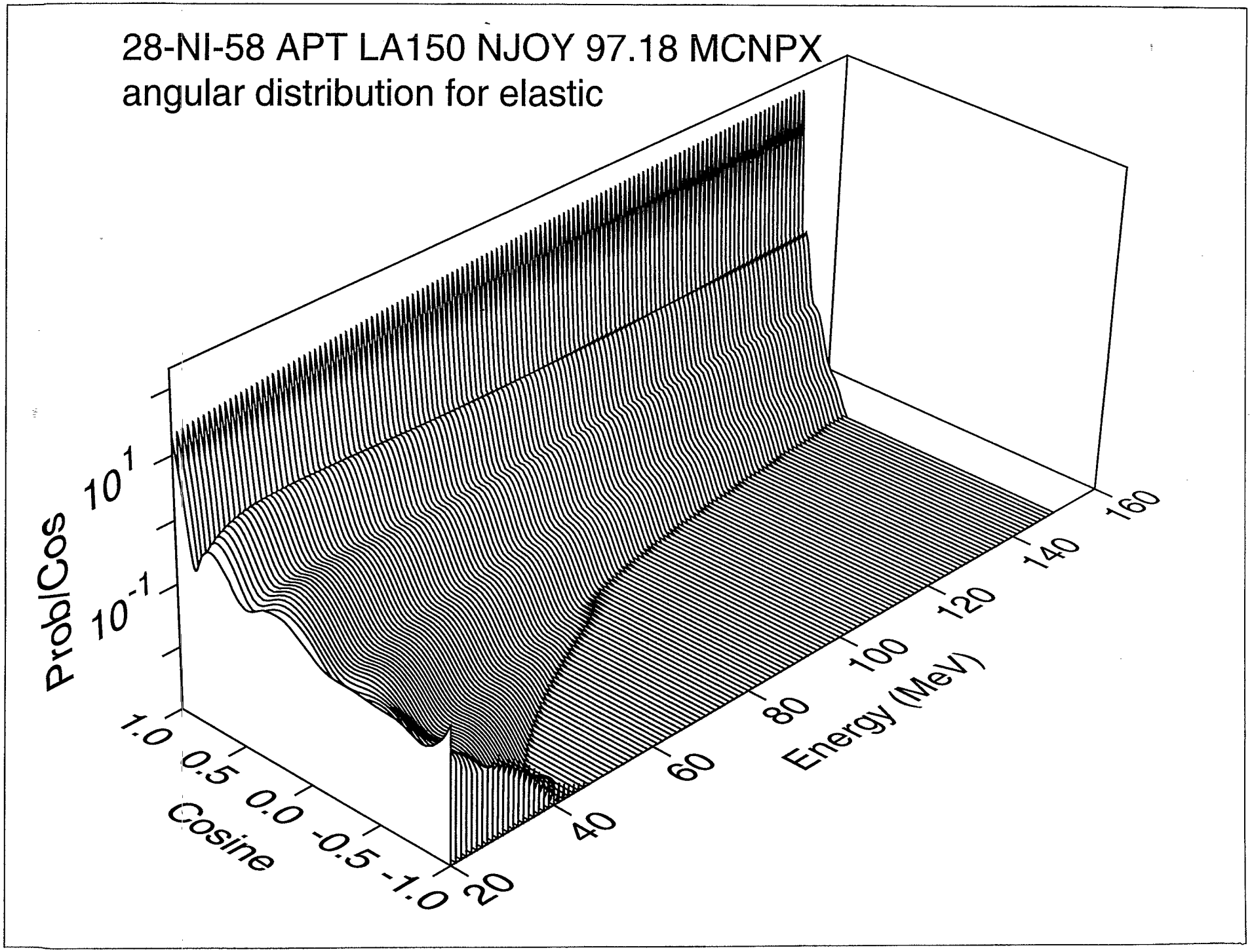


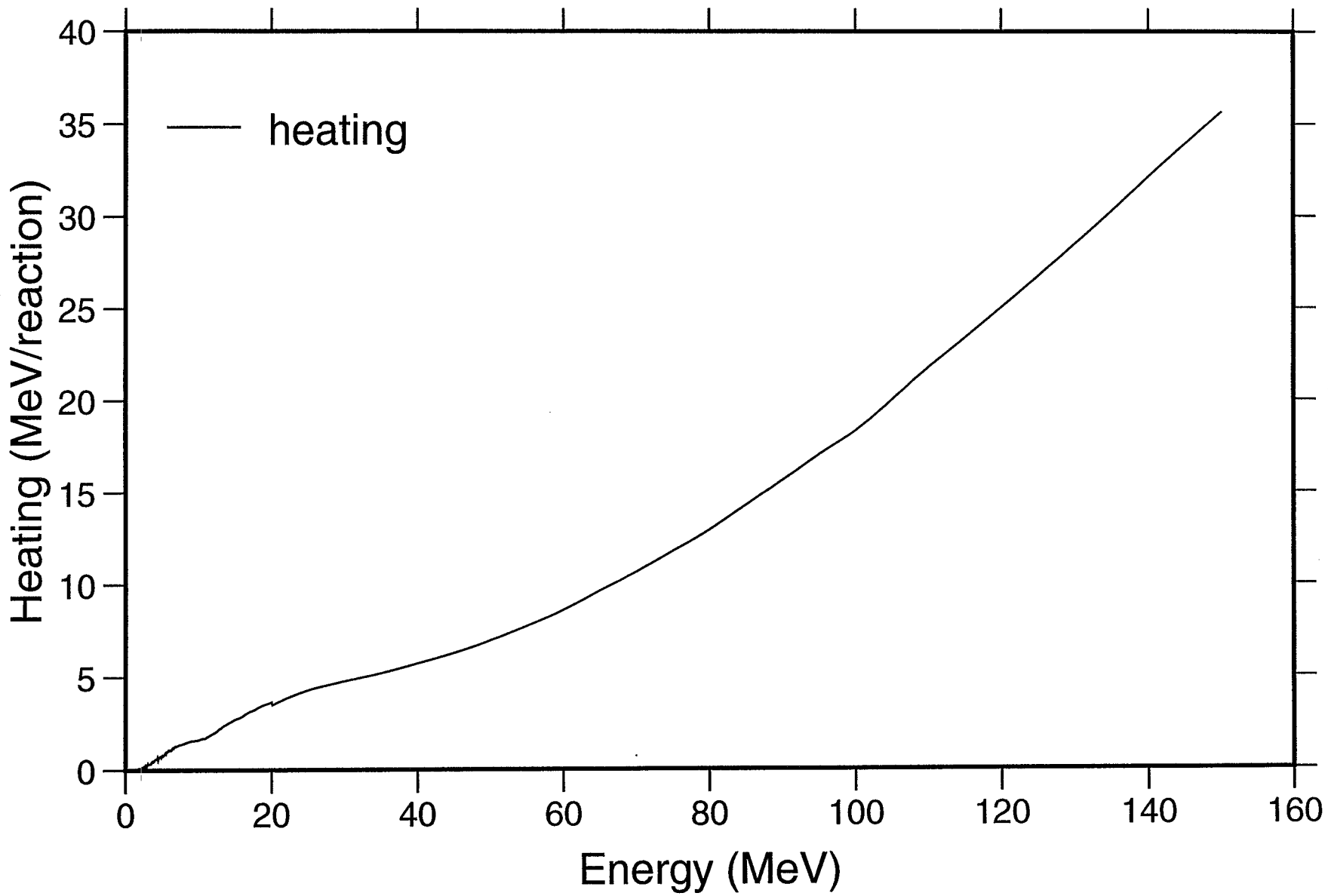


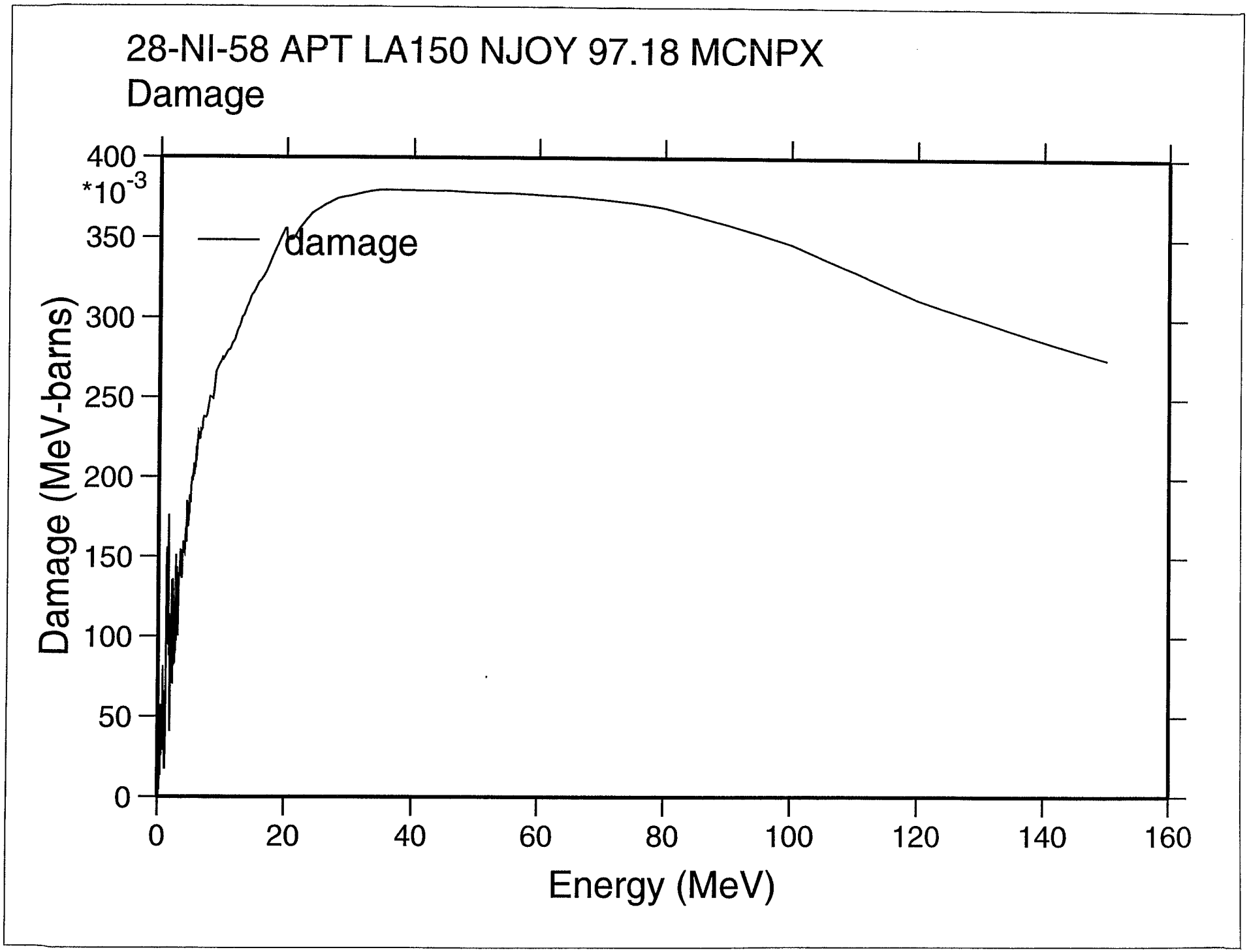







28-NI-58 APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic
Prob/Cos
10^1
10^{-1}
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


28-NI-58 APT LA150 NJOY 97.18 MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
5
10
15
20
25
30
35
40
0
20
40
60
80
100
120
140
160


28-NI-58 APT LA150 NJOY 97.18 MCNPX
Damage
damage
Damage (MeV-barns)
*10^-3
400
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF n + 60Ni CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

S. Chiba, M. B. Chadwick, P. G. Young, and A. J. Koning
22 Sept. 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI.5 (Release 2) evaluation by Larson, C. Perey, Hetrich, and Fu.

INCIDENT NEUTRON ENERGIES > 20 MeV

The ENDF/B-VI Release 2 evaluation extends to 20 MeV and includes cross sections and energy-angle data for all significant reactions. The present evaluation utilizes a more compact composite reaction spectrum representation above 20 MeV in order to reduce the length of the file. No essential data for applications is lost with this representation.

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT= 1	Total Cross Section
	MT= 2	Elastic Scattering Cross Section
	MT= 3	Nonelastic Cross Section
	MT= 5	Sum of Binary (n,n') and (n,x) Reactions
MF=4	MT= 2	Elastic Angular Distributions
MF=6	MT= 5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, Tritons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Ni58 and p + Ni58 reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of

all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Gilbert and Cameron (Gi65) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged- particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

SOME Ni-SPECIFIC INFORMATION CONCERNING THE EVAL.

The neutron total cross section was evaluated based on the least-squares method taking account of the experimental data((Du67, Bo71, St71, Sm79, Fe80, Pe82, Ha82a, Di97). The data for natural Ni (Di97) was also used because there was not enough data for Ni-60 above 20 MeV. The data for natural Ni were transformed to the Ni-60 cross section according to A*(2/3) law. Result of this estimation was used as the evaluated total cross section data above 20 MeV.

The evaluated total cross section data (1 to 250 MeV), s-wave strength function (Mu81) and elastic scattering angular distribution data (Bo71, Gu85, Tu73, Ya79) were used to obtain the neutron optical potential parameters. The parameter estimation was carried out based on Marquart-Bayesian approach (Sm91), where ECIS95 code (Ra96) was used for the optical model calculation. We have employed the energy dependence of the optical potential similar to Delaroche's work (De89). The initial potential parameters were adopted from Koning and Delaroche (Ko97). A total of 7 parameters concerning the central potential depth were estimated with associated covariance matrix, while the geometrical parameters were fixed to the result of a similar search for n + Ni-58. Presently obtained potential was used for the calculation of neutron transmission coefficients and DWBA cross sections in the energy region above 20 MeV. Below 20 MeV, the Harper neutron potential (Ha82b) was used for the calculation of transmission coefficients.

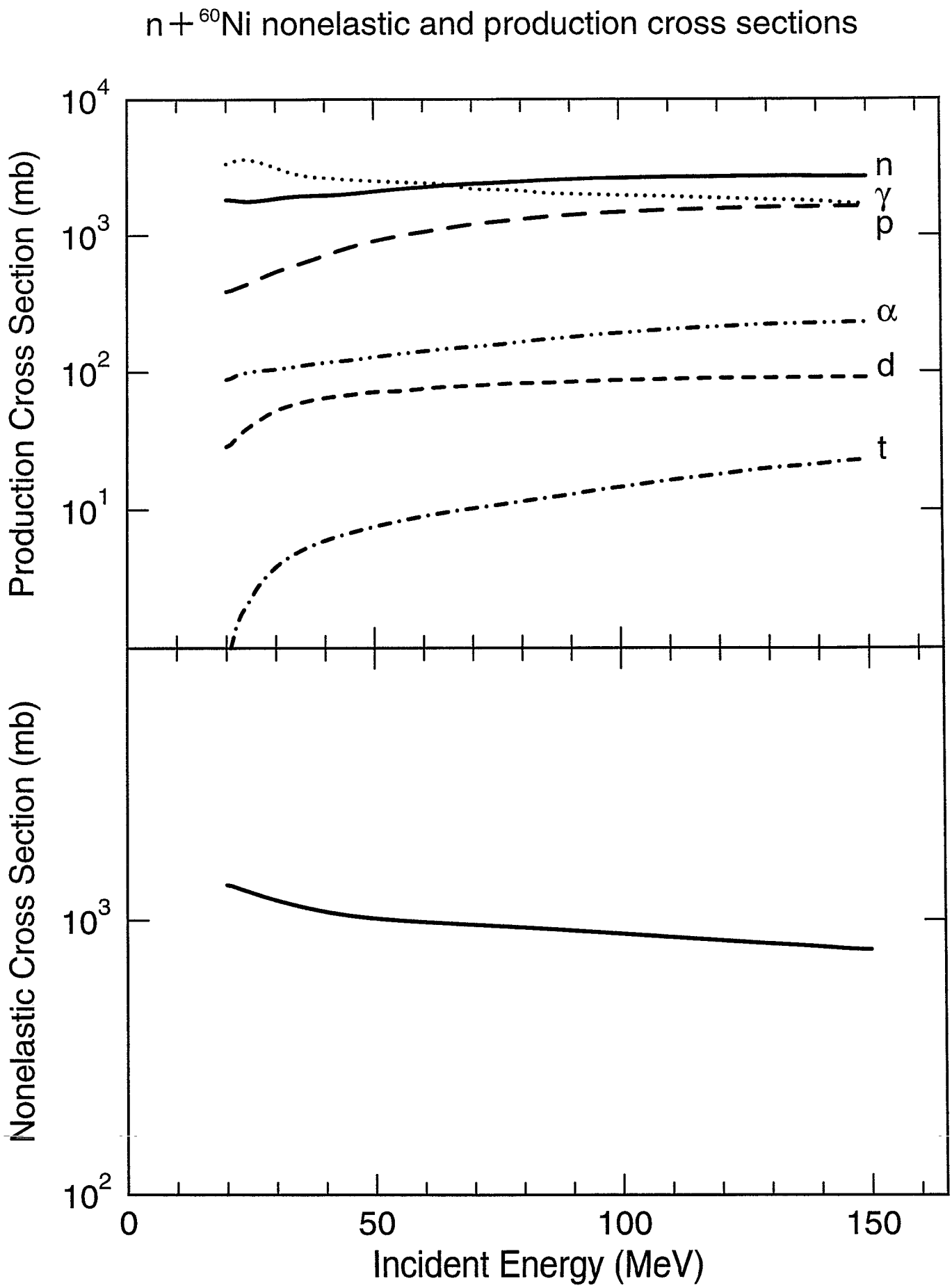
The proton optical potential was also searched to obtain a good description of proton-total reaction cross section as predicted by Wellisch-Axen systematic (We96) above 50 MeV. The parameter estimation was carried out by the Marquart-Bayesian approach similar to the neutron OMP, but trying to seek the best parameter to reproduce the reaction cross sections compiled by Carlson (Ca96) and Wellisch values. The experimental data in Carlson (Ca96) was scaled for Ni-60 according to A**(2/3) law. In this search, the geometrical parameters were fixed to be same as the neutron potential. The present potential gives a good description of the proton total reaction cross section from 10 MeV to 250 MeV. However, after some trial and error to reproduce both the elastic

28060 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

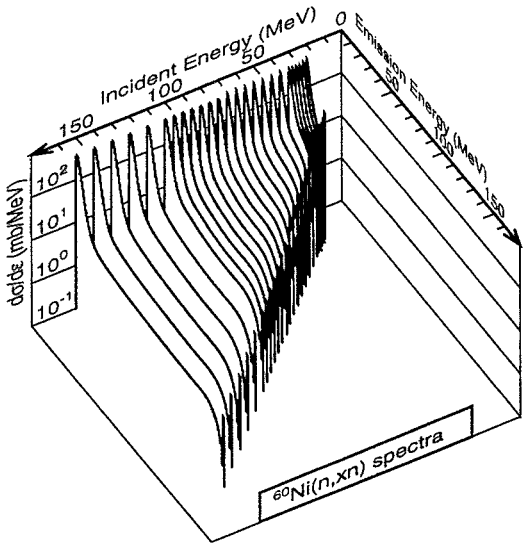
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	1.348E+00	1.033E+00	1.822E+00	3.878E-01	2.882E-02	8.594E-04	0.000E+00	8.832E-02	3.361E+00
2.200E+01	1.317E+00	1.031E+00	1.798E+00	4.084E-01	3.294E-02	1.430E-03	0.000E+00	9.432E-02	3.573E+00
2.400E+01	1.280E+00	1.060E+00	1.770E+00	4.348E-01	3.860E-02	1.993E-03	0.000E+00	9.866E-02	3.629E+00
2.600E+01	1.245E+00	1.093E+00	1.784E+00	4.688E-01	4.299E-02	2.639E-03	0.000E+00	1.015E-01	3.527E+00
2.800E+01	1.212E+00	1.160E+00	1.815E+00	5.043E-01	4.800E-02	3.269E-03	0.000E+00	1.032E-01	3.367E+00
3.000E+01	1.182E+00	1.225E+00	1.857E+00	5.395E-01	5.231E-02	3.847E-03	0.000E+00	1.047E-01	3.166E+00
3.500E+01	1.120E+00	1.381E+00	1.934E+00	6.187E-01	5.984E-02	5.056E-03	0.000E+00	1.110E-01	2.775E+00
4.000E+01	1.073E+00	1.498E+00	1.957E+00	7.113E-01	6.493E-02	6.000E-03	0.000E+00	1.172E-01	2.635E+00
4.500E+01	1.039E+00	1.587E+00	2.006E+00	8.127E-01	6.812E-02	6.792E-03	0.000E+00	1.221E-01	2.556E+00
5.000E+01	1.015E+00	1.623E+00	2.089E+00	9.044E-01	7.140E-02	7.548E-03	0.000E+00	1.286E-01	2.496E+00
5.500E+01	9.979E-01	1.628E+00	2.179E+00	9.862E-01	7.242E-02	8.263E-03	0.000E+00	1.355E-01	2.445E+00
6.000E+01	9.847E-01	1.607E+00	2.255E+00	1.060E+00	7.534E-02	8.965E-03	0.000E+00	1.419E-01	2.410E+00
6.500E+01	9.732E-01	1.543E+00	2.329E+00	1.131E+00	7.776E-02	9.614E-03	0.000E+00	1.479E-01	2.348E+00
7.000E+01	9.622E-01	1.478E+00	2.380E+00	1.203E+00	7.918E-02	1.022E-02	0.000E+00	1.528E-01	2.190E+00
7.500E+01	9.512E-01	1.417E+00	2.423E+00	1.257E+00	8.118E-02	1.079E-02	0.000E+00	1.578E-01	2.157E+00
8.000E+01	9.397E-01	1.348E+00	2.482E+00	1.311E+00	8.266E-02	1.148E-02	0.000E+00	1.653E-01	2.114E+00
8.500E+01	9.279E-01	1.260E+00	2.534E+00	1.364E+00	8.331E-02	1.219E-02	0.000E+00	1.729E-01	2.032E+00
9.000E+01	9.158E-01	1.185E+00	2.571E+00	1.406E+00	8.449E-02	1.290E-02	0.000E+00	1.790E-01	2.001E+00
9.500E+01	9.034E-01	1.112E+00	2.607E+00	1.447E+00	8.588E-02	1.382E-02	0.000E+00	1.868E-01	1.982E+00
1.000E+02	8.910E-01	1.061E+00	2.633E+00	1.477E+00	8.684E-02	1.459E-02	0.000E+00	1.925E-01	1.955E+00
1.100E+02	8.664E-01	9.049E-01	2.673E+00	1.530E+00	8.839E-02	1.638E-02	0.000E+00	2.045E-01	1.916E+00
1.200E+02	8.426E-01	8.008E-01	2.692E+00	1.567E+00	8.986E-02	1.807E-02	0.000E+00	2.130E-01	1.867E+00
1.300E+02	8.202E-01	7.117E-01	2.716E+00	1.600E+00	9.028E-02	1.996E-02	0.000E+00	2.216E-01	1.818E+00
1.400E+02	7.993E-01	6.333E-01	2.708E+00	1.614E+00	9.079E-02	2.139E-02	0.000E+00	2.261E-01	1.772E+00
1.500E+02	7.798E-01	5.768E-01	2.698E+00	1.630E+00	9.103E-02	2.297E-02	0.000E+00	2.298E-01	1.691E+00

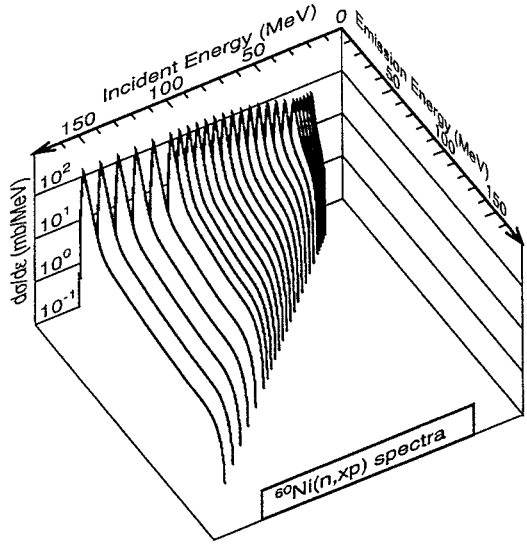
28060 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

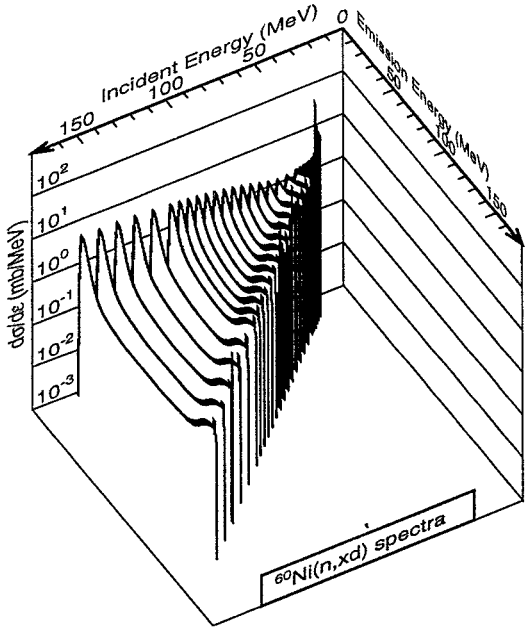
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	4.010E-01	4.122E-02	7.883E-04	0.000E+00	1.398E-01	9.303E-02	2.340E-02	6.993E-01
2.200E+01	4.552E-01	5.248E-02	1.515E-03	0.000E+00	1.534E-01	9.902E-02	2.272E-02	7.844E-01
2.400E+01	5.092E-01	6.842E-02	2.356E-03	0.000E+00	1.642E-01	1.036E-01	2.438E-02	8.721E-01
2.600E+01	5.681E-01	8.320E-02	3.476E-03	0.000E+00	1.726E-01	1.075E-01	2.528E-02	9.602E-01
2.800E+01	6.345E-01	1.015E-01	4.728E-03	0.000E+00	1.788E-01	1.108E-01	2.629E-02	1.057E+00
3.000E+01	7.077E-01	1.200E-01	6.035E-03	0.000E+00	1.839E-01	1.138E-01	2.673E-02	1.158E+00
3.500E+01	9.039E-01	1.648E-01	9.425E-03	0.000E+00	1.997E-01	1.222E-01	2.648E-02	1.427E+00
4.000E+01	1.126E+00	2.099E-01	1.272E-02	0.000E+00	2.155E-01	1.299E-01	2.506E-02	1.720E+00
4.500E+01	1.363E+00	2.498E-01	1.584E-02	0.000E+00	2.292E-01	1.373E-01	2.346E-02	2.019E+00
5.000E+01	1.603E+00	2.904E-01	1.882E-02	0.000E+00	2.453E-01	1.450E-01	2.157E-02	2.325E+00
5.500E+01	1.848E+00	3.153E-01	2.159E-02	0.000E+00	2.619E-01	1.522E-01	1.977E-02	2.619E+00
6.000E+01	2.086E+00	3.522E-01	2.423E-02	0.000E+00	2.776E-01	1.591E-01	1.814E-02	2.918E+00
6.500E+01	2.327E+00	3.865E-01	2.664E-02	0.000E+00	2.926E-01	1.657E-01	1.641E-02	3.215E+00
7.000E+01	2.568E+00	4.134E-01	2.886E-02	0.000E+00	3.058E-01	1.713E-01	1.499E-02	3.503E+00
7.500E+01	2.794E+00	4.457E-01	3.088E-02	0.000E+00	3.187E-01	1.754E-01	1.382E-02	3.779E+00
8.000E+01	3.015E+00	4.728E-01	3.275E-02	0.000E+00	3.362E-01	1.802E-01	1.274E-02	4.049E+00
8.500E+01	3.234E+00	4.905E-01	3.452E-02	0.000E+00	3.536E-01	1.843E-01	1.162E-02	4.308E+00
9.000E+01	3.437E+00	5.144E-01	3.619E-02	0.000E+00	3.688E-01	1.874E-01	1.071E-02	4.554E+00
9.500E+01	3.636E+00	5.364E-01	3.795E-02	0.000E+00	3.870E-01	1.905E-01	9.892E-03	4.798E+00
1.000E+02	3.831E+00	5.584E-01	3.946E-02	0.000E+00	4.012E-01	1.926E-01	9.312E-03	5.032E+00
1.100E+02	4.204E+00	5.931E-01	4.245E-02	0.000E+00	4.309E-01	1.964E-01	7.788E-03	5.474E+00
1.200E+02	4.561E+00	6.337E-01	4.480E-02	0.000E+00	4.544E-01	1.967E-01	6.800E-03	5.898E+00
1.300E+02	4.909E+00	6.489E-01	4.653E-02	0.000E+00	4.779E-01	2.025E-01	5.989E-03	6.290E+00
1.400E+02	5.240E+00	6.849E-01	4.703E-02	0.000E+00	4.930E-01	2.076E-01	5.299E-03	6.678E+00
1.500E+02	5.564E+00	7.102E-01	4.759E-02	0.000E+00	5.068E-01	2.112E-01	4.810E-03	7.044E+00

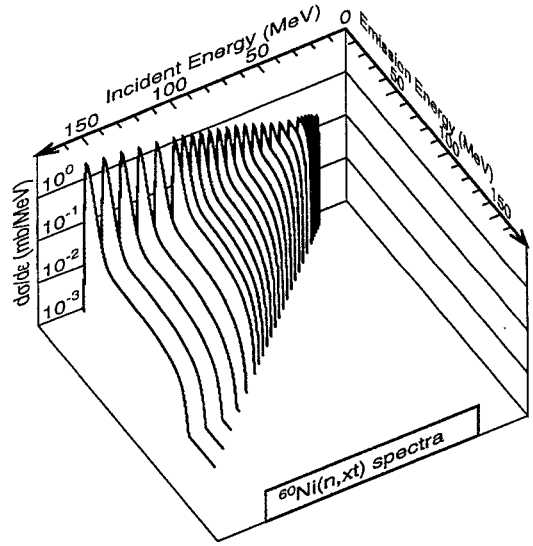

n + 60Ni nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
n
γ
p
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
0
50
100
150
Incident Energy (MeV)

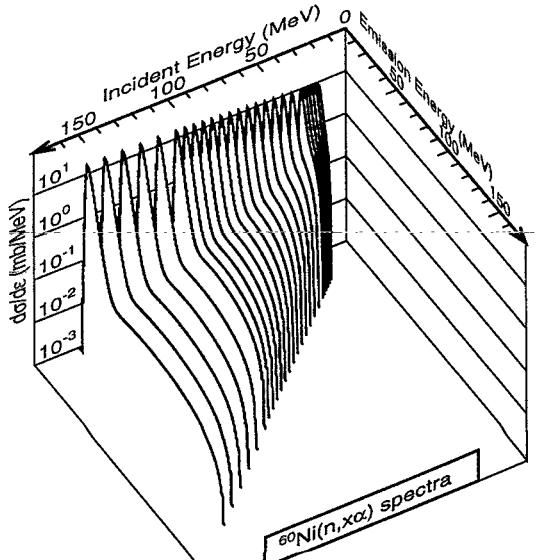
n + ^{60}Ni angle-integrated emission spectra

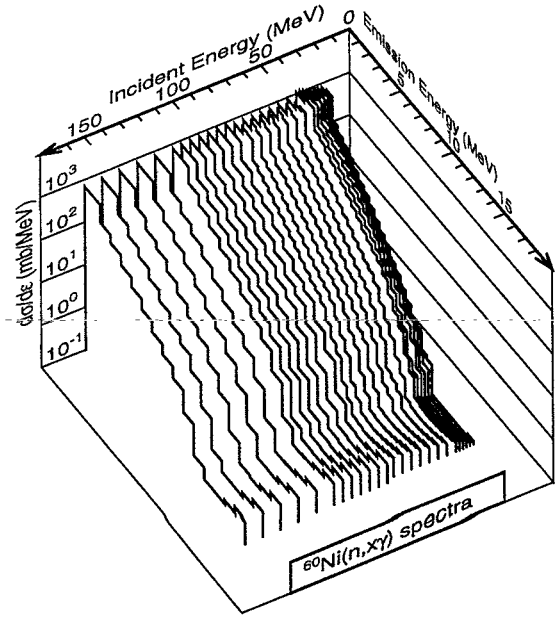




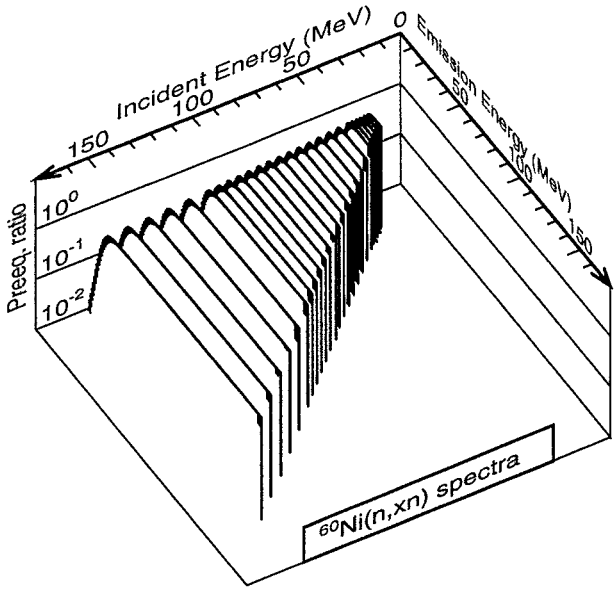


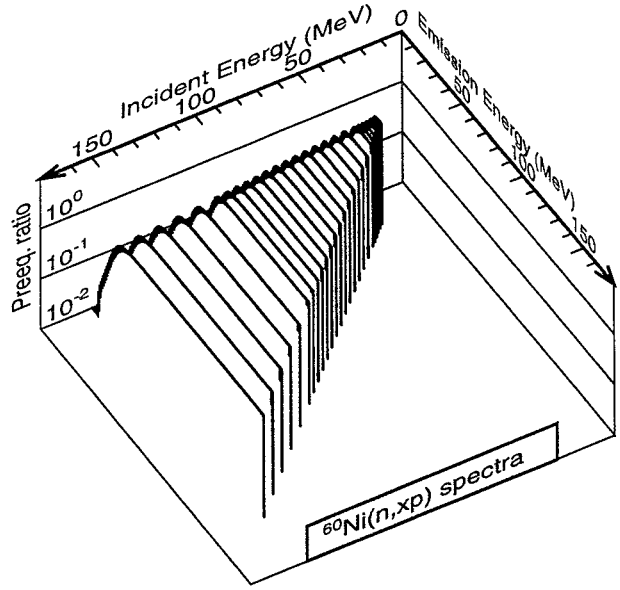


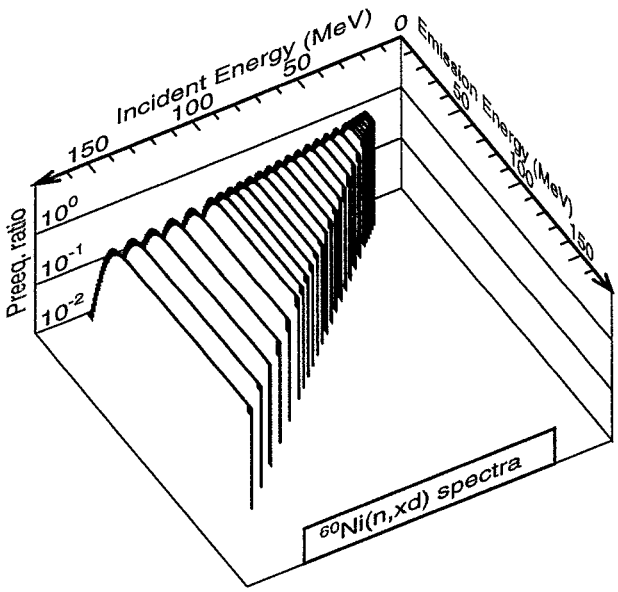


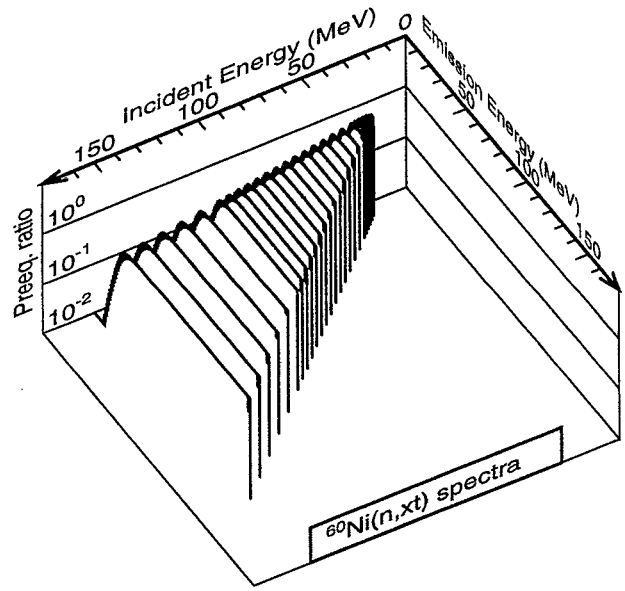


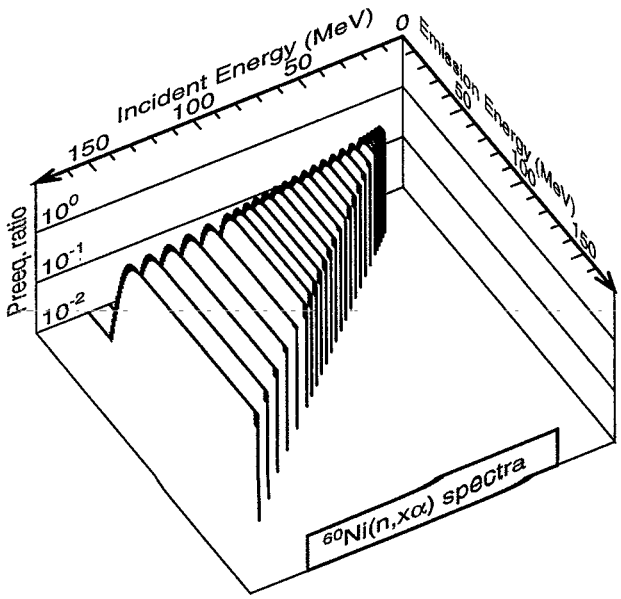
n + ^{60}Ni Kalbach preequilibrium ratios

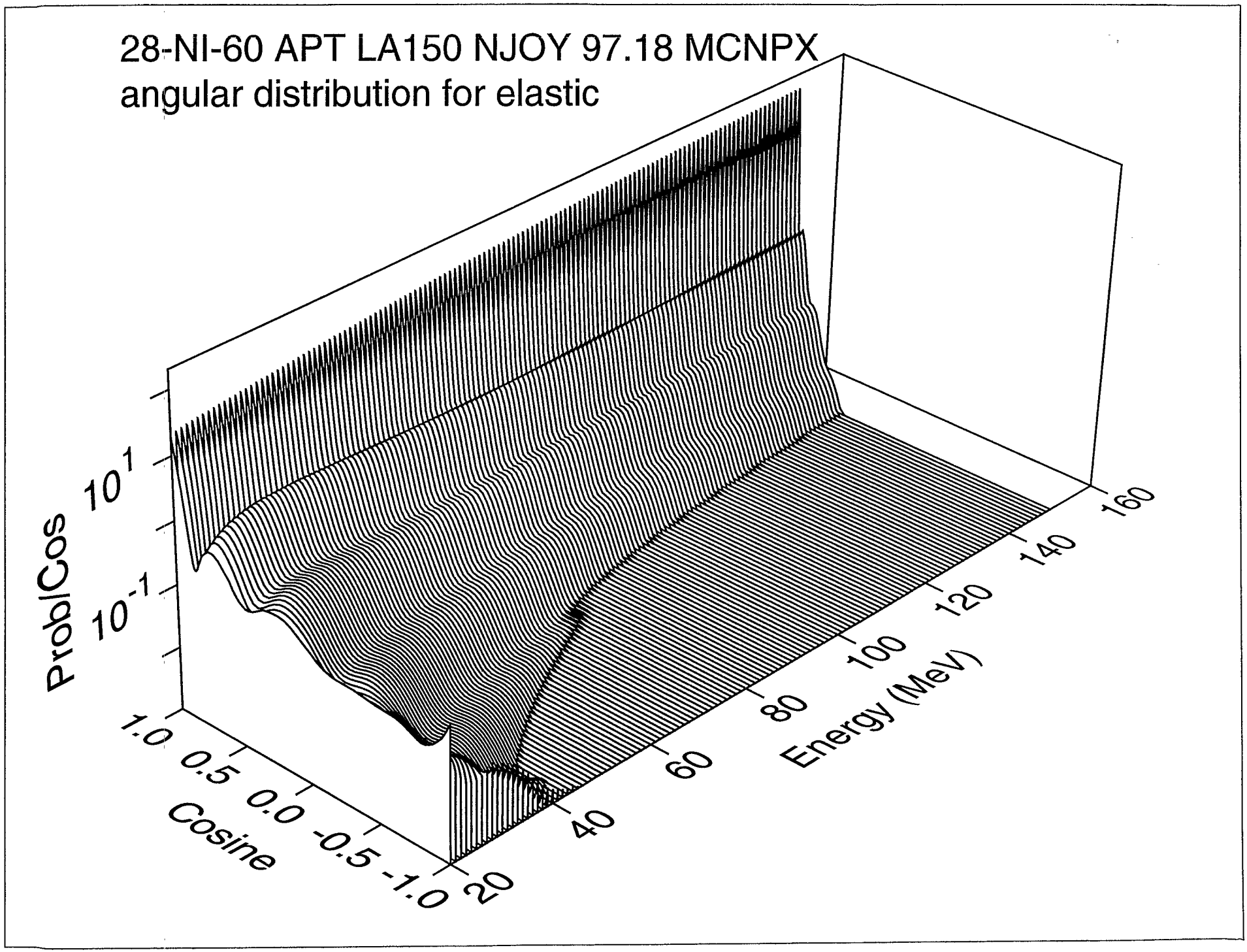


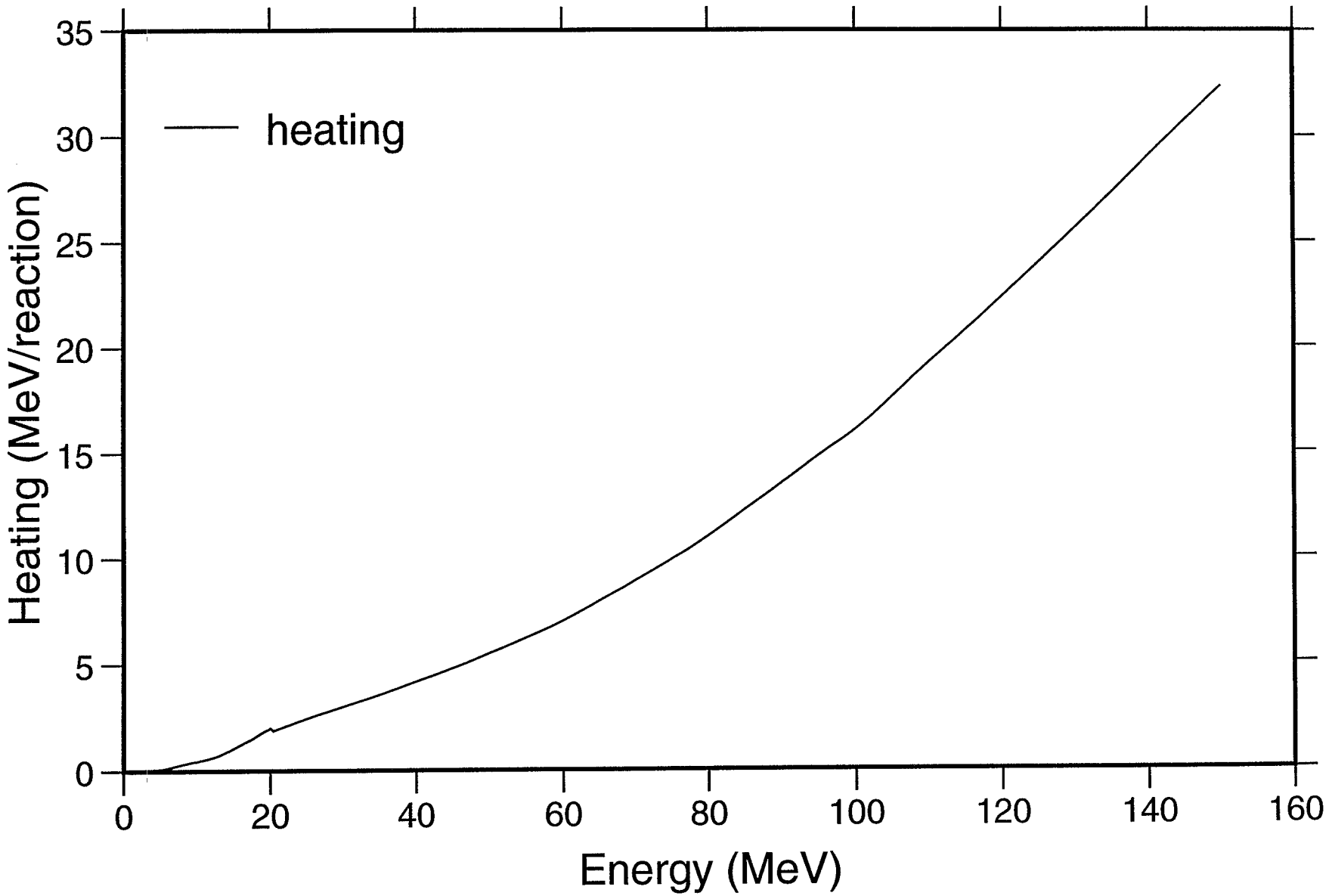


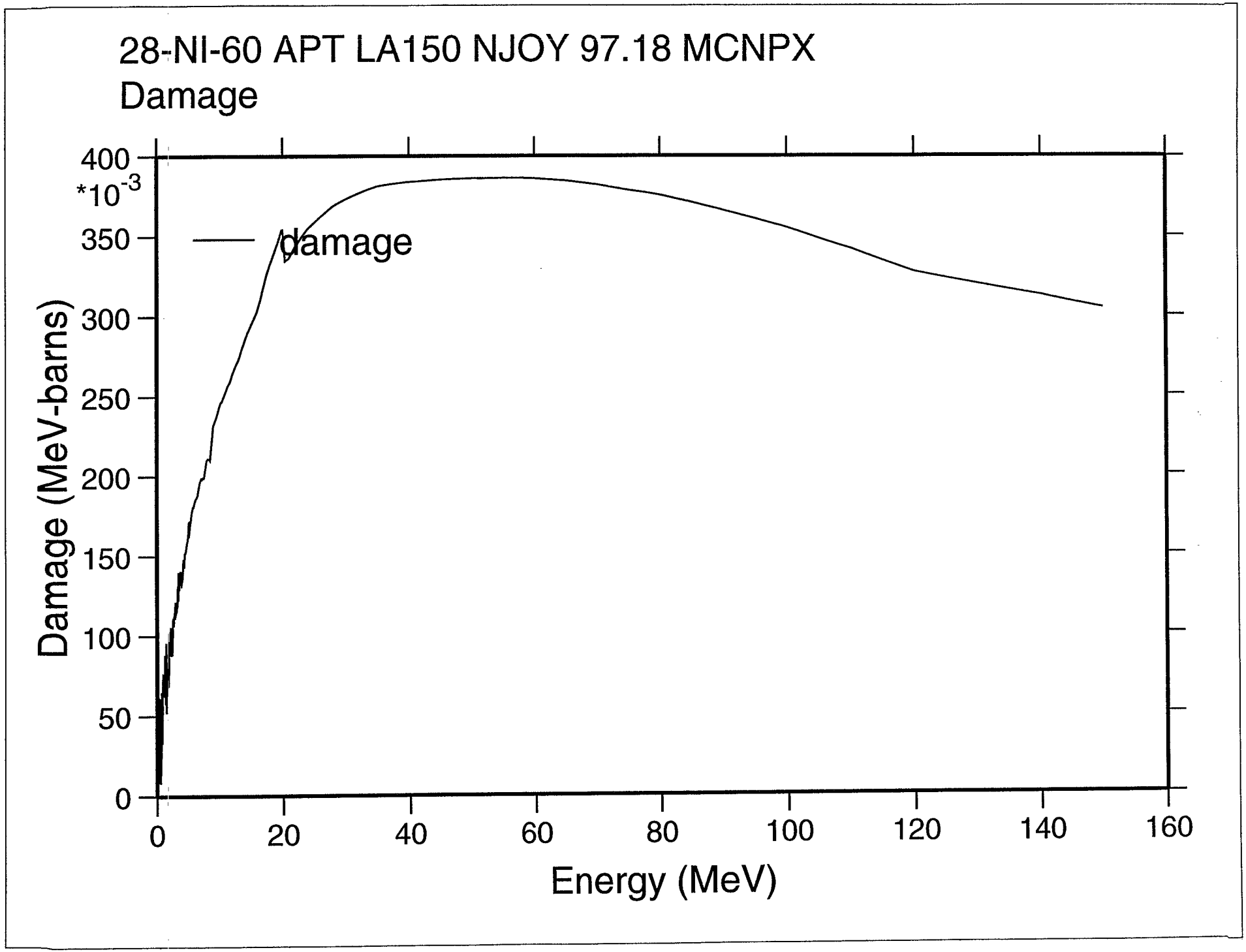







28-NI-60 APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic
Prob/Cos
10^1
10^{-1}
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


28-NI-60 APT LA150 NJOY 97.18 MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
5
10
15
20
25
30
35
0
20
40
60
80
100
120
140
160


28-NI-60 APT LA150 NJOY 97.18 MCNPX
Damage
damage
Damage (MeV-barns)
*10^-3
400
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF n + 61Ni CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

S. Chiba, M. B. Chadwick, P. G. Young, and A. J. Koning
22 Sept. 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI.5 (Release 2) evaluation by Larson, C. Perey, Hetrich, and Fu.

INCIDENT NEUTRON ENERGIES > 20 MeV

The ENDF/B-VI Release 2 evaluation extends to 20 MeV and includes cross sections and energy-angle data for all significant reactions. The present evaluation utilizes a more compact composite reaction spectrum representation above 20 MeV in order to reduce the length of the file. No essential data for applications is lost with this representation.

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT= 1	Total Cross Section
	MT= 2	Elastic Scattering Cross Section
	MT= 3	Nonelastic Cross Section
	MT= 5	Sum of Binary (n,n') and (n,x) Reactions
MF=4	MT= 2	Elastic Angular Distributions
MF=6	MT= 5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, Tritons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Ni58 and p + Ni58 reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of

all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Gilbert and Cameron (Gi65) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged- particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

SOME Ni-SPECIFIC INFORMATION CONCERNING THE EVAL.

The neutron total cross section was evaluated based on the least-squares method with GMA code system (Po81) taking account of the experimental data(Ci68, Pe73, Sc73, La83, Sm92, Di97). The data for natural Ni and Ni-58 were used because there was no data for Ni-61. These data were transformed to the Ni-61 cross section according to A*(2/3) law. In the GMA analysis, the systematic error was assumed to be 1 % for all the data set. Result of the GMA evaluation was used as the evaluated total cross section data above 20 MeV.

The evaluated total cross section data (1 to 250 MeV) and s-wave strength function (Mu81) were used to obtain the neutron optical potential parameters. The parameter estimation was carried out based on Marquart-Bayesian approach (Sm91), where ECIS95 code was used for the optical model calculation. We have employed the energy dependence of the optical potential similar to Delaroche's work(De89). The initial potential parameters were adopted from Koning and Delaroche (Ko97). Total of 7 parameters concerning the central potential depth were estimated with associated covariance matrix, while the geometrical parameters were fixed to the result of a similar search for n + Ni-58. Presently obtained potential was used for the calculation of neutron transmission coefficients and DWBA cross sections in the energy region above 20 MeV. Below 20 MeV, the Harper neutron potential (Ha82) was used for the calculation of transmission coefficients.

The proton optical potential was also searched for to obtain a good description of proton-total reaction cross section as predicted by Wellisch-Axen systematic (We96) above 50 MeV. The parameter estimation was carried out by the Marquart-Bayesian approach similar to the neutron OMP, but trying to seek the best parameter to reproduce the reaction cross sections compiled by Carlson (Ca96) and Wellisch values. The experimental data in Carlson (Ca96) was scaled for Ni-61 according to A**(2/3) law. In this search, the geometrical parameters were fixed to be same as the neutron potential. The present potential gives a good description of the proton total reaction cross section from 10 MeV to 250 MeV. However, after some trial and error to reproduce both the elastic scattering and reaction cross section data for Ni-58,

we have employed the following combination of proton potentials:

0 to 5 MeV	:	Harper potential (Ha82)
6 to 47 MeV	:	Koning and Delaroche (Ko97)
48 to 260 MeV	:	Present OMP

For deuterons, the Lohr-Haeberli (Lo74) global potential was used; for alpha particles the McFadden-Satchler (Mc66) potential was used; and for tritons the Becchetti-Greenlees (Be71) potential was used. The He-3 channel was ignored.

The direct collective inelastic scattering to the following levels in Ni-61 was considered by the DWBA-mode calculation of ECIS95:

Jpi	Ex(MeV)	Deformation length
1/2-	0.2830	0.31703
5/2-	0.9086	0.54912
7/2-	1.0152	0.63407
3/2-	1.0996	0.44835

The deformation lengths were estimated assuming a weak-coupling of 3/2- neutron hole to the excited 2+ core in Ni-62.

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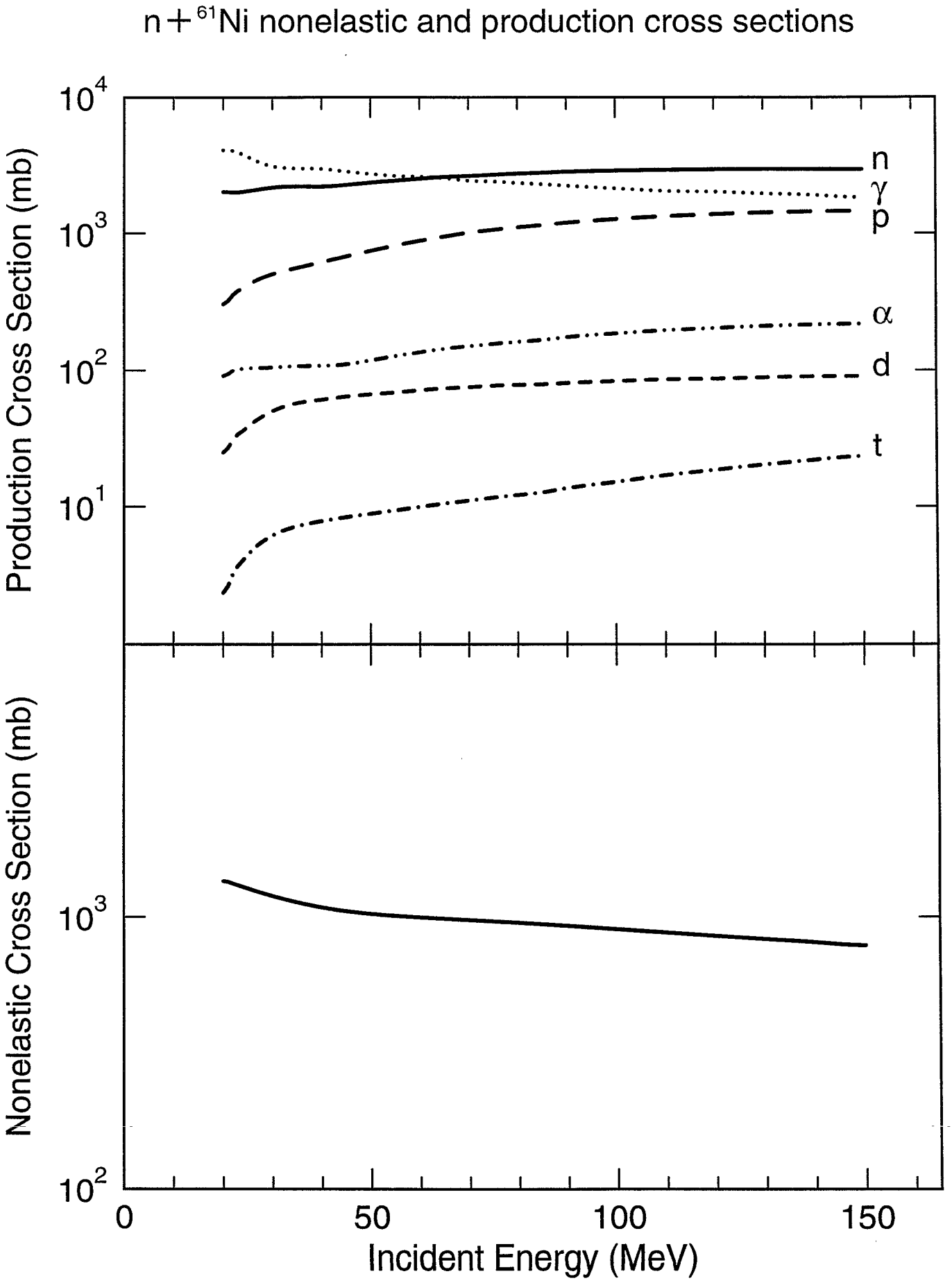
28061 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

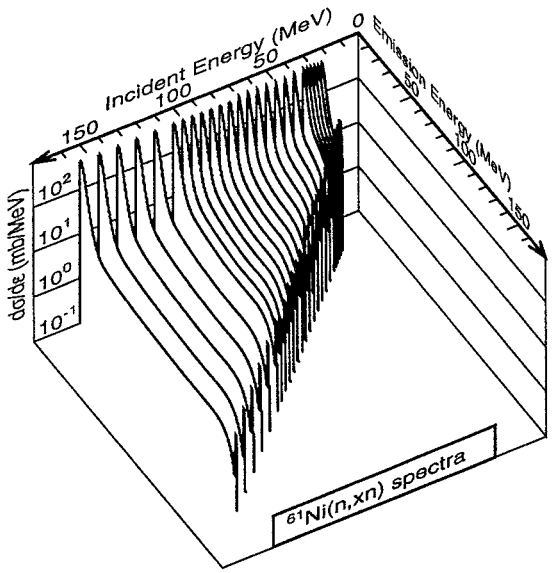
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	1.356E+00	1.051E+00	2.012E+00	3.028E-01	2.492E-02	2.357E-03	0.000E+00	9.061E-02	4.090E+00
2.200E+01	1.327E+00	1.047E+00	1.992E+00	3.542E-01	3.107E-02	3.231E-03	0.000E+00	9.941E-02	4.047E+00
2.400E+01	1.291E+00	1.076E+00	2.017E+00	3.971E-01	3.592E-02	4.069E-03	0.000E+00	1.029E-01	3.794E+00
2.600E+01	1.256E+00	1.108E+00	2.065E+00	4.389E-01	4.115E-02	4.872E-03	0.000E+00	1.041E-01	3.499E+00
2.800E+01	1.224E+00	1.175E+00	2.119E+00	4.741E-01	4.599E-02	5.583E-03	0.000E+00	1.044E-01	3.265E+00
3.000E+01	1.194E+00	1.240E+00	2.168E+00	5.027E-01	5.020E-02	6.178E-03	0.000E+00	1.051E-01	3.108E+00
3.500E+01	1.132E+00	1.397E+00	2.212E+00	5.595E-01	5.751E-02	7.211E-03	0.000E+00	1.076E-01	2.994E+00
4.000E+01	1.085E+00	1.515E+00	2.204E+00	6.158E-01	6.101E-02	7.853E-03	0.000E+00	1.081E-01	2.967E+00
4.500E+01	1.051E+00	1.604E+00	2.262E+00	6.772E-01	6.430E-02	8.383E-03	0.000E+00	1.109E-01	2.833E+00
5.000E+01	1.027E+00	1.641E+00	2.349E+00	7.436E-01	6.670E-02	8.872E-03	0.000E+00	1.181E-01	2.717E+00
5.500E+01	1.009E+00	1.645E+00	2.431E+00	8.130E-01	6.883E-02	9.385E-03	0.000E+00	1.266E-01	2.628E+00
6.000E+01	9.960E-01	1.624E+00	2.511E+00	8.813E-01	7.145E-02	9.942E-03	0.000E+00	1.351E-01	2.588E+00
6.500E+01	9.845E-01	1.559E+00	2.588E+00	9.460E-01	7.372E-02	1.050E-02	0.000E+00	1.436E-01	2.542E+00
7.000E+01	9.735E-01	1.494E+00	2.629E+00	1.009E+00	7.520E-02	1.103E-02	0.000E+00	1.500E-01	2.430E+00
7.500E+01	9.624E-01	1.432E+00	2.686E+00	1.059E+00	7.702E-02	1.162E-02	0.000E+00	1.559E-01	2.396E+00
8.000E+01	9.509E-01	1.362E+00	2.738E+00	1.106E+00	7.803E-02	1.215E-02	0.000E+00	1.614E-01	2.336E+00
8.500E+01	9.389E-01	1.273E+00	2.781E+00	1.148E+00	7.876E-02	1.272E-02	0.000E+00	1.663E-01	2.289E+00
9.000E+01	9.265E-01	1.197E+00	2.829E+00	1.196E+00	8.052E-02	1.367E-02	0.000E+00	1.742E-01	2.235E+00
9.500E+01	9.139E-01	1.124E+00	2.862E+00	1.236E+00	8.188E-02	1.445E-02	0.000E+00	1.802E-01	2.181E+00
1.000E+02	9.012E-01	1.072E+00	2.885E+00	1.273E+00	8.306E-02	1.523E-02	0.000E+00	1.855E-01	2.135E+00
1.100E+02	8.759E-01	9.149E-01	2.923E+00	1.334E+00	8.552E-02	1.699E-02	0.000E+00	1.955E-01	2.043E+00
1.200E+02	8.514E-01	8.103E-01	2.941E+00	1.378E+00	8.631E-02	1.861E-02	0.000E+00	2.027E-01	2.013E+00
1.300E+02	8.281E-01	7.208E-01	2.952E+00	1.414E+00	8.825E-02	2.038E-02	0.000E+00	2.099E-01	1.951E+00
1.400E+02	8.063E-01	6.422E-01	2.953E+00	1.439E+00	8.973E-02	2.202E-02	0.000E+00	2.147E-01	1.907E+00
1.500E+02	7.859E-01	5.857E-01	2.943E+00	1.455E+00	8.995E-02	2.335E-02	0.000E+00	2.170E-01	1.830E+00

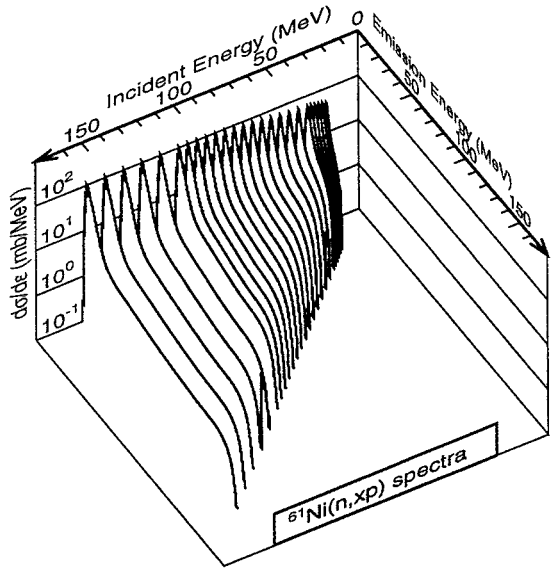
28061 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

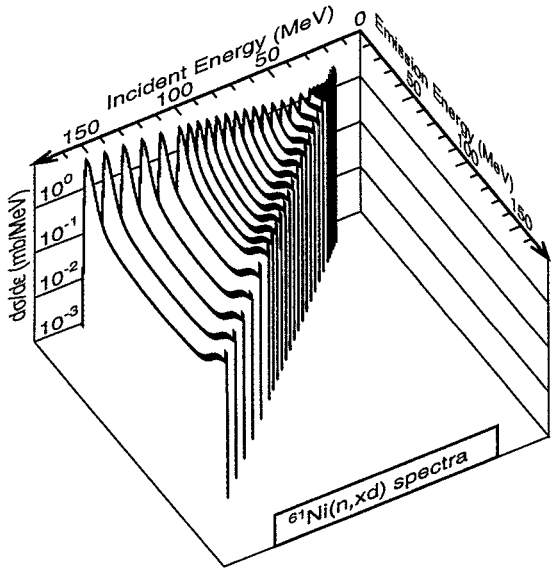
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	3.185E-01	3.447E-02	2.452E-03	0.000E+00	1.390E-01	9.209E-02	2.268E-02	6.092E-01
2.200E+01	3.864E-01	4.839E-02	3.789E-03	0.000E+00	1.554E-01	9.810E-02	2.200E-02	7.141E-01
2.400E+01	4.480E-01	6.155E-02	5.273E-03	0.000E+00	1.639E-01	1.026E-01	2.339E-02	8.047E-01
2.600E+01	5.131E-01	7.750E-02	6.863E-03	0.000E+00	1.684E-01	1.064E-01	2.411E-02	8.964E-01
2.800E+01	5.807E-01	9.451E-02	8.482E-03	0.000E+00	1.711E-01	1.097E-01	2.497E-02	9.895E-01
3.000E+01	6.496E-01	1.120E-01	1.007E-02	0.000E+00	1.742E-01	1.127E-01	2.535E-02	1.084E+00
3.500E+01	8.252E-01	1.541E-01	1.368E-02	0.000E+00	1.828E-01	1.198E-01	2.515E-02	1.321E+00
4.000E+01	1.014E+00	1.900E-01	1.681E-02	0.000E+00	1.887E-01	1.258E-01	2.389E-02	1.560E+00
4.500E+01	1.212E+00	2.280E-01	1.966E-02	0.000E+00	1.975E-01	1.321E-01	2.245E-02	1.811E+00
5.000E+01	1.423E+00	2.616E-01	2.218E-02	0.000E+00	2.128E-01	1.393E-01	2.071E-02	2.080E+00
5.500E+01	1.642E+00	2.927E-01	2.460E-02	0.000E+00	2.309E-01	1.467E-01	1.904E-02	2.356E+00
6.000E+01	1.865E+00	3.265E-01	2.687E-02	0.000E+00	2.492E-01	1.535E-01	1.750E-02	2.638E+00
6.500E+01	2.091E+00	3.585E-01	2.895E-02	0.000E+00	2.678E-01	1.599E-01	1.586E-02	2.922E+00
7.000E+01	2.318E+00	3.848E-01	3.086E-02	0.000E+00	2.830E-01	1.657E-01	1.450E-02	3.197E+00
7.500E+01	2.535E+00	4.128E-01	3.265E-02	0.000E+00	2.973E-01	1.700E-01	1.338E-02	3.461E+00
8.000E+01	2.750E+00	4.345E-01	3.421E-02	0.000E+00	3.110E-01	1.737E-01	1.235E-02	3.716E+00
8.500E+01	2.960E+00	4.525E-01	3.567E-02	0.000E+00	3.237E-01	1.766E-01	1.127E-02	3.960E+00
9.000E+01	3.161E+00	4.750E-01	3.734E-02	0.000E+00	3.416E-01	1.803E-01	1.040E-02	4.206E+00
9.500E+01	3.361E+00	4.973E-01	3.871E-02	0.000E+00	3.561E-01	1.828E-01	9.602E-03	4.445E+00
1.000E+02	3.555E+00	5.183E-01	4.001E-02	0.000E+00	3.694E-01	1.848E-01	9.044E-03	4.676E+00
1.100E+02	3.924E+00	5.570E-01	4.244E-02	0.000E+00	3.947E-01	1.880E-01	7.572E-03	5.114E+00
1.200E+02	4.285E+00	5.742E-01	4.398E-02	0.000E+00	4.152E-01	1.884E-01	6.619E-03	5.513E+00
1.300E+02	4.625E+00	6.058E-01	4.494E-02	0.000E+00	4.349E-01	1.948E-01	5.838E-03	5.912E+00
1.400E+02	4.952E+00	6.361E-01	4.550E-02	0.000E+00	4.505E-01	2.015E-01	5.174E-03	6.291E+00
1.500E+02	5.277E+00	6.561E-01	4.568E-02	0.000E+00	4.607E-01	2.057E-01	4.704E-03	6.650E+00

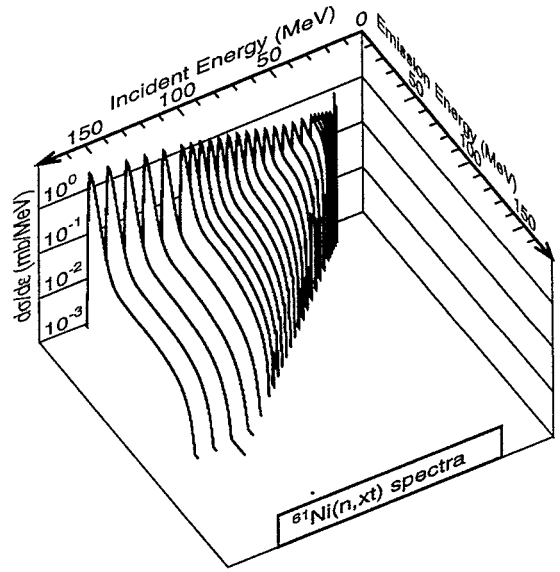

n + 61Ni nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
n
γ
p
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
0
50
100
150
Incident Energy (MeV)

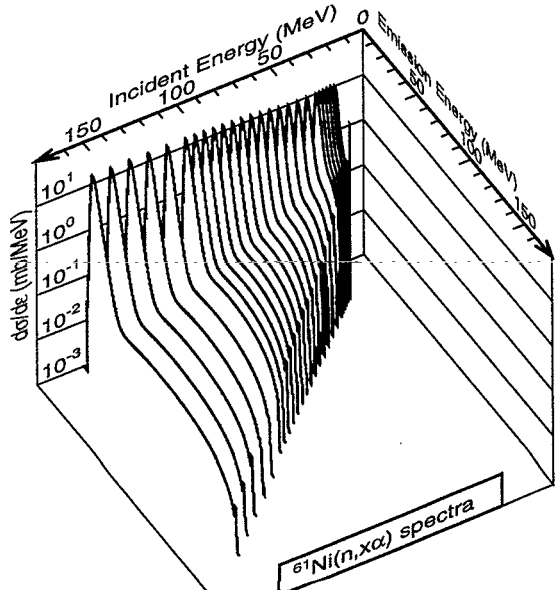
n + ^{61}Ni angle-integrated emission spectra

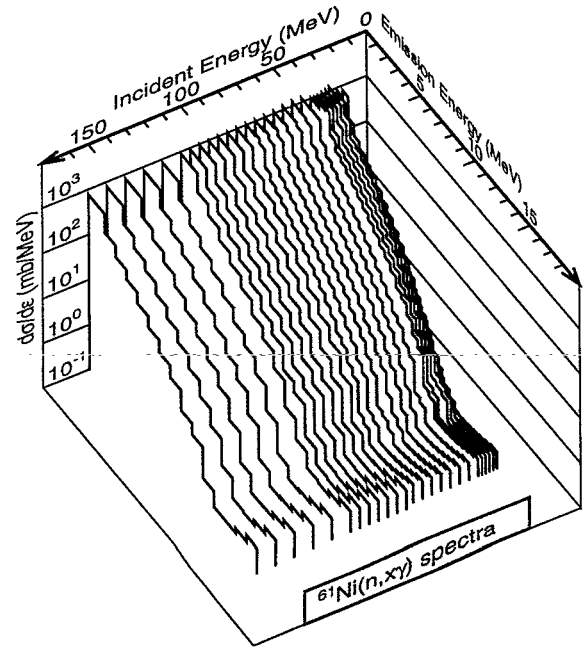




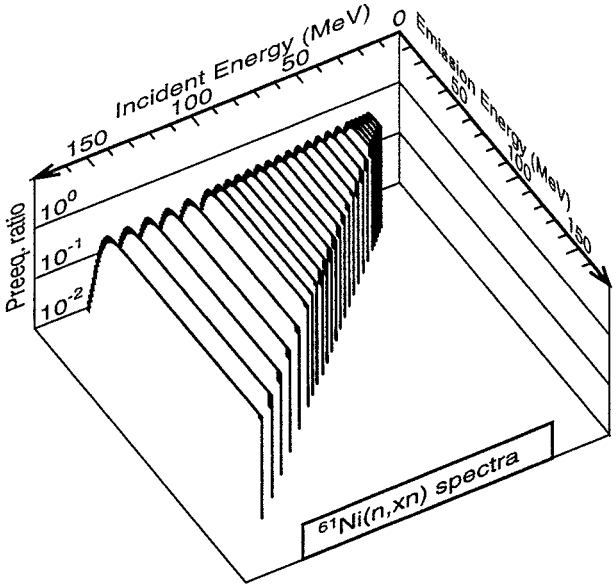


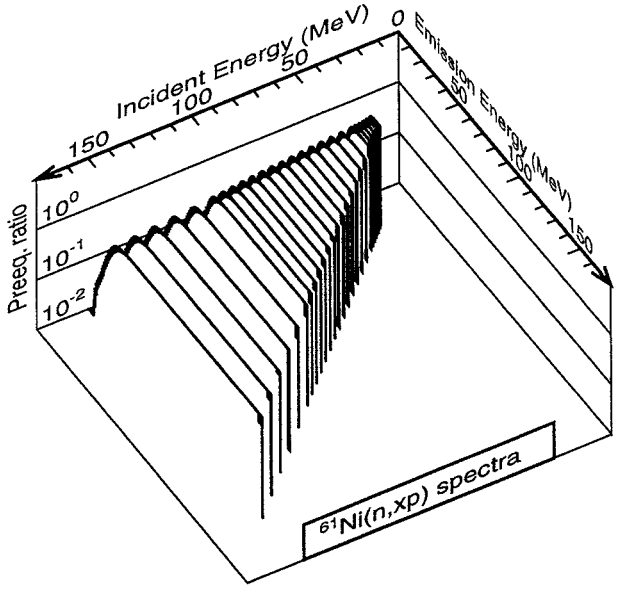


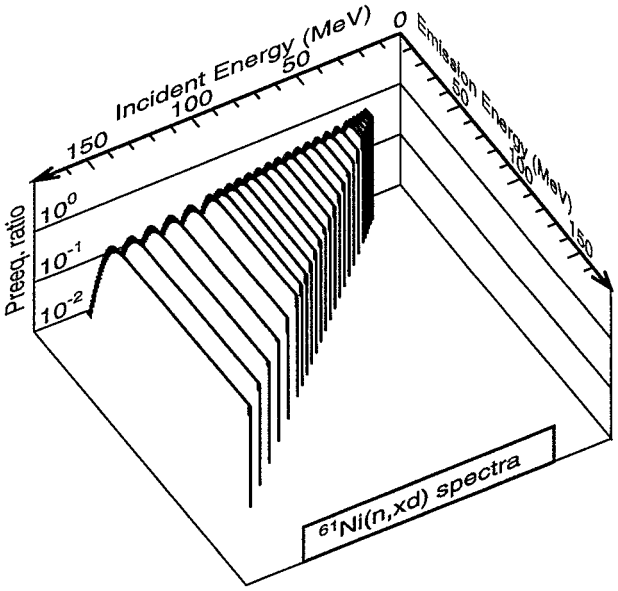


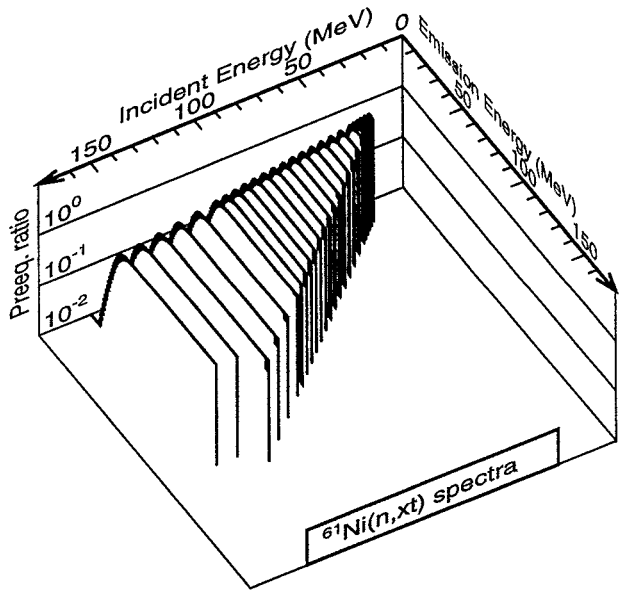


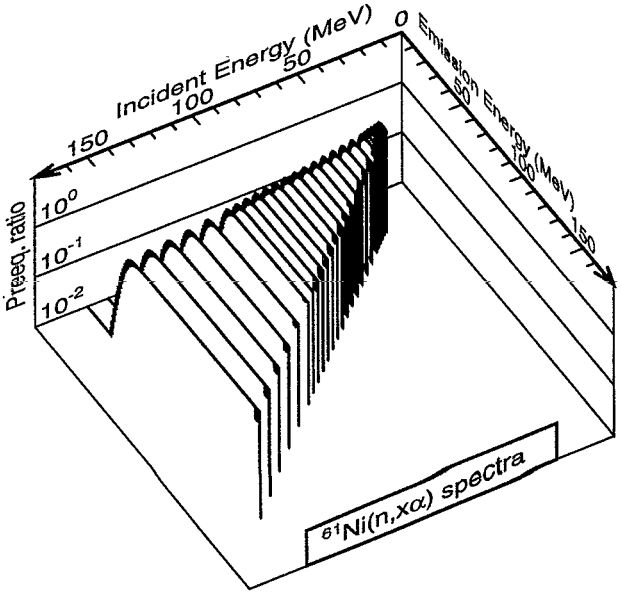
n + ^{61}Ni Kalbach preequilibrium ratios

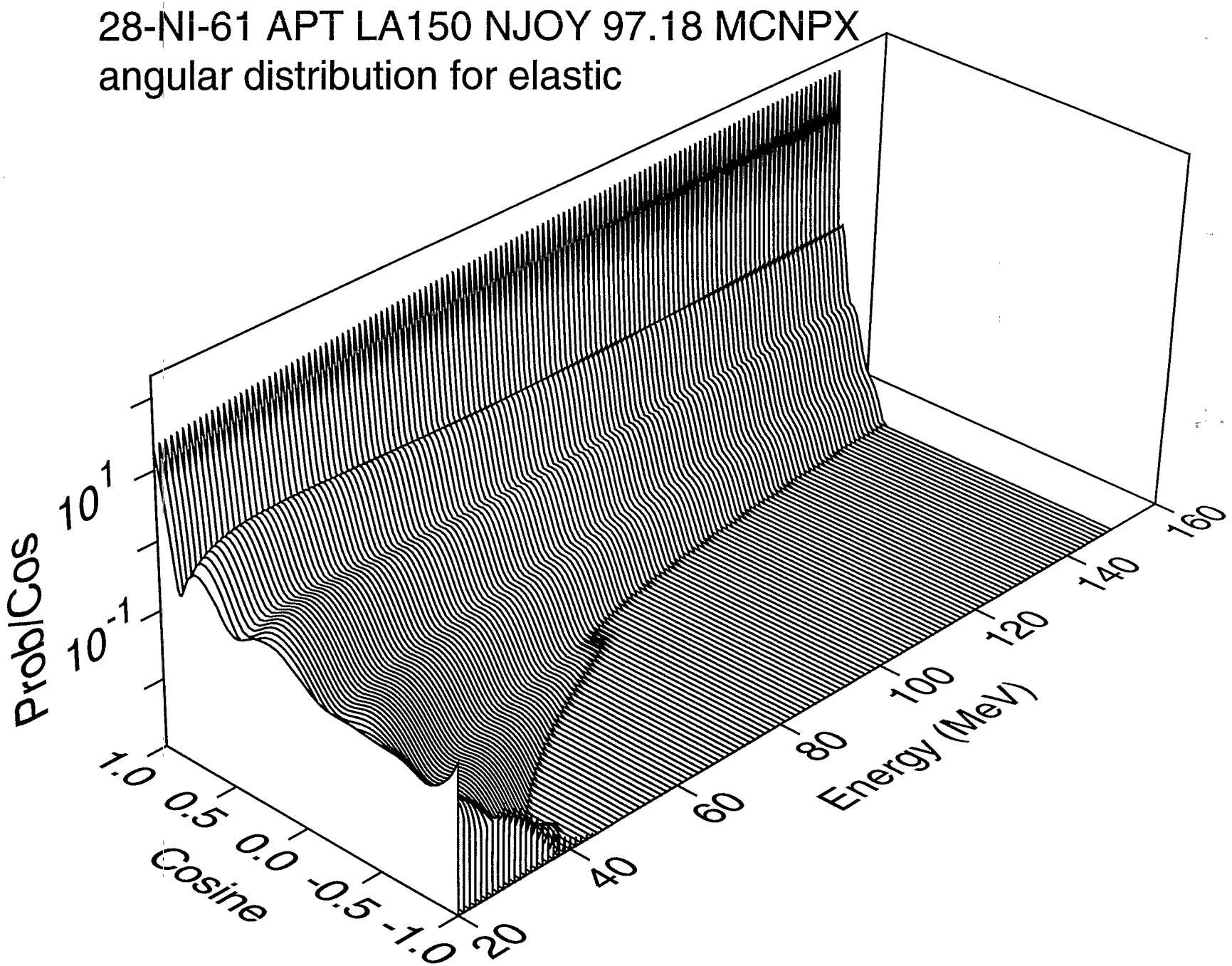


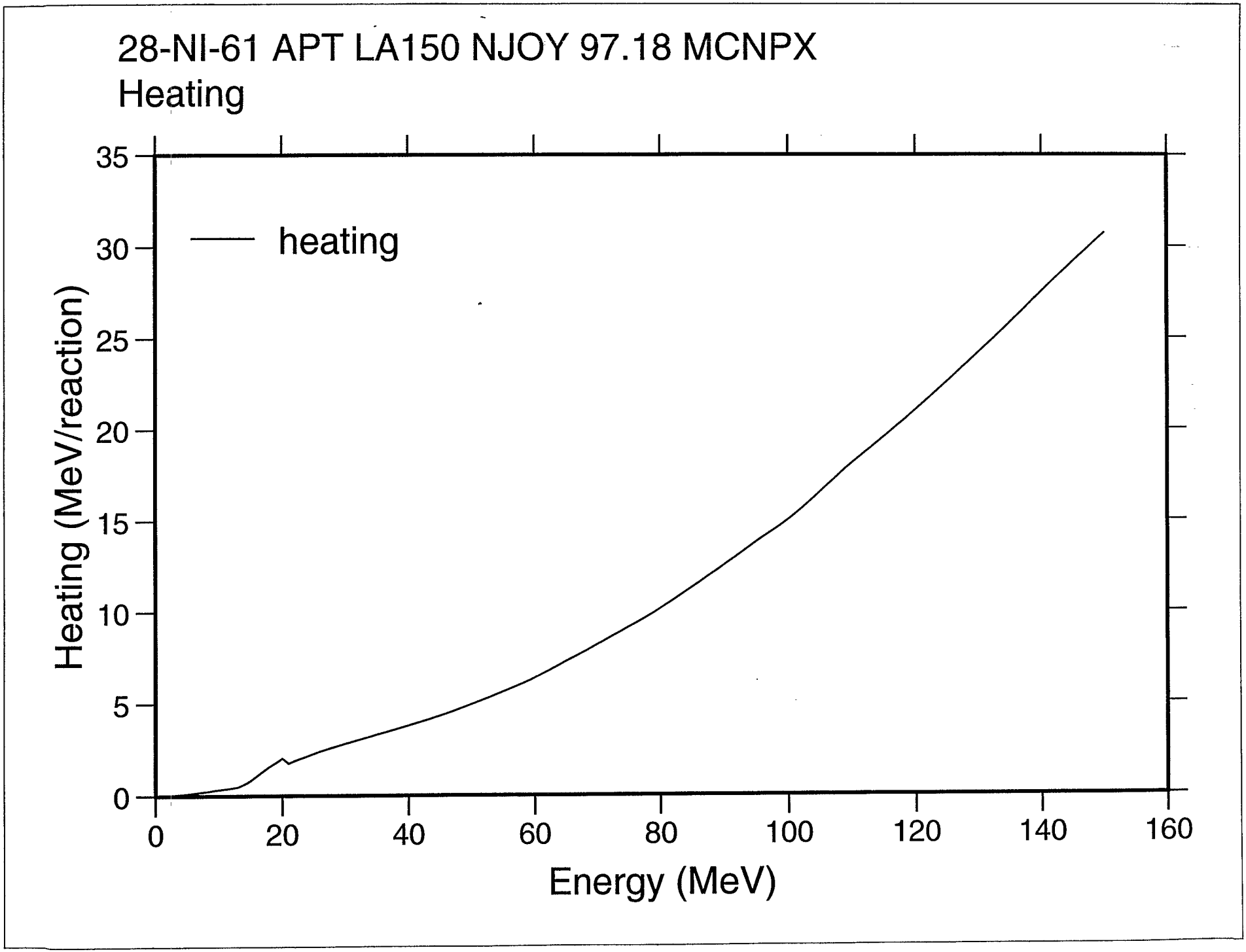


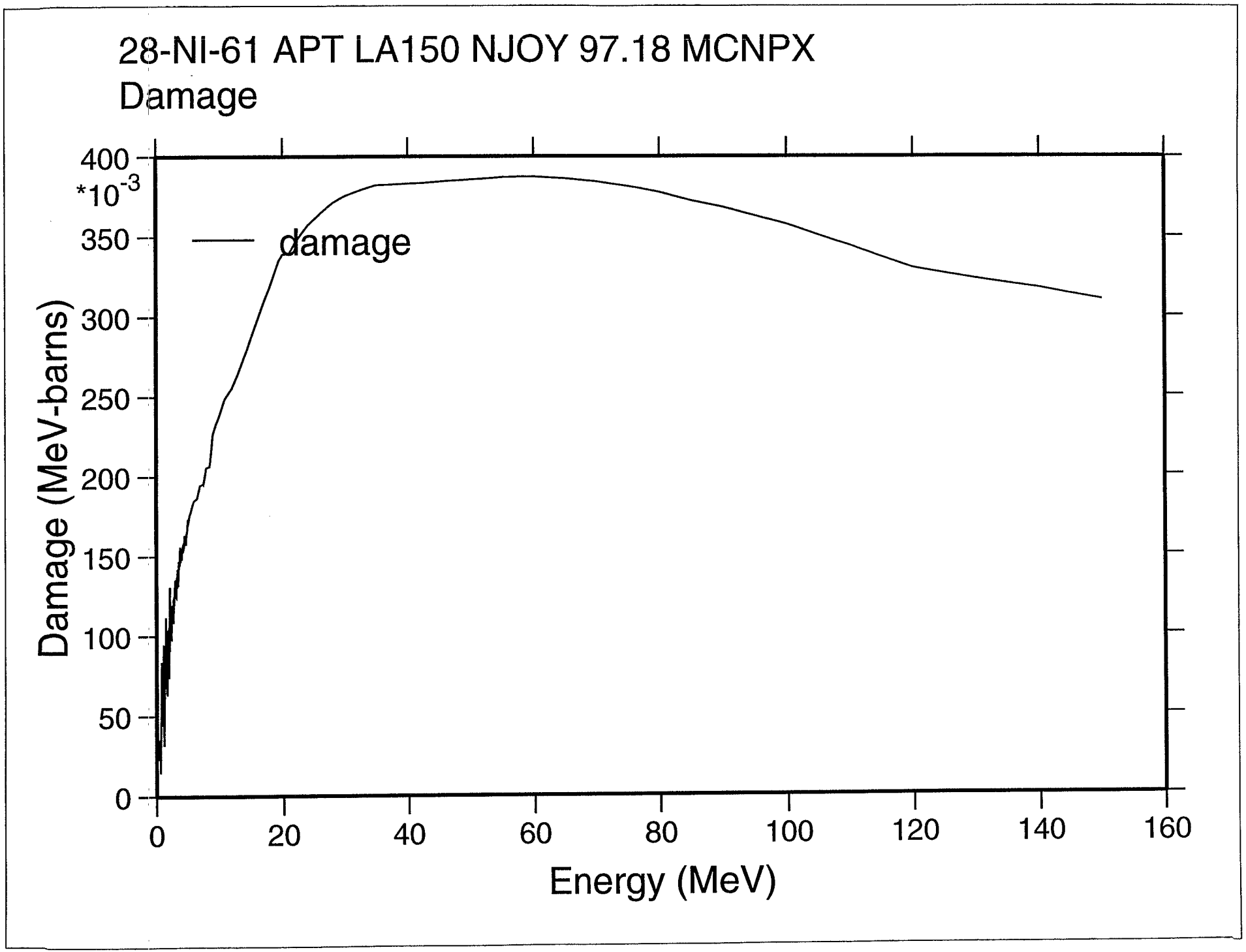







28-NI-61 APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic
Prob/Cos
10^{1}
10^{-1}
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


28-NI-61 APT LA150 NJOY 97.18 MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
5
10
15
20
25
30
35
0
20
40
60
80
100
120
140
160


28-NI-61 APT LA150 NJOY 97.18 MCNPX
Damage
damage
Damage (MeV-barns)
*10^-3
400
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF n + 62Ni CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

S. Chiba, M. B. Chadwick, P. G. Young, and A. J. Koning
22 Sept. 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI.5 (Release 2) evaluation by Larson, C. Perey, Hetrich, and Fu.

INCIDENT NEUTRON ENERGIES > 20 MeV

The ENDF/B-VI Release 2 evaluation extends to 20 MeV and includes cross sections and energy-angle data for all significant reactions. The present evaluation utilizes a more compact composite reaction spectrum representation above 20 MeV in order to reduce the length of the file. No essential data for applications is lost with this representation.

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT= 1	Total Cross Section
	MT= 2	Elastic Scattering Cross Section
	MT= 3	Nonelastic Cross Section
	MT= 5	Sum of Binary (n,n') and (n,x) Reactions
MF=4	MT= 2	Elastic Angular Distributions
MF=6	MT= 5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, Tritons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Ni58 and p + Ni58 reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of

all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Gilbert and Cameron (Gi65) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged- particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

SOME Ni-SPECIFIC INFORMATION CONCERNING THE EVAL.

The neutron total cross section was evaluated based on the least-squares method with GMA code system (Po81) taking account of the experimental data(Ci68, Pe73, Sc73, La83, Di97, Fa66, Du67). The data for natural Ni were also used because there was not enough data for Ni-62 above 20 MeV. The data for natural Ni were transformed to the Ni-62 cross section according to A*(2/3) law. In the GMA analysis, the systematic error was assumed to be 1 % for all the data set. Result of the GMA evaluation was used as the evaluated total cross section data above 20 MeV.

The evaluated total cross section data (1 to 250 MeV) and s-wave strength function (Mu81) were used to obtain the neutron optical potential parameters. The parameter estimation was carried out based on Marquart-Bayesian approach (Sm91), where ECIS95 code was used for the optical model calculation. We have employed the energy dependence of the optical potential similar to Delaroche's work(De89). The initial potential parameters were adopted from Koning and Delaroche (Ko97). Total of 7 parameters concerning the central potential depth were estimated with associated covariance matrix, while the geometrical parameters were fixed to the result of a similar search for n + Ni-58. Presently obtained potential was used for the calculation of neutron transmission coefficients and DWBA cross sections in the energy region above 20 MeV. Below 20 MeV, the Harper neutron potential (Ha82) was used for the calculation of transmission coefficients.

The proton optical potential was also searched for to obtain a good description of proton-total reaction cross section as predicted by Wellisch-Axen systematic (We96) above 50 MeV. The parameter estimation was carried out by the Marquart-Bayesian approach similar to the neutron OMP, but trying to seek the best parameter to reproduce the reaction cross sections compiled by Carlson (Ca96) and Wellisch values. The experimental data in Carlson (Ca96) was scaled for Ni-62 according to A**(2/3) law. In this search, the geometrical parameters were fixed to be same as the neutron potential. The present potential gives a good description of the proton total reaction cross section from 10 MeV to 250 MeV. However, after some trial and error to reproduce both the elastic scattering and reaction cross section data for Ni-58,

we have employed the following combination of proton potentials:

0 to 5 MeV	:	Harper potential (Ha82)
6 to 47 MeV	:	Koning and Delaroche (Ko97)
48 to 260 MeV	:	Present OMP

For deuterons, the Lohr-Haeberli (Lo74) global potential was used; for alpha particles the McFadden-Satchler (Mc66) potential was used; and for tritons the Becchetti-Greenlees (Be71) potential was used. The He-3 channel was ignored.

The direct collective inelastic scattering to the following levels in Ni-62 was considered by the DWBA-mode calculation of ECIS95:

Jpi	Ex(MeV)	Deformation length
2+	1.173	1.008
3-	3.757	0.83

The data for the 2+ level was retrieved from the literature (Ra87). The data for the 3- level was estimated to be an average of the same quantity for Ni-58 and Ni-60.

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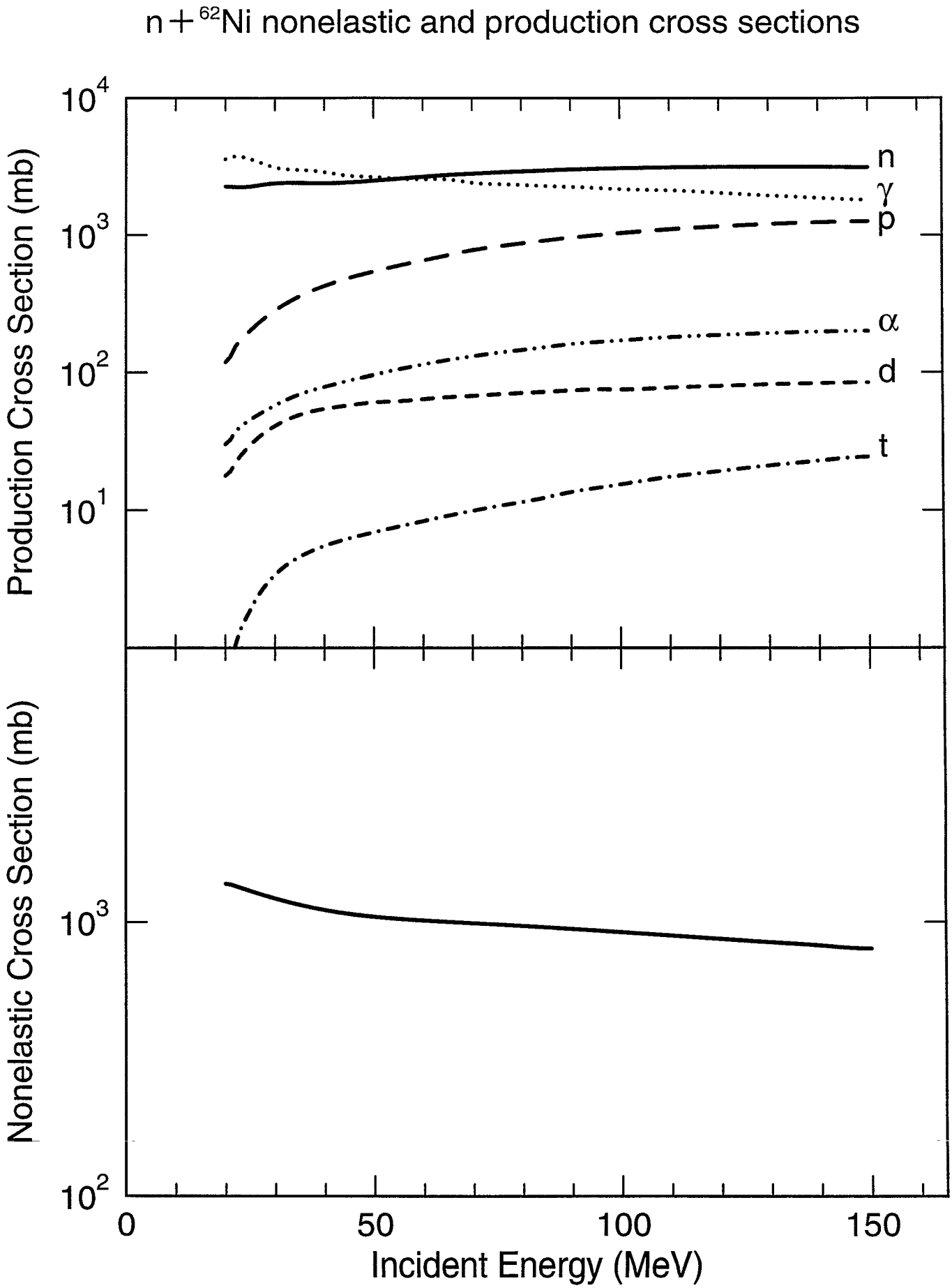
28062 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

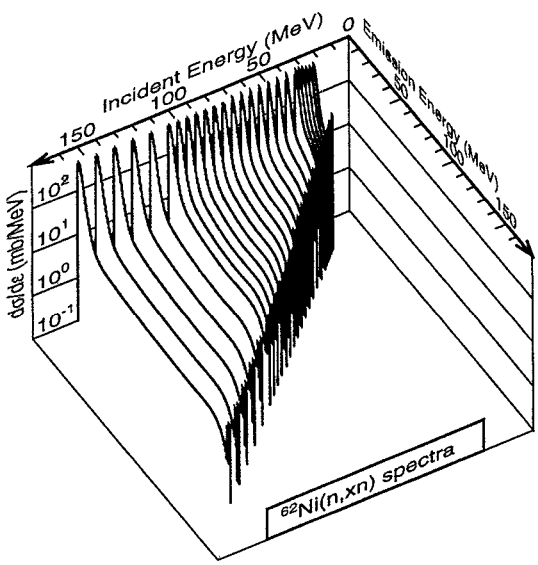
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	1.375E+00	1.059E+00	2.242E+00	1.188E-01	1.778E-02	5.573E-04	0.000E+00	3.009E-02	3.568E+00
2.200E+01	1.349E+00	1.052E+00	2.223E+00	1.538E-01	2.190E-02	1.033E-03	0.000E+00	3.691E-02	3.754E+00
2.400E+01	1.312E+00	1.080E+00	2.225E+00	1.871E-01	2.714E-02	1.589E-03	0.000E+00	4.288E-02	3.648E+00
2.600E+01	1.277E+00	1.112E+00	2.270E+00	2.185E-01	3.200E-02	2.186E-03	0.000E+00	4.780E-02	3.474E+00
2.800E+01	1.245E+00	1.179E+00	2.328E+00	2.510E-01	3.664E-02	2.793E-03	0.000E+00	5.270E-02	3.260E+00
3.000E+01	1.216E+00	1.244E+00	2.368E+00	2.831E-01	4.093E-02	3.368E-03	0.000E+00	5.784E-02	3.088E+00
3.500E+01	1.154E+00	1.403E+00	2.384E+00	3.579E-01	4.931E-02	4.562E-03	0.000E+00	6.966E-02	2.964E+00
4.000E+01	1.105E+00	1.522E+00	2.368E+00	4.267E-01	5.453E-02	5.484E-03	0.000E+00	7.866E-02	2.845E+00
4.500E+01	1.070E+00	1.614E+00	2.402E+00	4.878E-01	5.792E-02	6.227E-03	0.000E+00	8.761E-02	2.679E+00
5.000E+01	1.045E+00	1.651E+00	2.472E+00	5.413E-01	6.079E-02	6.901E-03	0.000E+00	9.603E-02	2.617E+00
5.500E+01	1.028E+00	1.656E+00	2.555E+00	5.976E-01	6.202E-02	7.586E-03	0.000E+00	1.050E-01	2.552E+00
6.000E+01	1.014E+00	1.635E+00	2.636E+00	6.524E-01	6.416E-02	8.314E-03	0.000E+00	1.141E-01	2.531E+00
6.500E+01	1.002E+00	1.570E+00	2.719E+00	7.117E-01	6.635E-02	9.088E-03	0.000E+00	1.233E-01	2.525E+00
7.000E+01	9.906E-01	1.504E+00	2.777E+00	7.732E-01	6.774E-02	9.868E-03	0.000E+00	1.312E-01	2.388E+00
7.500E+01	9.792E-01	1.441E+00	2.837E+00	8.213E-01	6.954E-02	1.068E-02	0.000E+00	1.388E-01	2.334E+00
8.000E+01	9.675E-01	1.370E+00	2.883E+00	8.670E-01	7.100E-02	1.146E-02	0.000E+00	1.456E-01	2.304E+00
8.500E+01	9.554E-01	1.281E+00	2.933E+00	9.112E-01	7.240E-02	1.238E-02	0.000E+00	1.528E-01	2.257E+00
9.000E+01	9.428E-01	1.204E+00	2.980E+00	9.569E-01	7.398E-02	1.352E-02	0.000E+00	1.607E-01	2.230E+00
9.500E+01	9.299E-01	1.130E+00	3.013E+00	9.952E-01	7.526E-02	1.446E-02	0.000E+00	1.663E-01	2.191E+00
1.000E+02	9.170E-01	1.078E+00	3.045E+00	1.032E+00	7.515E-02	1.541E-02	0.000E+00	1.713E-01	2.148E+00
1.100E+02	8.911E-01	9.193E-01	3.092E+00	1.099E+00	7.759E-02	1.747E-02	0.000E+00	1.811E-01	2.104E+00
1.200E+02	8.659E-01	8.139E-01	3.112E+00	1.151E+00	7.978E-02	1.923E-02	0.000E+00	1.879E-01	2.014E+00
1.300E+02	8.420E-01	7.238E-01	3.122E+00	1.199E+00	8.209E-02	2.115E-02	0.000E+00	1.941E-01	1.931E+00
1.400E+02	8.196E-01	6.447E-01	3.123E+00	1.235E+00	8.375E-02	2.293E-02	0.000E+00	1.990E-01	1.856E+00
1.500E+02	7.986E-01	5.879E-01	3.100E+00	1.256E+00	8.483E-02	2.438E-02	0.000E+00	2.012E-01	1.803E+00

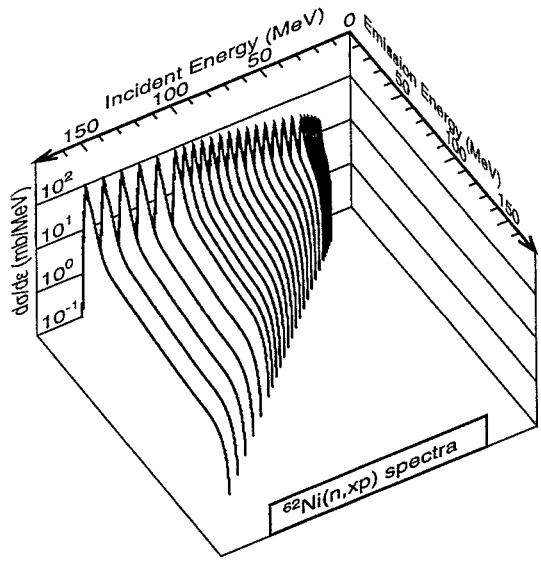
28062 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

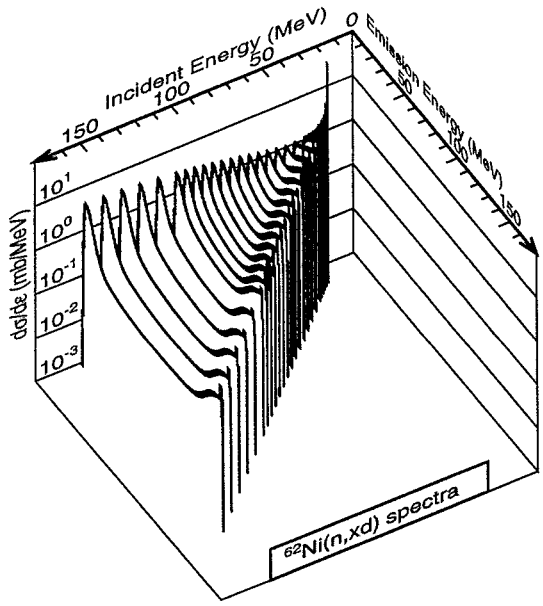
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	1.235E-01	2.182E-02	4.630E-04	0.000E+00	4.263E-02	8.329E-02	2.179E-02	2.935E-01
2.200E+01	1.697E-01	3.070E-02	9.952E-04	0.000E+00	5.355E-02	8.924E-02	2.062E-02	3.648E-01
2.400E+01	2.189E-01	4.289E-02	1.729E-03	0.000E+00	6.343E-02	9.373E-02	2.198E-02	4.427E-01
2.600E+01	2.704E-01	5.613E-02	2.632E-03	0.000E+00	7.185E-02	9.765E-02	2.269E-02	5.213E-01
2.800E+01	3.276E-01	7.052E-02	3.661E-03	0.000E+00	8.010E-02	1.013E-01	2.353E-02	6.068E-01
3.000E+01	3.893E-01	8.586E-02	4.770E-03	0.000E+00	8.875E-02	1.047E-01	2.391E-02	6.972E-01
3.500E+01	5.585E-01	1.252E-01	7.618E-03	0.000E+00	1.099E-01	1.121E-01	2.376E-02	9.371E-01
4.000E+01	7.370E-01	1.627E-01	1.039E-02	0.000E+00	1.272E-01	1.192E-01	2.260E-02	1.179E+00
4.500E+01	9.250E-01	1.979E-01	1.298E-02	0.000E+00	1.441E-01	1.261E-01	2.126E-02	1.427E+00
5.000E+01	1.114E+00	2.330E-01	1.541E-02	0.000E+00	1.611E-01	1.331E-01	1.963E-02	1.676E+00
5.500E+01	1.315E+00	2.581E-01	1.779E-02	0.000E+00	1.794E-01	1.396E-01	1.806E-02	1.928E+00
6.000E+01	1.519E+00	2.887E-01	2.006E-02	0.000E+00	1.978E-01	1.462E-01	1.661E-02	2.188E+00
6.500E+01	1.736E+00	3.191E-01	2.229E-02	0.000E+00	2.167E-01	1.522E-01	1.506E-02	2.461E+00
7.000E+01	1.953E+00	3.434E-01	2.434E-02	0.000E+00	2.335E-01	1.585E-01	1.378E-02	2.726E+00
7.500E+01	2.163E+00	3.714E-01	2.635E-02	0.000E+00	2.500E-01	1.630E-01	1.272E-02	2.987E+00
8.000E+01	2.371E+00	3.971E-01	2.817E-02	0.000E+00	2.652E-01	1.670E-01	1.175E-02	3.241E+00
8.500E+01	2.571E+00	4.202E-01	2.999E-02	0.000E+00	2.813E-01	1.708E-01	1.072E-02	3.484E+00
9.000E+01	2.766E+00	4.412E-01	3.193E-02	0.000E+00	2.987E-01	1.746E-01	9.898E-03	3.723E+00
9.500E+01	2.960E+00	4.621E-01	3.358E-02	0.000E+00	3.120E-01	1.773E-01	9.148E-03	3.954E+00
1.000E+02	3.156E+00	4.632E-01	3.518E-02	0.000E+00	3.244E-01	1.786E-01	8.621E-03	4.166E+00
1.100E+02	3.538E+00	4.940E-01	3.817E-02	0.000E+00	3.489E-01	1.812E-01	7.223E-03	4.608E+00
1.200E+02	3.900E+00	5.277E-01	4.002E-02	0.000E+00	3.675E-01	1.825E-01	6.321E-03	5.024E+00
1.300E+02	4.247E+00	5.588E-01	4.147E-02	0.000E+00	3.851E-01	1.887E-01	5.580E-03	5.427E+00
1.400E+02	4.585E+00	5.841E-01	4.258E-02	0.000E+00	3.999E-01	1.958E-01	4.950E-03	5.813E+00
1.500E+02	4.910E+00	6.143E-01	4.326E-02	0.000E+00	4.093E-01	2.011E-01	4.506E-03	6.182E+00

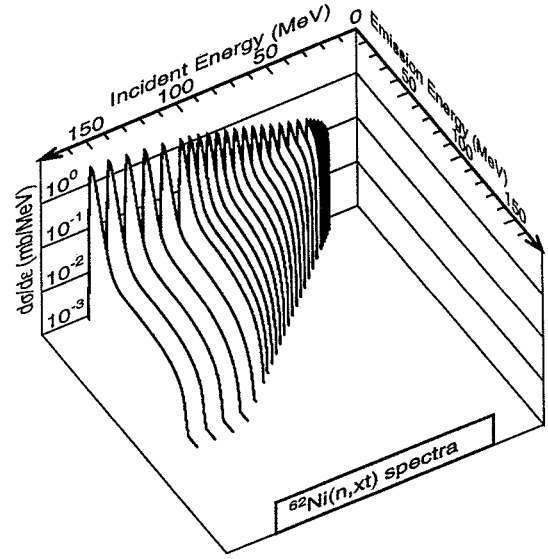

n + 62Ni nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
n
γ
p
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
0
50
100
150
Incident Energy (MeV)

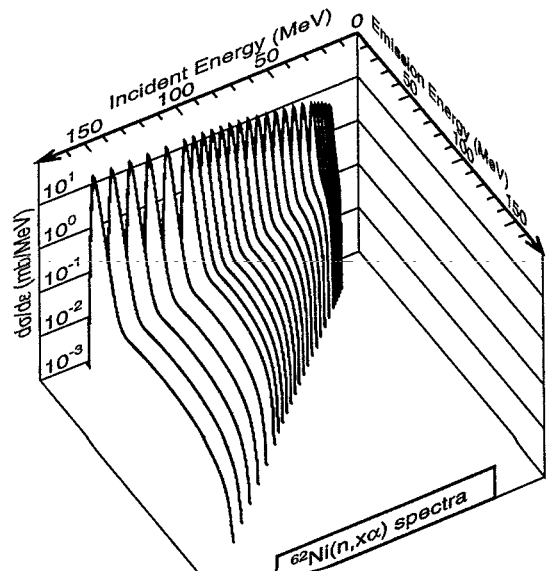
n + ^{62}Ni angle-integrated emission spectra

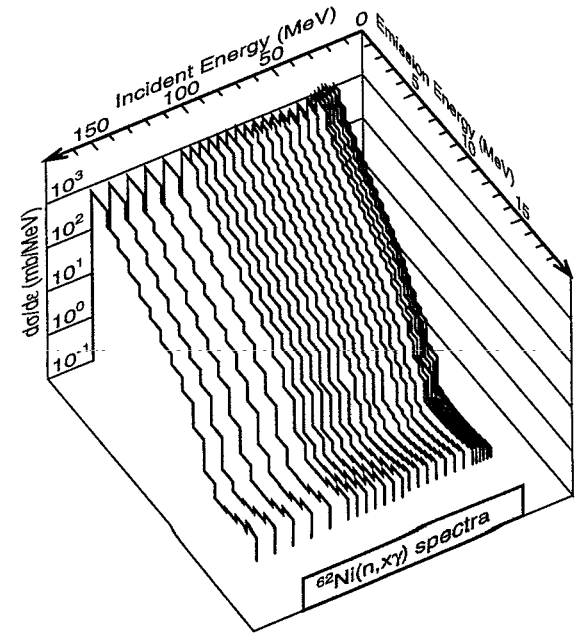




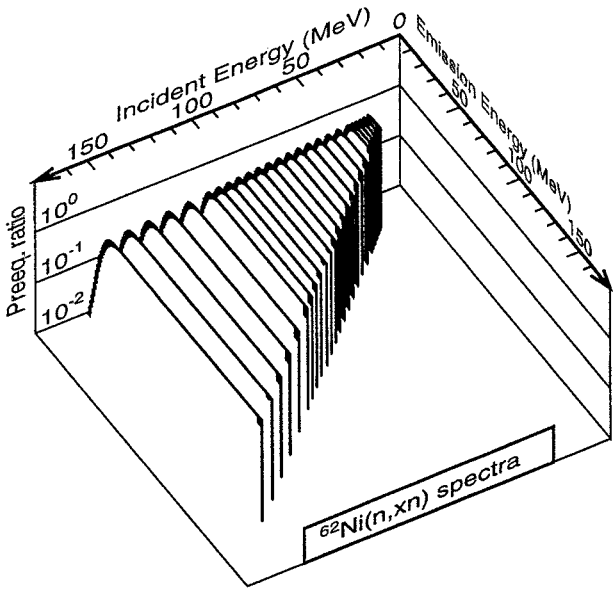


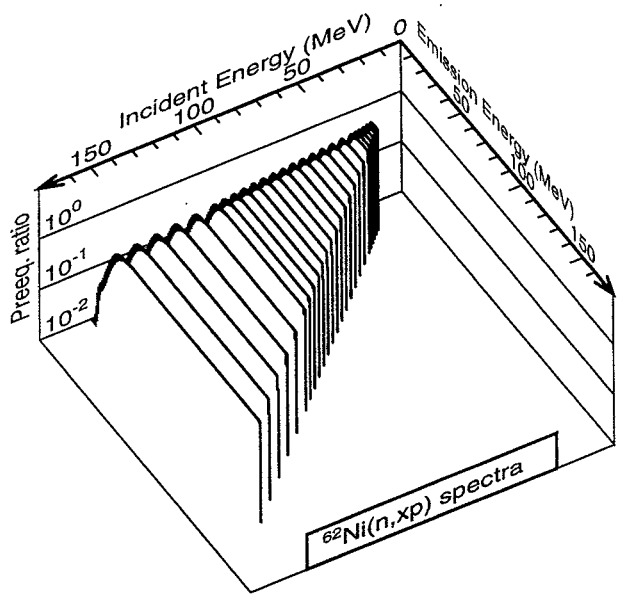


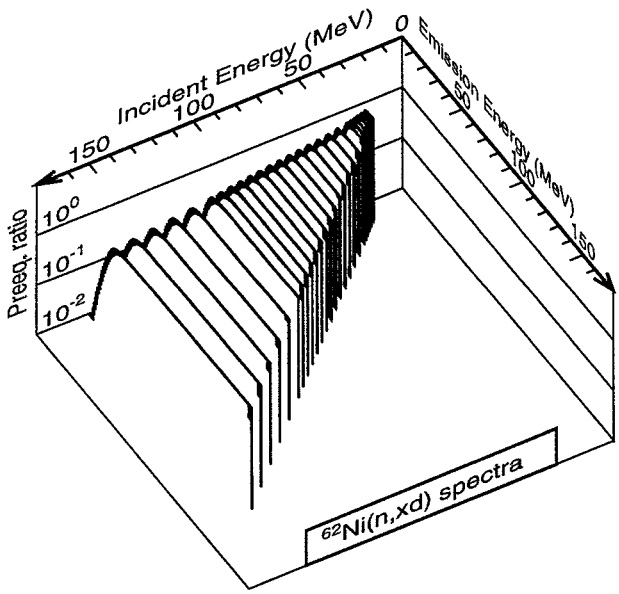


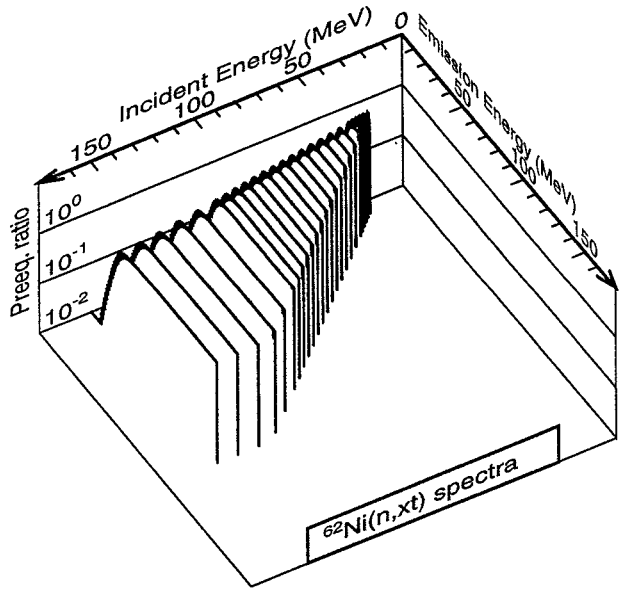


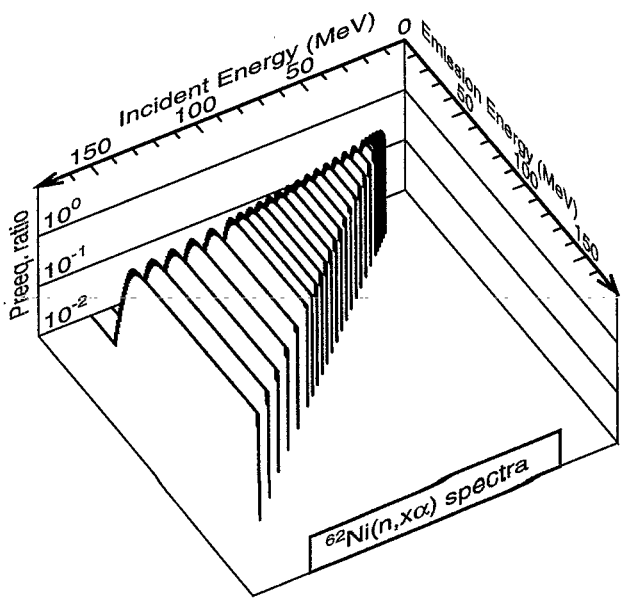
n + ^{62}Ni Kalbach preequilibrium ratios

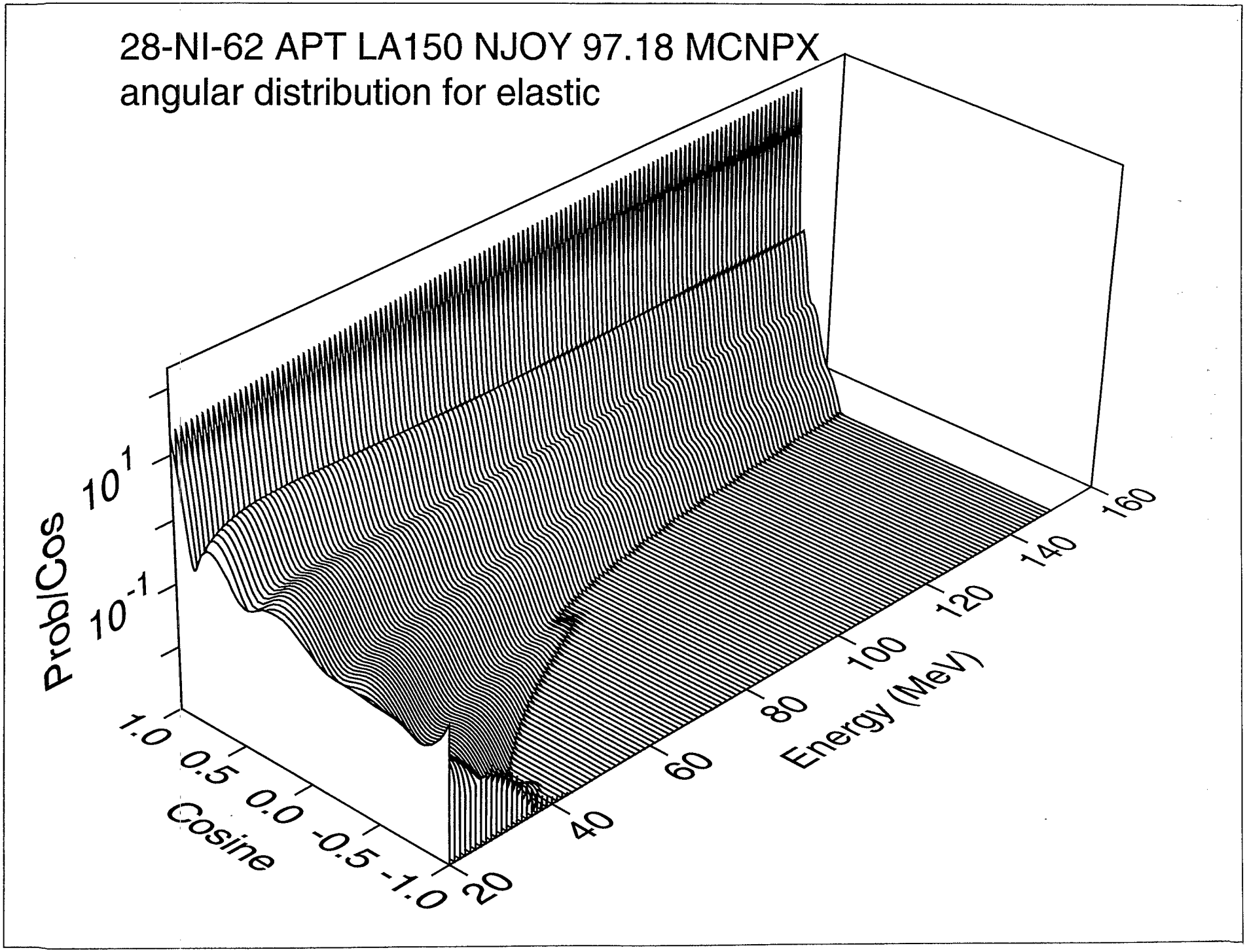


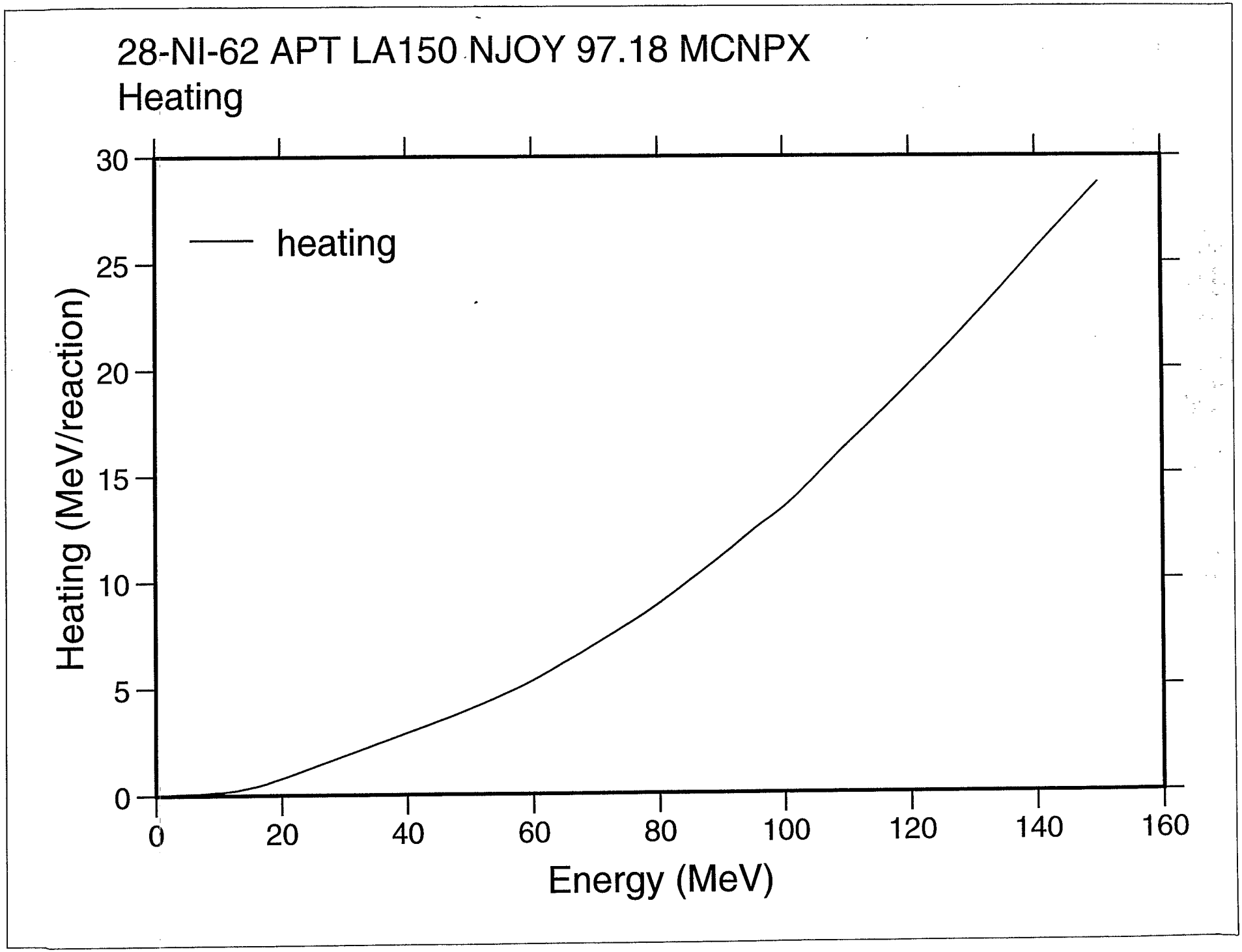


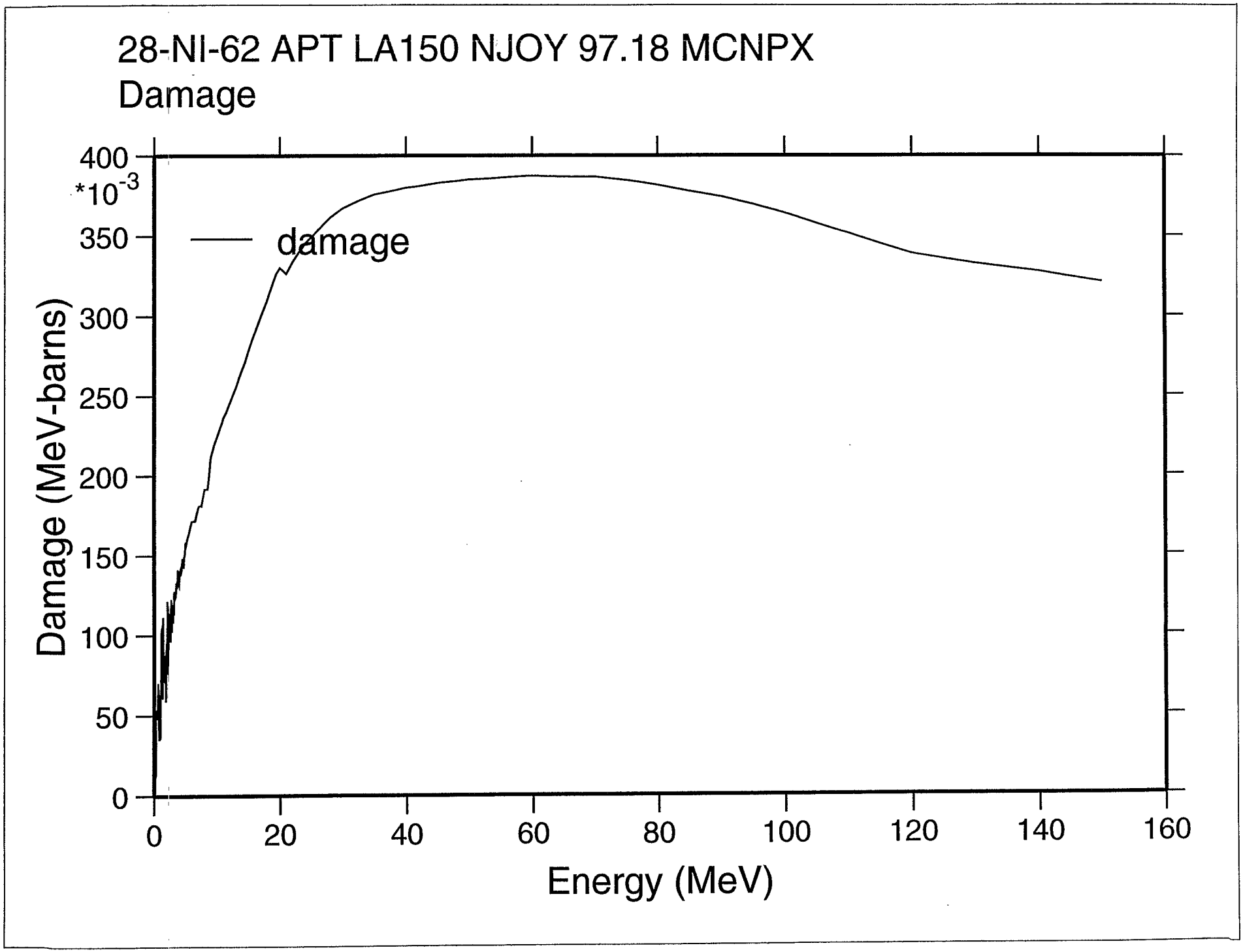







28-NI-62 APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic
Prob/Cos
10^1
10^{-1}
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


28-NI-62 APT LA150 NJOY 97.18 MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
5
10
15
20
25
30
0
20
40
60
80
100
120
140
160


28-NI-62 APT LA150 NJOY 97.18 MCNPX
Damage
damage
Damage (MeV-barns)
*10^-3
400
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF n + 64Ni CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

S. Chiba, M. B. Chadwick, P. G. Young, and A. J. Koning
22 Sept. 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI.5 (Release 2) evaluation by Larson, C. Perey, Hetrich, and Fu.

INCIDENT NEUTRON ENERGIES > 20 MeV

The ENDF/B-VI Release 2 evaluation extends to 20 MeV and includes cross sections and energy-angle data for all significant reactions. The present evaluation utilizes a more compact composite reaction spectrum representation above 20 MeV in order to reduce the length of the file. No essential data for applications is lost with this representation.

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT= 1	Total Cross Section
	MT= 2	Elastic Scattering Cross Section
	MT= 3	Nonelastic Cross Section
	MT= 5	Sum of Binary (n,n') and (n,x) Reactions
MF=4	MT= 2	Elastic Angular Distributions
MF=6	MT= 5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, Tritons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Ni58 and p + Ni58 reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of

all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Gilbert and Cameron (Gi65) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged- particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

SOME Ni-SPECIFIC INFORMATION CONCERNING THE EVAL.

The neutron total cross section was evaluated based on the least-squares method with GMA code system (Po81) taking account of the experimental data(Ci68, Pe73, Sc73, La83, Di97, Fa66, Du67). The data for natural Ni were also used because there was not enough data for Ni-64 at MeV region. The data for natural Ni were transformed to the Ni-64 cross section according to A*(2/3) law. In the GMA analysis, the systematic error was assumed to be 1 % for all the data set. Result of the GMA evaluation was used as the evaluated total cross section data above 20 MeV.

The evaluated total cross section data (1 to 250 MeV) and s-wave strength function (Mu81) were used to obtain the neutron optical potential parameters. The parameter estimation was carried out based on Marquart-Bayesian approach (Sm91), where ECIS95 code was used for the optical model calculation. We have employed the energy dependence of the optical potential similar to Delaroche's work(De89). The initial potential parameters were adopted from Koning and Delaroche (Ko97). Total of 7 parameters concerning the central potential depth were estimated with associated covariance matrix, while the geometircal parameters were fixed to the result of a similar search for n + Ni-58. Presently obtained potential was used for the calculation of neutron transmission coefficients and DWBA cross sections in the energy region above 20 MeV. Below 20 MeV, the Harper neutron potential (Ha82) was used for the calculation of transmission coefficients.

The proton optical potential was also searched for to obtain a good description of proton-total reaction cross section as predicted by Wellisch-Axen systematic (We96) above 50 MeV. The parameter estimation was carried out by the Marquart-Bayesian approach similar to the neutron OMP, but trying to seek the best parameter to reproduce the reaction cross sections compiled by Carlson (Ca96) and Wellisch values. The experimental data in Carlson (Ca96) was scaled for Ni-64 according to A**(2/3) law. In this search, the geometrical parameters were fixed to be same as the neutron potential. The present potential gives a good description of the proton total reaction cross section from 10 MeV to 250 MeV. However, after some trial and error to reproduce both the elastic scattering and reaction cross section data for Ni-58,

we have employed the following combination of proton potentials:

0 to 5 MeV	:	Harper potential (Ha82)
6 to 47 MeV	:	Koning and Delaroche (Ko97)
48 to 260 MeV	:	Present OMP

For deuterons, the Lohr-Haeberli (Lo74) global potential was used; for alpha particles the McFadden-Satchler (Mc66) potential was used; and for tritons the Becchetti-Greenlees (Be71) potential was used. The He-3 channel was ignored.

The direct collective inelastic scattering to the following levels in Ni-64 was considered by the DWBA-mode calculation of ECIS95 (Ra96):

Jpi	Ex(MeV)	Deformation length
2+	1.3458	0.9215
3-	3.56	0.838

The data for 2+ level was retrieved from the literature (Ra87). The deformation length for the 3- level was scaled from the same quantity for Ni-62 according to A**(1/3) law.

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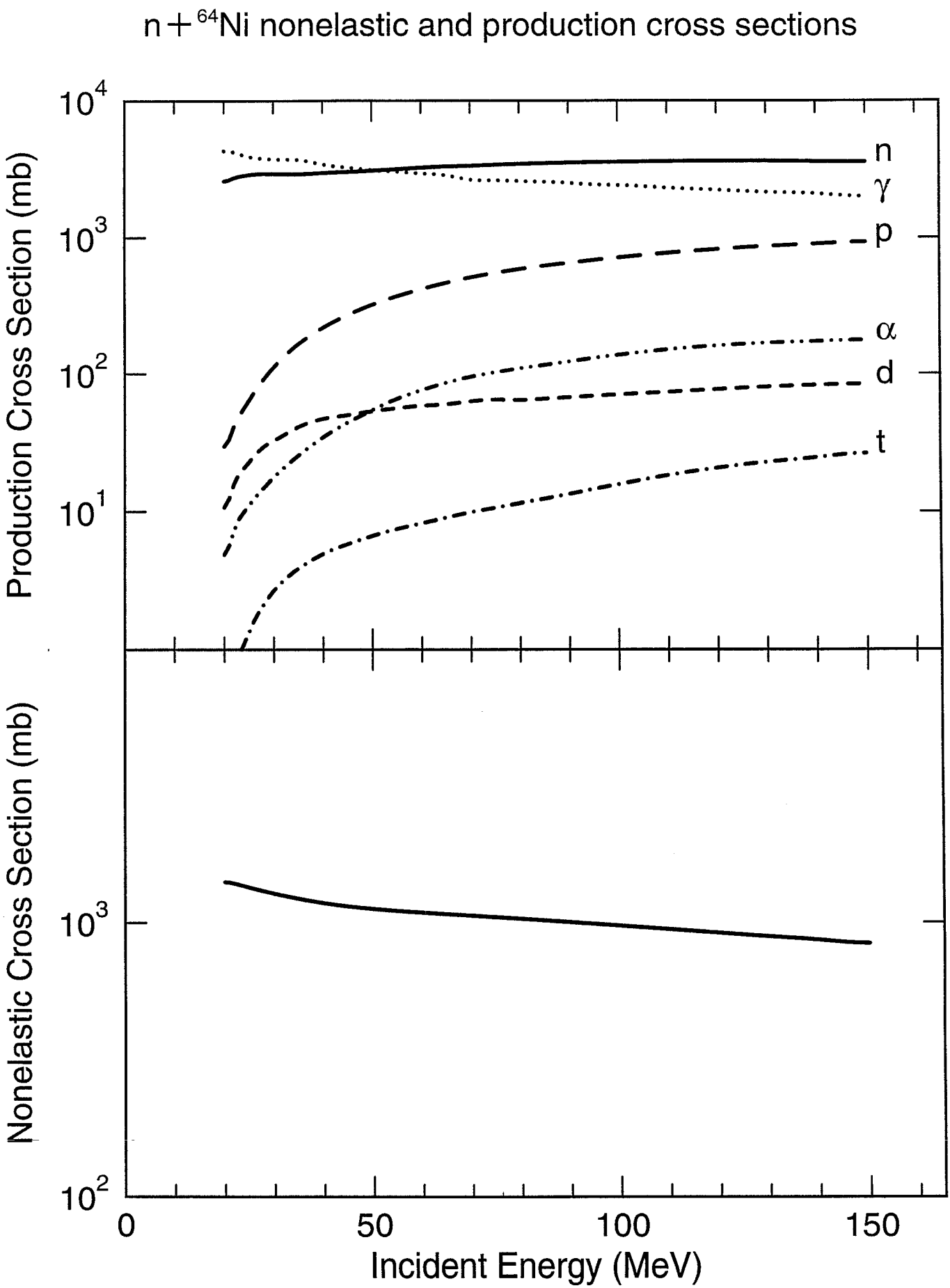
28064 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

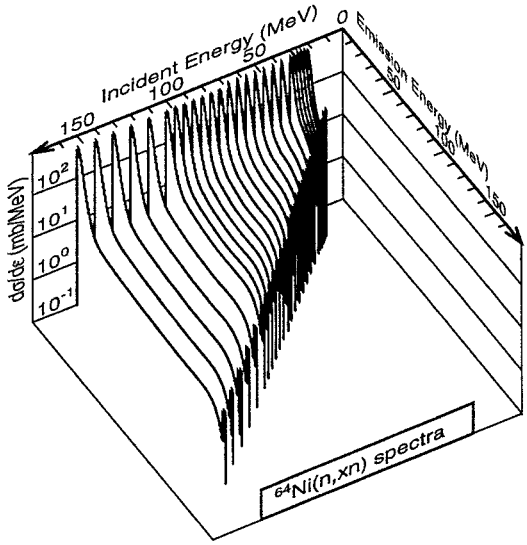
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	1.408E+00	1.078E+00	2.574E+00	2.954E-02	1.073E-02	2.980E-04	0.000E+00	4.875E-03	4.298E+00
2.200E+01	1.390E+00	1.062E+00	2.718E+00	4.152E-02	1.587E-02	6.495E-04	0.000E+00	7.367E-03	4.212E+00
2.400E+01	1.358E+00	1.085E+00	2.831E+00	5.587E-02	2.061E-02	1.100E-03	0.000E+00	9.951E-03	3.987E+00
2.600E+01	1.328E+00	1.113E+00	2.899E+00	7.242E-02	2.508E-02	1.608E-03	0.000E+00	1.232E-02	3.831E+00
2.800E+01	1.301E+00	1.175E+00	2.925E+00	9.136E-02	2.955E-02	2.142E-03	0.000E+00	1.483E-02	3.779E+00
3.000E+01	1.276E+00	1.237E+00	2.921E+00	1.121E-01	3.261E-02	2.672E-03	0.000E+00	1.766E-02	3.732E+00
3.500E+01	1.221E+00	1.390E+00	2.907E+00	1.661E-01	4.099E-02	3.877E-03	0.000E+00	2.546E-02	3.694E+00
4.000E+01	1.178E+00	1.506E+00	2.963E+00	2.193E-01	4.702E-02	4.944E-03	0.000E+00	3.454E-02	3.413E+00
4.500E+01	1.146E+00	1.595E+00	3.015E+00	2.720E-01	5.006E-02	5.834E-03	0.000E+00	4.407E-02	3.234E+00
5.000E+01	1.122E+00	1.633E+00	3.075E+00	3.237E-01	5.333E-02	6.675E-03	0.000E+00	5.430E-02	3.097E+00
5.500E+01	1.103E+00	1.638E+00	3.148E+00	3.740E-01	5.600E-02	7.493E-03	0.000E+00	6.551E-02	3.020E+00
6.000E+01	1.087E+00	1.618E+00	3.226E+00	4.219E-01	5.841E-02	8.232E-03	0.000E+00	7.576E-02	2.925E+00
6.500E+01	1.073E+00	1.553E+00	3.298E+00	4.687E-01	5.984E-02	9.042E-03	0.000E+00	8.597E-02	2.841E+00
7.000E+01	1.060E+00	1.488E+00	3.339E+00	5.135E-01	6.284E-02	9.899E-03	0.000E+00	9.503E-02	2.633E+00
7.500E+01	1.046E+00	1.426E+00	3.394E+00	5.525E-01	6.457E-02	1.064E-02	0.000E+00	1.025E-01	2.607E+00
8.000E+01	1.032E+00	1.356E+00	3.439E+00	5.892E-01	6.411E-02	1.148E-02	0.000E+00	1.098E-01	2.572E+00
8.500E+01	1.018E+00	1.266E+00	3.478E+00	6.228E-01	6.558E-02	1.235E-02	0.000E+00	1.164E-01	2.543E+00
9.000E+01	1.004E+00	1.189E+00	3.513E+00	6.549E-01	6.716E-02	1.334E-02	0.000E+00	1.232E-01	2.497E+00
9.500E+01	9.891E-01	1.115E+00	3.542E+00	6.866E-01	6.877E-02	1.451E-02	0.000E+00	1.309E-01	2.433E+00
1.000E+02	9.744E-01	1.063E+00	3.558E+00	7.165E-01	7.032E-02	1.568E-02	0.000E+00	1.377E-01	2.408E+00
1.100E+02	9.451E-01	9.040E-01	3.598E+00	7.723E-01	7.334E-02	1.821E-02	0.000E+00	1.508E-01	2.305E+00
1.200E+02	9.165E-01	7.993E-01	3.615E+00	8.206E-01	7.678E-02	2.060E-02	0.000E+00	1.610E-01	2.224E+00
1.300E+02	8.890E-01	7.103E-01	3.617E+00	8.645E-01	7.999E-02	2.275E-02	0.000E+00	1.686E-01	2.140E+00
1.400E+02	8.630E-01	6.325E-01	3.585E+00	9.001E-01	8.255E-02	2.458E-02	0.000E+00	1.734E-01	2.092E+00
1.500E+02	8.386E-01	5.776E-01	3.563E+00	9.312E-01	8.389E-02	2.634E-02	0.000E+00	1.772E-01	1.995E+00

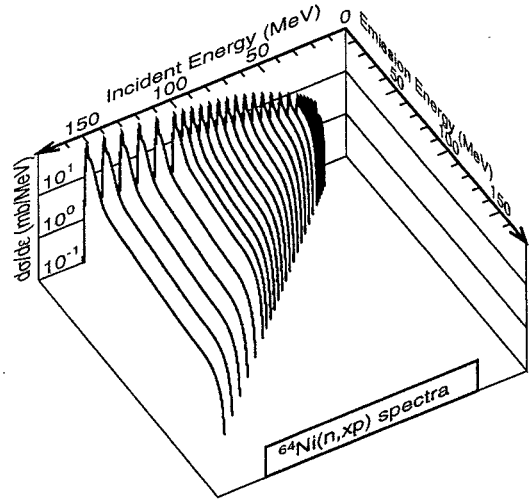
28064 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

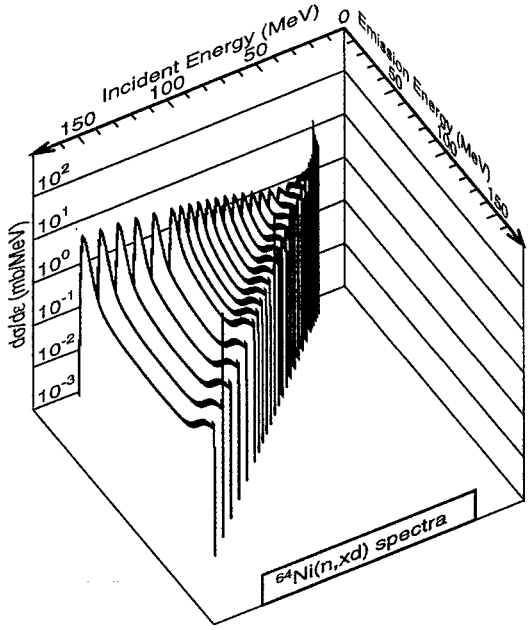
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	3.226E-02	1.161E-02	2.300E-04	0.000E+00	6.576E-03	7.800E-02	2.021E-02	1.489E-01
2.200E+01	5.050E-02	2.022E-02	5.864E-04	0.000E+00	1.021E-02	8.388E-02	1.803E-02	1.834E-01
2.400E+01	7.393E-02	3.008E-02	1.122E-03	0.000E+00	1.418E-02	8.877E-02	1.880E-02	2.269E-01
2.600E+01	1.031E-01	4.110E-02	1.815E-03	0.000E+00	1.804E-02	9.313E-02	1.907E-02	2.762E-01
2.800E+01	1.389E-01	5.370E-02	2.632E-03	0.000E+00	2.215E-02	9.693E-02	1.952E-02	3.339E-01
3.000E+01	1.812E-01	6.402E-02	3.527E-03	0.000E+00	2.673E-02	1.004E-01	1.965E-02	3.956E-01
3.500E+01	3.096E-01	9.848E-02	5.963E-03	0.000E+00	3.951E-02	1.080E-01	1.929E-02	5.809E-01
4.000E+01	4.601E-01	1.342E-01	8.443E-03	0.000E+00	5.462E-02	1.158E-01	1.828E-02	7.914E-01
4.500E+01	6.287E-01	1.630E-01	1.083E-02	0.000E+00	7.068E-02	1.233E-01	1.723E-02	1.014E+00
5.000E+01	8.057E-01	1.951E-01	1.314E-02	0.000E+00	8.827E-02	1.305E-01	1.598E-02	1.249E+00
5.500E+01	9.900E-01	2.250E-01	1.535E-02	0.000E+00	1.077E-01	1.373E-01	1.479E-02	1.490E+00
6.000E+01	1.180E+00	2.539E-01	1.738E-02	0.000E+00	1.259E-01	1.435E-01	1.369E-02	1.734E+00
6.500E+01	1.376E+00	2.753E-01	1.938E-02	0.000E+00	1.445E-01	1.489E-01	1.248E-02	1.977E+00
7.000E+01	1.574E+00	3.096E-01	2.131E-02	0.000E+00	1.615E-01	1.547E-01	1.148E-02	2.232E+00
7.500E+01	1.771E+00	3.341E-01	2.302E-02	0.000E+00	1.760E-01	1.585E-01	1.065E-02	2.473E+00
8.000E+01	1.969E+00	3.363E-01	2.473E-02	0.000E+00	1.906E-01	1.615E-01	9.880E-03	2.692E+00
8.500E+01	2.163E+00	3.570E-01	2.635E-02	0.000E+00	2.041E-01	1.642E-01	9.048E-03	2.924E+00
9.000E+01	2.352E+00	3.762E-01	2.799E-02	0.000E+00	2.181E-01	1.664E-01	8.377E-03	3.149E+00
9.500E+01	2.536E+00	3.942E-01	2.974E-02	0.000E+00	2.337E-01	1.684E-01	7.763E-03	3.370E+00
1.000E+02	2.718E+00	4.112E-01	3.136E-02	0.000E+00	2.481E-01	1.701E-01	7.339E-03	3.586E+00
1.100E+02	3.071E+00	4.374E-01	3.430E-02	0.000E+00	2.761E-01	1.730E-01	6.169E-03	3.998E+00
1.200E+02	3.413E+00	4.687E-01	3.655E-02	0.000E+00	2.993E-01	1.746E-01	5.422E-03	4.398E+00
1.300E+02	3.756E+00	4.993E-01	3.838E-02	0.000E+00	3.180E-01	1.790E-01	4.810E-03	4.796E+00
1.400E+02	4.086E+00	5.274E-01	3.981E-02	0.000E+00	3.317E-01	1.855E-01	4.289E-03	5.174E+00
1.500E+02	4.410E+00	5.323E-01	4.129E-02	0.000E+00	3.433E-01	1.905E-01	3.928E-03	5.521E+00

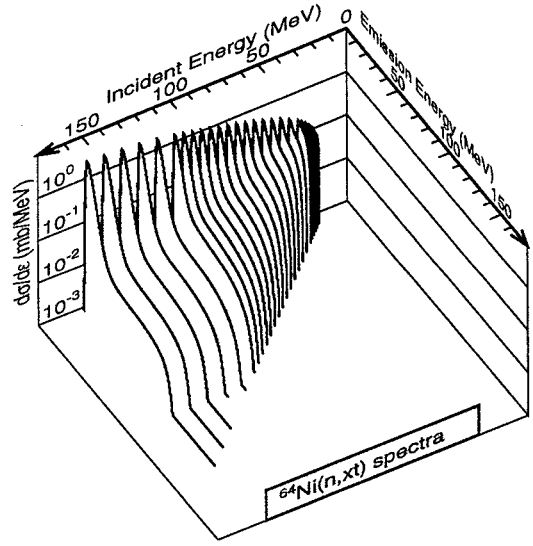

n + 64Ni nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
n
γ
p
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
0
50
100
150
Incident Energy (MeV)

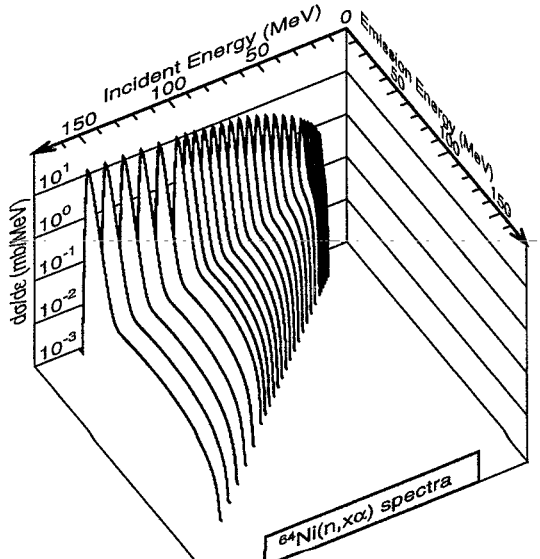
n + ^{64}Ni angle-integrated emission spectra

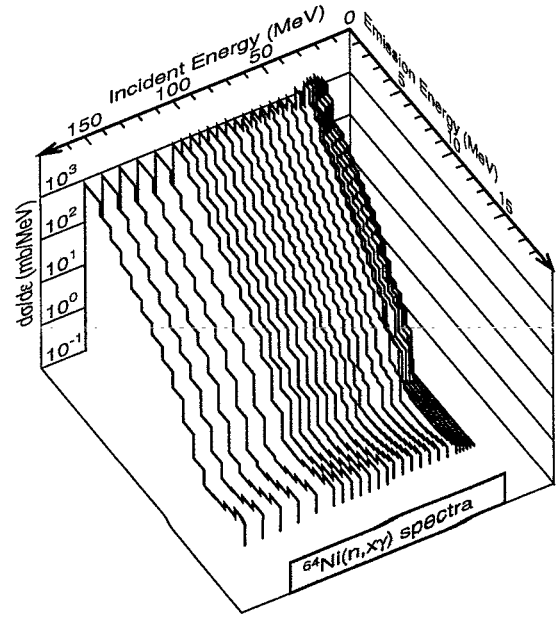




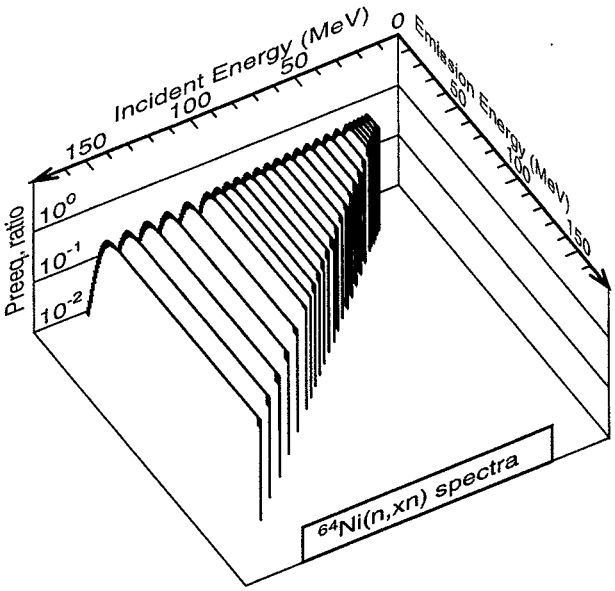


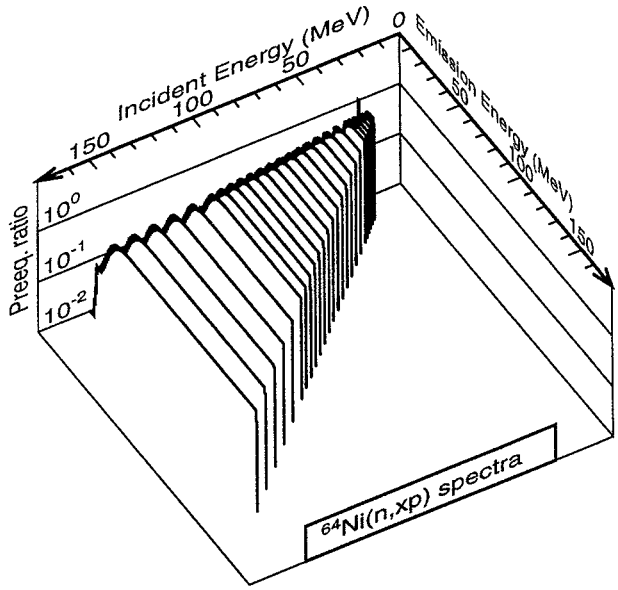


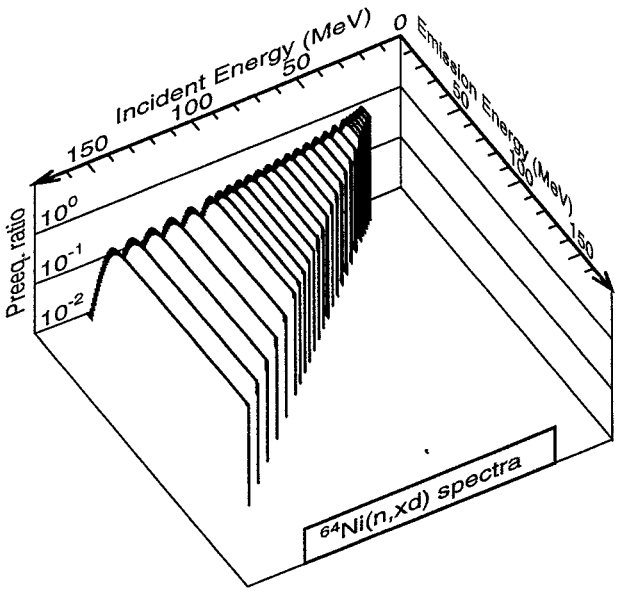


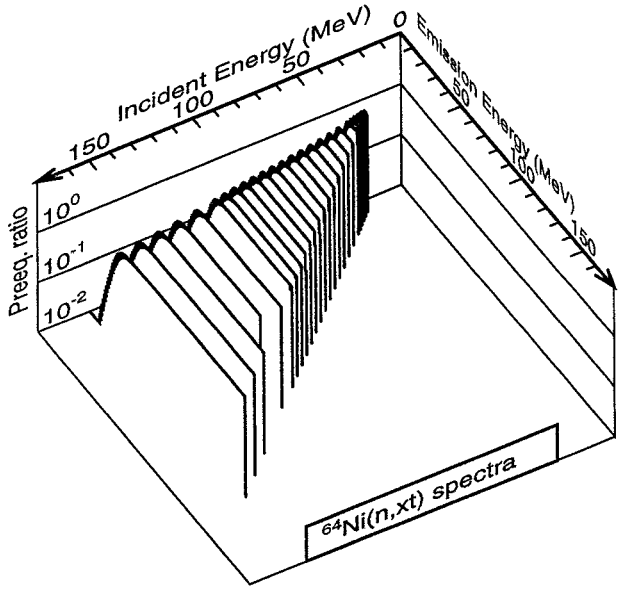


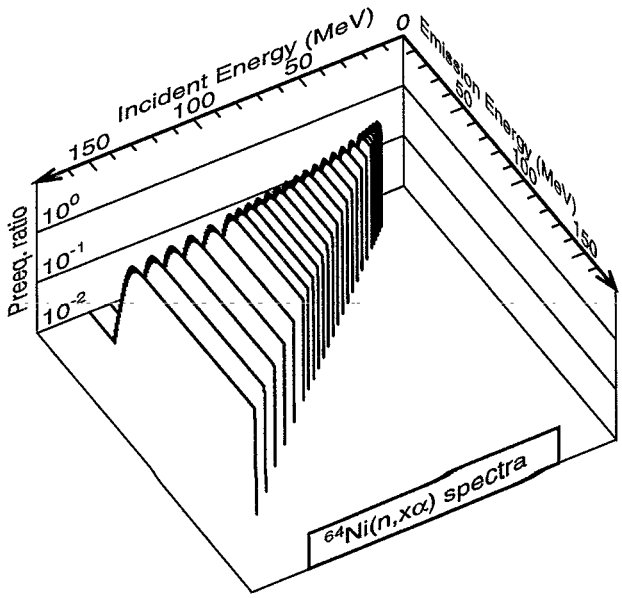
n + ^{64}Ni Kalbach preequilibrium ratios

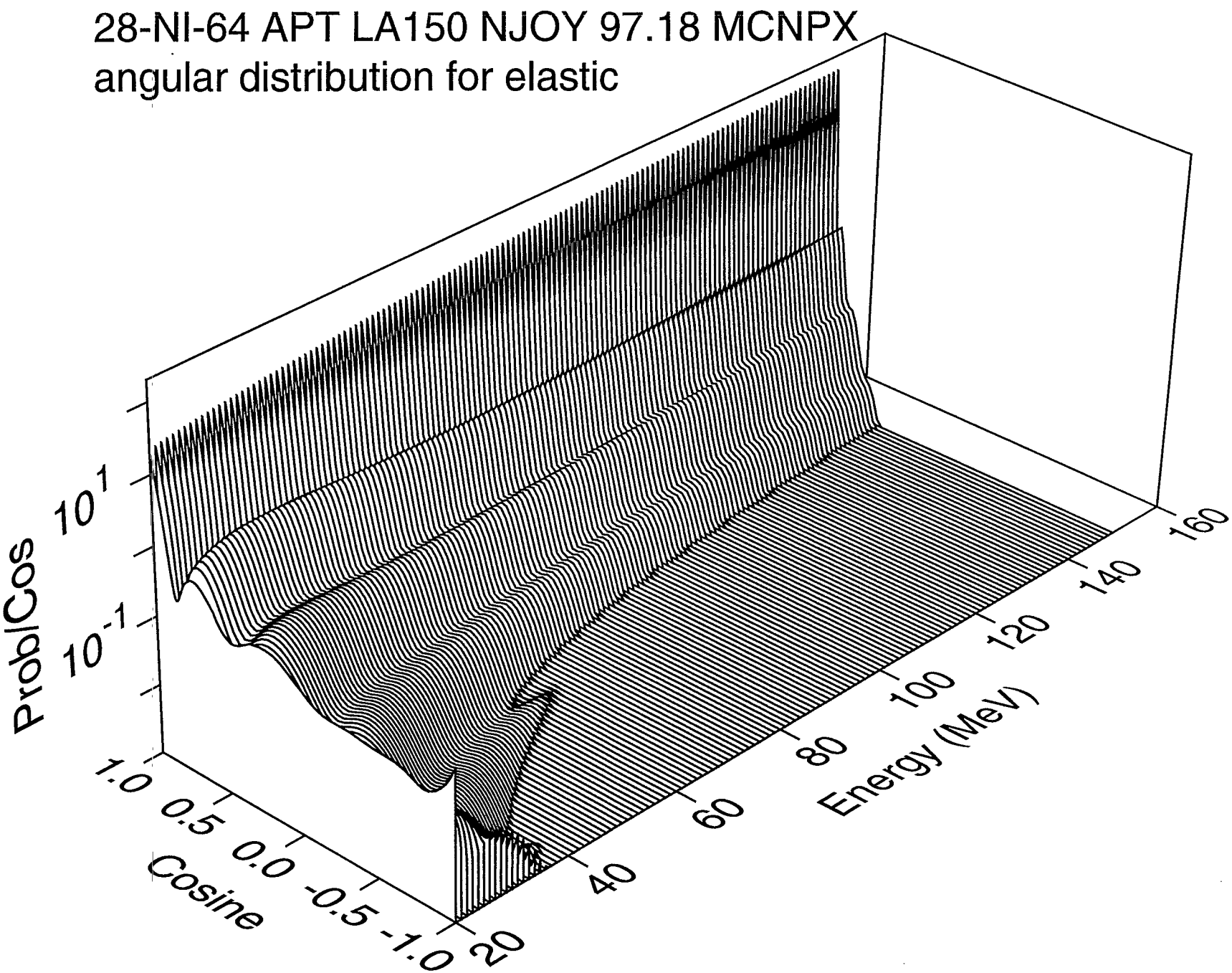


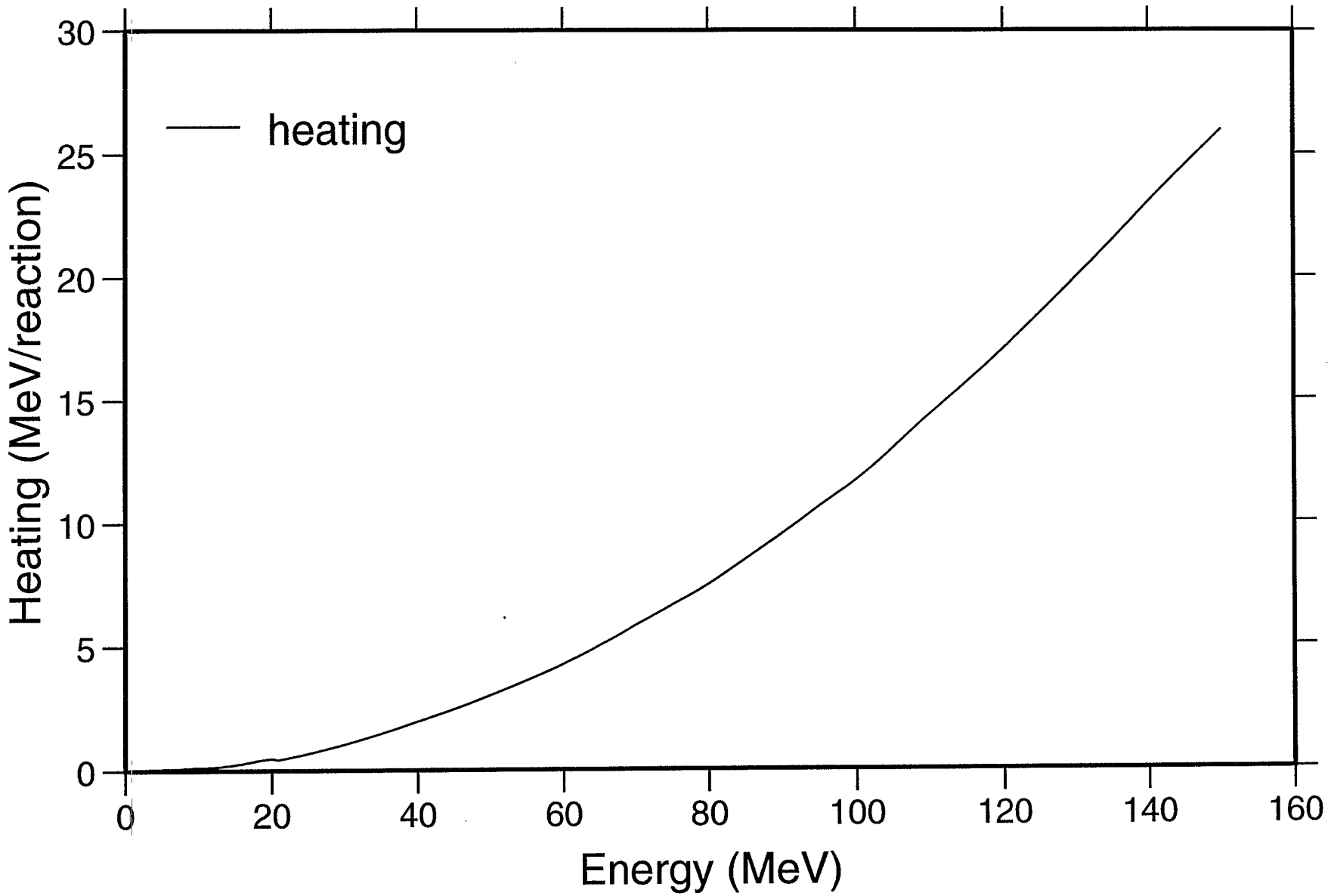


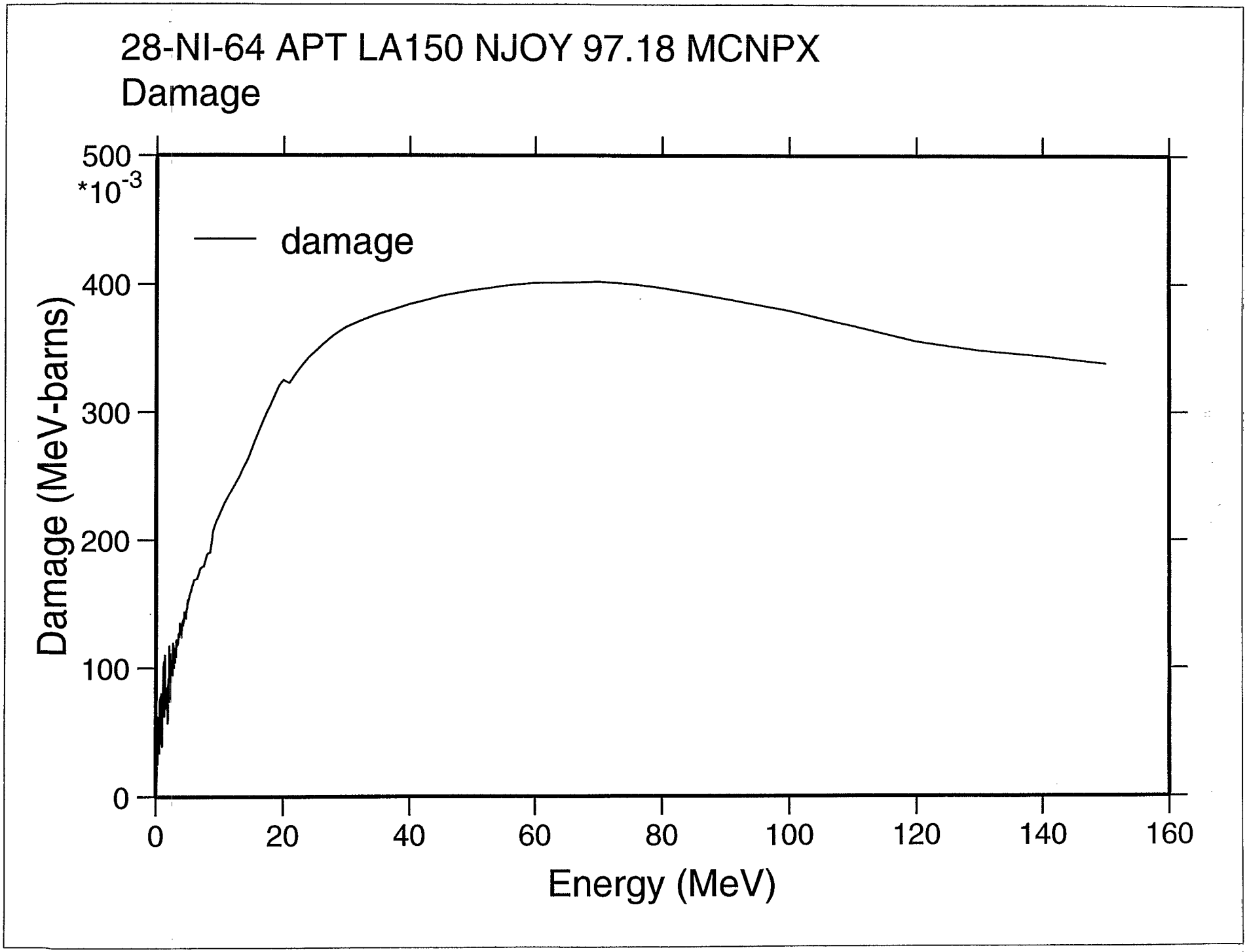







28-NI-64 APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic
Prob/Cos
10^{1}
10^{-1}
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


28-NI-64 APT LA150 NJOY 97.18 MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
5
10
15
20
25
30
0
20
40
60
80
100
120
140
160


28-NI-64 APT LA150 NJOY 97.18 MCNPX
Damage
damage
Damage (MeV-barns)
*10^-3
500
400
300
200
100
0
0
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF n + 63Cu CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

A. J. Koning, M. B. Chadwick, and P. G. Young
15 February 1998

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI (Release 2) evaluation by D. Hetrick, C.Y. Fu, and D. Larson.

INCIDENT NEUTRON ENERGIES > 20 MeV

The ENDF/B-VI Release 2 evaluation extends to 20 MeV and includes cross sections and energy-angle data for all significant reactions. The present evaluation utilizes a more compact composite reaction spectrum representation above 20 MeV in order to reduce the length of the file. No essential data for applications is lost with this representation.

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT= 1	Total Cross Section
	MT= 2	Elastic Scattering Cross Section
	MT= 3	Nonelastic Cross Section
	MT= 5	Sum of Binary (n,n') and (n,x) Reactions
MF=4	MT= 2	Elastic Angular Distributions
MF=6	MT= 5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, Tritons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Cu65 and p + Cu65 reactions (Ch98). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96a). The recoil energy distributions are represented in the laboratory system in

MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk et al. (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

SPECIFIC INFORMATION CONCERNING THE Cu-63 EVALUATION

This evaluation is documented in some detail in Ref. (Ko98b).

The neutron total cross section above 20 MeV was obtained by evaluating experimental data, with a particular emphasis on the Finlay (Fi93) elemental data. This resulted in an evaluated elemental Cu total cross section; to obtain an isotopic 63Cu total cross section, it was assumed that 63Cu and 65Cu have total cross sections in an A**2/3 ratio to one another. The total neutron nonelastic cross section was obtained directly from an optical model calculation (see below), after verifying that it was in good agreement with the experimental data (Ko98b).

To obtain the neutron optical potential we used total cross section data from 1.2 to 4.5 MeV (Gu86) and from 5.3 to 600 MeV (Fi93), and elastic scattering angular distribution data from 1.6 to 96 MeV (Br50, Sa60, Ki74, El82, Gu86). The optical potential parameters were obtained using a combination of a grid search code and the interactive optical model viewer ECISVIEW [Ko97], both built around the coupled channels code ECIS96 [Ra94]. The energy dependence of the optical model parameters is as described in [Ko98]. This optical potential was used for the calculation, with ECIS96, of neutron transmission coefficients and DWBA cross sections for the entire energy region above 20 MeV.

Due to the lack of proton elastic scattering data in numerical form, we used a combination of global optical models for the proton channel. The Becchetti-Greenlees potential [Be69]was adopted below 47 MeV, and the non-relativistic version of the Madland potential [Ma88] above 47 MeV. At this particular energy point the two potentials join smoothly.

For deuterons, the Lohr-Haeberli global potential [Lo74] was used; for alpha particles the Moyen potential (MacFadden-Satchler [Ma66]) was used; and for tritons the Becchetti-Greenlees potential [Be71] was used. The He-3 channel was ignored, due to its small importance.

Following Delaroche et al. [De82], we adopted the weak-coupling model for direct collective inelastic scattering for Cu-63, using Ni-64 as a basis. For the calculation of the cross sections, ECIS96 was used in DWBA mode. We used the following direct transitions for Cu-63 (ground state 3/2-) :

Jpi	Ex(MeV)	Deformation lengths
0.5-	0.669	Delta(2)=0.319
2.5-	0.962	Delta(2)=0.552
3.5-	1.327	Delta(2)=0.638
1.5-	1.547	Delta(2)=0.451
1.5-	3.382	Delta(3)=0.313
2.5-	3.632	Delta(3)=0.384
3.5-	3.882	Delta(3)=0.444
4.5-	4.132	Delta(3)=0.496

No measurements exist for neutron-induced emission spectra above 20 MeV for 63Cu. However, for Cu-65 there exists 25.7 MeV (n,xn) data by Marcinkowski et al (Ma83). This has been used to benchmark the Cu-65 data. Without adjusting any of the level density or pre-equilibrium parameters the GNASH calculation was in good agreement with these data. Hence we also adopted these parameters for the whole energy region for Cu-63.

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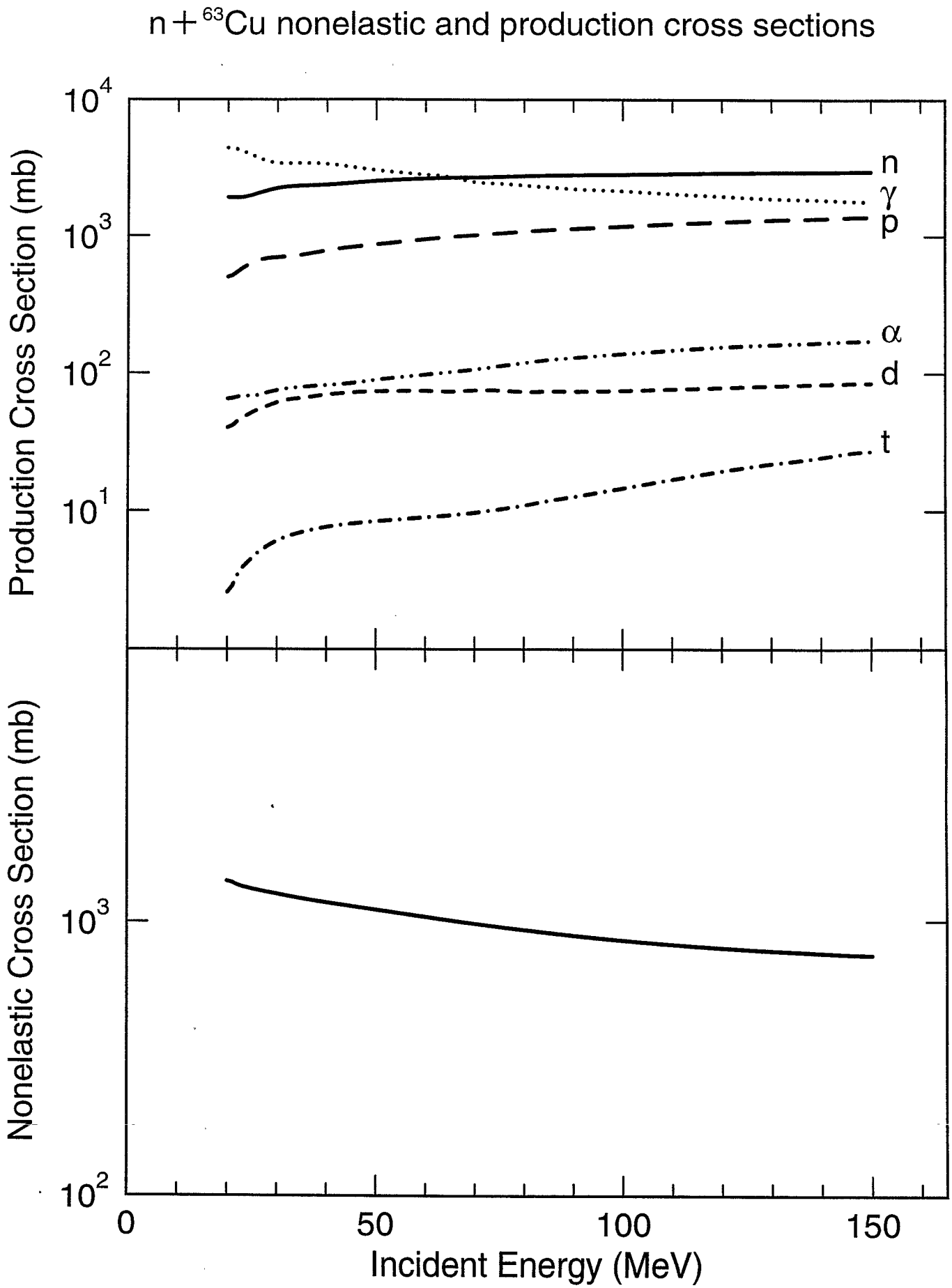
29063 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

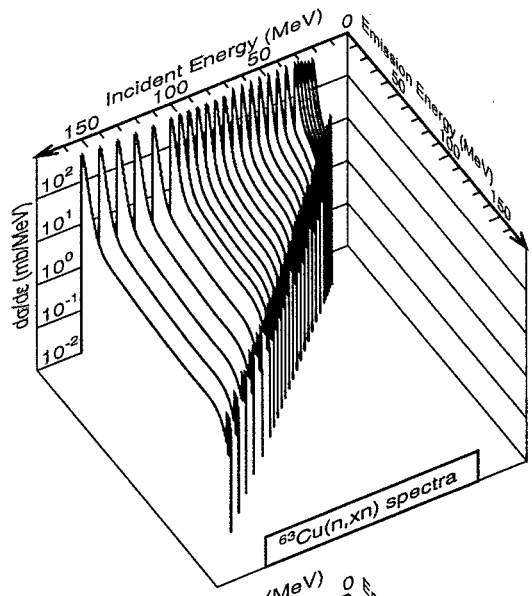
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	1.407E+00	1.065E+00	1.910E+00	4.988E-01	4.002E-02	2.586E-03	0.000E+00	6.481E-02	4.414E+00
2.200E+01	1.365E+00	1.059E+00	1.902E+00	5.460E-01	4.450E-02	3.430E-03	0.000E+00	6.696E-02	4.313E+00
2.400E+01	1.330E+00	1.059E+00	1.947E+00	6.094E-01	4.932E-02	4.219E-03	0.000E+00	6.797E-02	4.038E+00
2.600E+01	1.304E+00	1.088E+00	2.044E+00	6.566E-01	5.376E-02	4.943E-03	0.000E+00	6.883E-02	3.764E+00
2.800E+01	1.283E+00	1.127E+00	2.150E+00	6.840E-01	5.733E-02	5.571E-03	0.000E+00	7.199E-02	3.535E+00
3.000E+01	1.262E+00	1.174E+00	2.238E+00	6.949E-01	6.112E-02	6.098E-03	0.000E+00	7.484E-02	3.429E+00
3.500E+01	1.214E+00	1.314E+00	2.331E+00	7.261E-01	6.574E-02	7.022E-03	0.000E+00	7.908E-02	3.412E+00
4.000E+01	1.174E+00	1.438E+00	2.372E+00	7.821E-01	6.955E-02	7.672E-03	0.000E+00	8.154E-02	3.365E+00
4.500E+01	1.138E+00	1.525E+00	2.448E+00	8.292E-01	7.215E-02	8.109E-03	0.000E+00	8.452E-02	3.204E+00
5.000E+01	1.104E+00	1.585E+00	2.529E+00	8.667E-01	7.361E-02	8.438E-03	0.000E+00	8.927E-02	3.036E+00
5.500E+01	1.071E+00	1.613E+00	2.594E+00	9.050E-01	7.402E-02	8.718E-03	0.000E+00	9.358E-02	2.923E+00
6.000E+01	1.040E+00	1.597E+00	2.639E+00	9.450E-01	7.420E-02	9.014E-03	0.000E+00	9.757E-02	2.816E+00
6.500E+01	1.010E+00	1.573E+00	2.675E+00	9.826E-01	7.331E-02	9.305E-03	0.000E+00	1.019E-01	2.704E+00
7.000E+01	9.818E-01	1.539E+00	2.685E+00	1.011E+00	7.481E-02	9.701E-03	0.000E+00	1.065E-01	2.483E+00
7.500E+01	9.557E-01	1.482E+00	2.719E+00	1.045E+00	7.473E-02	1.026E-02	0.000E+00	1.125E-01	2.423E+00
8.000E+01	9.315E-01	1.415E+00	2.752E+00	1.077E+00	7.305E-02	1.094E-02	0.000E+00	1.186E-01	2.346E+00
8.500E+01	9.093E-01	1.344E+00	2.784E+00	1.109E+00	7.358E-02	1.185E-02	0.000E+00	1.252E-01	2.283E+00
9.000E+01	8.890E-01	1.282E+00	2.805E+00	1.133E+00	7.352E-02	1.269E-02	0.000E+00	1.299E-01	2.213E+00
9.500E+01	8.705E-01	1.216E+00	2.818E+00	1.156E+00	7.408E-02	1.360E-02	0.000E+00	1.346E-01	2.178E+00
1.000E+02	8.536E-01	1.143E+00	2.830E+00	1.179E+00	7.473E-02	1.458E-02	0.000E+00	1.390E-01	2.143E+00
1.100E+02	8.243E-01	1.014E+00	2.866E+00	1.228E+00	7.669E-02	1.690E-02	0.000E+00	1.476E-01	2.039E+00
1.200E+02	8.003E-01	8.986E-01	2.900E+00	1.270E+00	7.870E-02	1.939E-02	0.000E+00	1.556E-01	1.957E+00
1.300E+02	7.809E-01	8.038E-01	2.927E+00	1.311E+00	8.110E-02	2.191E-02	0.000E+00	1.618E-01	1.880E+00
1.400E+02	7.654E-01	7.200E-01	2.949E+00	1.346E+00	8.324E-02	2.440E-02	0.000E+00	1.671E-01	1.843E+00
1.500E+02	7.532E-01	6.497E-01	2.978E+00	1.382E+00	8.490E-02	2.704E-02	0.000E+00	1.722E-01	1.796E+00

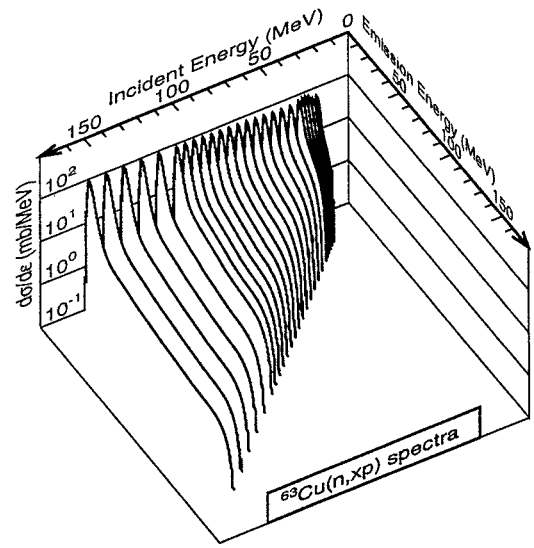
29063 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

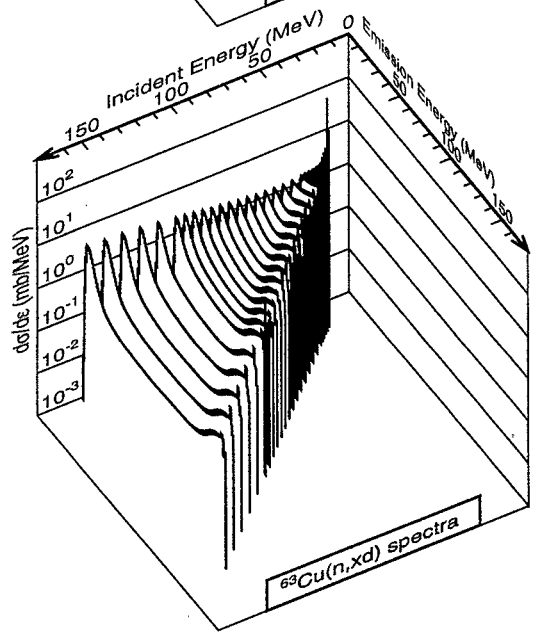
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	4.860E-01	6.443E-02	2.857E-03	0.000E+00	9.816E-02	8.659E-02	1.914E-02	7.571E-01
2.200E+01	5.510E-01	7.874E-02	4.264E-03	0.000E+00	1.054E-01	9.097E-02	2.127E-02	8.517E-01
2.400E+01	6.307E-01	9.552E-02	5.792E-03	0.000E+00	1.101E-01	9.531E-02	2.259E-02	9.600E-01
2.600E+01	7.112E-01	1.129E-01	7.391E-03	0.000E+00	1.134E-01	9.962E-02	2.360E-02	1.068E+00
2.800E+01	7.890E-01	1.291E-01	8.993E-03	0.000E+00	1.198E-01	1.038E-01	2.403E-02	1.175E+00
3.000E+01	8.585E-01	1.478E-01	1.056E-02	0.000E+00	1.258E-01	1.073E-01	2.408E-02	1.274E+00
3.500E+01	1.046E+00	1.852E-01	1.401E-02	0.000E+00	1.382E-01	1.151E-01	2.367E-02	1.522E+00
4.000E+01	1.252E+00	2.265E-01	1.721E-02	0.000E+00	1.470E-01	1.227E-01	2.272E-02	1.788E+00
4.500E+01	1.453E+00	2.661E-01	1.996E-02	0.000E+00	1.556E-01	1.293E-01	2.150E-02	2.045E+00
5.000E+01	1.644E+00	3.014E-01	2.238E-02	0.000E+00	1.668E-01	1.350E-01	2.035E-02	2.290E+00
5.500E+01	1.825E+00	3.302E-01	2.450E-02	0.000E+00	1.775E-01	1.397E-01	1.921E-02	2.516E+00
6.000E+01	2.002E+00	3.552E-01	2.642E-02	0.000E+00	1.875E-01	1.434E-01	1.789E-02	2.733E+00
6.500E+01	2.179E+00	3.718E-01	2.809E-02	0.000E+00	1.978E-01	1.461E-01	1.675E-02	2.939E+00
7.000E+01	2.342E+00	4.065E-01	2.973E-02	0.000E+00	2.083E-01	1.494E-01	1.570E-02	3.152E+00
7.500E+01	2.504E+00	4.275E-01	3.123E-02	0.000E+00	2.215E-01	1.522E-01	1.458E-02	3.351E+00
8.000E+01	2.667E+00	4.286E-01	3.278E-02	0.000E+00	2.346E-01	1.536E-01	1.351E-02	3.530E+00
8.500E+01	2.822E+00	4.471E-01	3.437E-02	0.000E+00	2.489E-01	1.559E-01	1.250E-02	3.720E+00
9.000E+01	2.979E+00	4.597E-01	3.592E-02	0.000E+00	2.601E-01	1.574E-01	1.165E-02	3.903E+00
9.500E+01	3.133E+00	4.784E-01	3.746E-02	0.000E+00	2.712E-01	1.588E-01	1.084E-02	4.090E+00
1.000E+02	3.292E+00	4.968E-01	3.900E-02	0.000E+00	2.820E-01	1.599E-01	1.003E-02	4.280E+00
1.100E+02	3.605E+00	5.330E-01	4.195E-02	0.000E+00	3.036E-01	1.624E-01	8.652E-03	4.655E+00
1.200E+02	3.922E+00	5.636E-01	4.408E-02	0.000E+00	3.242E-01	1.645E-01	7.518E-03	5.026E+00
1.300E+02	4.246E+00	5.995E-01	4.589E-02	0.000E+00	3.419E-01	1.716E-01	6.628E-03	5.412E+00
1.400E+02	4.579E+00	6.322E-01	4.774E-02	0.000E+00	3.579E-01	1.797E-01	5.877E-03	5.803E+00
1.500E+02	4.931E+00	6.504E-01	5.003E-02	0.000E+00	3.738E-01	1.864E-01	5.264E-03	6.197E+00

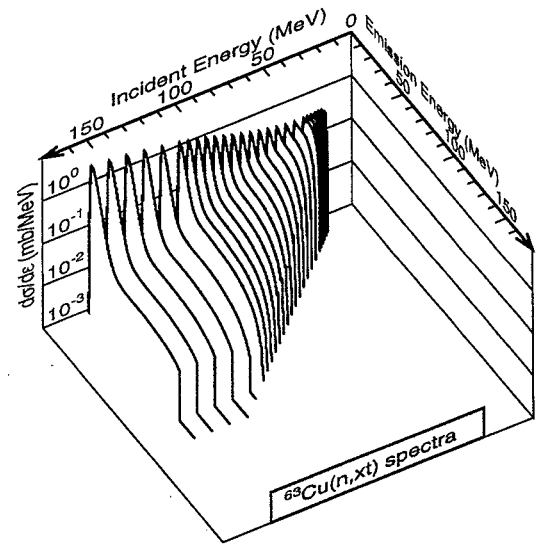

n + 63Cu nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
n
γ
p
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
0
50
100
150
Incident Energy (MeV)

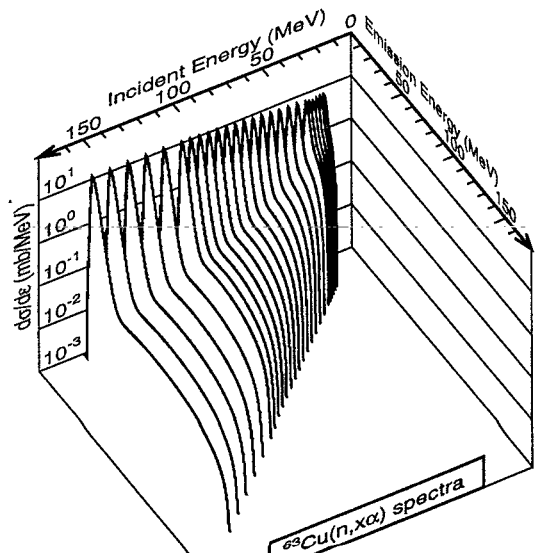
n + ^{63}Cu angle-integrated emission spectra

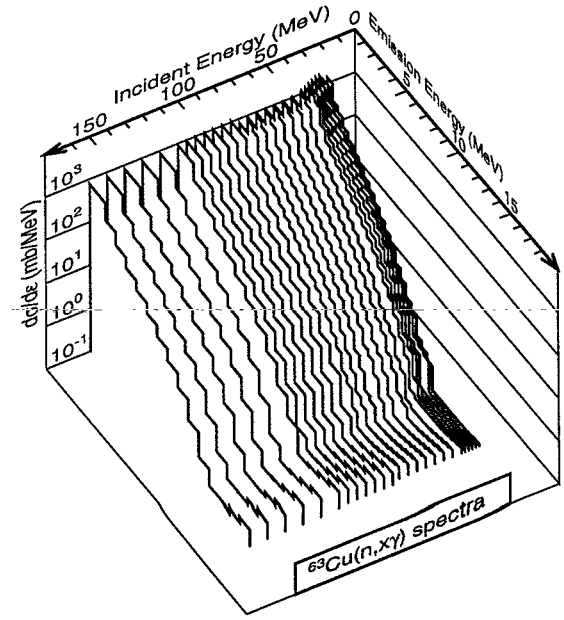




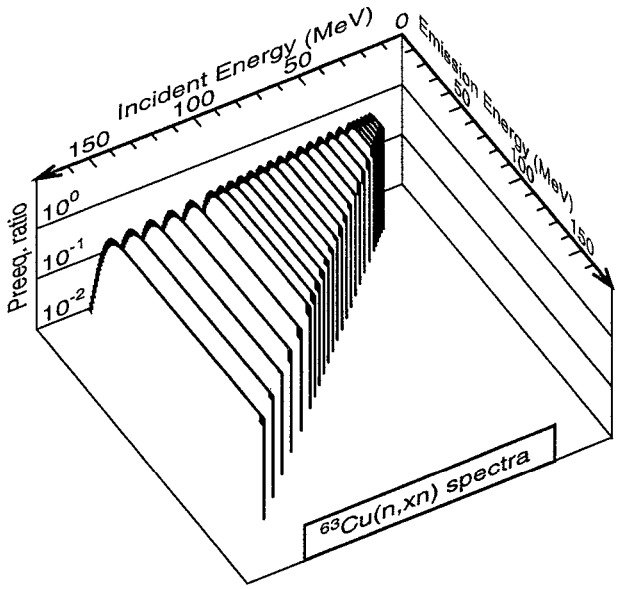


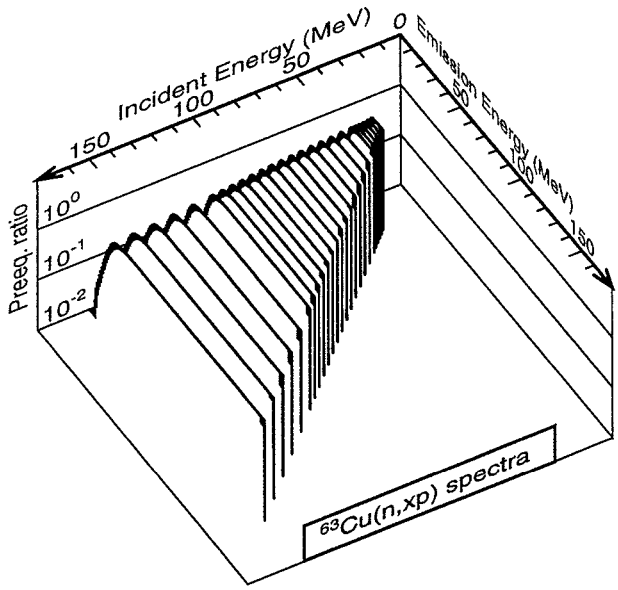


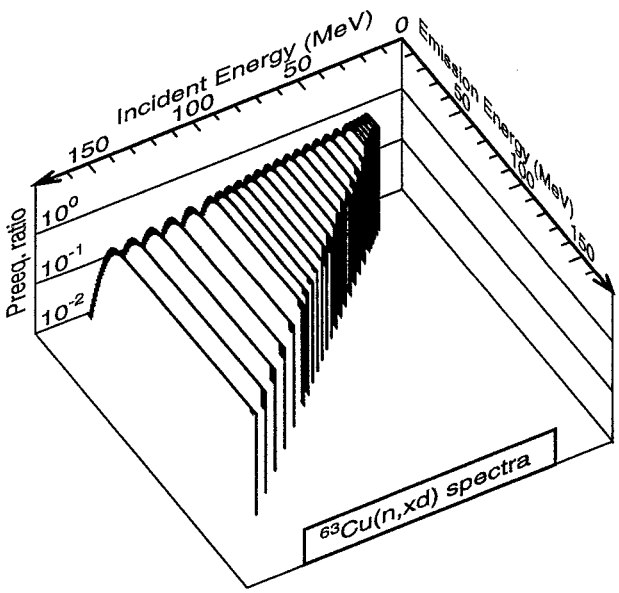


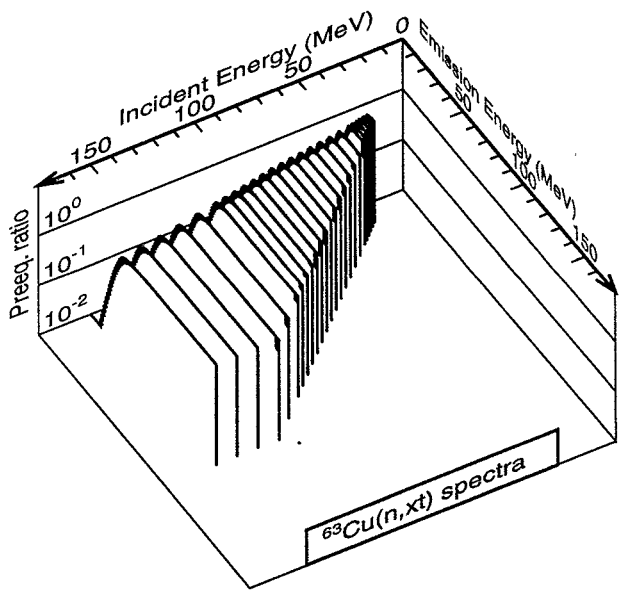


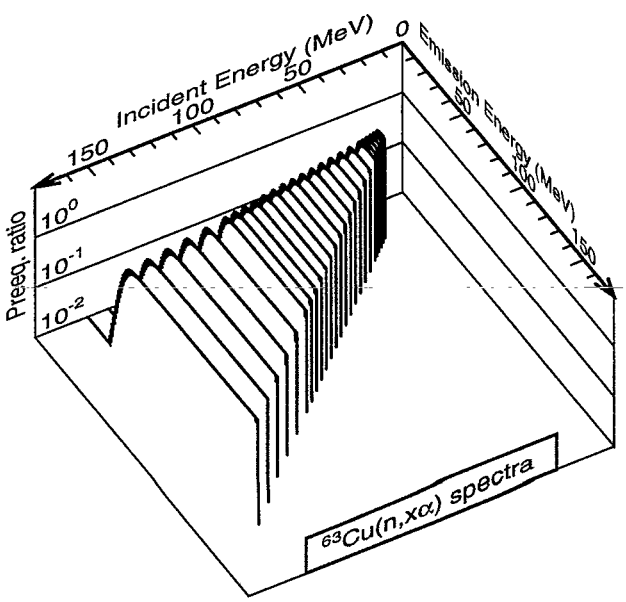
n + ^{63}Cu Kalbach preequilibrium ratios

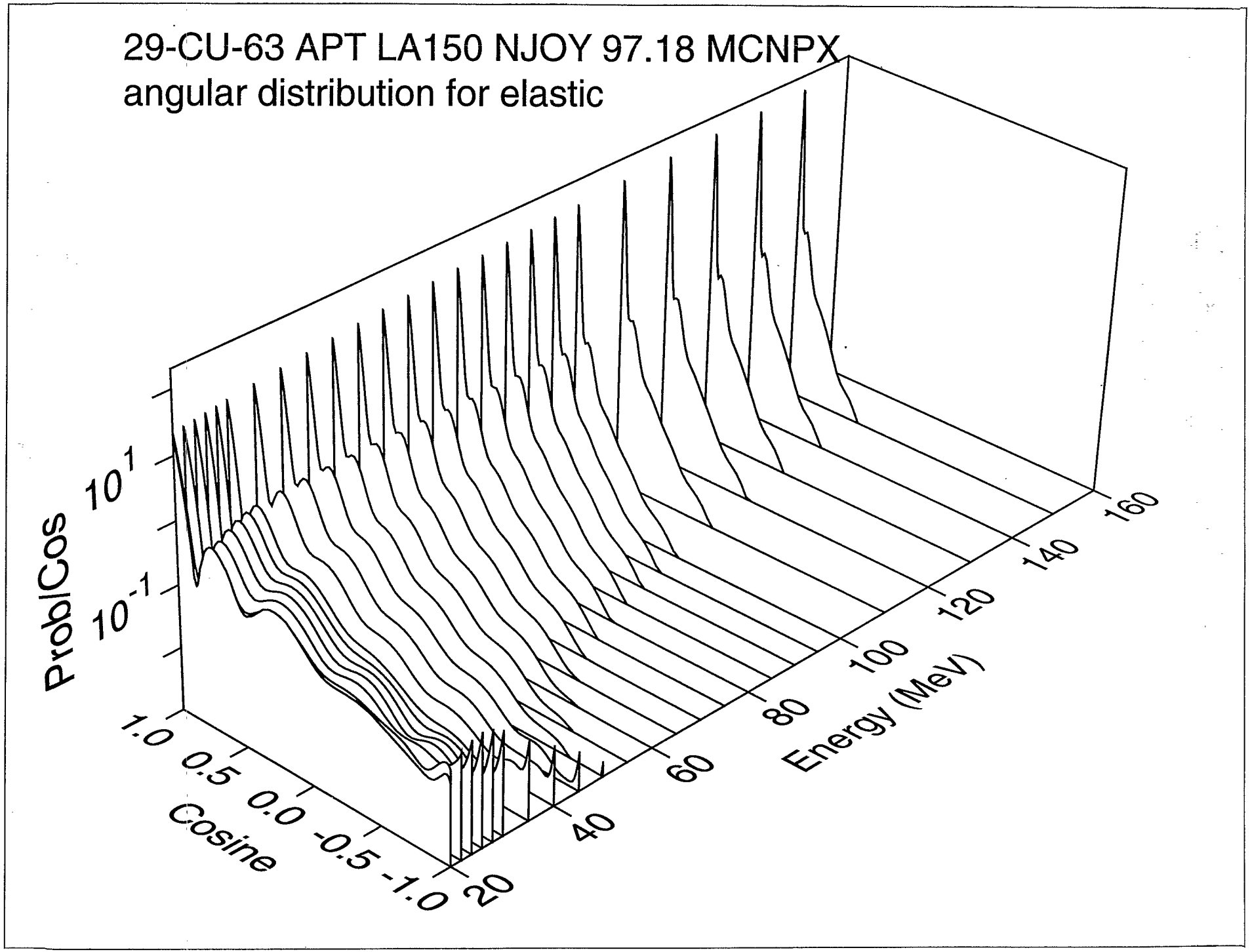


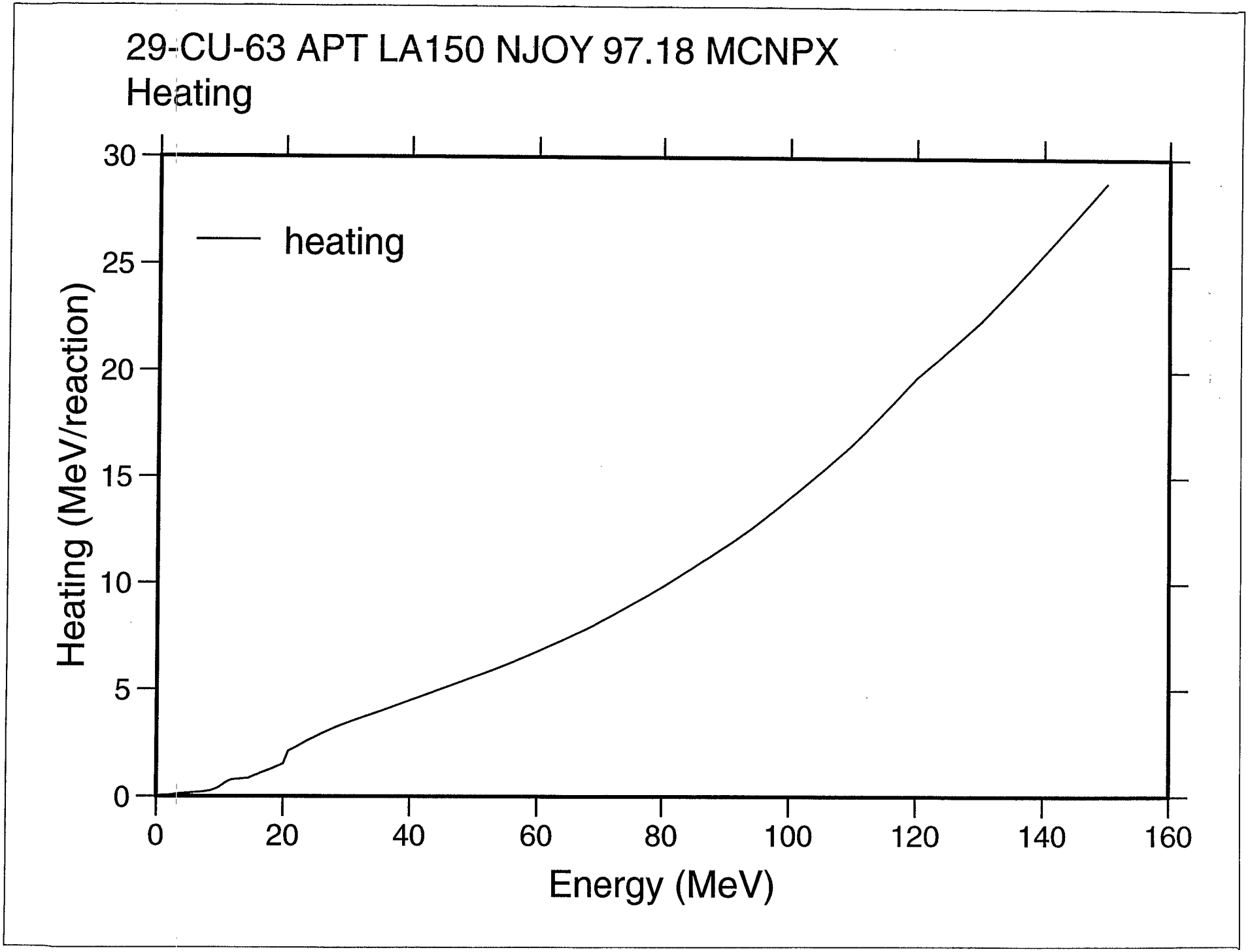


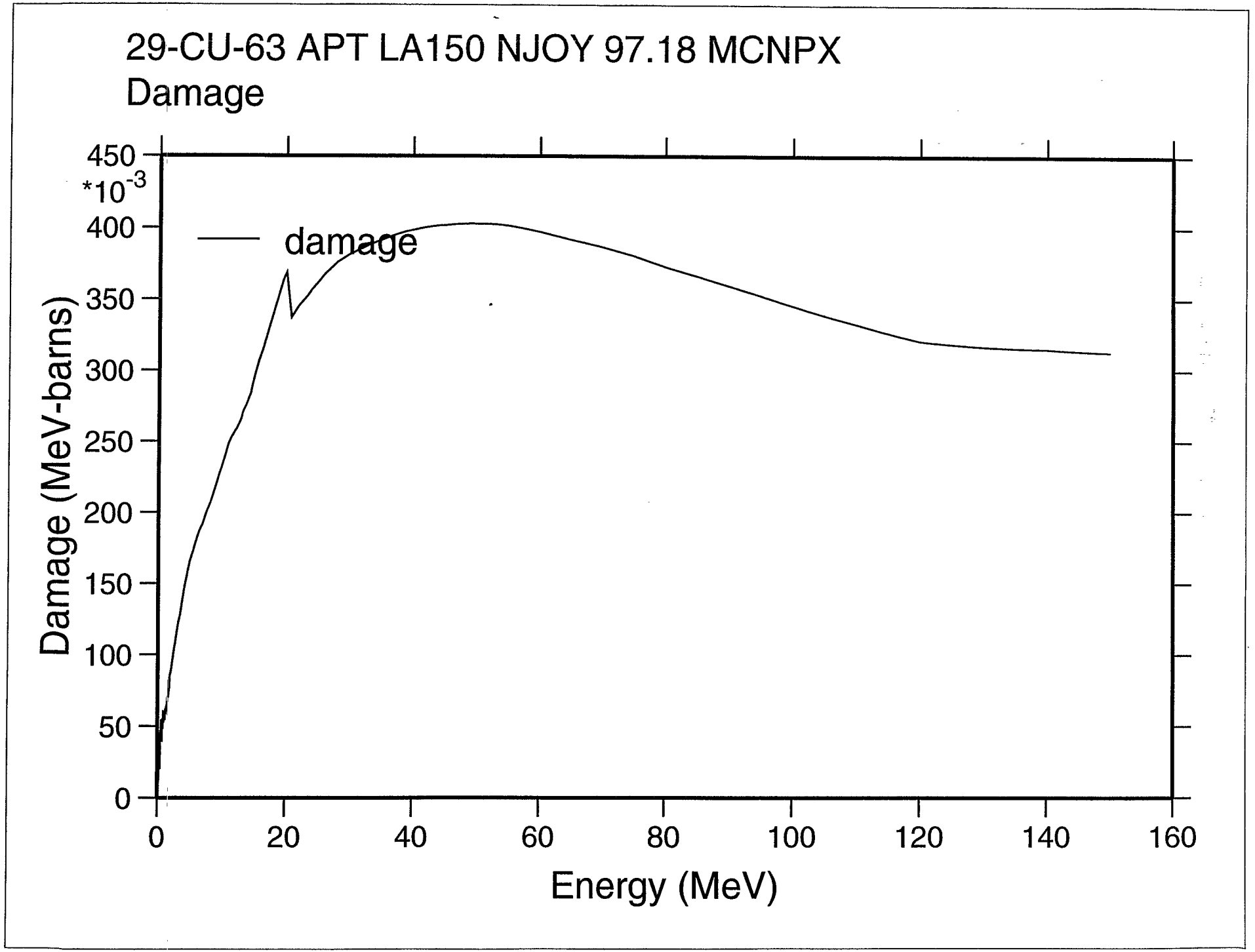







29-CU-63 APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic
Prob/Cos
10^1
10^{-1}
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


29-CU-63 APT LA150 NJOY 97.18 MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
5
10
15
20
25
30
0
20
40
60
80
100
120
140
160


29-CU-63 APT LA150 NJOY 97.18 MCNPX
Damage
damage
Damage (MeV-barns)
*10^-3
450
400
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF n + 65Cu CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

A. J. Koning, M. B. Chadwick, and P. G. Young
15 February 1998

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI (Release 2) evaluation by D. Hetrick, C.Y. Fu, and D. Larson.

INCIDENT NEUTRON ENERGIES > 20 MeV

The ENDF/B-VI Release 2 evaluation extends to 20 MeV and includes cross sections and energy-angle data for all significant reactions. The present evaluation utilizes a more compact composite reaction spectrum representation above 20 MeV in order to reduce the length of the file. No essential data for applications is lost with this representation.

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT= 1	Total Cross Section
	MT= 2	Elastic Scattering Cross Section
	MT= 3	Nonelastic Cross Section
	MT= 5	Sum of Binary (n,n') and (n,x) Reactions
MF=4	MT= 2	Elastic Angular Distributions
MF=6	MT= 5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, Tritons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Cu65 and p + Cu65 reactions (Ch98). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96a). The recoil

energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk et al. (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged- particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

SPECIFIC INFORMATION CONCERNING THE Cu-65 EVALUATION

This evaluation is documented in some detail in Ref. (Ko98b).

The neutron total cross section above 20 MeV was obtained by evaluating experimental data, with a particular emphasis on the Finlay (Fi93) elemental data. This resulted in an evaluated elemental Cu total cross section; to obtain an isotopic 65Cu total cross section, it was assumed that 63Cu and 65Cu have total cross sections in an A**2/3 ratio to one another. The total neutron nonelastic cross section was obtained directly from an optical model calculation (see below), after verifying that it was in good agreement with the experimental data (Ko98b).

To obtain the neutron optical potential we used total cross section data from 1.2 to 4.5 MeV (Gu86) and from 5.3 to 600 MeV (Fi93), and elastic scattering angular distribution data from 1.6 to 96 MeV (Br50, Sa60, Ki74, El82, Gu86). The optical potential parameters were obtained using a combination of a grid search code and the interactive optical model viewer ECISVIEW [Ko97], both built around the coupled channels code ECIS96 [Ra94]. The energy dependence of the optical model parameters is as described in [Ko98]. This optical potential was used for the calculation, with ECIS96, of neutron transmission coefficients and DWBA cross sections for the entire energy region above 20 MeV.

Due to the lack of proton elastic scattering data in numerical form, we used a combination of global optical models for the proton channel. The Becchetti-Greenlees potential [Be69]was adopted below 47 MeV, and the non-relativistic version of the Madland potential [Ma88] above 47 MeV. At this particular energy point the two potentials join smoothly.

For deuterons, the Lohr-Haeberli global potential [Lo74] was used; for alpha particles the Moyen potential (MacFadden-Satchler [Ma66]) was used; and for tritons the Becchetti-Greenlees potential [Be71] was used. The He-3 channel was ignored, due to its small importance.

Following Delaroche et al. [De82], we adopted the weak-coupling model for direct collective inelastic scattering for Cu-65, using Ni-64 as a basis. For the calculation of the cross sections, ECIS96 was used in DWBA mode. We used the following direct

transitions for Cu-65 (ground state 3/2-) :

Jpi	Ex(MeV)	Deformation length (Delta) or parameter (Beta)
0.5-	0.771	Beta(2)=0.0566
2.5-	1.116	Beta(2)=0.0980
3.5-	1.481	Beta(2)=0.1132
1.5-	1.743	Beta(2)=0.0800
1.5-	3.185	Delta(3)=0.3167
2.5-	3.435	Delta(3)=0.3879
3.5-	3.685	Delta(3)=0.4479
4.5-	3.935	Delta(3)=0.5008

Only one measurement exists for neutron-induced emission spectra above 20 MeV for 65Cu: the 25.7 MeV (n,xn) data by Marcinkowski et al (Ma83). Without adjusting any of the level density or pre-equilibrium parameters the GNASH calculation was in good agreement with these data (Ko98b). Hence we adopted these parameters for the whole energy region.

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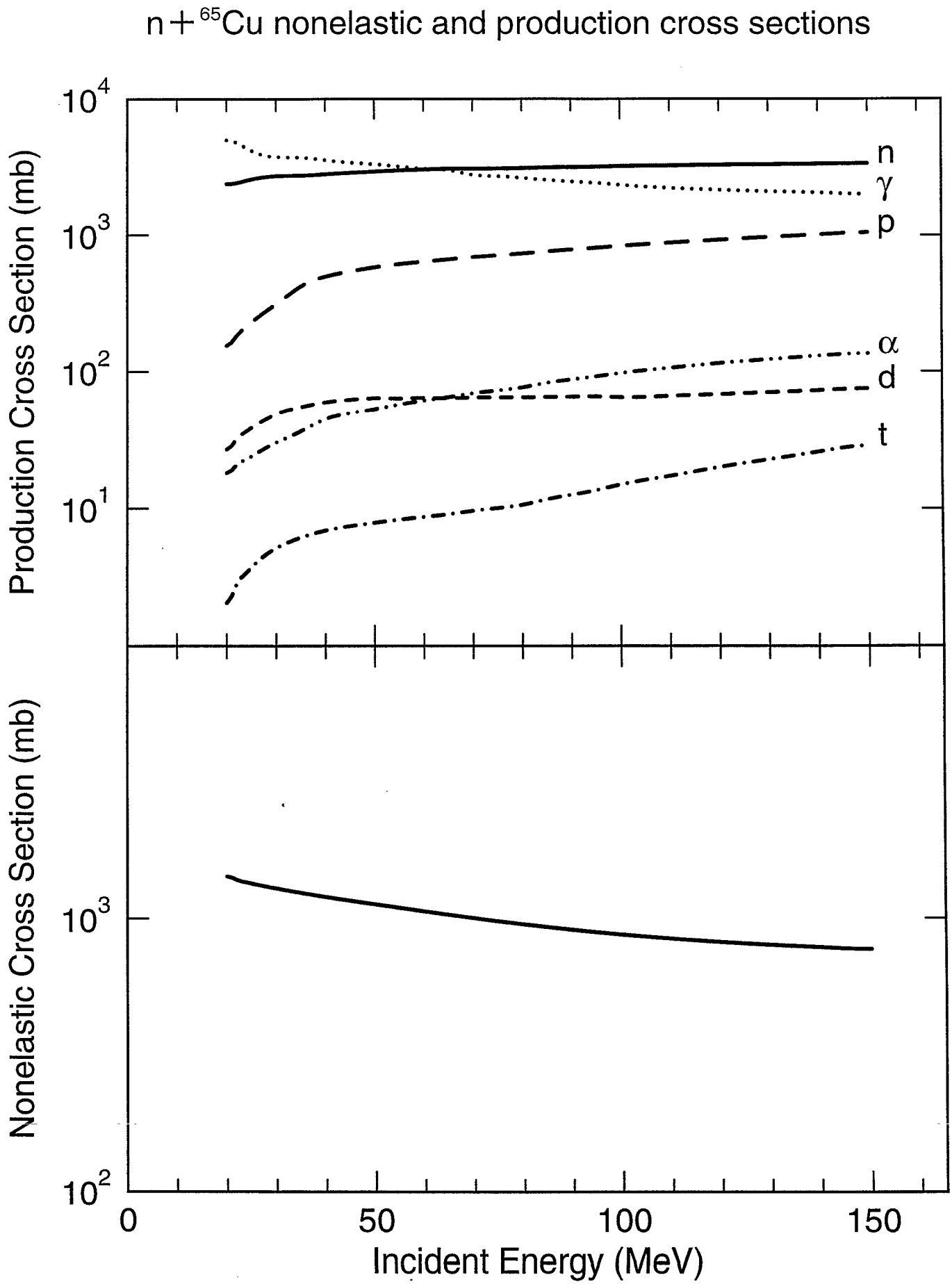
29065 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

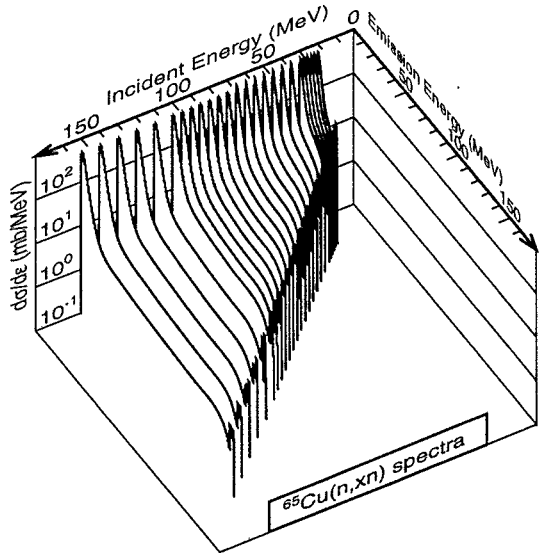
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	1.425E+00	1.099E+00	2.363E+00	1.555E-01	2.698E-02	2.052E-03	0.000E+00	1.813E-02	4.955E+00
2.200E+01	1.384E+00	1.090E+00	2.399E+00	1.833E-01	3.204E-02	2.793E-03	0.000E+00	2.069E-02	4.765E+00
2.400E+01	1.354E+00	1.084E+00	2.503E+00	2.147E-01	3.670E-02	3.408E-03	0.000E+00	2.296E-02	4.349E+00
2.600E+01	1.329E+00	1.114E+00	2.600E+00	2.463E-01	4.096E-02	4.055E-03	0.000E+00	2.519E-02	4.024E+00
2.800E+01	1.307E+00	1.154E+00	2.661E+00	2.796E-01	4.505E-02	4.639E-03	0.000E+00	2.785E-02	3.807E+00
3.000E+01	1.286E+00	1.201E+00	2.700E+00	3.137E-01	4.888E-02	5.152E-03	0.000E+00	3.032E-02	3.727E+00
3.500E+01	1.238E+00	1.342E+00	2.725E+00	4.220E-01	5.489E-02	6.163E-03	0.000E+00	3.666E-02	3.684E+00
4.000E+01	1.197E+00	1.470E+00	2.786E+00	4.998E-01	5.947E-02	6.917E-03	0.000E+00	4.501E-02	3.526E+00
4.500E+01	1.160E+00	1.559E+00	2.855E+00	5.459E-01	6.222E-02	7.455E-03	0.000E+00	4.975E-02	3.380E+00
5.000E+01	1.127E+00	1.620E+00	2.913E+00	5.846E-01	6.385E-02	7.892E-03	0.000E+00	5.302E-02	3.280E+00
5.500E+01	1.094E+00	1.648E+00	2.973E+00	6.161E-01	6.349E-02	8.318E-03	0.000E+00	5.733E-02	3.166E+00
6.000E+01	1.061E+00	1.631E+00	3.017E+00	6.416E-01	6.416E-02	8.690E-03	0.000E+00	6.116E-02	3.054E+00
6.500E+01	1.031E+00	1.607E+00	3.052E+00	6.664E-01	6.386E-02	9.098E-03	0.000E+00	6.491E-02	2.986E+00
7.000E+01	1.003E+00	1.571E+00	3.054E+00	6.922E-01	6.457E-02	9.611E-03	0.000E+00	6.924E-02	2.748E+00
7.500E+01	9.760E-01	1.513E+00	3.068E+00	7.131E-01	6.467E-02	1.006E-02	0.000E+00	7.249E-02	2.687E+00
8.000E+01	9.516E-01	1.445E+00	3.085E+00	7.348E-01	6.473E-02	1.061E-02	0.000E+00	7.625E-02	2.612E+00
8.500E+01	9.291E-01	1.372E+00	3.121E+00	7.601E-01	6.501E-02	1.165E-02	0.000E+00	8.230E-02	2.524E+00
9.000E+01	9.084E-01	1.308E+00	3.139E+00	7.862E-01	6.533E-02	1.259E-02	0.000E+00	8.728E-02	2.456E+00
9.500E+01	8.896E-01	1.241E+00	3.157E+00	8.095E-01	6.568E-02	1.360E-02	0.000E+00	9.196E-02	2.404E+00
1.000E+02	8.723E-01	1.167E+00	3.188E+00	8.360E-01	6.482E-02	1.492E-02	0.000E+00	9.743E-02	2.323E+00
1.100E+02	8.426E-01	1.034E+00	3.219E+00	8.811E-01	6.626E-02	1.724E-02	0.000E+00	1.063E-01	2.207E+00
1.200E+02	8.182E-01	9.165E-01	3.254E+00	9.254E-01	6.813E-02	1.999E-02	0.000E+00	1.152E-01	2.140E+00
1.300E+02	7.985E-01	8.196E-01	3.278E+00	9.688E-01	7.031E-02	2.276E-02	0.000E+00	1.227E-01	2.085E+00
1.400E+02	7.827E-01	7.339E-01	3.310E+00	1.012E+00	7.271E-02	2.595E-02	0.000E+00	1.305E-01	2.045E+00
1.500E+02	7.703E-01	6.621E-01	3.331E+00	1.049E+00	7.483E-02	2.866E-02	0.000E+00	1.356E-01	1.998E+00

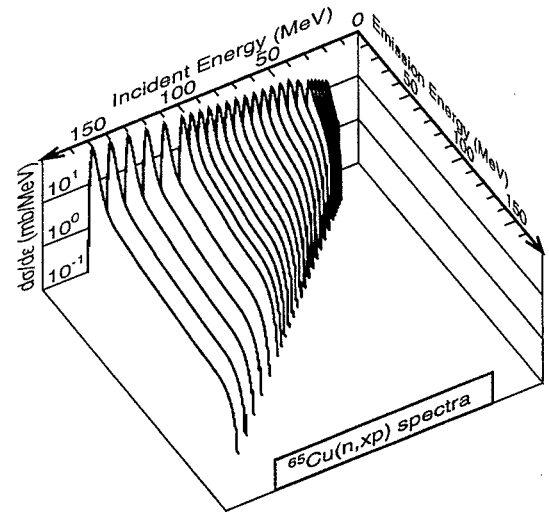
29065 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

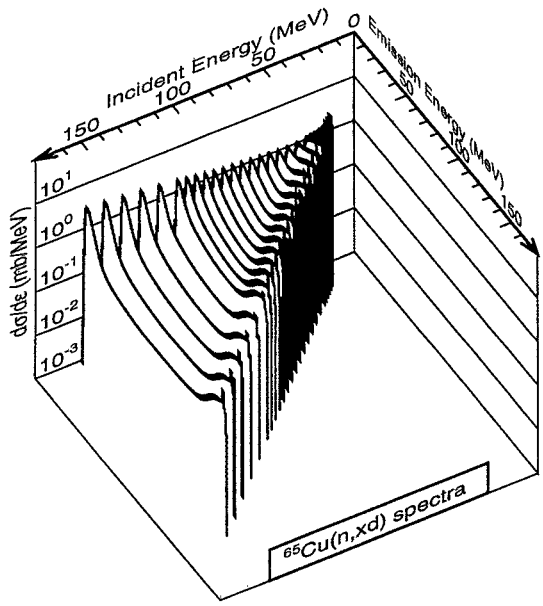
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	1.800E-01	3.867E-02	2.193E-03	0.000E+00	2.715E-02	7.703E-02	1.807E-02	3.431E-01
2.200E+01	2.268E-01	5.147E-02	3.347E-03	0.000E+00	3.214E-02	8.133E-02	2.023E-02	4.153E-01
2.400E+01	2.808E-01	6.504E-02	4.421E-03	0.000E+00	3.679E-02	8.587E-02	2.154E-02	4.945E-01
2.600E+01	3.406E-01	7.928E-02	5.711E-03	0.000E+00	4.125E-02	9.023E-02	2.263E-02	5.797E-01
2.800E+01	4.085E-01	9.446E-02	7.038E-03	0.000E+00	4.618E-02	9.428E-02	2.315E-02	6.736E-01
3.000E+01	4.798E-01	1.105E-01	8.357E-03	0.000E+00	5.100E-02	9.782E-02	2.325E-02	7.708E-01
3.500E+01	6.831E-01	1.460E-01	1.147E-02	0.000E+00	6.259E-02	1.060E-01	2.288E-02	1.032E+00
4.000E+01	8.868E-01	1.841E-01	1.426E-02	0.000E+00	7.634E-02	1.140E-01	2.194E-02	1.297E+00
4.500E+01	1.078E+00	2.189E-01	1.668E-02	0.000E+00	8.632E-02	1.205E-01	2.071E-02	1.541E+00
5.000E+01	1.259E+00	2.499E-01	1.884E-02	0.000E+00	9.455E-02	1.258E-01	1.955E-02	1.767E+00
5.500E+01	1.430E+00	2.685E-01	2.079E-02	0.000E+00	1.037E-01	1.299E-01	1.840E-02	1.972E+00
6.000E+01	1.592E+00	2.940E-01	2.245E-02	0.000E+00	1.122E-01	1.333E-01	1.709E-02	2.171E+00
6.500E+01	1.748E+00	3.115E-01	2.404E-02	0.000E+00	1.205E-01	1.363E-01	1.597E-02	2.356E+00
7.000E+01	1.902E+00	3.355E-01	2.560E-02	0.000E+00	1.294E-01	1.390E-01	1.495E-02	2.546E+00
7.500E+01	2.056E+00	3.561E-01	2.693E-02	0.000E+00	1.368E-01	1.408E-01	1.386E-02	2.730E+00
8.000E+01	2.210E+00	3.755E-01	2.823E-02	0.000E+00	1.451E-01	1.420E-01	1.282E-02	2.914E+00
8.500E+01	2.352E+00	3.915E-01	2.987E-02	0.000E+00	1.571E-01	1.440E-01	1.185E-02	3.086E+00
9.000E+01	2.504E+00	4.085E-01	3.138E-02	0.000E+00	1.674E-01	1.451E-01	1.103E-02	3.267E+00
9.500E+01	2.655E+00	4.247E-01	3.285E-02	0.000E+00	1.774E-01	1.461E-01	1.025E-02	3.446E+00
1.000E+02	2.806E+00	4.185E-01	3.460E-02	0.000E+00	1.888E-01	1.470E-01	9.468E-03	3.604E+00
1.100E+02	3.113E+00	4.501E-01	3.690E-02	0.000E+00	2.082E-01	1.487E-01	8.154E-03	3.965E+00
1.200E+02	3.421E+00	4.778E-01	3.921E-02	0.000E+00	2.280E-01	1.510E-01	7.073E-03	4.324E+00
1.300E+02	3.737E+00	5.092E-01	4.152E-02	0.000E+00	2.457E-01	1.575E-01	6.225E-03	4.697E+00
1.400E+02	4.058E+00	5.341E-01	4.458E-02	0.000E+00	2.641E-01	1.662E-01	5.510E-03	5.073E+00
1.500E+02	4.399E+00	5.656E-01	4.726E-02	0.000E+00	2.780E-01	1.730E-01	4.929E-03	5.468E+00

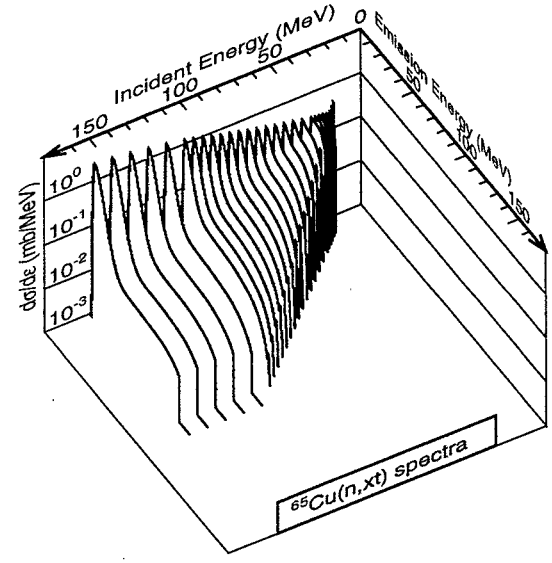

n + 65Cu nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
n
γ
p
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
0
50
100
150
Incident Energy (MeV)

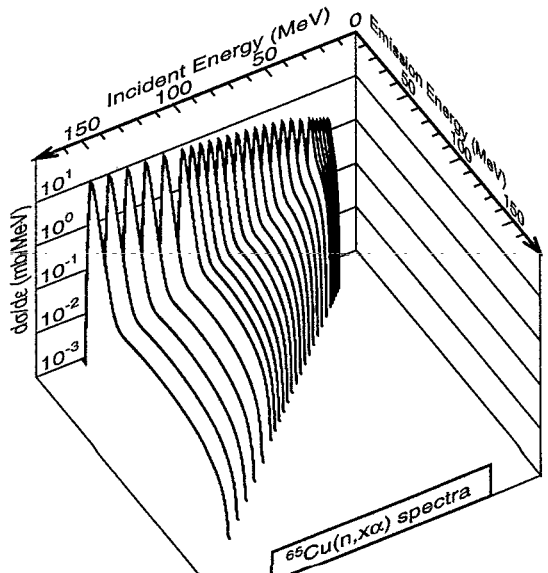
n + ^{65}Cu angle-integrated emission spectra

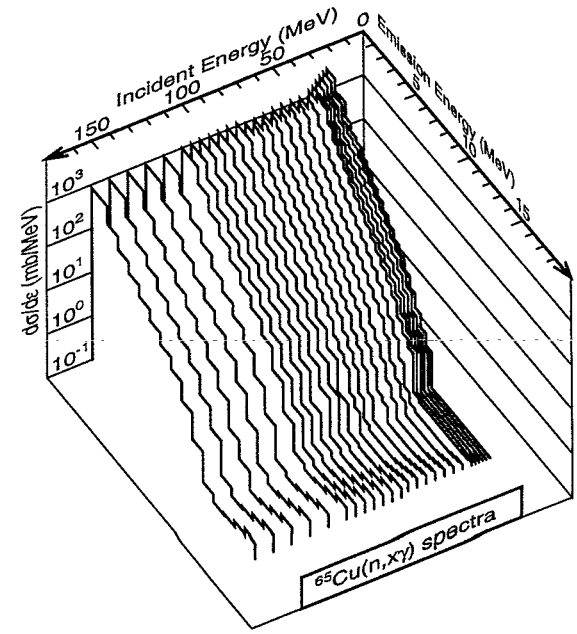




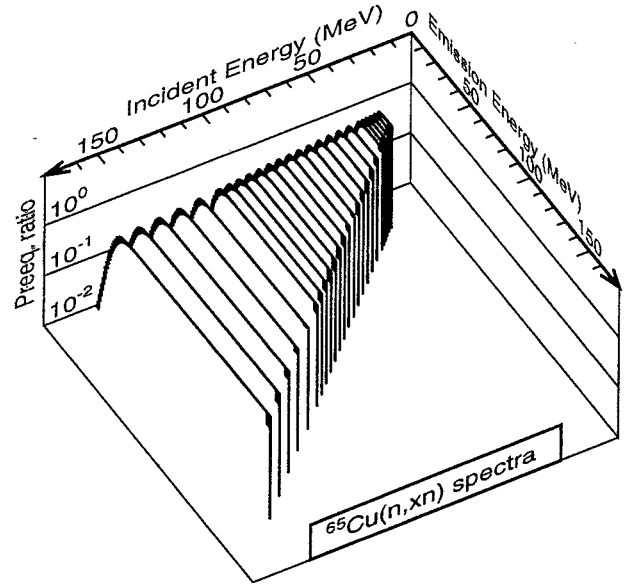


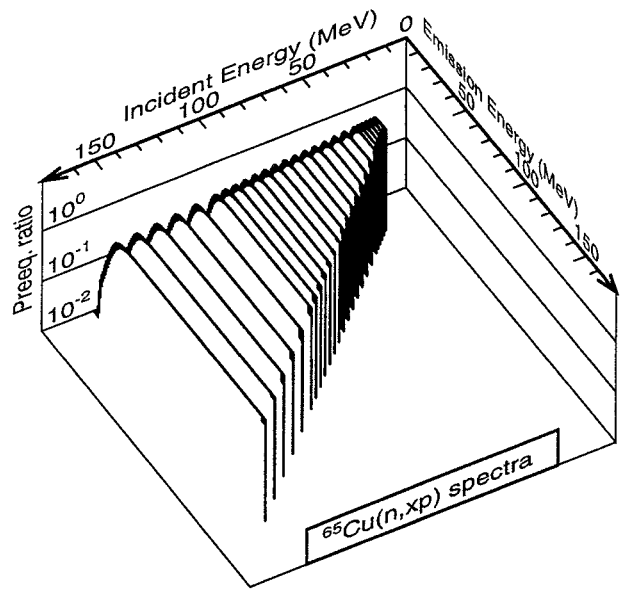


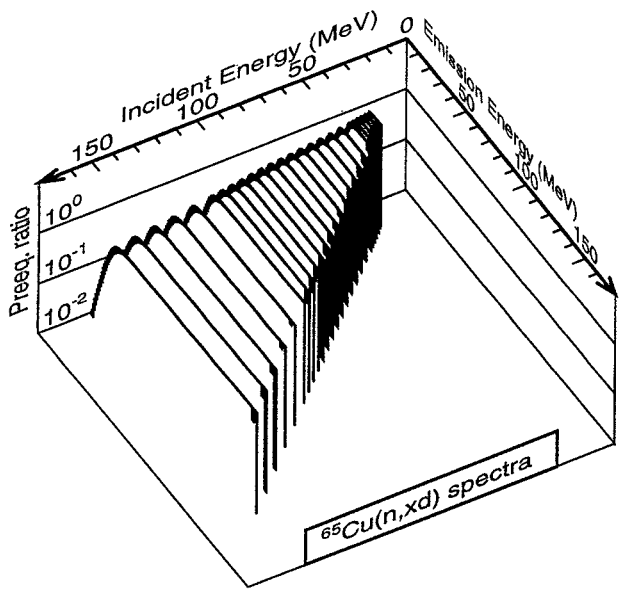


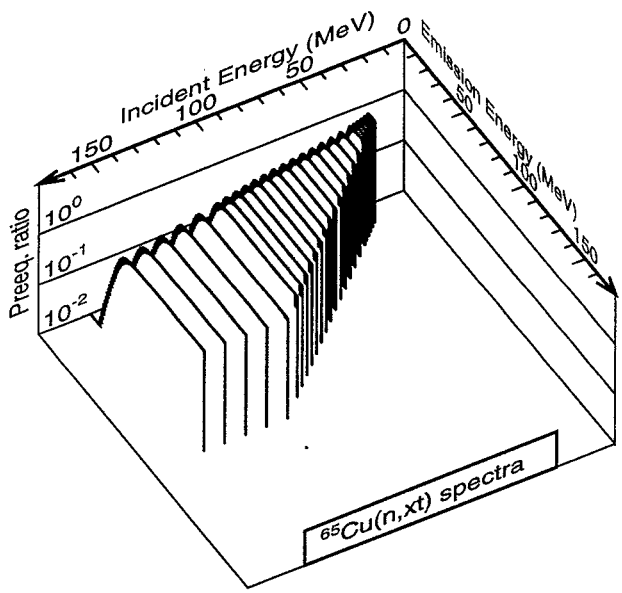


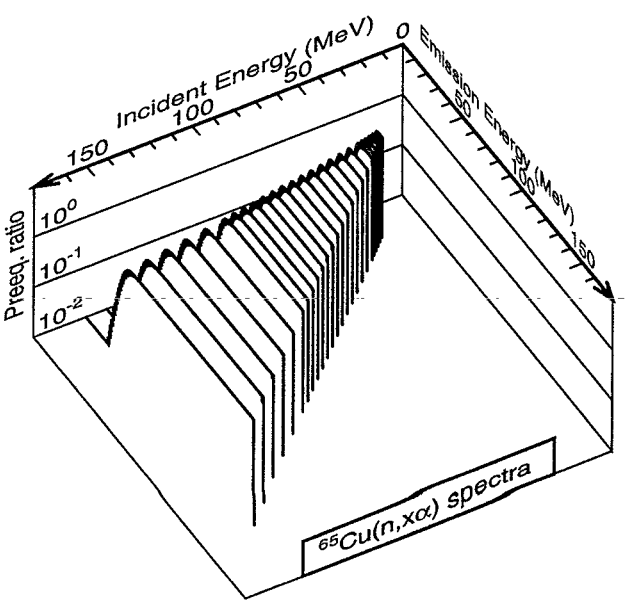
n + ^{65}Cu Kalbach preequilibrium ratios











EVALUATION OF n + 93Nb CROSS SECTIONS FOR THE ENERGY RANGE 1 to 150 MeV

M. B. Chadwick, and P. G. Young
10 December 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident proton energy range from 1 to 150 MeV. The evaluation utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above are:

MF=3	MT= 2	Integral of nuclear plus interference components of the elastic scattering cross section
	MT= 5	Sum of binary (p,n') and (p,x) reactions
MF=6	MT= 2	Elastic (p,p) angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
	MT= 5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n +93Nb and n +93Nb reactions (Ch98). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic proton angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96a). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk et al. (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged- particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission

coefficients were calculated using the Kopecky-Uhl model (Ko90).

SPECIFIC INFORMATION CONCERNING THE NB-93 EVALUATION

The total neutron cross section was obtained from the Finlay(Fi93) measurements.

The following optical potentials were used in the GNASH calculations. For incident neutrons, the Wilmore-Hodgson potential was used below 15 MeV, and the Madland potential (Ma88) was used at higher energies. For incident protons, the Becchetti-Greenlees (Be69) potential was used up to 50 MeV, above which the Madland potential (Ma88) was used. In both cases, the matching energy between the potentials was chosen to result in continuity of the reaction cross section. For protons at 50 MeV the reaction cross section (and transmission coefficients) was renormalized slightly to smoothen the transition between the potentials. The Perey (Pe63) potential was used for indident deuterons. For tritons, the Becchetti-Greenlees (Be71) was used up to 80 MeV, above which the Watanabe potential was used. The Moyen (McFadden Satchler) (Mc66) potential was used for alpha particles over the whole energy range.

Direct inelastic scattering to low-lying states in Nb93 was determined as follows. Coherent excitation of 2+ and 3- vibrations were assumed to be fragmented over Nb93 states, after coupling these excitations with the 4.5+ core. The magnitudes of the deformation lengths of 2+ and 3- excitations was obtained by fitting values of 34 and 46 mb respectively at 14 MeV, obtained in ref. (Ch93) and accounting for measurements well. This strength was then fragmented over Nb states. For the 3- excitation, the 7 states are in the "continuum" region of the GNASH calculation at approximately 2.5 MeV, with spins 1.5-,2.5-, ..,7.5-. For the 2+, the 5 states (2.5+,3.5+,...6.5+) near 1 MeV were assumed to be those whose inelastic cross section in the existing ENDF <20 MeV file are significant (note that the ENDF file below 20 MeV appears to incorporate inelastic information only up to 5 MeV for many states, after which a value of zero at 20 MeV was inserted).

Experimental data is used to benchmark the calculations. For incident neutrons, experimental neutron emission spectra data exist at 20 and 26 MeV by Marcinkowski (Ma83). For incident protons, spectra data exist at 14 and 26 MeV by Watanabe et al. (Wa97), and at 65 MeV by Sakai et al (Sa80). Our evaluation agrees reasonably well with these measurements.

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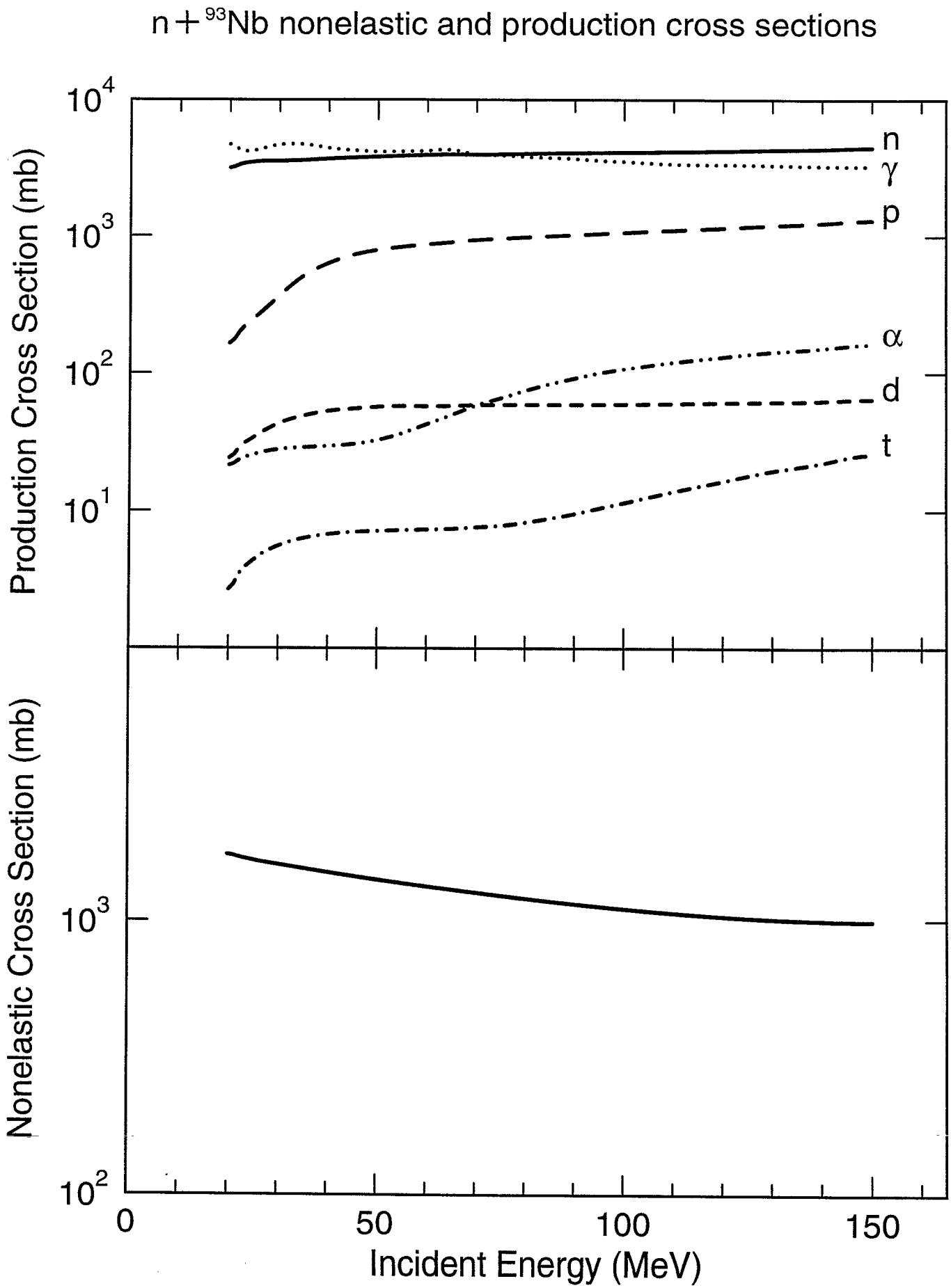
41093 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

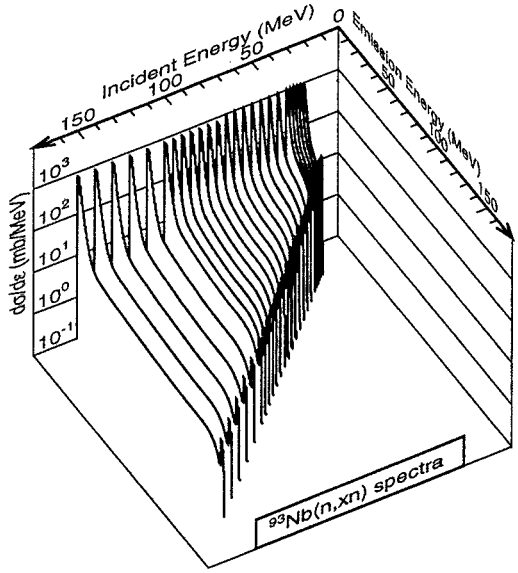
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	1.741E+00	1.614E+00	3.165E+00	1.649E-01	2.419E-02	2.673E-03	0.000E+00	2.138E-02	4.697E+00
2.200E+01	1.708E+00	1.472E+00	3.347E+00	1.992E-01	2.859E-02	3.432E-03	0.000E+00	2.339E-02	4.269E+00
2.400E+01	1.675E+00	1.384E+00	3.466E+00	2.338E-01	3.254E-02	4.109E-03	0.000E+00	2.502E-02	4.190E+00
2.600E+01	1.644E+00	1.316E+00	3.525E+00	2.700E-01	3.620E-02	4.686E-03	0.000E+00	2.626E-02	4.318E+00
2.800E+01	1.620E+00	1.260E+00	3.548E+00	3.113E-01	3.978E-02	5.174E-03	0.000E+00	2.725E-02	4.523E+00
3.000E+01	1.599E+00	1.252E+00	3.555E+00	3.640E-01	4.312E-02	5.579E-03	0.000E+00	2.794E-02	4.667E+00
3.500E+01	1.545E+00	1.331E+00	3.594E+00	5.107E-01	4.916E-02	6.319E-03	0.000E+00	2.883E-02	4.695E+00
4.000E+01	1.494E+00	1.466E+00	3.678E+00	6.320E-01	5.320E-02	6.776E-03	0.000E+00	2.948E-02	4.399E+00
4.500E+01	1.449E+00	1.615E+00	3.742E+00	7.247E-01	5.537E-02	7.035E-03	0.000E+00	3.052E-02	4.225E+00
5.000E+01	1.406E+00	1.743E+00	3.806E+00	7.881E-01	5.708E-02	7.171E-03	0.000E+00	3.272E-02	4.138E+00
5.500E+01	1.367E+00	1.839E+00	3.874E+00	8.332E-01	5.791E-02	7.274E-03	0.000E+00	3.680E-02	4.162E+00
6.000E+01	1.330E+00	1.885E+00	3.933E+00	8.691E-01	5.768E-02	7.352E-03	0.000E+00	4.272E-02	4.218E+00
6.500E+01	1.296E+00	1.929E+00	3.971E+00	9.009E-01	5.807E-02	7.445E-03	0.000E+00	4.990E-02	4.283E+00
7.000E+01	1.263E+00	1.911E+00	3.955E+00	9.375E-01	5.895E-02	7.643E-03	0.000E+00	5.856E-02	3.967E+00
7.500E+01	1.232E+00	1.886E+00	3.978E+00	9.610E-01	5.921E-02	7.851E-03	0.000E+00	6.621E-02	3.912E+00
8.000E+01	1.202E+00	1.838E+00	4.009E+00	9.844E-01	5.927E-02	8.266E-03	0.000E+00	7.503E-02	3.808E+00
8.500E+01	1.175E+00	1.790E+00	4.042E+00	1.004E+00	5.928E-02	8.843E-03	0.000E+00	8.392E-02	3.749E+00
9.000E+01	1.150E+00	1.730E+00	4.068E+00	1.023E+00	5.935E-02	9.564E-03	0.000E+00	9.219E-02	3.687E+00
9.500E+01	1.126E+00	1.644E+00	4.089E+00	1.046E+00	5.955E-02	1.052E-02	0.000E+00	1.007E-01	3.585E+00
1.000E+02	1.104E+00	1.579E+00	4.109E+00	1.066E+00	5.979E-02	1.151E-02	0.000E+00	1.077E-01	3.520E+00
1.100E+02	1.066E+00	1.424E+00	4.156E+00	1.109E+00	6.055E-02	1.388E-02	0.000E+00	1.209E-01	3.377E+00
1.200E+02	1.036E+00	1.284E+00	4.205E+00	1.153E+00	6.144E-02	1.653E-02	0.000E+00	1.324E-01	3.352E+00
1.300E+02	1.014E+00	1.158E+00	4.282E+00	1.203E+00	6.212E-02	1.963E-02	0.000E+00	1.441E-01	3.315E+00
1.400E+02	9.996E-01	1.040E+00	4.353E+00	1.252E+00	6.331E-02	2.247E-02	0.000E+00	1.532E-01	3.271E+00
1.500E+02	9.925E-01	9.275E-01	4.447E+00	1.309E+00	6.511E-02	2.584E-02	0.000E+00	1.636E-01	3.251E+00

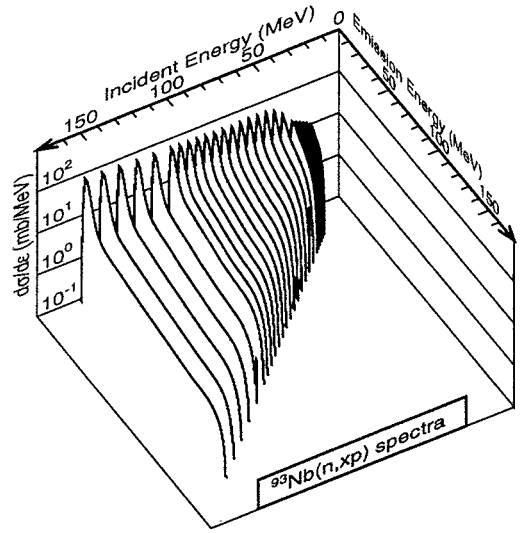
41093 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

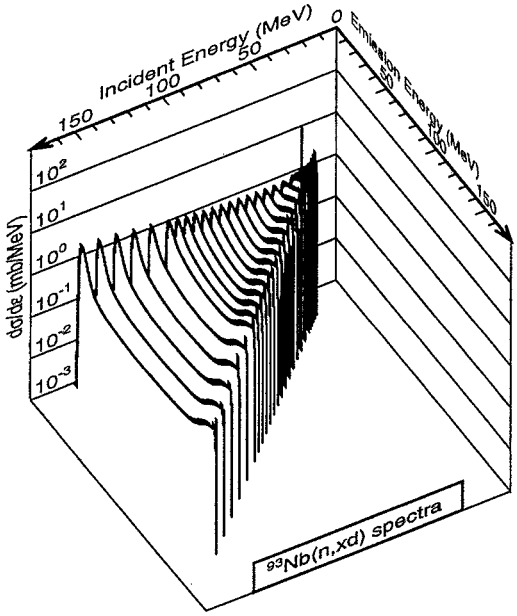
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	1.725E-01	2.892E-02	2.534E-03	0.000E+00	3.192E-02	4.614E-02	8.936E-03	2.910E-01
2.200E+01	2.191E-01	3.770E-02	3.595E-03	0.000E+00	3.587E-02	4.940E-02	9.504E-03	3.551E-01
2.400E+01	2.692E-01	4.677E-02	4.698E-03	0.000E+00	3.936E-02	5.229E-02	1.007E-02	4.224E-01
2.600E+01	3.243E-01	5.624E-02	5.792E-03	0.000E+00	4.229E-02	5.482E-02	1.032E-02	4.937E-01
2.800E+01	3.869E-01	6.644E-02	6.859E-03	0.000E+00	4.487E-02	5.718E-02	1.017E-02	5.725E-01
3.000E+01	4.588E-01	7.711E-02	7.876E-03	0.000E+00	4.700E-02	5.941E-02	1.001E-02	6.602E-01
3.500E+01	6.592E-01	1.028E-01	1.022E-02	0.000E+00	5.094E-02	6.454E-02	9.425E-03	8.971E-01
4.000E+01	8.625E-01	1.281E-01	1.223E-02	0.000E+00	5.420E-02	6.934E-02	8.815E-03	1.135E+00
4.500E+01	1.056E+00	1.498E-01	1.393E-02	0.000E+00	5.762E-02	7.333E-02	8.347E-03	1.359E+00
5.000E+01	1.230E+00	1.707E-01	1.532E-02	0.000E+00	6.226E-02	7.658E-02	7.940E-03	1.563E+00
5.500E+01	1.391E+00	1.884E-01	1.657E-02	0.000E+00	6.917E-02	7.940E-02	7.572E-03	1.752E+00
6.000E+01	1.543E+00	2.008E-01	1.767E-02	0.000E+00	7.852E-02	8.163E-02	7.170E-03	1.929E+00
6.500E+01	1.690E+00	2.164E-01	1.863E-02	0.000E+00	8.967E-02	8.356E-02	6.901E-03	2.105E+00
7.000E+01	1.839E+00	2.347E-01	1.957E-02	0.000E+00	1.029E-01	8.581E-02	6.516E-03	2.289E+00
7.500E+01	1.981E+00	2.505E-01	2.037E-02	0.000E+00	1.151E-01	8.695E-02	6.195E-03	2.460E+00
8.000E+01	2.114E+00	2.643E-01	2.119E-02	0.000E+00	1.289E-01	8.816E-02	5.864E-03	2.622E+00
8.500E+01	2.240E+00	2.774E-01	2.204E-02	0.000E+00	1.431E-01	8.917E-02	5.588E-03	2.778E+00
9.000E+01	2.367E+00	2.904E-01	2.294E-02	0.000E+00	1.566E-01	9.005E-02	5.312E-03	2.932E+00
9.500E+01	2.490E+00	3.027E-01	2.399E-02	0.000E+00	1.704E-01	9.090E-02	4.984E-03	3.083E+00
1.000E+02	2.617E+00	3.153E-01	2.507E-02	0.000E+00	1.824E-01	9.152E-02	4.741E-03	3.236E+00
1.100E+02	2.873E+00	3.399E-01	2.755E-02	0.000E+00	2.051E-01	9.280E-02	4.226E-03	3.542E+00
1.200E+02	3.137E+00	3.621E-01	3.031E-02	0.000E+00	2.253E-01	9.376E-02	3.792E-03	3.853E+00
1.300E+02	3.416E+00	3.741E-01	3.357E-02	0.000E+00	2.459E-01	9.809E-02	3.417E-03	4.171E+00
1.400E+02	3.725E+00	3.941E-01	3.663E-02	0.000E+00	2.625E-01	1.033E-01	3.072E-03	4.525E+00
1.500E+02	4.054E+00	4.131E-01	4.023E-02	0.000E+00	2.813E-01	1.086E-01	2.745E-03	4.900E+00

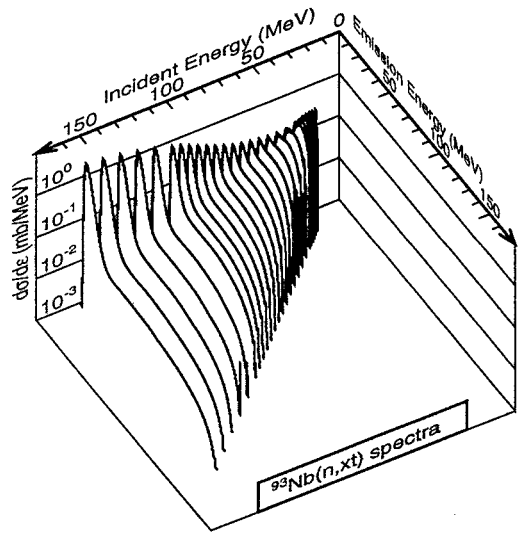

n + 93Nb nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
n
γ
p
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
0
50
100
150
Incident Energy (MeV)

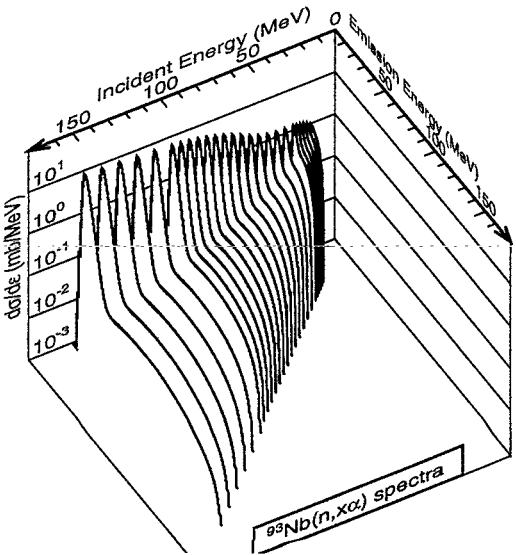
n + ^{93}Nb angle-integrated emission spectra

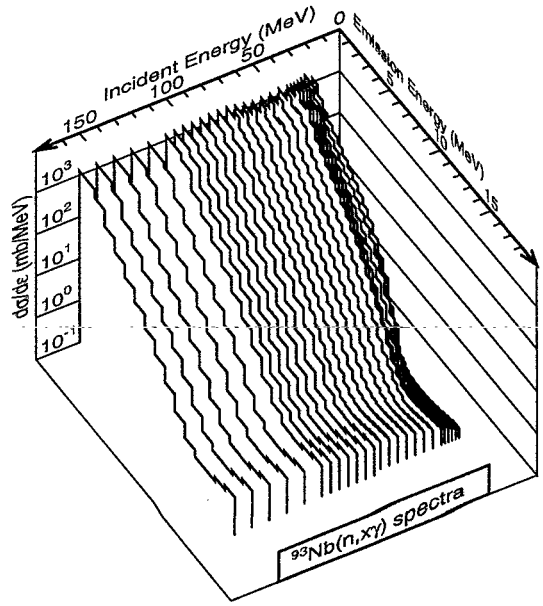




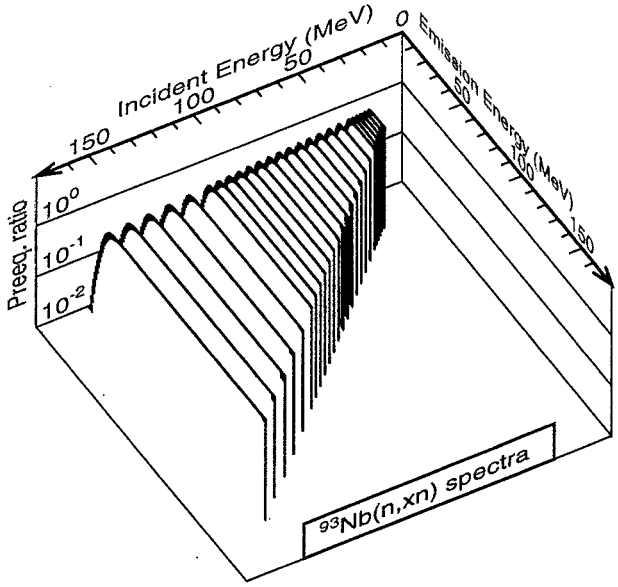


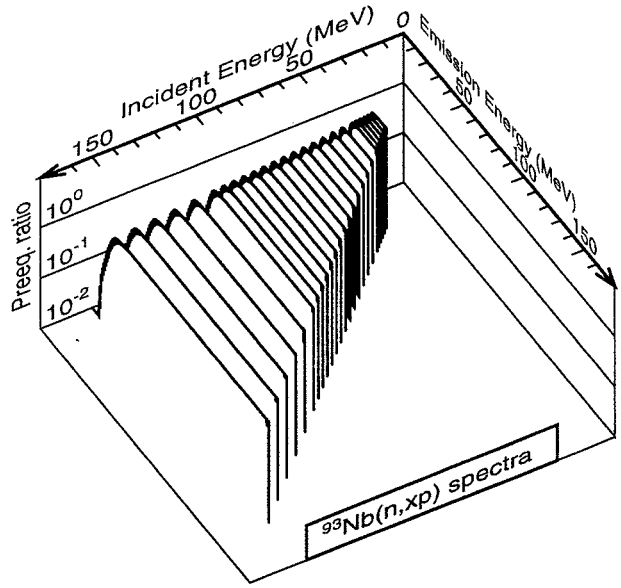


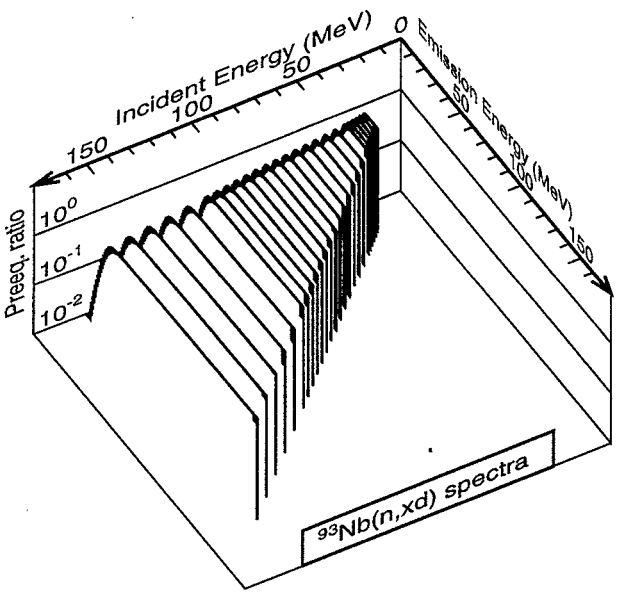


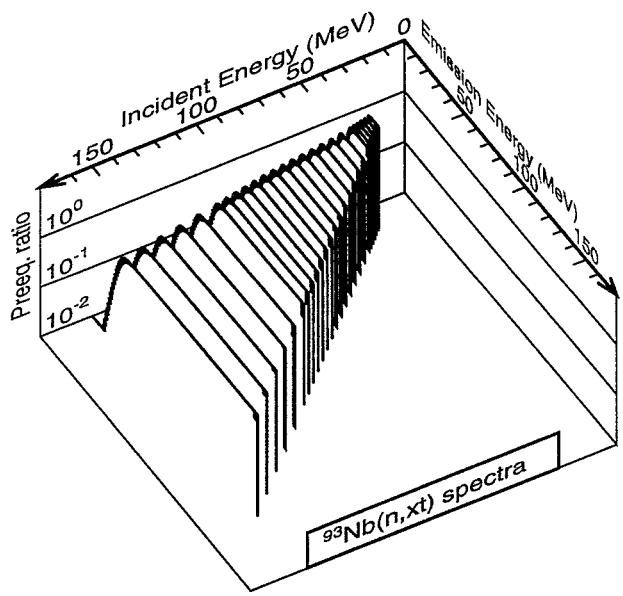


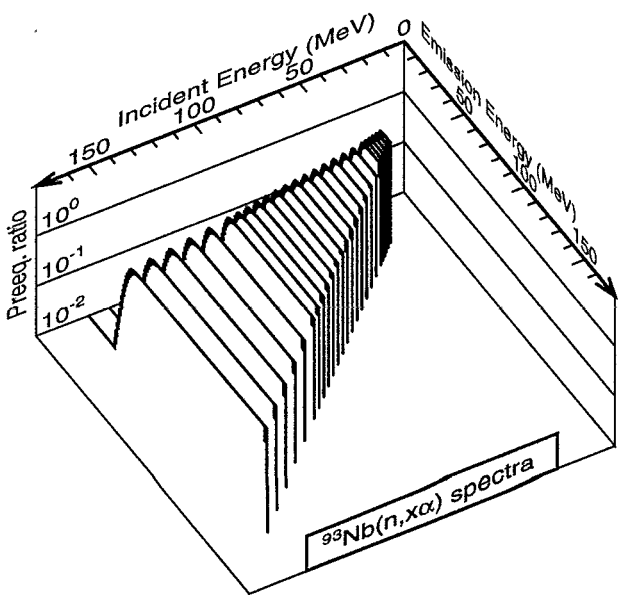
n + ^{93}Nb Kalbach preequilibrium ratios

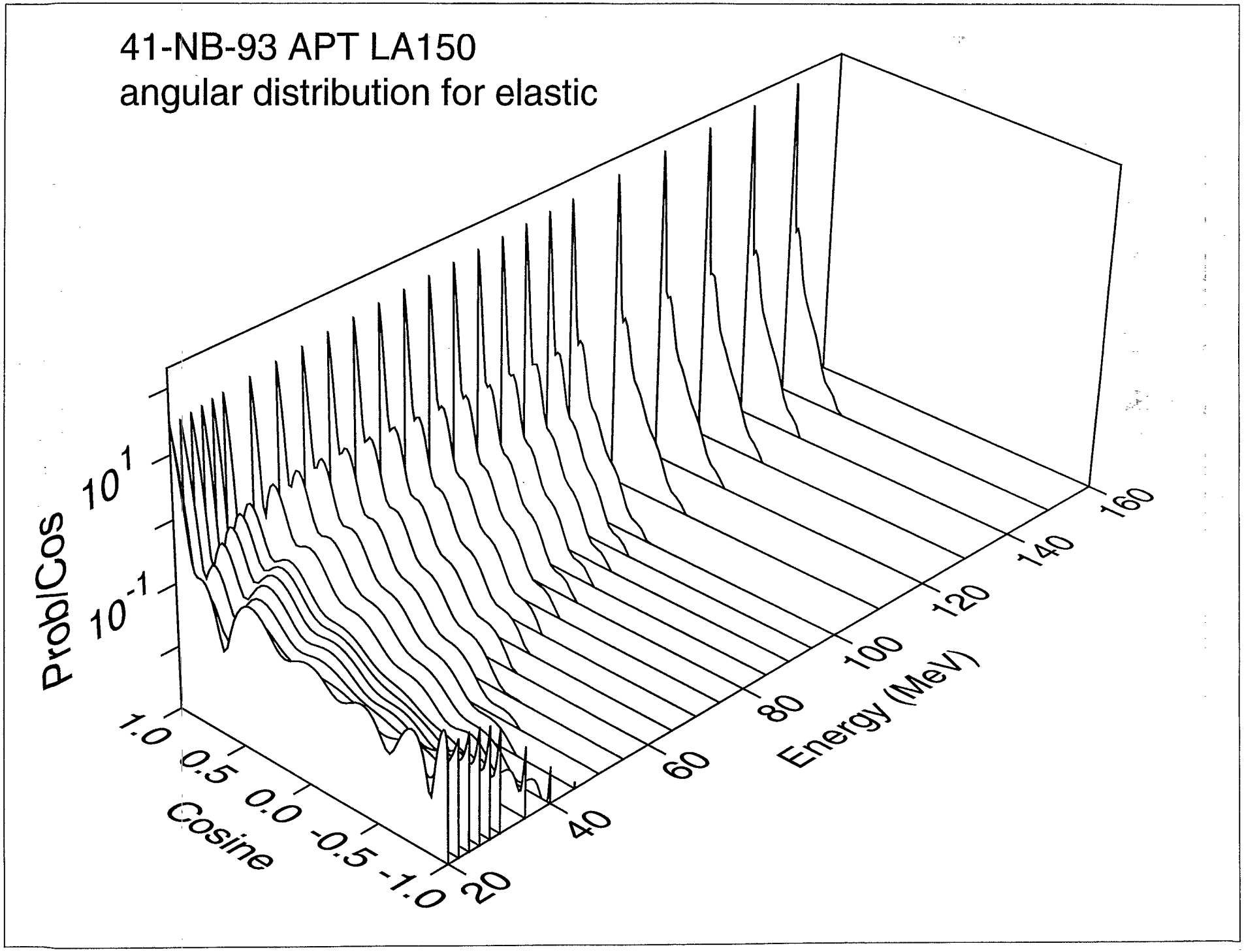











41-NB-93 APT LA150
angular distribution for elastic
Prob/Cos
10^1
10^{-1}
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF n + 182W CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

M. B. Chadwick and P. G. Young
16 October 1996

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI.0 (Release 0) evaluation, which was carried over from ENDF/B-V.2 [Ar80]. The following modifications were made to the ENDF/B-VI.0 evaluation:

1. The derived MF=3 files for MT=203 and 207 were removed.

INCIDENT NEUTRON ENERGIES > 20 MeV

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT=	1	Total Cross Section
	MT=	2	Elastic Scattering Cross Section
	MT=	3	Nonelastic Cross Section
	MT=	5	Sum of Binary (n,n') and (n,x) Reactions
MF=4	MT=	2	Elastic Angular Distributions
MF=6	MT=	5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + W, n + Ta, p + Ta, and p + W reactions (Ch96a). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Coupled-channels and spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

Because of the almost total absence of W data, the neutron total cross section above 20 MeV is based on the measurements of Finlay et al. (Fi93) of the n + Ta total cross section. A coupled-channels neutron optical model potential based on earlier work to 100 MeV (Yo90) is utilized to 80 MeV, and the global spherical optical model potential of Madland (Ma88) is used at higher energies. For protons, the Beccetti-Greenlees potential (Be69) is utilized below 50 MeV, and the Madland Semmering potential (Ma88) at higher energies. The Perey potential (Pe63) is used for deuterons, and the Beccetti-Greenlees potential (Be71) for tritons. The ECIS79 code (Ra72) was used for the coupled-channels optical model calculations, and the SCAT2 code (Be92) was utilized for the spherical optical model calculations. Minor normalizations were made to the reaction cross sections and transmission coefficients to produce agreement with the (sparse) measurements for W and values inferred from systematics of proton and neutron reaction cross sections from measurements on other targets.

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96b). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. Note that all other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation requires a modification of the original ENDF-6 format.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed above. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

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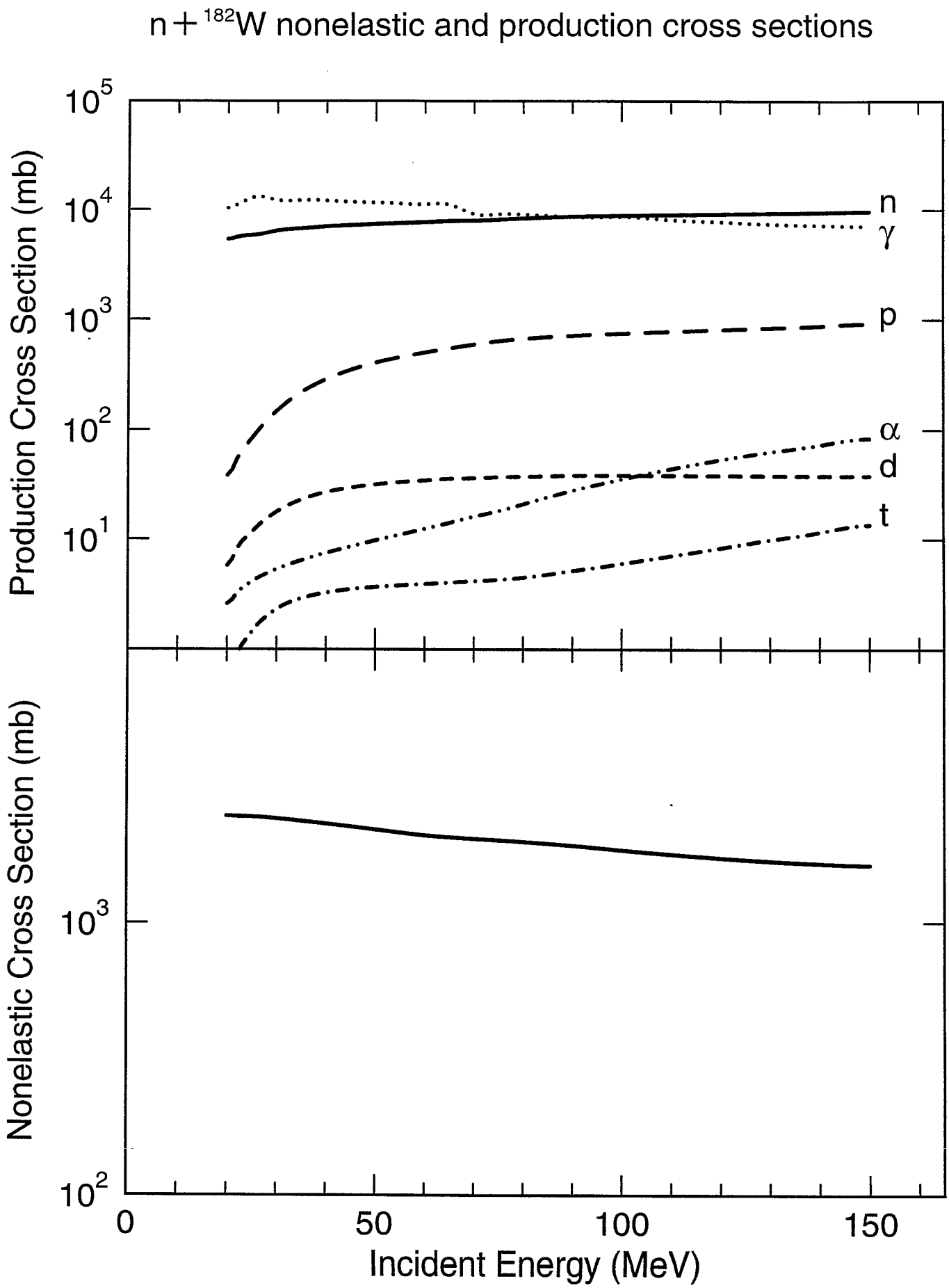
74182 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

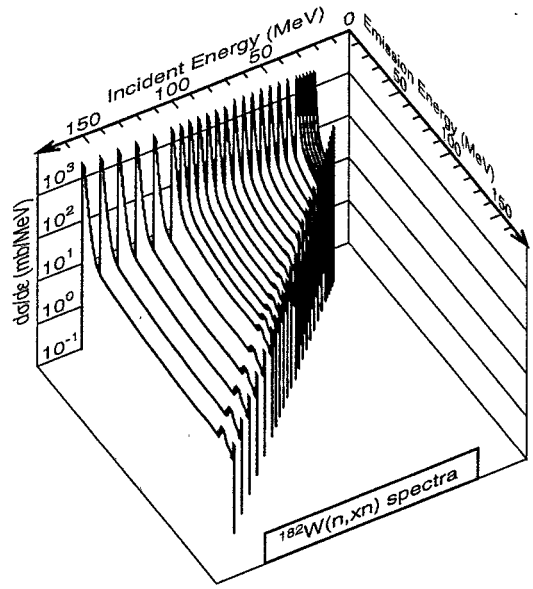
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	2.446E+00	2.938E+00	5.384E+00	3.822E-02	5.754E-03	4.983E-04	0.000E+00	2.574E-03	1.033E+01
2.200E+01	2.439E+00	2.791E+00	5.665E+00	5.443E-02	8.260E-03	8.634E-04	0.000E+00	3.213E-03	1.118E+01
2.400E+01	2.435E+00	2.631E+00	5.822E+00	7.357E-02	1.050E-02	1.250E-03	0.000E+00	3.806E-03	1.236E+01
2.600E+01	2.424E+00	2.459E+00	5.940E+00	9.573E-02	1.298E-02	1.634E-03	0.000E+00	4.368E-03	1.317E+01
2.800E+01	2.411E+00	2.274E+00	6.180E+00	1.210E-01	1.541E-02	1.976E-03	0.000E+00	4.868E-03	1.275E+01
3.000E+01	2.394E+00	2.116E+00	6.463E+00	1.484E-01	1.782E-02	2.297E-03	0.000E+00	5.335E-03	1.217E+01
3.500E+01	2.344E+00	1.866E+00	6.779E+00	2.198E-01	2.299E-02	2.884E-03	0.000E+00	6.414E-03	1.219E+01
4.000E+01	2.292E+00	1.764E+00	7.076E+00	2.870E-01	2.693E-02	3.244E-03	0.000E+00	7.502E-03	1.208E+01
4.500E+01	2.238E+00	1.808E+00	7.266E+00	3.501E-01	2.961E-02	3.497E-03	0.000E+00	8.598E-03	1.177E+01
5.000E+01	2.183E+00	1.917E+00	7.453E+00	4.067E-01	3.168E-02	3.657E-03	0.000E+00	9.750E-03	1.164E+01
5.500E+01	2.129E+00	2.091E+00	7.609E+00	4.571E-01	3.327E-02	3.790E-03	0.000E+00	1.099E-02	1.143E+01
6.000E+01	2.081E+00	2.256E+00	7.761E+00	5.042E-01	3.450E-02	3.894E-03	0.000E+00	1.245E-02	1.128E+01
6.500E+01	2.048E+00	2.382E+00	7.940E+00	5.503E-01	3.572E-02	4.019E-03	0.000E+00	1.410E-02	1.119E+01
7.000E+01	2.021E+00	2.479E+00	8.010E+00	5.944E-01	3.619E-02	4.146E-03	0.000E+00	1.610E-02	9.138E+00
7.500E+01	1.997E+00	2.530E+00	8.189E+00	6.369E-01	3.701E-02	4.275E-03	0.000E+00	1.810E-02	9.153E+00
8.000E+01	1.971E+00	2.554E+00	8.404E+00	6.674E-01	3.733E-02	4.473E-03	0.000E+00	2.096E-02	9.081E+00
8.500E+01	1.941E+00	2.577E+00	8.563E+00	6.923E-01	3.780E-02	4.779E-03	0.000E+00	2.427E-02	8.861E+00
9.000E+01	1.910E+00	2.558E+00	8.710E+00	7.122E-01	3.828E-02	5.174E-03	0.000E+00	2.794E-02	8.647E+00
9.500E+01	1.874E+00	2.498E+00	8.814E+00	7.320E-01	3.841E-02	5.556E-03	0.000E+00	3.158E-02	8.590E+00
1.000E+02	1.837E+00	2.435E+00	8.890E+00	7.468E-01	3.837E-02	6.009E-03	0.000E+00	3.554E-02	8.678E+00
1.100E+02	1.774E+00	2.310E+00	9.036E+00	7.781E-01	3.831E-02	7.073E-03	0.000E+00	4.409E-02	8.155E+00
1.200E+02	1.721E+00	2.119E+00	9.182E+00	8.087E-01	3.821E-02	8.378E-03	0.000E+00	5.333E-02	7.817E+00
1.300E+02	1.678E+00	1.962E+00	9.323E+00	8.405E-01	3.809E-02	9.918E-03	0.000E+00	6.308E-02	7.453E+00
1.400E+02	1.645E+00	1.788E+00	9.498E+00	8.764E-01	3.803E-02	1.167E-02	0.000E+00	7.321E-02	7.282E+00
1.500E+02	1.624E+00	1.646E+00	9.695E+00	9.181E-01	3.811E-02	1.359E-02	0.000E+00	8.367E-02	7.169E+00

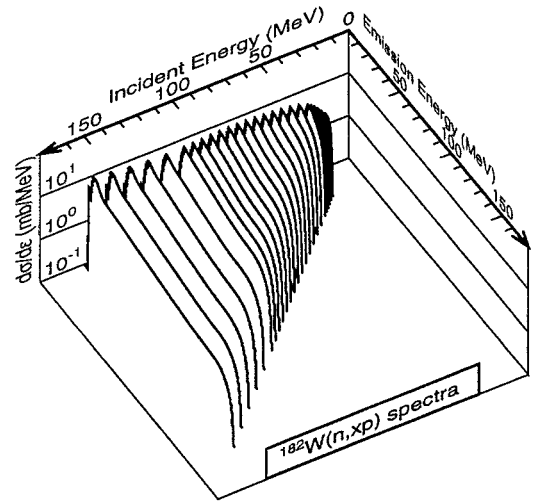
74182 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

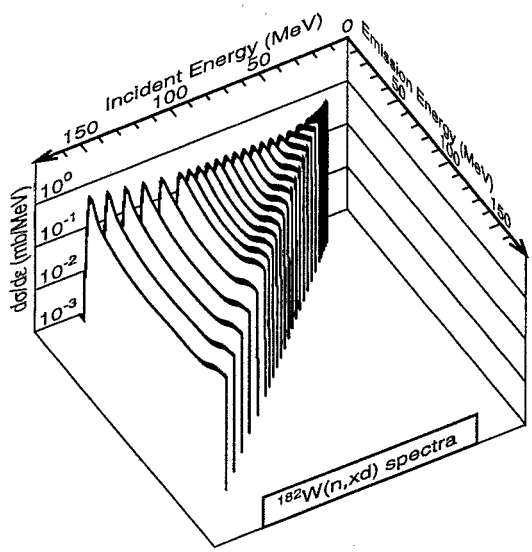
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	2.642E-02	3.830E-03	2.823E-04	0.000E+00	2.870E-03	1.687E-02	2.208E-03	5.247E-02
2.200E+01	3.984E-02	6.069E-03	5.381E-04	0.000E+00	3.722E-03	1.835E-02	2.298E-03	7.082E-02
2.400E+01	5.658E-02	8.369E-03	8.466E-04	0.000E+00	4.561E-03	1.975E-02	2.379E-03	9.248E-02
2.600E+01	7.707E-02	1.118E-02	1.193E-03	0.000E+00	5.389E-03	2.100E-02	2.502E-03	1.183E-01
2.800E+01	1.019E-01	1.426E-02	1.545E-03	0.000E+00	6.168E-03	2.222E-02	2.644E-03	1.487E-01
3.000E+01	1.307E-01	1.763E-02	1.911E-03	0.000E+00	6.933E-03	2.331E-02	2.812E-03	1.833E-01
3.500E+01	2.162E-01	2.643E-02	2.732E-03	0.000E+00	8.757E-03	2.555E-02	3.214E-03	2.829E-01
4.000E+01	3.129E-01	3.543E-02	3.417E-03	0.000E+00	1.055E-02	2.777E-02	3.504E-03	3.935E-01
4.500E+01	4.181E-01	4.362E-02	4.037E-03	0.000E+00	1.235E-02	2.948E-02	3.670E-03	5.112E-01
5.000E+01	5.253E-01	5.154E-02	4.567E-03	0.000E+00	1.417E-02	3.093E-02	3.698E-03	6.302E-01
5.500E+01	6.328E-01	5.900E-02	5.060E-03	0.000E+00	1.605E-02	3.203E-02	3.711E-03	7.487E-01
6.000E+01	7.431E-01	6.602E-02	5.489E-03	0.000E+00	1.809E-02	3.304E-02	3.665E-03	8.694E-01
6.500E+01	8.594E-01	7.321E-02	5.927E-03	0.000E+00	2.034E-02	3.412E-02	3.544E-03	9.965E-01
7.000E+01	9.797E-01	7.829E-02	6.310E-03	0.000E+00	2.293E-02	3.532E-02	3.422E-03	1.126E+00
7.500E+01	1.105E+00	8.482E-02	6.657E-03	0.000E+00	2.550E-02	3.611E-02	3.226E-03	1.261E+00
8.000E+01	1.215E+00	9.017E-02	6.971E-03	0.000E+00	2.878E-02	3.692E-02	2.997E-03	1.381E+00
8.500E+01	1.320E+00	9.604E-02	7.411E-03	0.000E+00	3.241E-02	3.752E-02	1.556E-03	1.495E+00
9.000E+01	1.419E+00	1.020E-01	7.917E-03	0.000E+00	3.638E-02	3.801E-02	1.520E-03	1.605E+00
9.500E+01	1.520E+00	1.068E-01	8.311E-03	0.000E+00	4.031E-02	3.819E-02	1.469E-03	1.715E+00
1.000E+02	1.612E+00	1.109E-01	8.715E-03	0.000E+00	4.451E-02	3.830E-02	1.424E-03	1.816E+00
1.100E+02	1.805E+00	1.187E-01	9.573E-03	0.000E+00	5.355E-02	3.849E-02	1.349E-03	2.026E+00
1.200E+02	2.001E+00	1.253E-01	1.051E-02	0.000E+00	6.338E-02	3.857E-02	1.248E-03	2.240E+00
1.300E+02	2.203E+00	1.305E-01	1.154E-02	0.000E+00	7.391E-02	3.990E-02	1.177E-03	2.460E+00
1.400E+02	2.417E+00	1.348E-01	1.267E-02	0.000E+00	8.504E-02	4.213E-02	1.107E-03	2.693E+00
1.500E+02	2.649E+00	1.386E-01	1.391E-02	0.000E+00	9.669E-02	4.440E-02	1.074E-03	2.943E+00

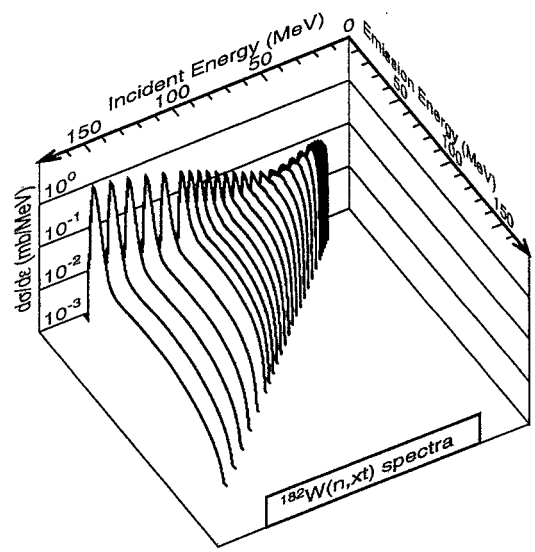

n + 182W nonelastic and production cross sections
Production Cross Section (mb)
10^5
10^4
10^3
10^2
10^1
n
γ
p
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
0
50
100
150
Incident Energy (MeV)

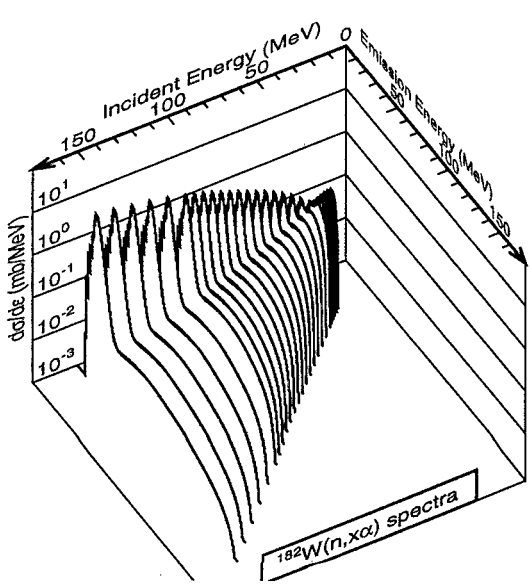
n + ^{182}W angle-integrated emission spectra

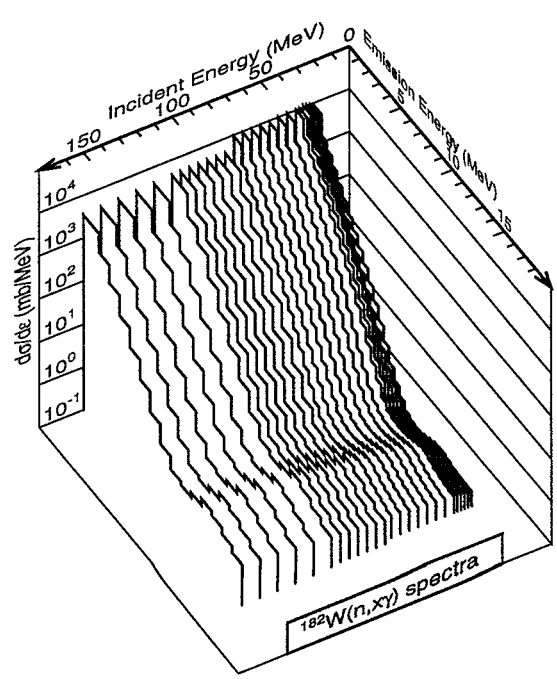




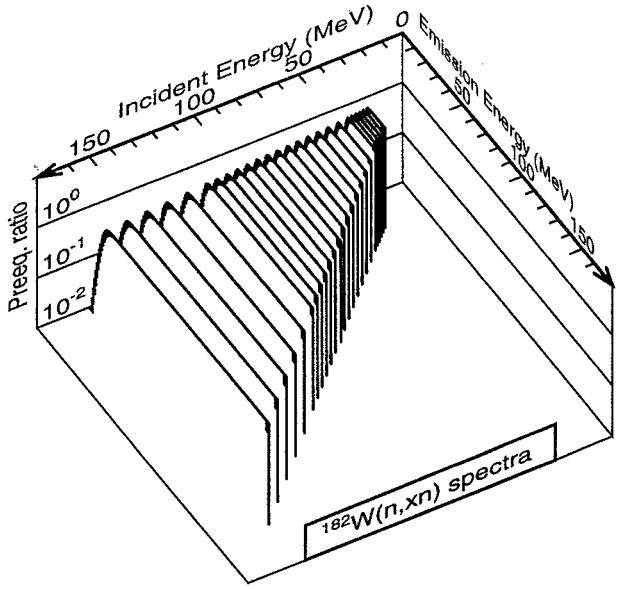


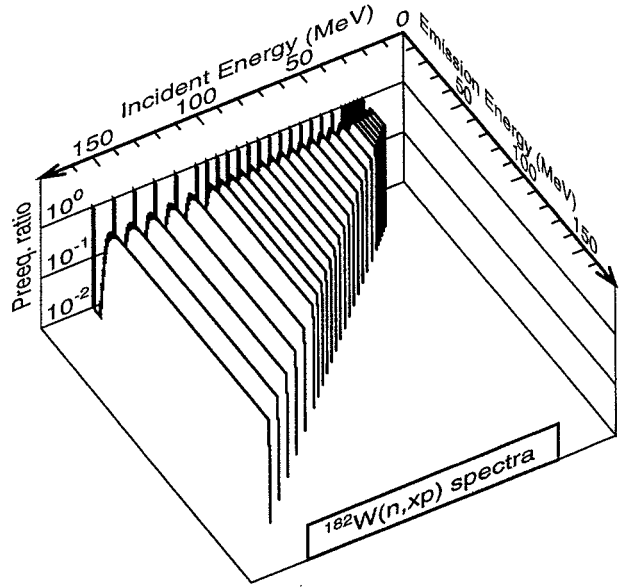


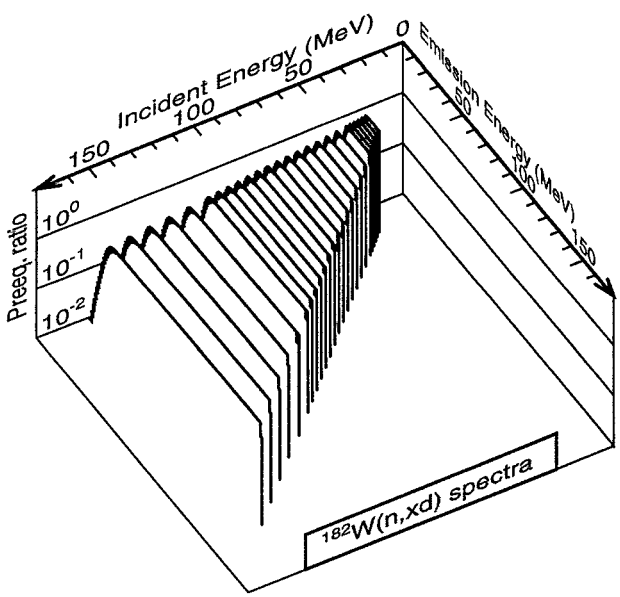


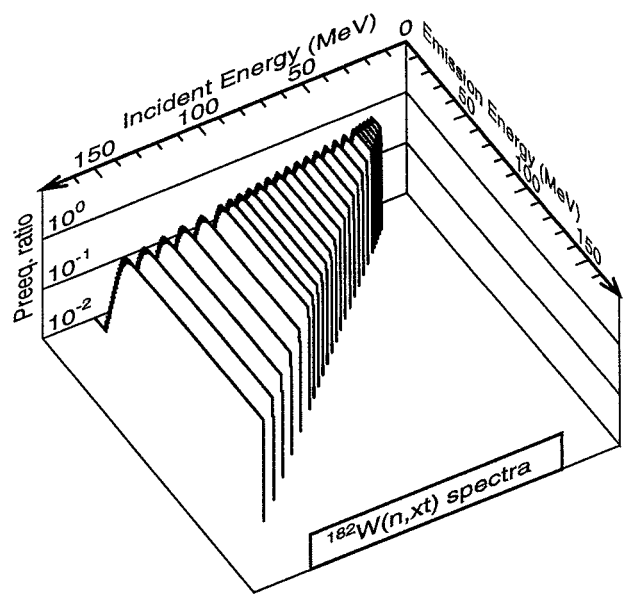


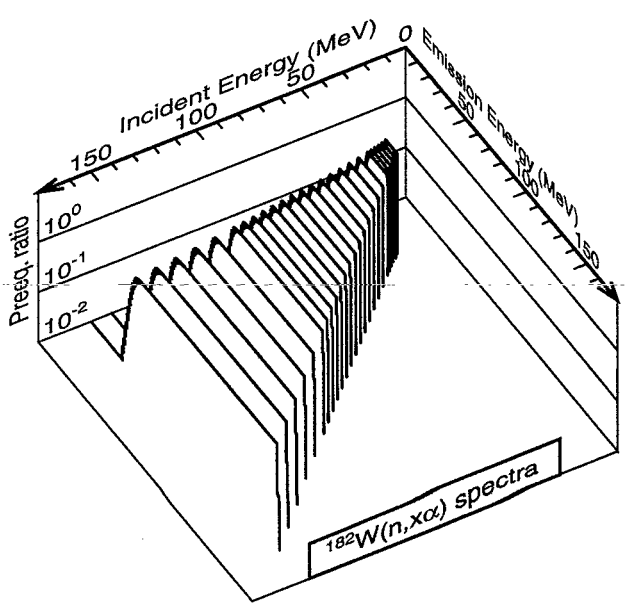
n + ^{182}W Kalbach preequilibrium ratios

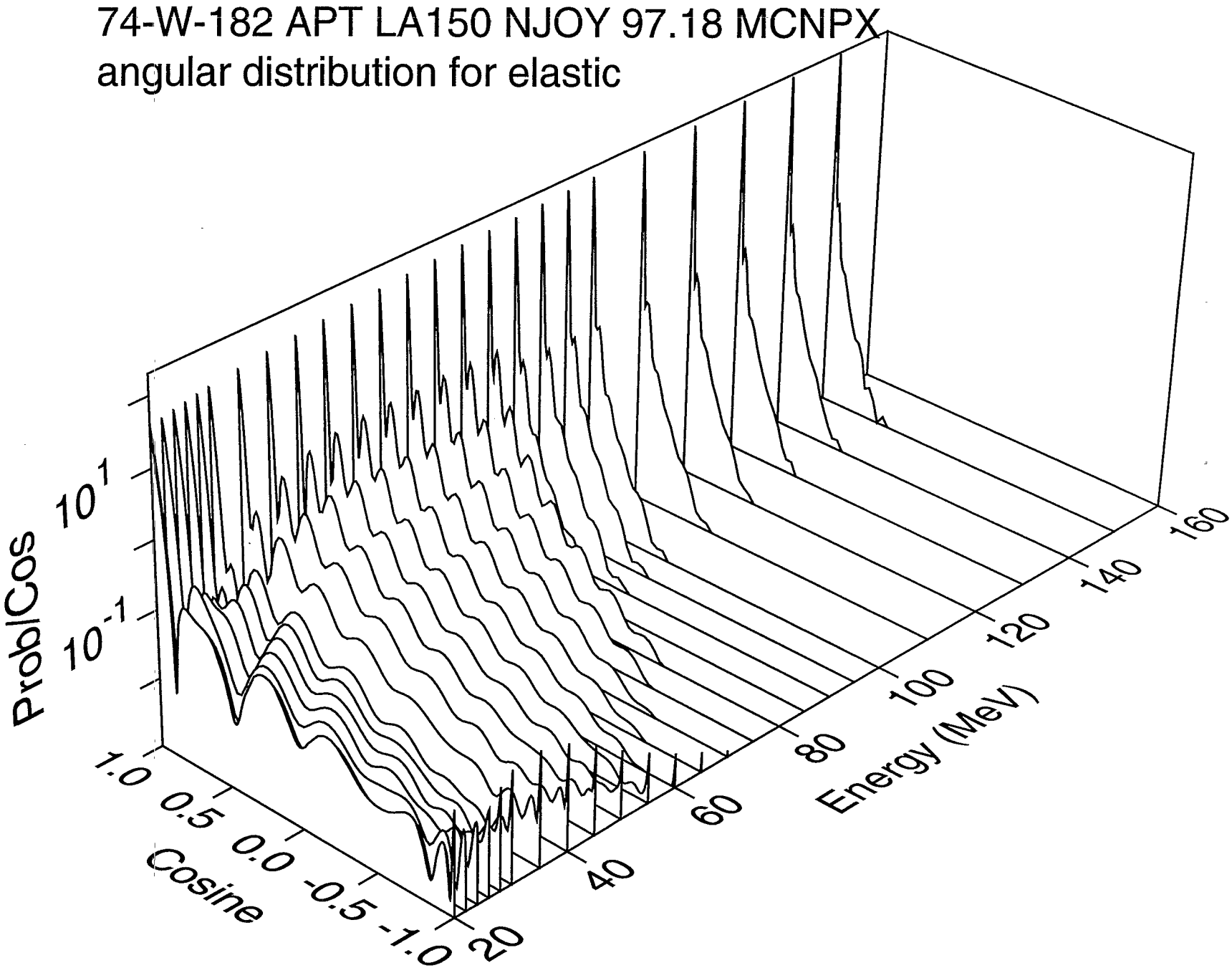


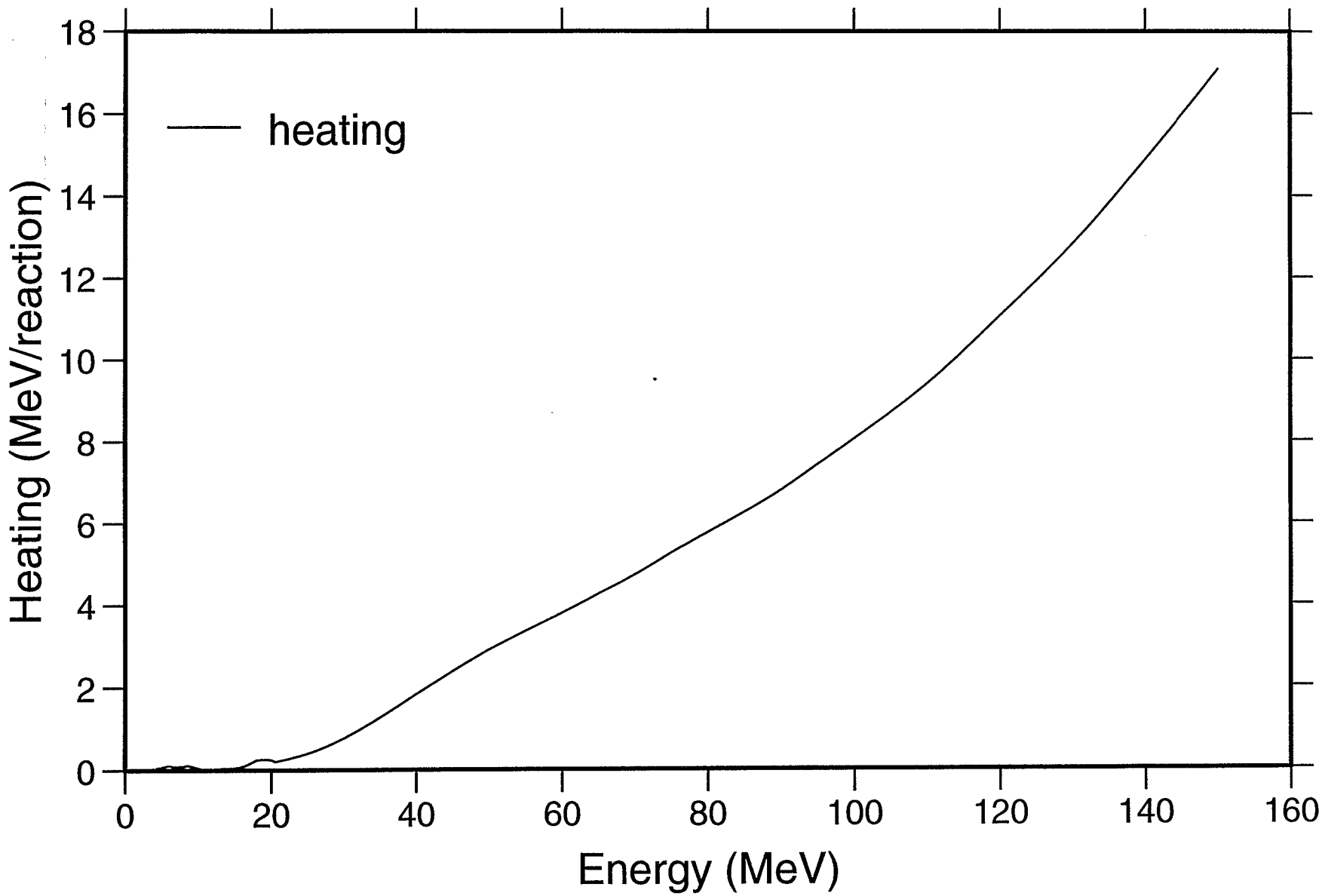


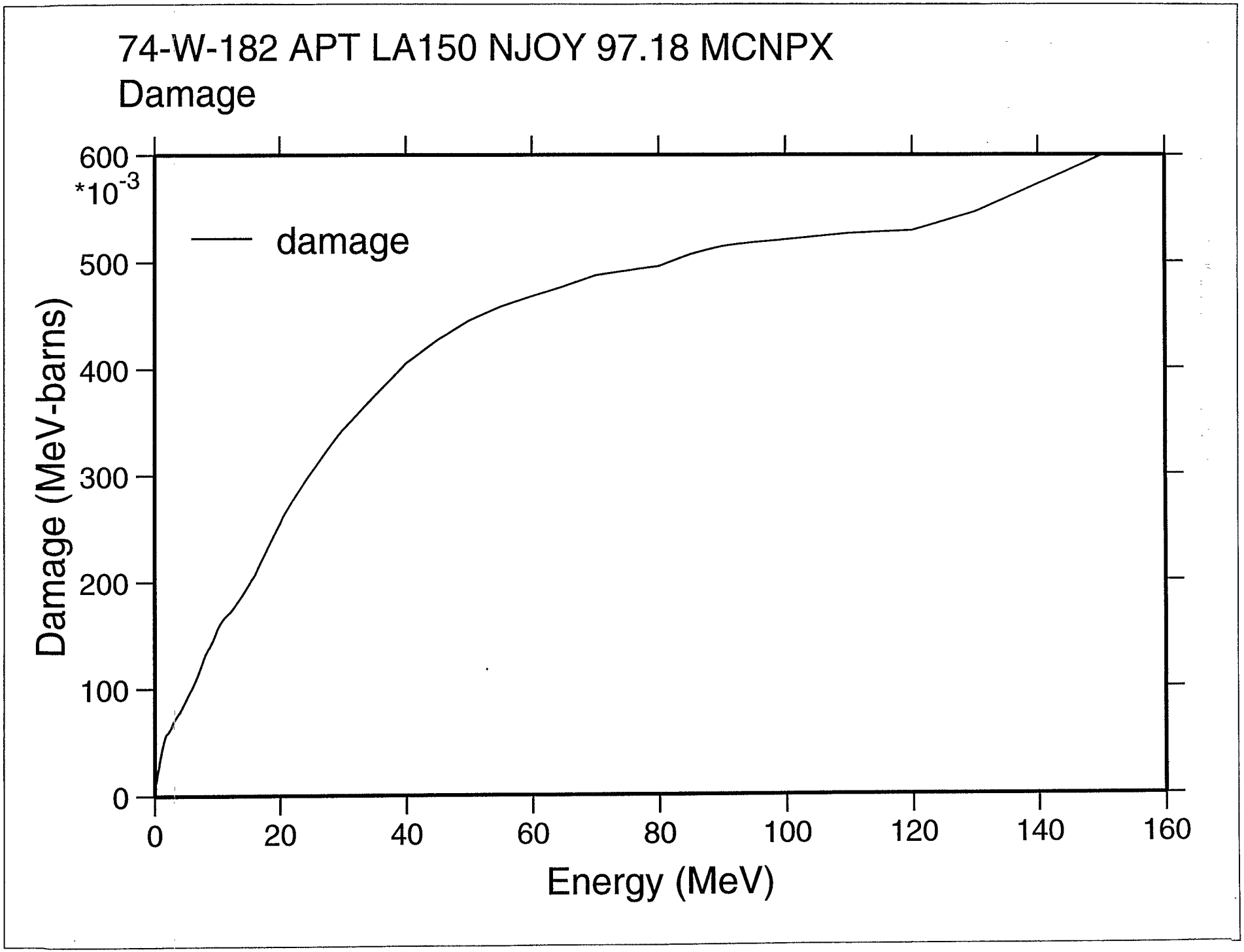







74-W-182 APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic
Prob/Cos
10^{1}
10^{-1}
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


74-W-182 APT LA150 NJOY 97.18 MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
2
4
6
8
10
12
14
16
18
0
20
40
60
80
100
120
140
160


74-W-182 APT LA150 NJOY 97.18 MCNPX
Damage
damage
Damage (MeV-barns)
*10^-3
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF n + 183W CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

M. B. Chadwick and P. G. Young
16 October 1996

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI.0 (Release 0) evaluation, which was carried over from ENDF/B-V.2 [Ar80]. The following modifications were made to the ENDF/B-VI.0 evaluation:

1. The derived MF=3 files for MT=203 and 207 were removed.

INCIDENT NEUTRON ENERGIES > 20 MeV

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT=	1	Total Cross Section
	MT=	2	Elastic Scattering Cross Section
	MT=	3	Nonelastic Cross Section
	MT=	5	Sum of Binary (n,n') and (n,x) Reactions
MF=4	MT=	2	Elastic Angular Distributions
MF=6	MT=	5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + W, n + Ta, p + Ta, and p + W reactions (Ch96a). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Coupled-channels and spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

Because of the almost total absence of W data, the neutron total cross section above 20 MeV is based on the measurements of

Finlay et al. (Fi93) of the n + Ta total cross section. A coupled-channels neutron optical model potential based on earlier work to 100 MeV (Yo90) is utilized to 80 MeV, and the global spherical optical model potential of Madland (Ma88) is used at higher energies. For protons, the Beccetti-Greenlees potential (Be69) is utilized below 50 MeV, and the Madland Semmering potential (Ma88) at higher energies. The Perey potential (Pe63) is used for deuterons, and the Beccetti-Greenlees potential (Be71) for tritons. The ECIS79 code (Ra72) was used for the coupled-channels optical model calculations, and the SCAT2 code (Be92) was utilized for the spherical optical model calculations. Minor normalizations were made to the reaction cross sections and transmission coefficients to produce agreement with the (sparse) measurements for W and values inferred from systematics of proton and neutron reaction cross sections from measurements on other targets.

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96b). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. Note that all other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation requires a modification of the original ENDF-6 format.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed above. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

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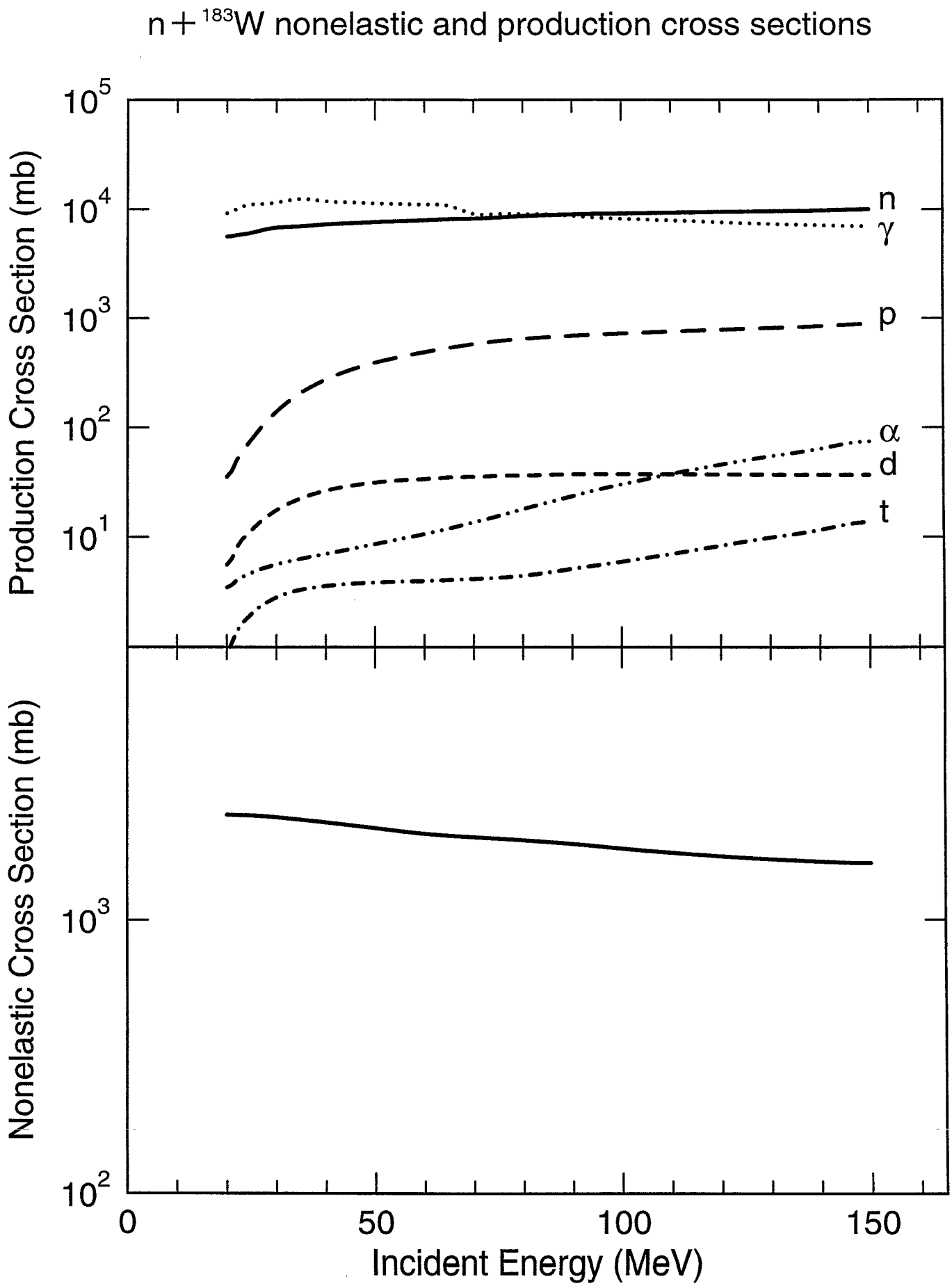
74183 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

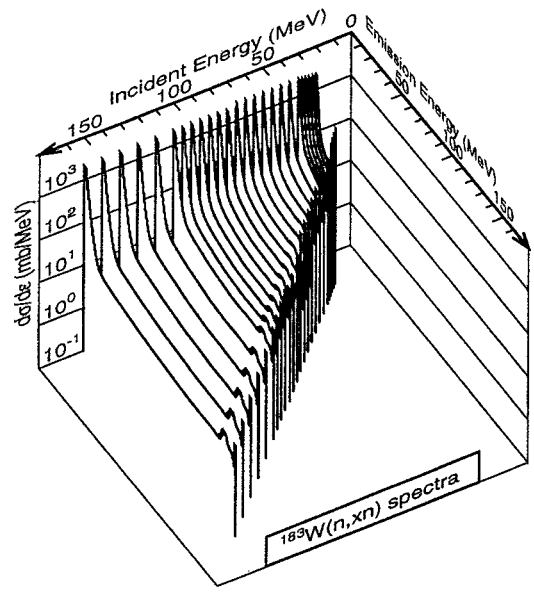
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	2.446E+00	2.938E+00	5.639E+00	3.518E-02	5.546E-03	9.391E-04	0.000E+00	3.476E-03	9.209E+00
2.200E+01	2.439E+00	2.791E+00	5.824E+00	5.013E-02	7.960E-03	1.385E-03	0.000E+00	4.031E-03	1.008E+01
2.400E+01	2.435E+00	2.631E+00	5.993E+00	6.805E-02	1.037E-02	1.811E-03	0.000E+00	4.507E-03	1.092E+01
2.600E+01	2.424E+00	2.459E+00	6.277E+00	8.906E-02	1.279E-02	2.207E-03	0.000E+00	4.929E-03	1.116E+01
2.800E+01	2.411E+00	2.274E+00	6.596E+00	1.132E-01	1.517E-02	2.538E-03	0.000E+00	5.278E-03	1.126E+01
3.000E+01	2.394E+00	2.116E+00	6.806E+00	1.396E-01	1.753E-02	2.833E-03	0.000E+00	5.593E-03	1.155E+01
3.500E+01	2.344E+00	1.866E+00	7.014E+00	2.084E-01	2.253E-02	3.320E-03	0.000E+00	6.319E-03	1.245E+01
4.000E+01	2.292E+00	1.764E+00	7.316E+00	2.751E-01	2.638E-02	3.587E-03	0.000E+00	7.000E-03	1.181E+01
4.500E+01	2.238E+00	1.808E+00	7.482E+00	3.367E-01	2.920E-02	3.761E-03	0.000E+00	7.735E-03	1.156E+01
5.000E+01	2.183E+00	1.917E+00	7.679E+00	3.924E-01	3.129E-02	3.854E-03	0.000E+00	8.576E-03	1.130E+01
5.500E+01	2.129E+00	2.091E+00	7.819E+00	4.420E-01	3.279E-02	3.930E-03	0.000E+00	9.516E-03	1.121E+01
6.000E+01	2.081E+00	2.256E+00	7.976E+00	4.886E-01	3.361E-02	3.982E-03	0.000E+00	1.059E-02	1.106E+01
6.500E+01	2.048E+00	2.382E+00	8.158E+00	5.342E-01	3.480E-02	4.068E-03	0.000E+00	1.191E-02	1.078E+01
7.000E+01	2.021E+00	2.479E+00	8.248E+00	5.781E-01	3.524E-02	4.158E-03	0.000E+00	1.355E-02	9.094E+00
7.500E+01	1.997E+00	2.530E+00	8.457E+00	6.182E-01	3.597E-02	4.266E-03	0.000E+00	1.544E-02	9.088E+00
8.000E+01	1.971E+00	2.554E+00	8.694E+00	6.470E-01	3.624E-02	4.448E-03	0.000E+00	1.793E-02	9.050E+00
8.500E+01	1.941E+00	2.577E+00	8.877E+00	6.703E-01	3.665E-02	4.746E-03	0.000E+00	2.061E-02	9.027E+00
9.000E+01	1.910E+00	2.558E+00	9.011E+00	6.917E-01	3.718E-02	5.117E-03	0.000E+00	2.348E-02	8.745E+00
9.500E+01	1.874E+00	2.498E+00	9.126E+00	7.098E-01	3.726E-02	5.506E-03	0.000E+00	2.679E-02	8.407E+00
1.000E+02	1.837E+00	2.435E+00	9.194E+00	7.256E-01	3.726E-02	5.930E-03	0.000E+00	3.011E-02	8.227E+00
1.100E+02	1.774E+00	2.310E+00	9.339E+00	7.554E-01	3.718E-02	6.988E-03	0.000E+00	3.744E-02	7.953E+00
1.200E+02	1.721E+00	2.119E+00	9.476E+00	7.842E-01	3.703E-02	8.296E-03	0.000E+00	4.558E-02	7.618E+00
1.300E+02	1.678E+00	1.962E+00	9.620E+00	8.138E-01	3.689E-02	9.849E-03	0.000E+00	5.439E-02	7.358E+00
1.400E+02	1.645E+00	1.788E+00	9.794E+00	8.465E-01	3.681E-02	1.162E-02	0.000E+00	6.391E-02	7.156E+00
1.500E+02	1.624E+00	1.646E+00	9.999E+00	8.834E-01	3.675E-02	1.361E-02	0.000E+00	7.435E-02	7.013E+00

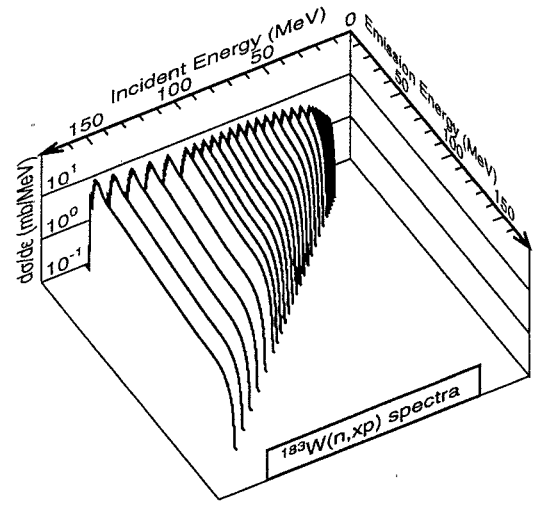
74183 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

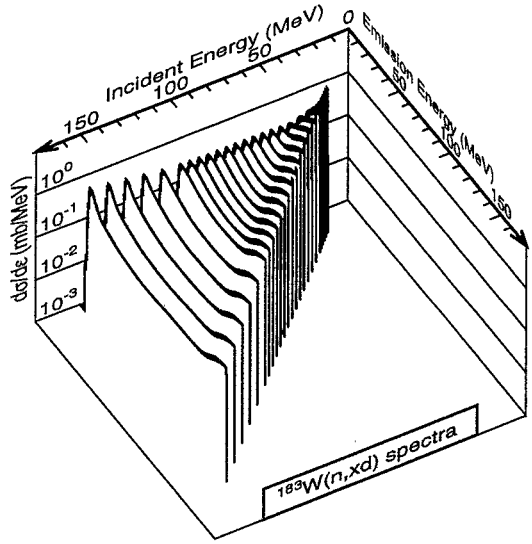
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	2.440E-02	3.676E-03	5.682E-04	0.000E+00	4.015E-03	1.682E-02	2.254E-03	5.173E-02
2.200E+01	3.677E-02	5.824E-03	9.141E-04	0.000E+00	4.839E-03	1.828E-02	2.273E-03	6.890E-02
2.400E+01	5.239E-02	8.273E-03	1.291E-03	0.000E+00	5.604E-03	1.964E-02	2.353E-03	8.956E-02
2.600E+01	7.174E-02	1.102E-02	1.689E-03	0.000E+00	6.330E-03	2.094E-02	2.475E-03	1.142E-01
2.800E+01	9.540E-02	1.403E-02	2.072E-03	0.000E+00	6.981E-03	2.213E-02	2.615E-03	1.432E-01
3.000E+01	1.230E-01	1.733E-02	2.452E-03	0.000E+00	7.593E-03	2.321E-02	2.781E-03	1.764E-01
3.500E+01	2.050E-01	2.588E-02	3.251E-03	0.000E+00	9.065E-03	2.536E-02	3.180E-03	2.718E-01
4.000E+01	3.002E-01	3.467E-02	3.898E-03	0.000E+00	1.045E-02	2.746E-02	3.466E-03	3.801E-01
4.500E+01	4.025E-01	4.309E-02	4.480E-03	0.000E+00	1.184E-02	2.913E-02	3.631E-03	4.946E-01
5.000E+01	5.072E-01	5.098E-02	4.964E-03	0.000E+00	1.330E-02	3.057E-02	3.658E-03	6.107E-01
5.500E+01	6.124E-01	5.816E-02	5.412E-03	0.000E+00	1.483E-02	3.163E-02	3.671E-03	7.261E-01
6.000E+01	7.207E-01	6.388E-02	5.796E-03	0.000E+00	1.647E-02	3.260E-02	3.625E-03	8.430E-01
6.500E+01	8.348E-01	7.080E-02	6.194E-03	0.000E+00	1.835E-02	3.357E-02	3.506E-03	9.672E-01
7.000E+01	9.539E-01	7.561E-02	6.536E-03	0.000E+00	2.052E-02	3.473E-02	3.385E-03	1.095E+00
7.500E+01	1.074E+00	8.171E-02	6.838E-03	0.000E+00	2.285E-02	3.556E-02	3.191E-03	1.224E+00
8.000E+01	1.180E+00	8.670E-02	7.114E-03	0.000E+00	2.569E-02	3.641E-02	2.965E-03	1.339E+00
8.500E+01	1.282E+00	9.219E-02	7.523E-03	0.000E+00	2.871E-02	3.697E-02	1.539E-03	1.448E+00
9.000E+01	1.382E+00	9.806E-02	8.008E-03	0.000E+00	3.189E-02	3.750E-02	1.504E-03	1.559E+00
9.500E+01	1.479E+00	1.025E-01	8.377E-03	0.000E+00	3.542E-02	3.767E-02	1.453E-03	1.665E+00
1.000E+02	1.574E+00	1.067E-01	8.752E-03	0.000E+00	3.892E-02	3.778E-02	1.409E-03	1.768E+00
1.100E+02	1.764E+00	1.141E-01	9.567E-03	0.000E+00	4.666E-02	3.789E-02	1.334E-03	1.974E+00
1.200E+02	1.958E+00	1.203E-01	1.046E-02	0.000E+00	5.528E-02	3.797E-02	1.234E-03	2.184E+00
1.300E+02	2.158E+00	1.253E-01	1.148E-02	0.000E+00	6.470E-02	3.920E-02	1.164E-03	2.400E+00
1.400E+02	2.369E+00	1.295E-01	1.259E-02	0.000E+00	7.495E-02	4.134E-02	1.095E-03	2.629E+00
1.500E+02	2.596E+00	1.322E-01	1.384E-02	0.000E+00	8.611E-02	4.365E-02	1.063E-03	2.872E+00

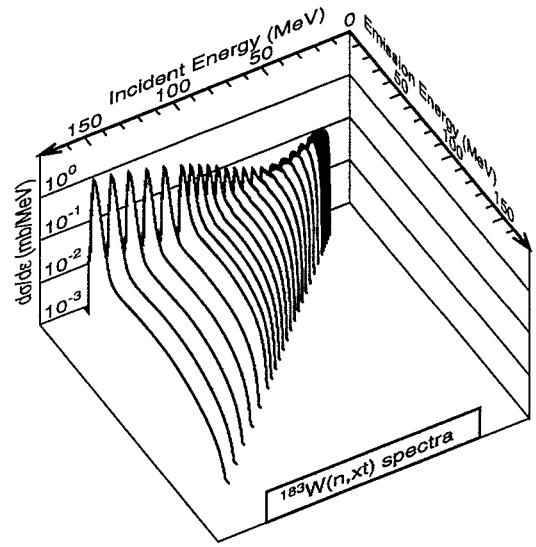

n + 183W nonelastic and production cross sections
Production Cross Section (mb)
10^5
10^4
10^3
10^2
10^1
n
γ
p
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
0
50
100
150
Incident Energy (MeV)

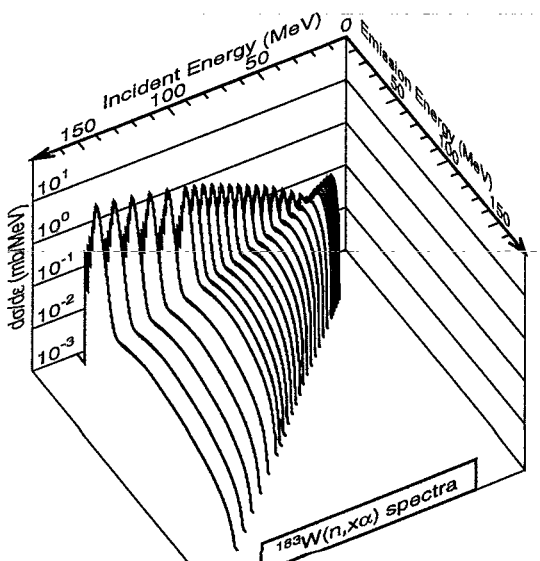
n + ^{183}W angle-integrated emission spectra

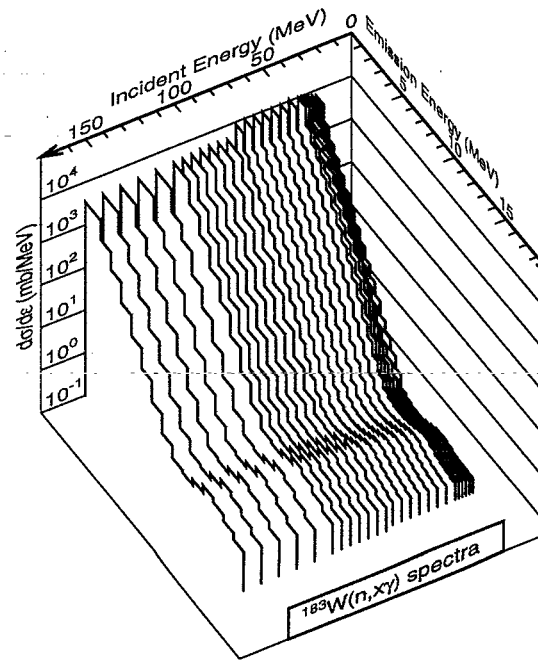




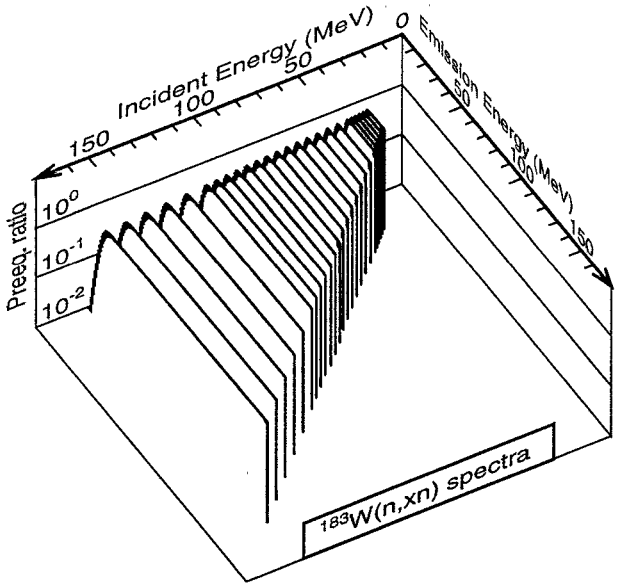


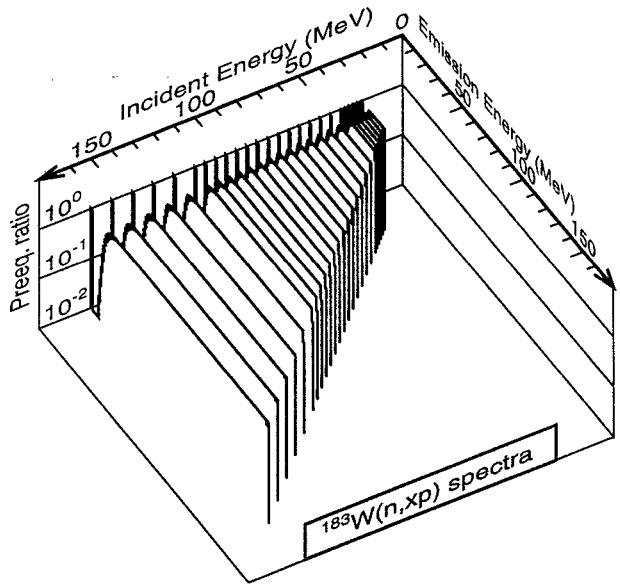


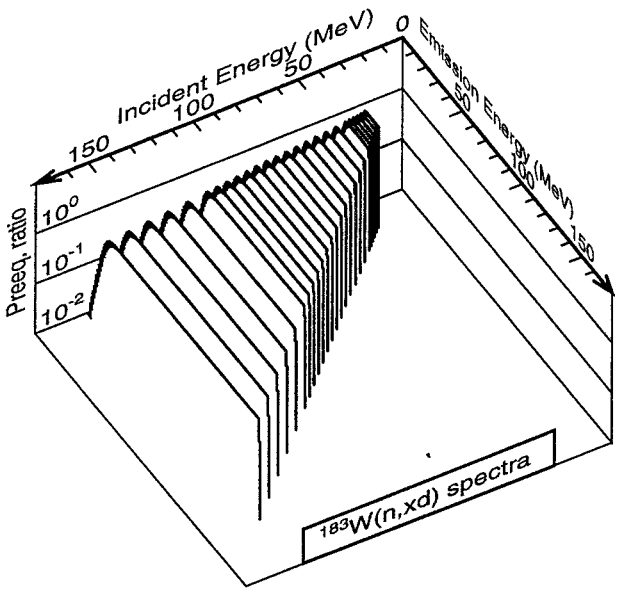


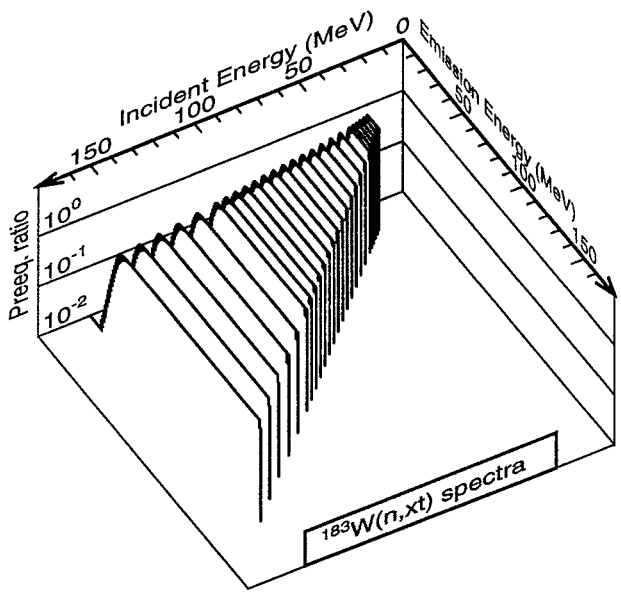


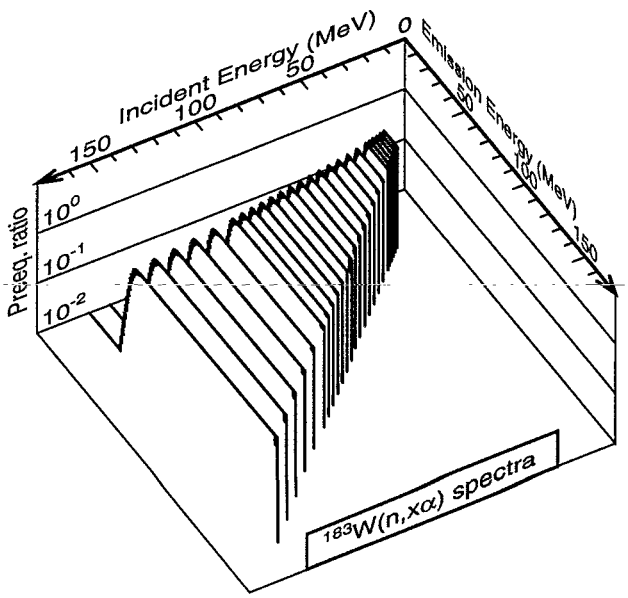
n + ^{183}W Kalbach preequilibrium ratios

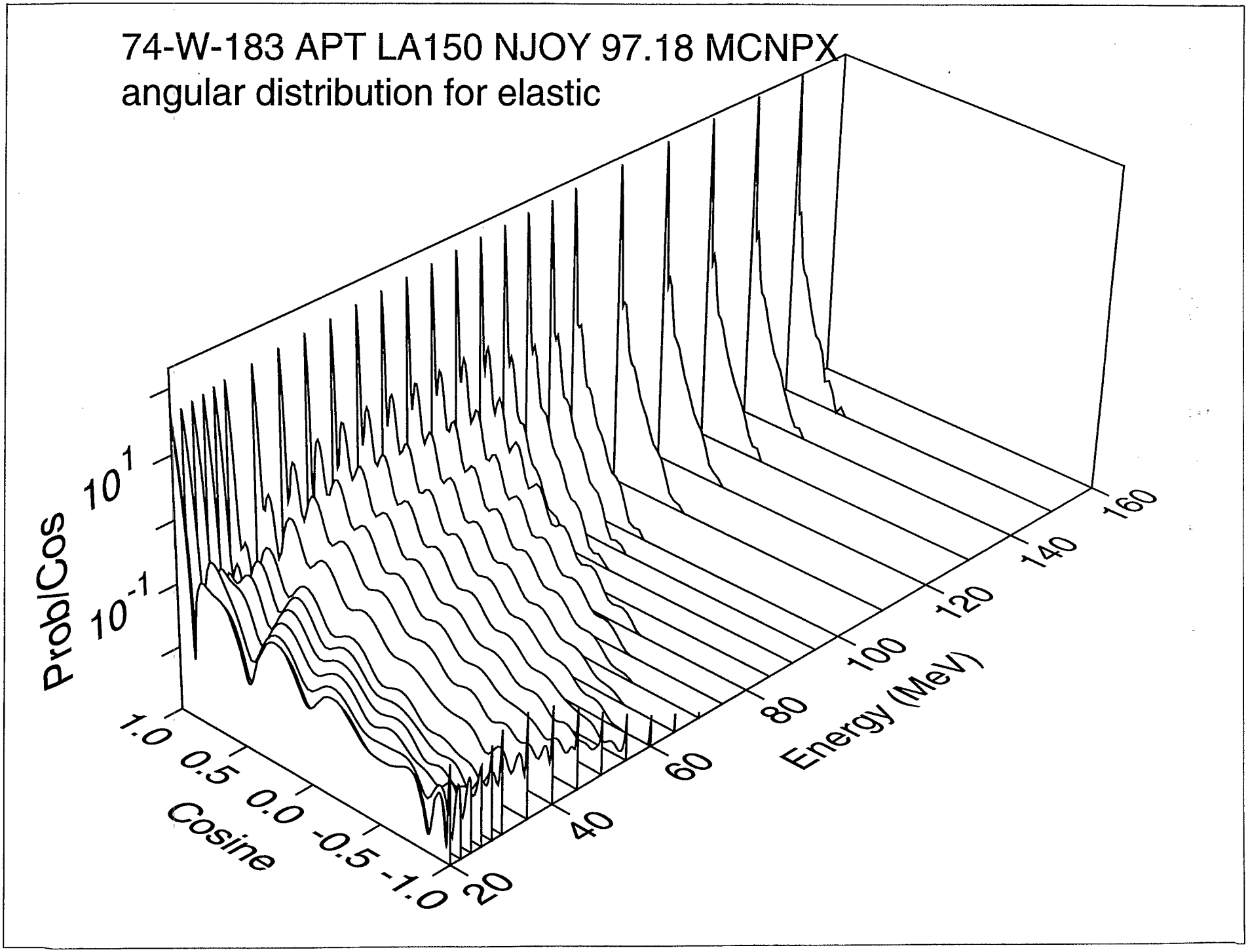


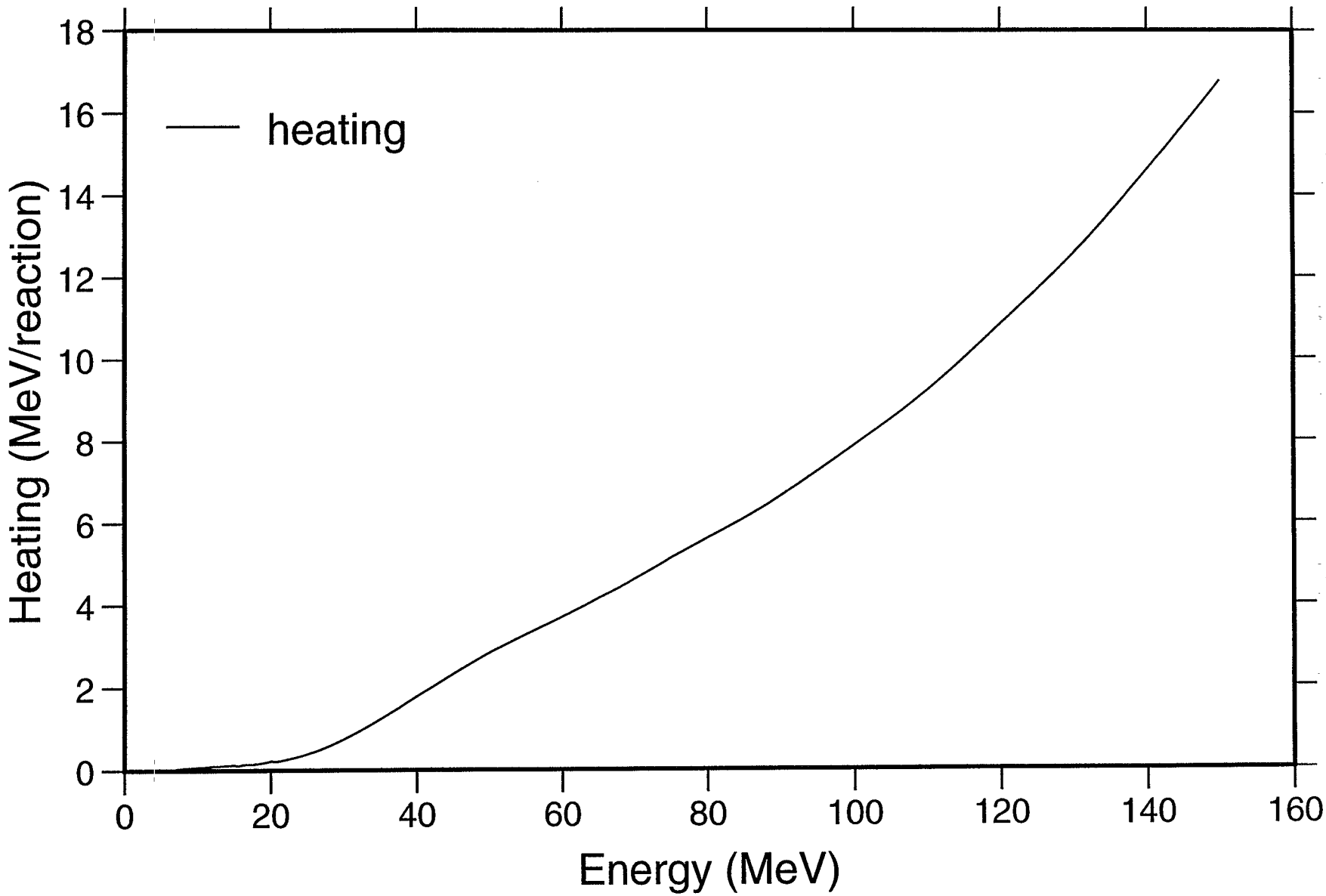


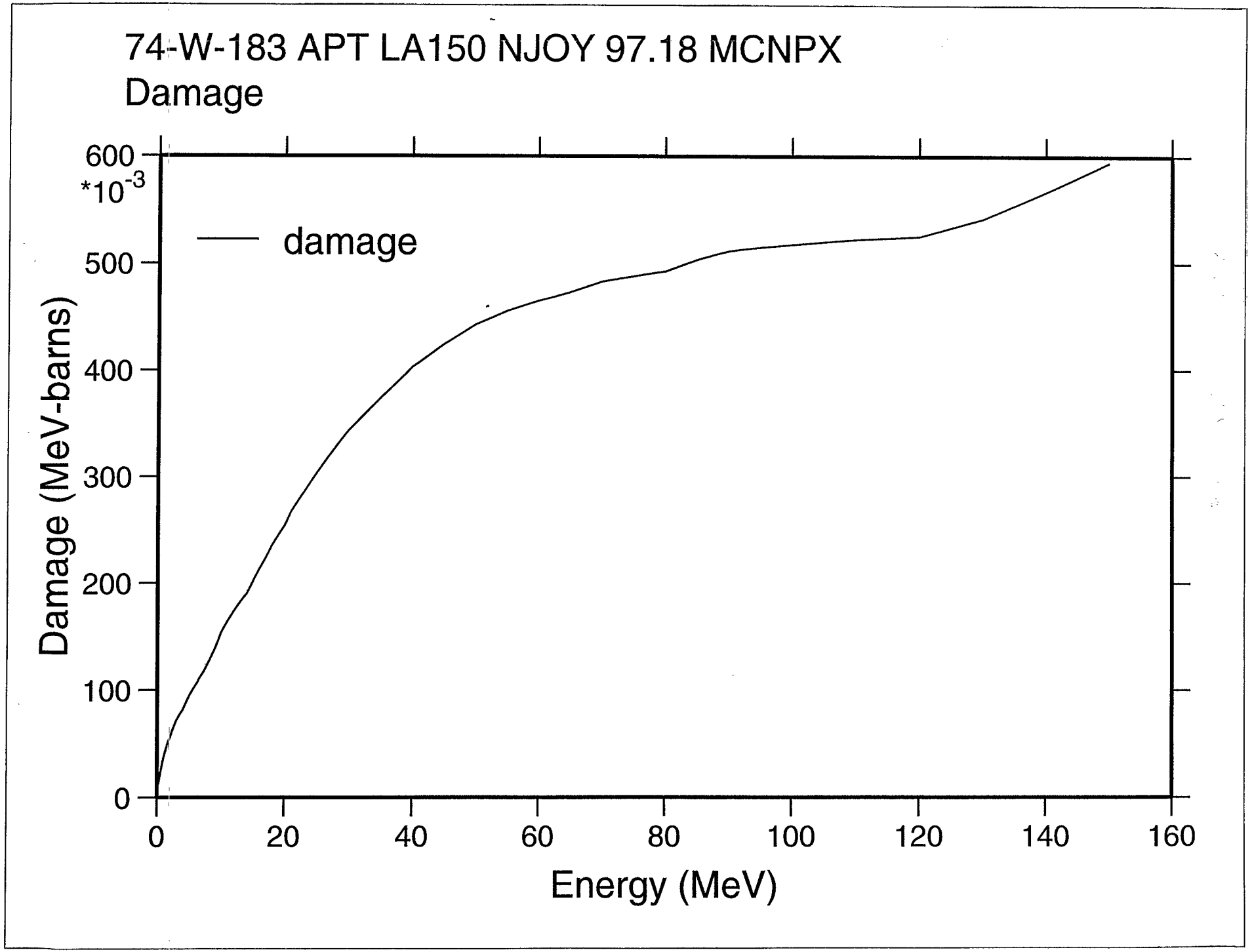







74-W-183 APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic
Prob/Cos
10^{1}
10^{-1}
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


74-W-183 APT LA150 NJOY 97.18 MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
2
4
6
8
10
12
14
16
18
0
20
40
60
80
100
120
140
160


74-W-183 APT LA150 NJOY 97.18 MCNPX
Damage
damage
Damage (MeV-barns)
*10^-3
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF n + 184W CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

M. B. Chadwick and P. G. Young
4 October 1996

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI.0 (Release 0) evaluation, which was carried over from ENDF/B-V.2 [Ar80]. The following modifications were made to the ENDF/B-VI.0 evaluation:

1. The derived MF=3 files for MT=203 and 207 were removed.

INCIDENT NEUTRON ENERGIES > 20 MeV

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT=	1	Total Cross Section
	MT=	2	Elastic Scattering Cross Section
	MT=	3	Nonelastic Cross Section
	MT=	5	Sum of Binary (n,n') and (n,x) Reactions
MF=4	MT=	2	Elastic Angular Distributions
MF=6	MT=	5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + W, n + Ta, p + Ta, and p + W reactions (Ch96a). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Coupled-channels and spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

Because of the almost total absence of W data, the neutron total cross section above 20 MeV is based on the measurements of

Finlay et al. (Fi93) of the n + Ta total cross section. A coupled-channels neutron optical model potential based on earlier work to 100 MeV (Yo90) is utilized to 80 MeV, and the global spherical optical model potential of Madland (Ma88) is used at higher energies. For protons, the Beccetti-Greenlees potential (Be69) is utilized below 50 MeV, and the Madland Semmering potential (Ma88) at higher energies. The Perey potential (Pe63) is used for deuterons, and the Beccetti-Greenlees potential (Be71) for tritons. The ECIS79 code (Ra72) was used for the coupled-channels optical model calculations, and the SCAT2 code (Be92) was utilized for the spherical optical model calculations. Minor normalizations were made to the reaction cross sections and transmission coefficients to produce agreement with the (sparse) measurements for W and values inferred from systematics of proton and neutron reaction cross sections from measurements on other targets.

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96b). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. Note that all other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation requires a modification of the original ENDF-6 format.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed above. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

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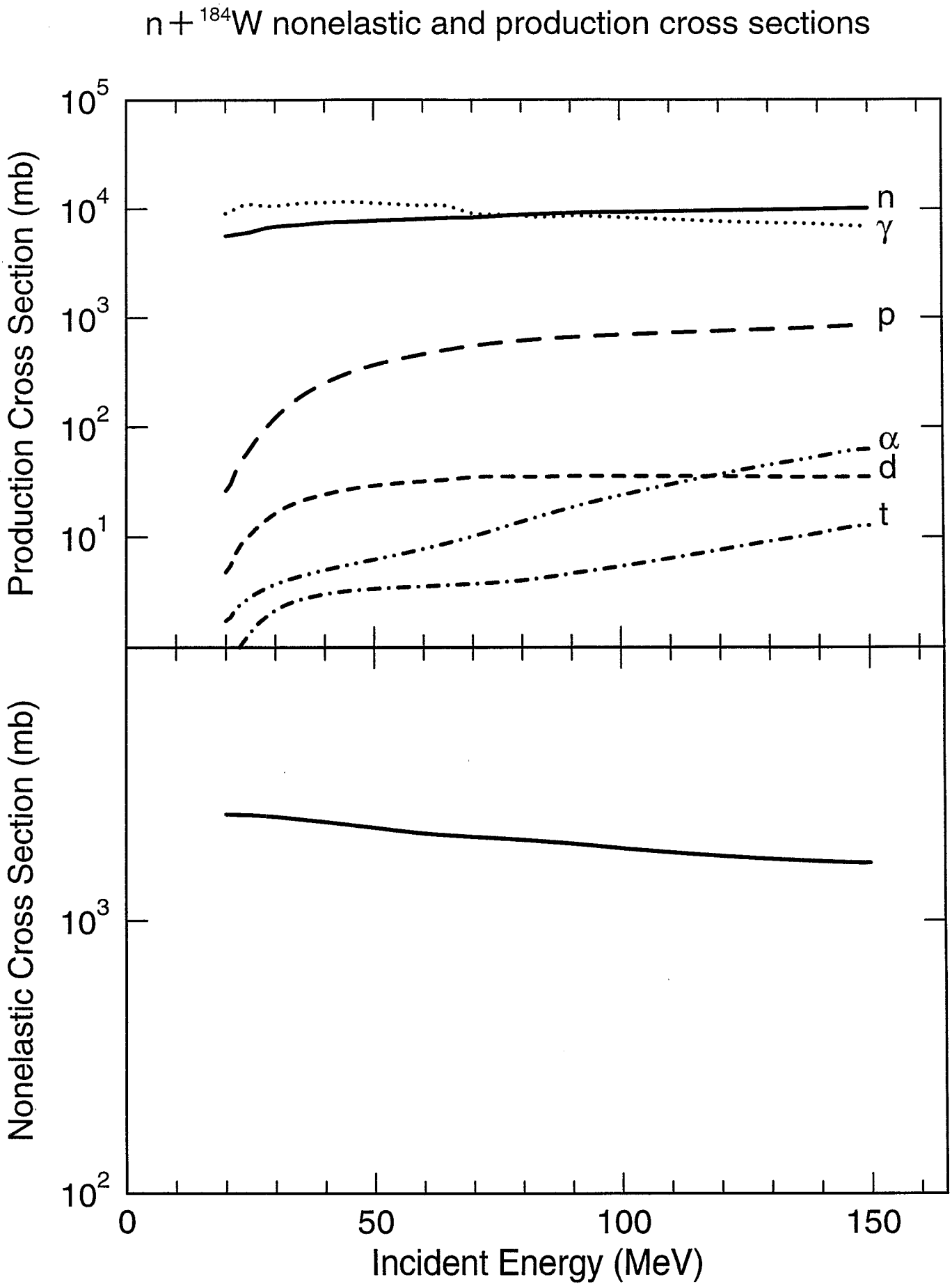
74184 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

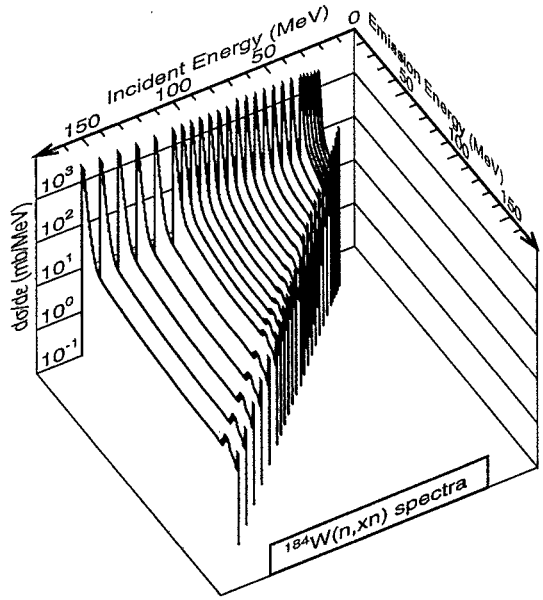
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	2.446E+00	2.938E+00	5.664E+00	2.629E-02	4.783E-03	4.824E-04	0.000E+00	1.729E-03	9.090E+00
2.200E+01	2.439E+00	2.791E+00	5.843E+00	3.945E-02	7.116E-03	8.257E-04	0.000E+00	2.211E-03	1.006E+01
2.400E+01	2.435E+00	2.631E+00	6.003E+00	5.548E-02	9.462E-03	1.188E-03	0.000E+00	2.654E-03	1.095E+01
2.600E+01	2.424E+00	2.459E+00	6.300E+00	7.452E-02	1.181E-02	1.546E-03	0.000E+00	3.057E-03	1.095E+01
2.800E+01	2.411E+00	2.274E+00	6.652E+00	9.675E-02	1.412E-02	1.865E-03	0.000E+00	3.402E-03	1.064E+01
3.000E+01	2.394E+00	2.116E+00	6.877E+00	1.213E-01	1.642E-02	2.163E-03	0.000E+00	3.724E-03	1.067E+01
3.500E+01	2.344E+00	1.866E+00	7.152E+00	1.876E-01	2.113E-02	2.705E-03	0.000E+00	4.406E-03	1.128E+01
4.000E+01	2.292E+00	1.764E+00	7.496E+00	2.520E-01	2.439E-02	3.037E-03	0.000E+00	5.015E-03	1.147E+01
4.500E+01	2.238E+00	1.808E+00	7.648E+00	3.134E-01	2.728E-02	3.260E-03	0.000E+00	5.619E-03	1.166E+01
5.000E+01	2.183E+00	1.917E+00	7.834E+00	3.689E-01	2.932E-02	3.390E-03	0.000E+00	6.252E-03	1.135E+01
5.500E+01	2.129E+00	2.091E+00	7.972E+00	4.189E-01	3.094E-02	3.494E-03	0.000E+00	6.980E-03	1.107E+01
6.000E+01	2.081E+00	2.256E+00	8.129E+00	4.656E-01	3.215E-02	3.567E-03	0.000E+00	7.827E-03	1.082E+01
6.500E+01	2.048E+00	2.382E+00	8.314E+00	5.115E-01	3.334E-02	3.664E-03	0.000E+00	8.861E-03	1.069E+01
7.000E+01	2.021E+00	2.479E+00	8.379E+00	5.548E-01	3.505E-02	3.758E-03	0.000E+00	1.017E-02	9.123E+00
7.500E+01	1.997E+00	2.530E+00	8.636E+00	5.905E-01	3.553E-02	3.876E-03	0.000E+00	1.185E-02	8.911E+00
8.000E+01	1.971E+00	2.554E+00	8.879E+00	6.200E-01	3.538E-02	4.048E-03	0.000E+00	1.388E-02	8.678E+00
8.500E+01	1.941E+00	2.577E+00	9.052E+00	6.456E-01	3.538E-02	4.316E-03	0.000E+00	1.608E-02	8.472E+00
9.000E+01	1.910E+00	2.558E+00	9.207E+00	6.657E-01	3.585E-02	4.669E-03	0.000E+00	1.861E-02	8.708E+00
9.500E+01	1.874E+00	2.498E+00	9.331E+00	6.838E-01	3.594E-02	5.030E-03	0.000E+00	2.126E-02	8.609E+00
1.000E+02	1.837E+00	2.435E+00	9.397E+00	6.998E-01	3.579E-02	5.431E-03	0.000E+00	2.393E-02	8.387E+00
1.100E+02	1.774E+00	2.310E+00	9.543E+00	7.290E-01	3.576E-02	6.429E-03	0.000E+00	3.012E-02	8.044E+00
1.200E+02	1.721E+00	2.119E+00	9.681E+00	7.567E-01	3.563E-02	7.679E-03	0.000E+00	3.720E-02	7.699E+00
1.300E+02	1.678E+00	1.962E+00	9.825E+00	7.847E-01	3.528E-02	9.179E-03	0.000E+00	4.519E-02	7.446E+00
1.400E+02	1.645E+00	1.788E+00	9.998E+00	8.149E-01	3.521E-02	1.090E-02	0.000E+00	5.383E-02	7.273E+00
1.500E+02	1.624E+00	1.646E+00	1.016E+01	8.501E-01	3.524E-02	1.272E-02	0.000E+00	6.254E-02	6.943E+00

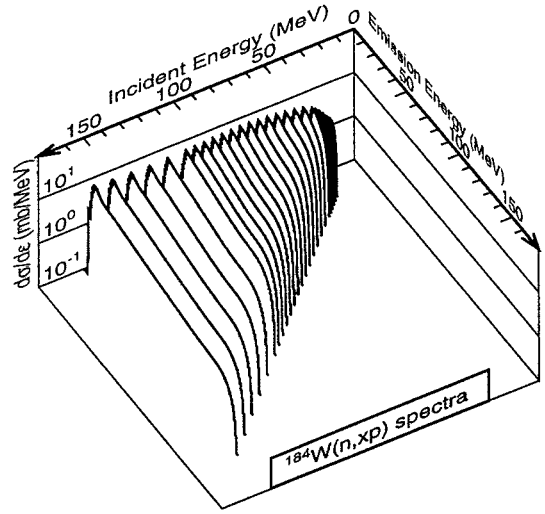
74184 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

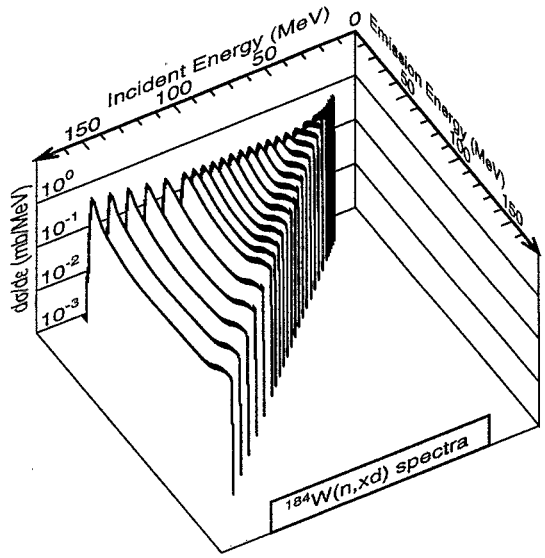
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	1.734E-02	3.067E-03	2.720E-04	0.000E+00	1.918E-03	1.665E-02	2.332E-03	4.158E-02
2.200E+01	2.776E-02	5.056E-03	5.113E-04	0.000E+00	2.558E-03	1.803E-02	2.249E-03	5.617E-02
2.400E+01	4.117E-02	7.354E-03	7.989E-04	0.000E+00	3.192E-03	1.937E-02	2.328E-03	7.422E-02
2.600E+01	5.802E-02	9.935E-03	1.121E-03	0.000E+00	3.811E-03	2.068E-02	2.448E-03	9.601E-02
2.800E+01	7.890E-02	1.278E-02	1.447E-03	0.000E+00	4.387E-03	2.187E-02	2.587E-03	1.220E-01
3.000E+01	1.036E-01	1.590E-02	1.786E-03	0.000E+00	4.953E-03	2.298E-02	2.751E-03	1.520E-01
3.500E+01	1.795E-01	2.373E-02	2.544E-03	0.000E+00	6.259E-03	2.514E-02	3.145E-03	2.403E-01
4.000E+01	2.679E-01	3.107E-02	3.180E-03	0.000E+00	7.487E-03	2.728E-02	3.429E-03	3.403E-01
4.500E+01	3.659E-01	3.917E-02	3.750E-03	0.000E+00	8.690E-03	2.897E-02	3.591E-03	4.501E-01
5.000E+01	4.669E-01	4.656E-02	4.231E-03	0.000E+00	9.891E-03	3.039E-02	3.619E-03	5.616E-01
5.500E+01	5.694E-01	5.368E-02	4.677E-03	0.000E+00	1.116E-02	3.145E-02	3.632E-03	6.740E-01
6.000E+01	6.750E-01	6.023E-02	5.064E-03	0.000E+00	1.253E-02	3.248E-02	3.586E-03	7.888E-01
6.500E+01	7.866E-01	6.694E-02	5.458E-03	0.000E+00	1.409E-02	3.347E-02	3.468E-03	9.101E-01
7.000E+01	9.020E-01	7.587E-02	5.799E-03	0.000E+00	1.588E-02	3.473E-02	3.349E-03	1.038E+00
7.500E+01	1.012E+00	8.143E-02	6.086E-03	0.000E+00	1.797E-02	3.564E-02	3.157E-03	1.156E+00
8.000E+01	1.118E+00	8.490E-02	6.365E-03	0.000E+00	2.034E-02	3.647E-02	2.933E-03	1.269E+00
8.500E+01	1.221E+00	8.859E-02	6.767E-03	0.000E+00	2.285E-02	3.701E-02	1.522E-03	1.378E+00
9.000E+01	1.318E+00	9.419E-02	7.227E-03	0.000E+00	2.565E-02	3.746E-02	1.487E-03	1.484E+00
9.500E+01	1.414E+00	9.860E-02	7.586E-03	0.000E+00	2.854E-02	3.766E-02	1.438E-03	1.587E+00
1.000E+02	1.507E+00	1.019E-01	7.956E-03	0.000E+00	3.145E-02	3.772E-02	1.393E-03	1.688E+00
1.100E+02	1.695E+00	1.094E-01	8.751E-03	0.000E+00	3.806E-02	3.783E-02	1.320E-03	1.891E+00
1.200E+02	1.887E+00	1.156E-01	9.630E-03	0.000E+00	4.556E-02	3.785E-02	1.221E-03	2.097E+00
1.300E+02	2.084E+00	1.194E-01	1.062E-02	0.000E+00	5.399E-02	3.903E-02	1.152E-03	2.308E+00
1.400E+02	2.292E+00	1.236E-01	1.172E-02	0.000E+00	6.319E-02	4.114E-02	1.084E-03	2.533E+00
1.500E+02	2.520E+00	1.275E-01	1.287E-02	0.000E+00	7.260E-02	4.329E-02	1.051E-03	2.777E+00

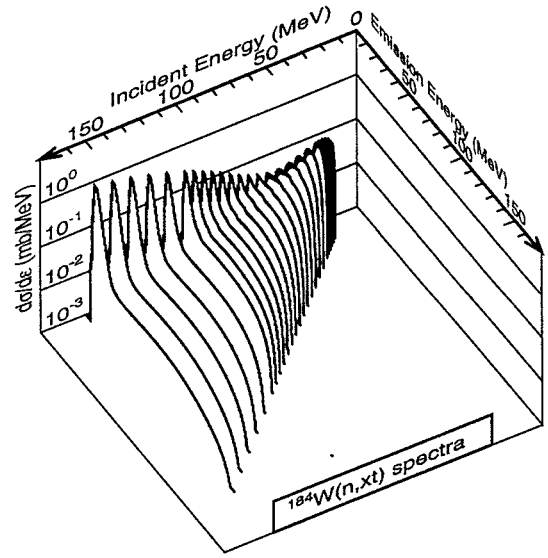

n + 184W nonelastic and production cross sections
Production Cross Section (mb)
10^5
10^4
10^3
10^2
10^1
n
γ
p
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
0
50
100
150
Incident Energy (MeV)

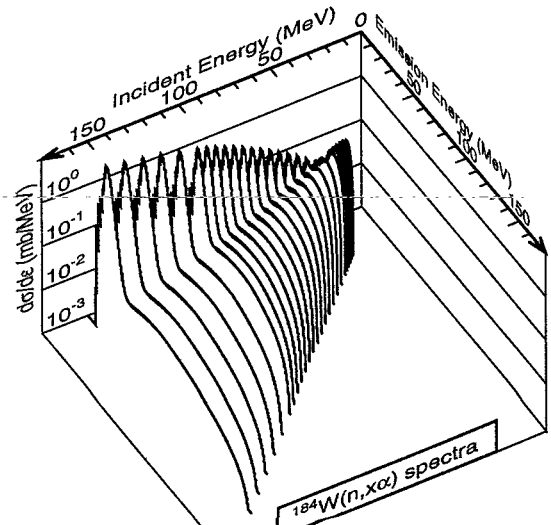
n + ^{184}W angle-integrated emission spectra

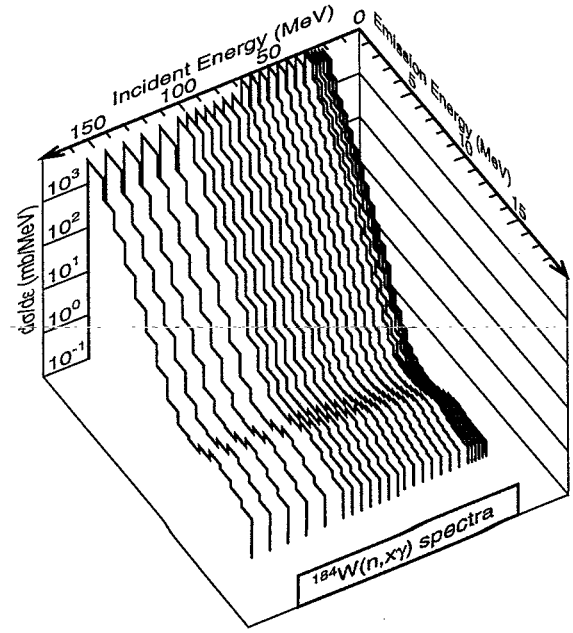




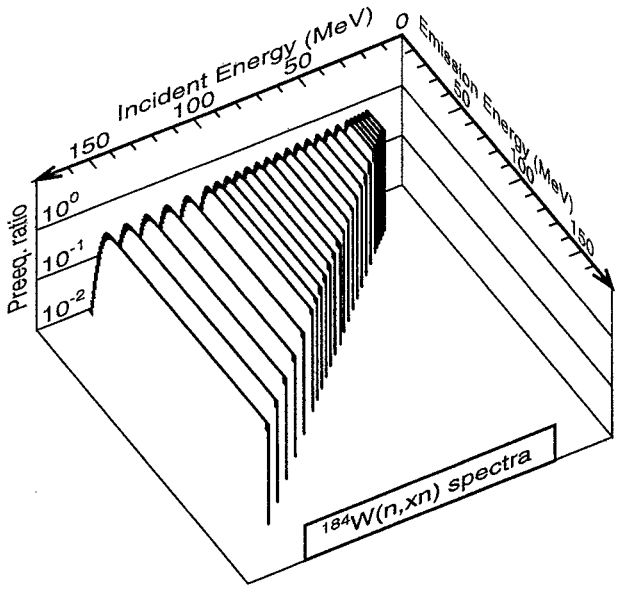


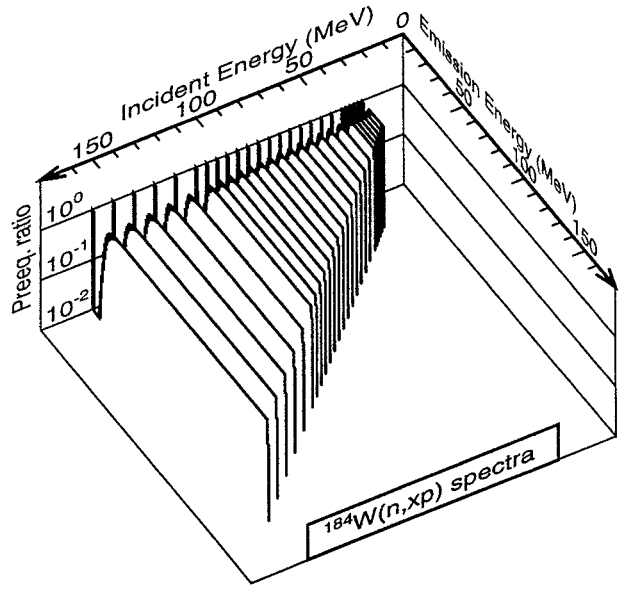


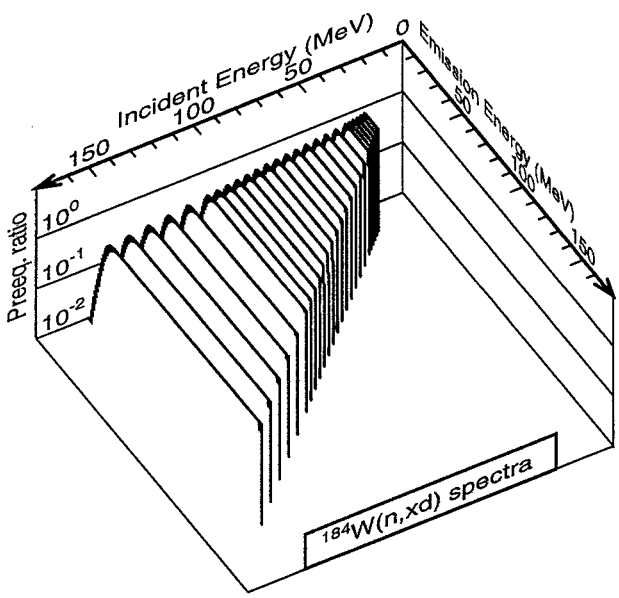


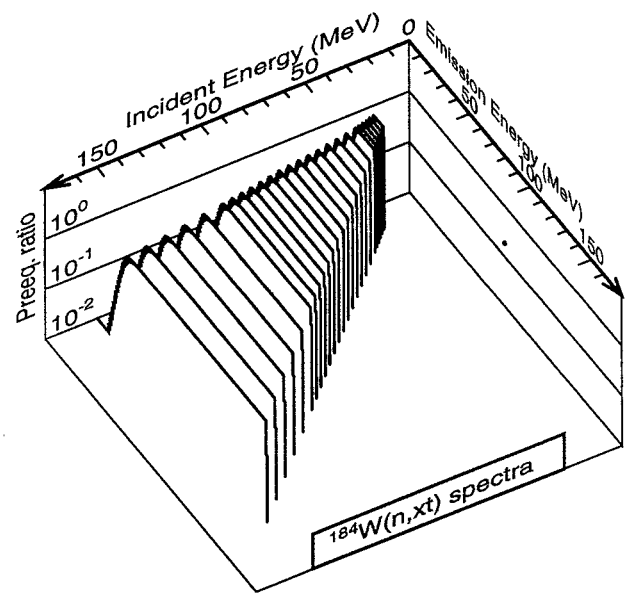


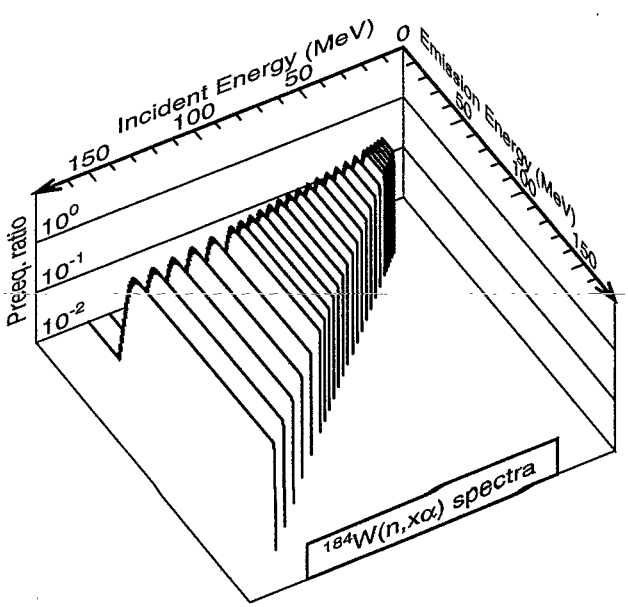
n + ^{184}W Kalbach preequilibrium ratios

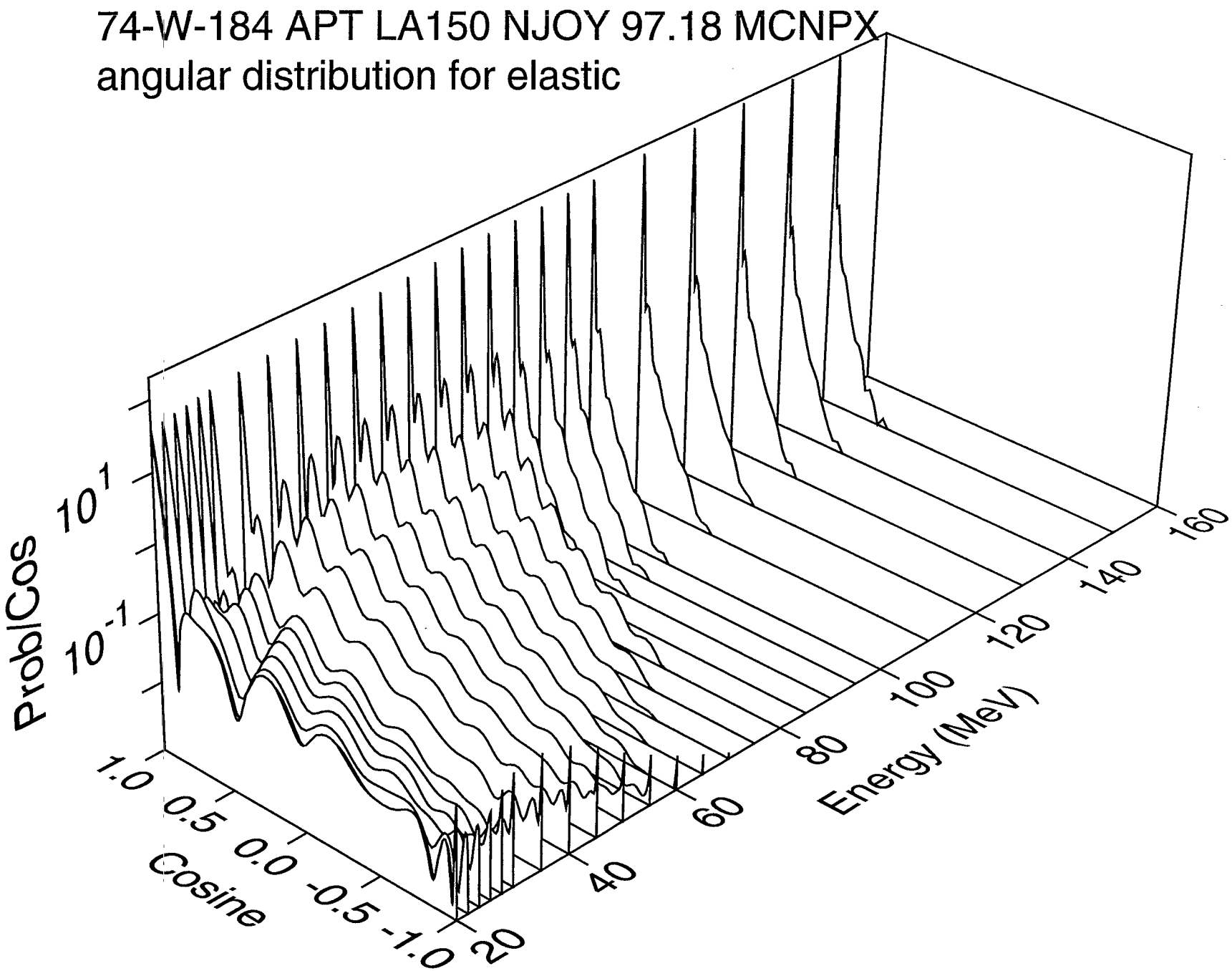


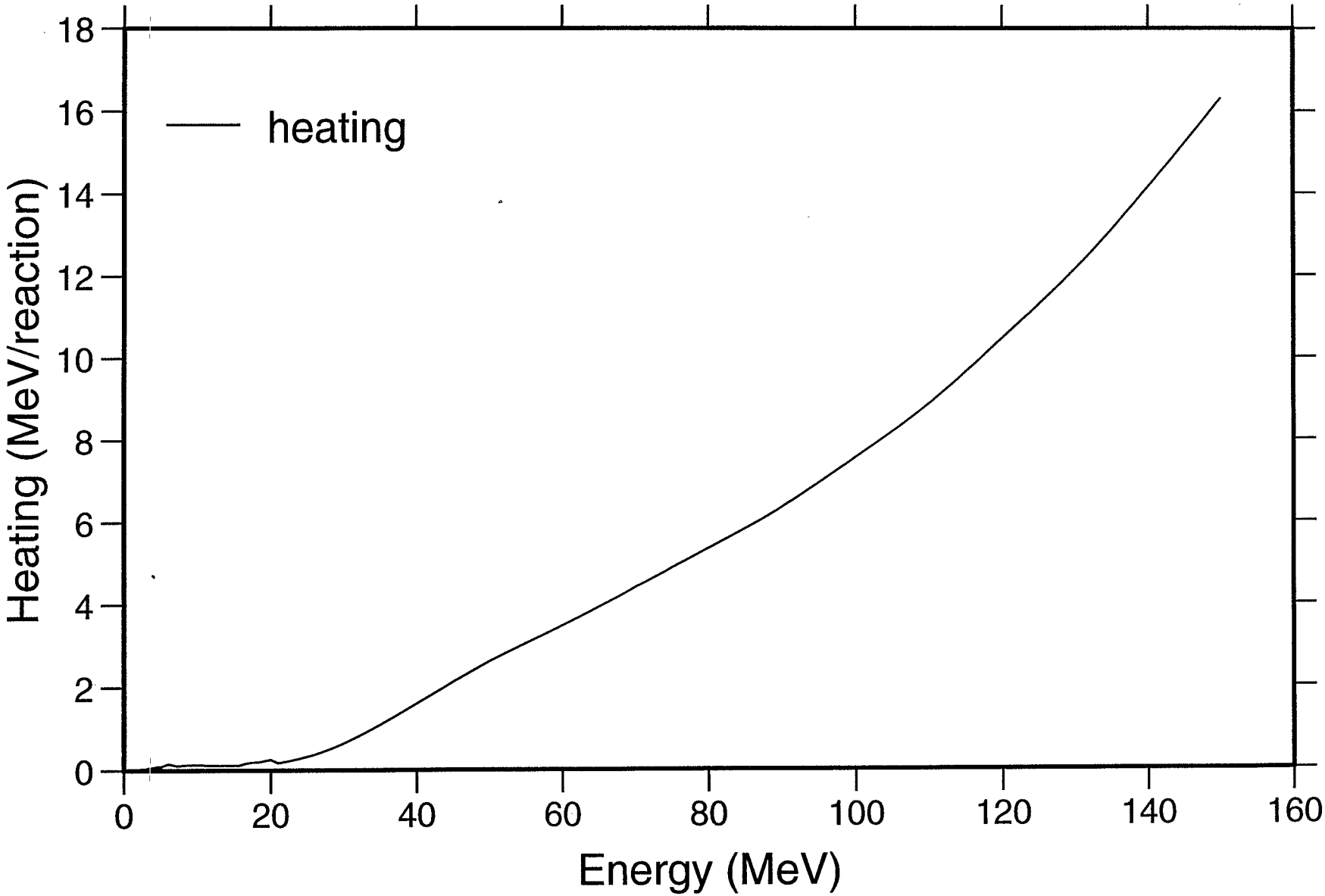


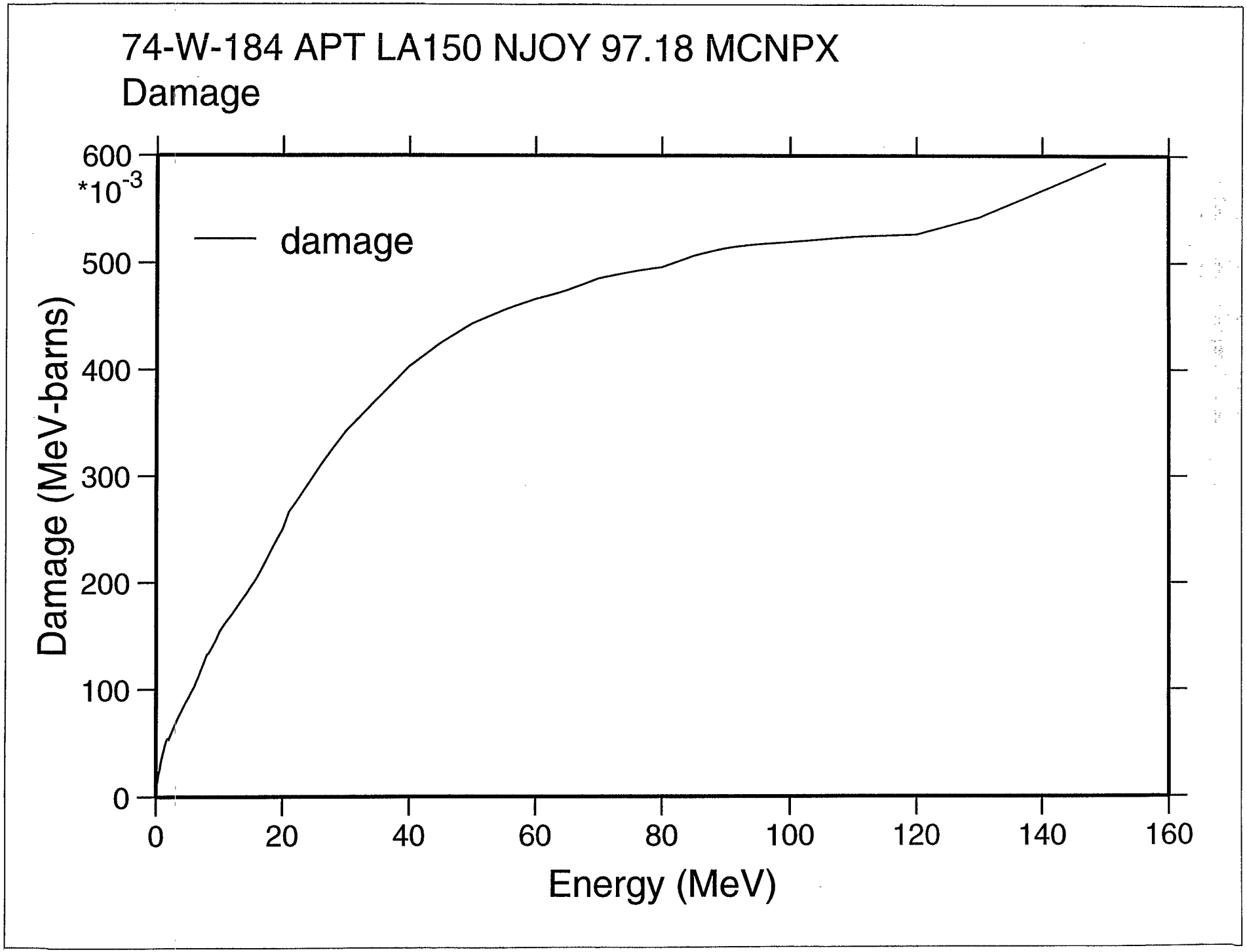







74-W-184 APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic
Prob/Cos
10^1
10^{-1}
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


74-W-184 APT LA150 NJOY 97.18 MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
2
4
6
8
10
12
14
16
18
0
20
40
60
80
100
120
140
160


74-W-184 APT LA150 NJOY 97.18 MCNPX
Damage
damage
Damage (MeV-barns)
*10^-3
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF n + 186W CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

M. B. Chadwick and P. G. Young
4 October 1996

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI.0 (Release 0) evaluation, which was carried over from ENDF/B-V.2 [Ar80]. The following modifications were made to the ENDF/B-VI.0 evaluation:

1. The derived MF=3 files for MT=203 and 207 were removed.

INCIDENT NEUTRON ENERGIES > 20 MeV

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT= 1	Total Cross Section
	MT= 2	Elastic Scattering Cross Section
	MT= 3	Nonelastic Cross Section
	MT= 5	Sum of Binary (n,n') and (n,x) Reactions
MF=4	MT= 2	Elastic Angular Distributions
MF=6	MT= 5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + W, n + Ta, p + Ta, and p + W reactions (Ch96a). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Coupled-channels and spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

Because of the almost total absence of W data, the neutron total cross section above 20 MeV is based on the measurements of

Finlay et al. (Fi93) of the n + Ta total cross section. A coupled-channels neutron optical model potential based on earlier work to 100 MeV (Yo90) is utilized to 80 MeV, and the global spherical optical model potential of Madland (Ma88) is used at higher energies. For protons, the Beccetti-Greenlees potential (Be69) is utilized below 50 MeV, and the Madland Semmering potential (Ma88) at higher energies. The Perey potential (Pe63) is used for deuterons, and the Beccetti-Greenlees potential (Be71) for tritons. The ECIS79 code (Ra72) was used for the coupled-channels optical model calculations, and the SCAT2 code (Be92) was utilized for the spherical optical model calculations. Minor normalizations were made to the reaction cross sections and transmission coefficients to produce agreement with the (sparse) measurements for W and values inferred from systematics of proton and neutron reaction cross sections from measurements on other targets.

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96b). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. Note that all other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation requires a modification of the original ENDF-6 format.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed above. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

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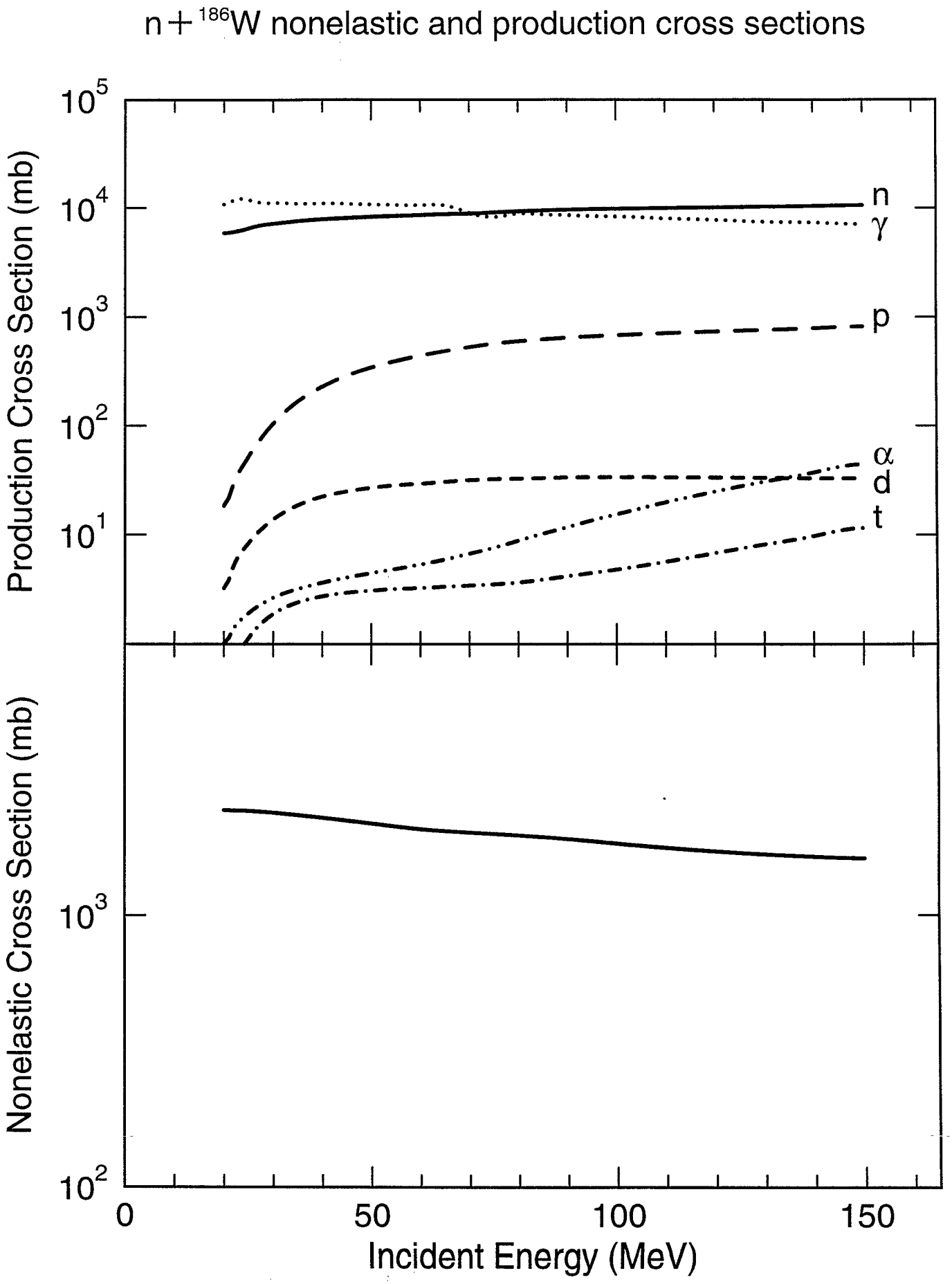
74186 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

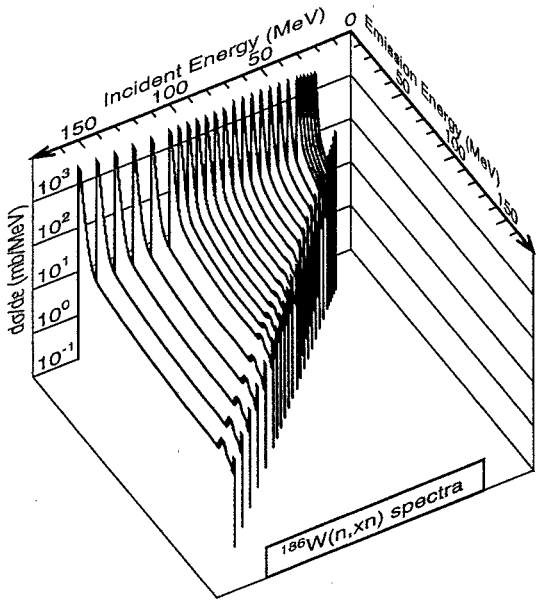
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	2.446E+00	2.938E+00	5.851E+00	1.826E-02	3.242E-03	3.612E-04	0.000E+00	1.020E-03	1.080E+01
2.200E+01	2.439E+00	2.791E+00	6.004E+00	2.947E-02	5.249E-03	6.553E-04	0.000E+00	1.390E-03	1.186E+01
2.400E+01	2.435E+00	2.631E+00	6.273E+00	4.372E-02	7.344E-03	9.764E-04	0.000E+00	1.743E-03	1.220E+01
2.600E+01	2.424E+00	2.459E+00	6.672E+00	6.100E-02	9.479E-03	1.301E-03	0.000E+00	2.073E-03	1.159E+01
2.800E+01	2.411E+00	2.274E+00	6.972E+00	8.143E-02	1.161E-02	1.596E-03	0.000E+00	2.362E-03	1.116E+01
3.000E+01	2.394E+00	2.116E+00	7.155E+00	1.042E-01	1.376E-02	1.873E-03	0.000E+00	2.630E-03	1.116E+01
3.500E+01	2.344E+00	1.866E+00	7.573E+00	1.671E-01	1.853E-02	2.394E-03	0.000E+00	3.183E-03	1.096E+01
4.000E+01	2.292E+00	1.764E+00	7.886E+00	2.291E-01	2.227E-02	2.718E-03	0.000E+00	3.641E-03	1.107E+01
4.500E+01	2.238E+00	1.808E+00	8.101E+00	2.894E-01	2.490E-02	2.939E-03	0.000E+00	4.050E-03	1.097E+01
5.000E+01	2.183E+00	1.917E+00	8.309E+00	3.445E-01	2.689E-02	3.074E-03	0.000E+00	4.449E-03	1.078E+01
5.500E+01	2.129E+00	2.091E+00	8.462E+00	3.944E-01	2.842E-02	3.181E-03	0.000E+00	4.869E-03	1.069E+01
6.000E+01	2.081E+00	2.256E+00	8.621E+00	4.412E-01	2.932E-02	3.255E-03	0.000E+00	5.349E-03	1.063E+01
6.500E+01	2.048E+00	2.382E+00	8.799E+00	4.873E-01	3.050E-02	3.347E-03	0.000E+00	5.945E-03	1.060E+01
7.000E+01	2.021E+00	2.479E+00	8.882E+00	5.310E-01	3.157E-02	3.432E-03	0.000E+00	6.697E-03	9.030E+00
7.500E+01	1.997E+00	2.530E+00	9.097E+00	5.705E-01	3.225E-02	3.524E-03	0.000E+00	7.605E-03	8.272E+00
8.000E+01	1.971E+00	2.554E+00	9.305E+00	6.001E-01	3.254E-02	3.659E-03	0.000E+00	8.816E-03	8.865E+00
8.500E+01	1.941E+00	2.577E+00	9.491E+00	6.240E-01	3.295E-02	3.885E-03	0.000E+00	1.021E-02	8.729E+00
9.000E+01	1.910E+00	2.558E+00	9.631E+00	6.461E-01	3.346E-02	4.171E-03	0.000E+00	1.174E-02	8.594E+00
9.500E+01	1.874E+00	2.498E+00	9.760E+00	6.641E-01	3.354E-02	4.471E-03	0.000E+00	1.351E-02	8.406E+00
1.000E+02	1.837E+00	2.435E+00	9.831E+00	6.799E-01	3.357E-02	4.810E-03	0.000E+00	1.538E-02	8.342E+00
1.100E+02	1.774E+00	2.310E+00	9.988E+00	7.086E-01	3.351E-02	5.675E-03	0.000E+00	1.975E-02	8.008E+00
1.200E+02	1.721E+00	2.119E+00	1.013E+01	7.347E-01	3.334E-02	6.788E-03	0.000E+00	2.482E-02	7.767E+00
1.300E+02	1.678E+00	1.962E+00	1.028E+01	7.599E-01	3.315E-02	8.153E-03	0.000E+00	3.064E-02	7.440E+00
1.400E+02	1.645E+00	1.788E+00	1.046E+01	7.868E-01	3.288E-02	9.749E-03	0.000E+00	3.723E-02	7.356E+00
1.500E+02	1.624E+00	1.646E+00	1.064E+01	8.176E-01	3.285E-02	1.150E-02	0.000E+00	4.435E-02	7.105E+00

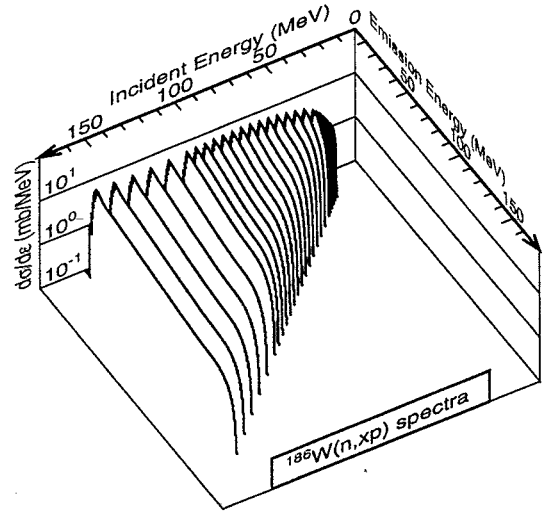
74186 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

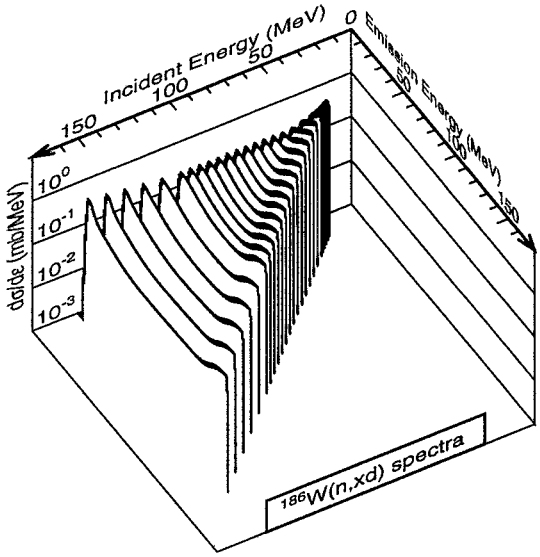
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	1.147E-02	1.956E-03	1.971E-04	0.000E+00	1.101E-03	1.634E-02	2.459E-03	3.352E-02
2.200E+01	1.984E-02	3.529E-03	3.940E-04	0.000E+00	1.570E-03	1.767E-02	2.201E-03	4.520E-02
2.400E+01	3.116E-02	5.426E-03	6.392E-04	0.000E+00	2.053E-03	1.904E-02	2.278E-03	6.060E-02
2.600E+01	4.573E-02	7.615E-03	9.192E-04	0.000E+00	2.537E-03	2.036E-02	2.396E-03	7.955E-02
2.800E+01	6.405E-02	1.006E-02	1.208E-03	0.000E+00	2.997E-03	2.158E-02	2.532E-03	1.024E-01
3.000E+01	8.601E-02	1.279E-02	1.512E-03	0.000E+00	3.452E-03	2.266E-02	2.693E-03	1.291E-01
3.500E+01	1.549E-01	2.015E-02	2.206E-03	0.000E+00	4.503E-03	2.486E-02	3.078E-03	2.097E-01
4.000E+01	2.366E-01	2.784E-02	2.792E-03	0.000E+00	5.470E-03	2.695E-02	3.356E-03	3.030E-01
4.500E+01	3.292E-01	3.505E-02	3.320E-03	0.000E+00	6.385E-03	2.866E-02	3.515E-03	4.061E-01
5.000E+01	4.257E-01	4.197E-02	3.769E-03	0.000E+00	7.271E-03	3.006E-02	3.541E-03	5.123E-01
5.500E+01	5.244E-01	4.851E-02	4.188E-03	0.000E+00	8.163E-03	3.115E-02	3.554E-03	6.200E-01
6.000E+01	6.267E-01	5.387E-02	4.551E-03	0.000E+00	9.095E-03	3.213E-02	3.509E-03	7.298E-01
6.500E+01	7.352E-01	6.014E-02	4.919E-03	0.000E+00	1.015E-02	3.311E-02	3.394E-03	8.469E-01
7.000E+01	8.479E-01	6.648E-02	5.237E-03	0.000E+00	1.133E-02	3.428E-02	3.277E-03	9.685E-01
7.500E+01	9.611E-01	7.200E-02	5.513E-03	0.000E+00	1.262E-02	3.514E-02	3.089E-03	1.089E+00
8.000E+01	1.064E+00	7.668E-02	5.761E-03	0.000E+00	1.413E-02	3.590E-02	2.870E-03	1.200E+00
8.500E+01	1.163E+00	8.173E-02	6.112E-03	0.000E+00	1.578E-02	3.650E-02	1.490E-03	1.304E+00
9.000E+01	1.262E+00	8.714E-02	6.524E-03	0.000E+00	1.756E-02	3.685E-02	1.456E-03	1.411E+00
9.500E+01	1.356E+00	9.126E-02	6.838E-03	0.000E+00	1.952E-02	3.707E-02	1.407E-03	1.512E+00
1.000E+02	1.449E+00	9.516E-02	7.162E-03	0.000E+00	2.154E-02	3.708E-02	1.364E-03	1.611E+00
1.100E+02	1.635E+00	1.022E-01	7.864E-03	0.000E+00	2.620E-02	3.716E-02	1.292E-03	1.810E+00
1.200E+02	1.824E+00	1.079E-01	8.647E-03	0.000E+00	3.158E-02	3.708E-02	1.195E-03	2.011E+00
1.300E+02	2.018E+00	1.126E-01	9.542E-03	0.000E+00	3.776E-02	3.821E-02	1.127E-03	2.218E+00
1.400E+02	2.222E+00	1.157E-01	1.055E-02	0.000E+00	4.475E-02	4.019E-02	1.060E-03	2.435E+00
1.500E+02	2.444E+00	1.192E-01	1.164E-02	0.000E+00	5.234E-02	4.227E-02	1.029E-03	2.670E+00

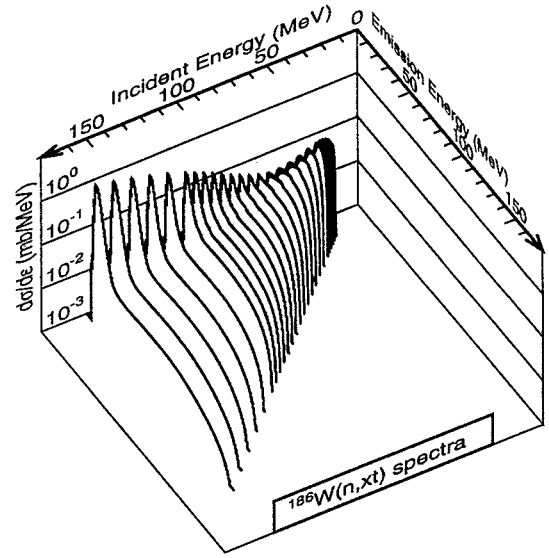

n + 186W nonelastic and production cross sections
Production Cross Section (mb)
10^5
10^4
10^3
10^2
10^1
n
γ
p
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
0
50
100
150
Incident Energy (MeV)

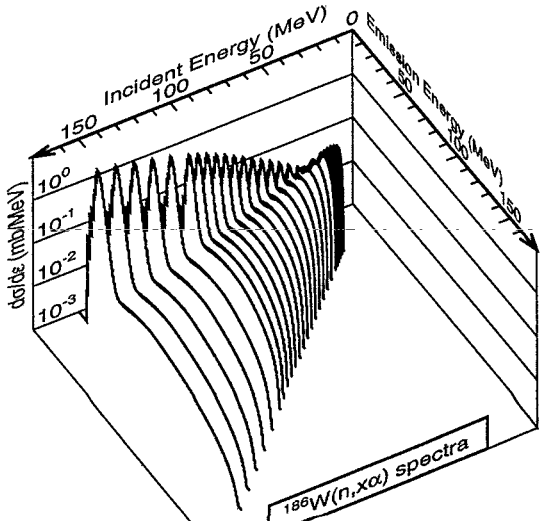
n + ^{186}W angle-integrated emission spectra

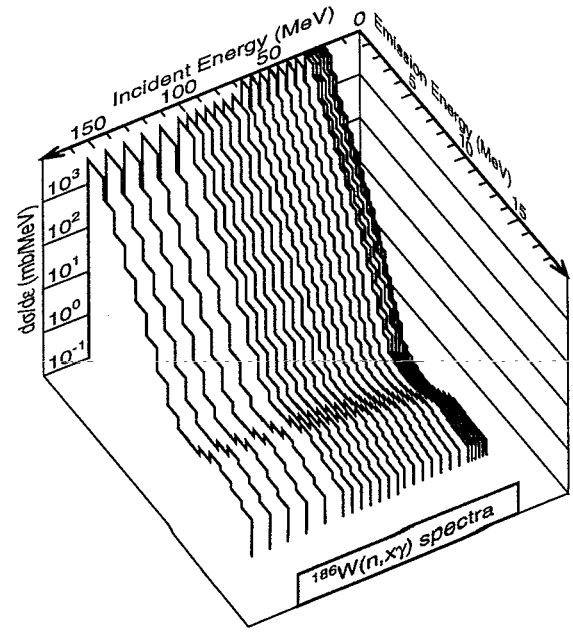




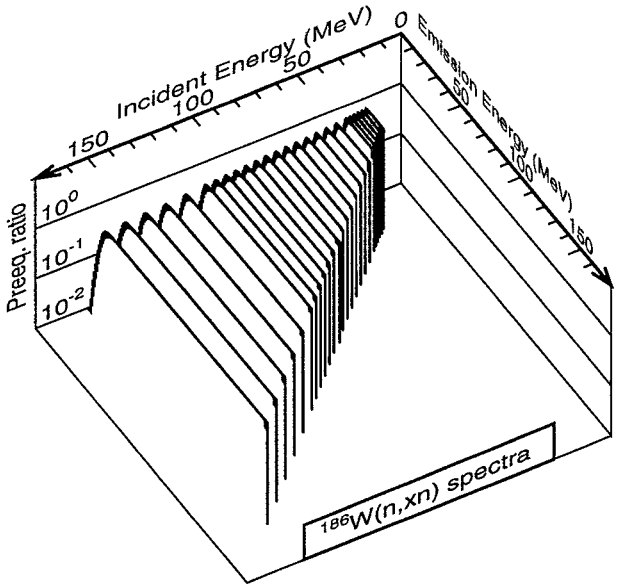


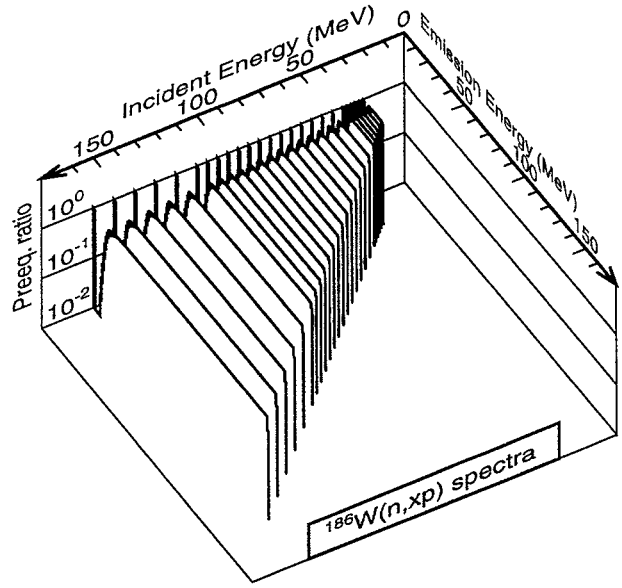


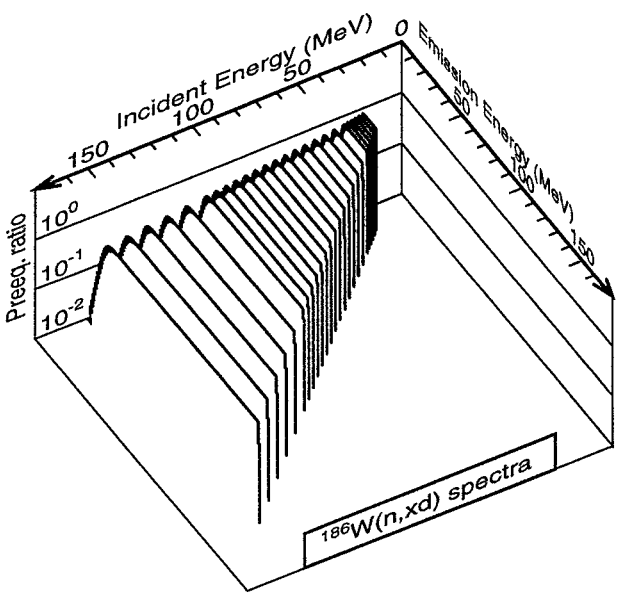


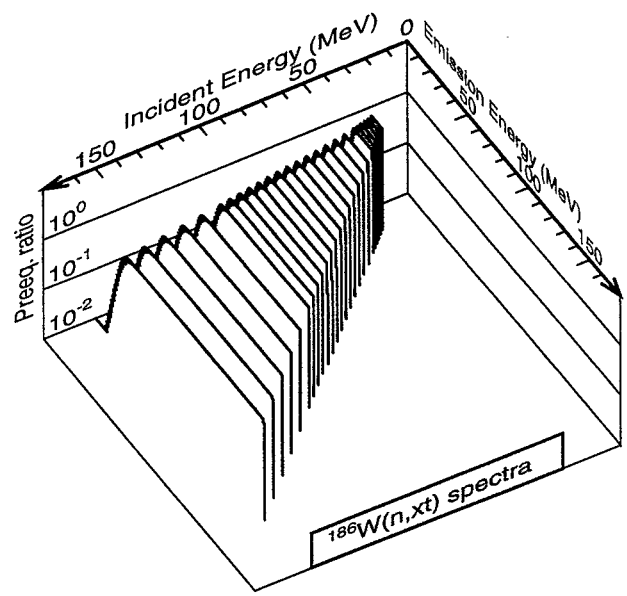


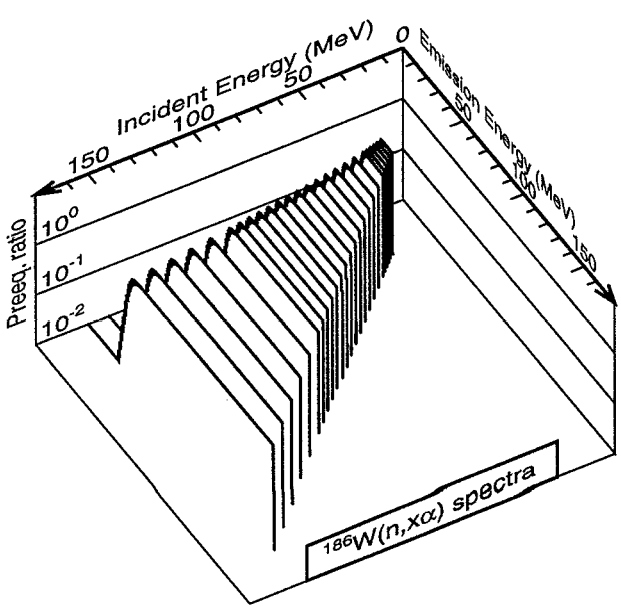
n + ^{186}W Kalbach preequilibrium ratios

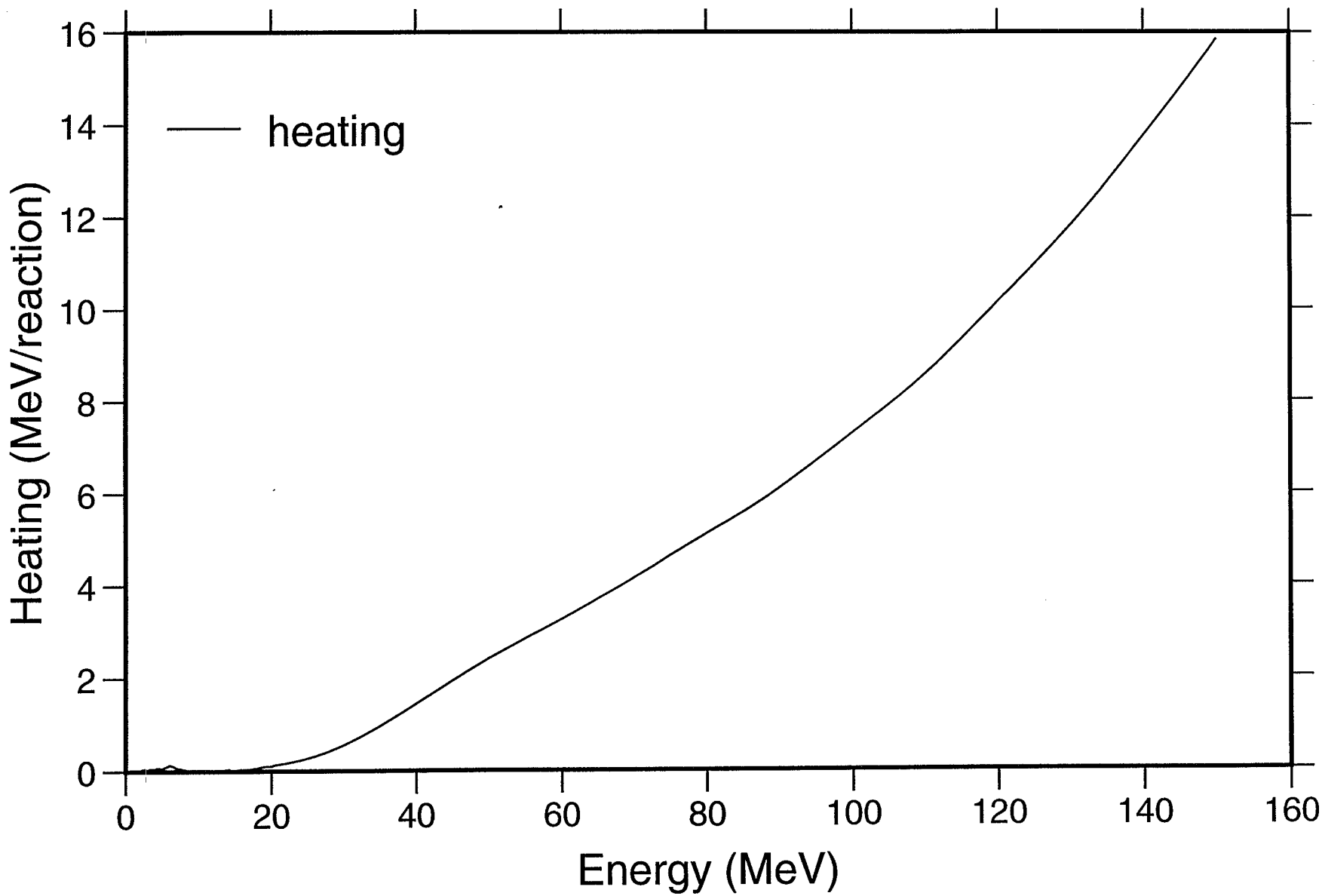


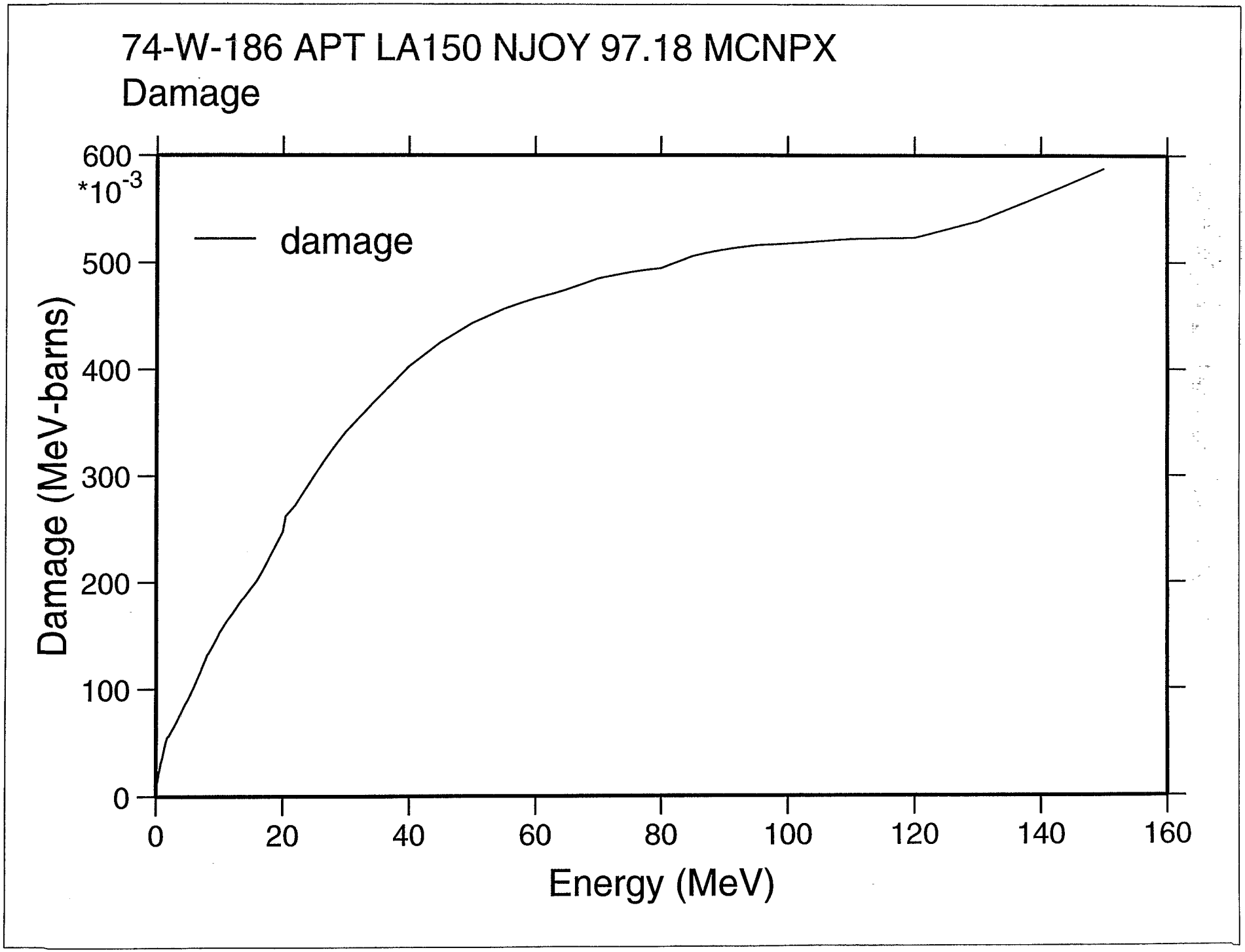


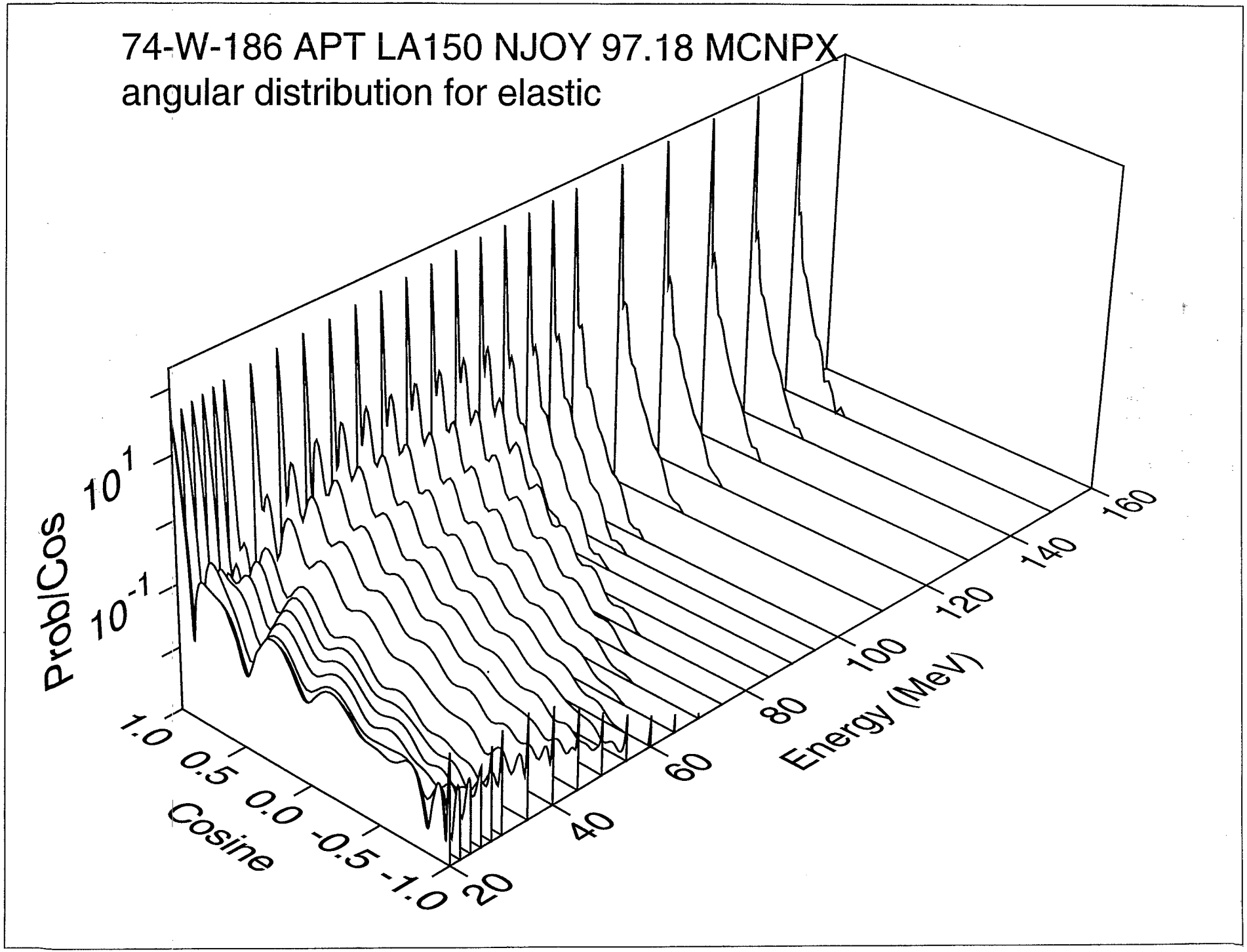







74-W-186 APT LA150 NJOY 97.18 MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
2
4
6
8
10
12
14
16
0
20
40
60
80
100
120
140
160


74-W-186 APT LA150 NJOY 97.18 MCNPX
Damage
damage
Damage (MeV-barns)
*10^-3
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140
160
Energy (MeV)


74-W-186 APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic
ProbCos
10^1
10^{-1}
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF n + 206Pb CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

M. B. Chadwick, P. G. Young, and A. J. Koning
9 August 1996

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI.0 (Release 0) evaluation by Fu91. The following modifications were made to the ENDF/B-VI.0 evaluation:

1. The covariance files (MF=33) were removed from the file.

2. The derived MF=3 files for MT=203,205,207 were removed.

INCIDENT NEUTRON ENERGIES > 20 MeV

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT=	1	Total Cross Section
	MT=	2	Elastic Scattering Cross Section
	MT=	3	Nonelastic Cross Section
	MT=	5	Sum of Binary (n,n') and (n,x) Reactions
MF=4	MT=	2	Elastic Angular Distributions
MF=6	MT=	5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Pb and p + Pb208 reactions (Ch96a). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Coupled-channel and spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of

all recoil nuclei in the GNASH calculations (Ch96b). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. Note that all other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation requires a modification of the original ENDF-6 format.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

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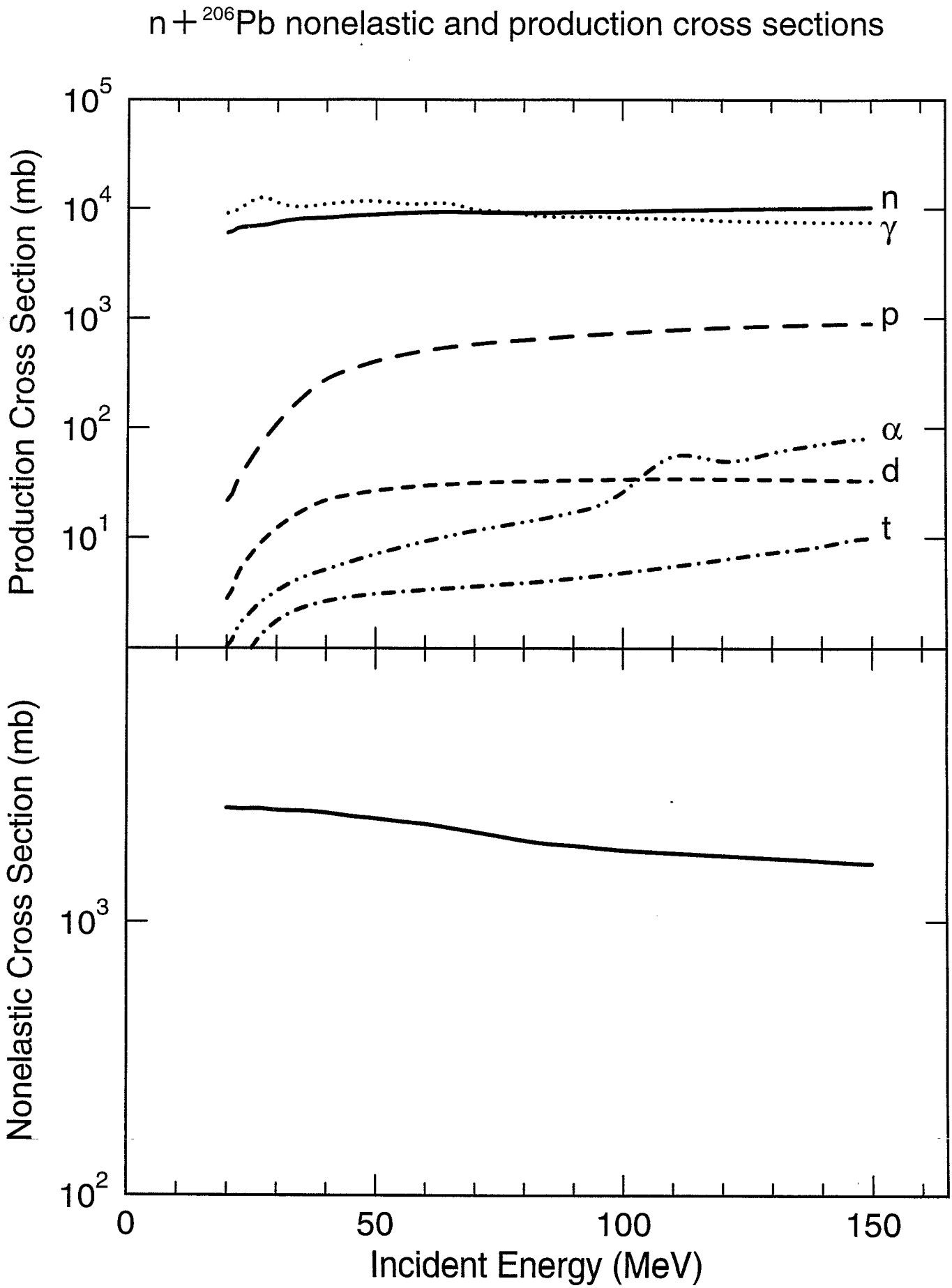
82206 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

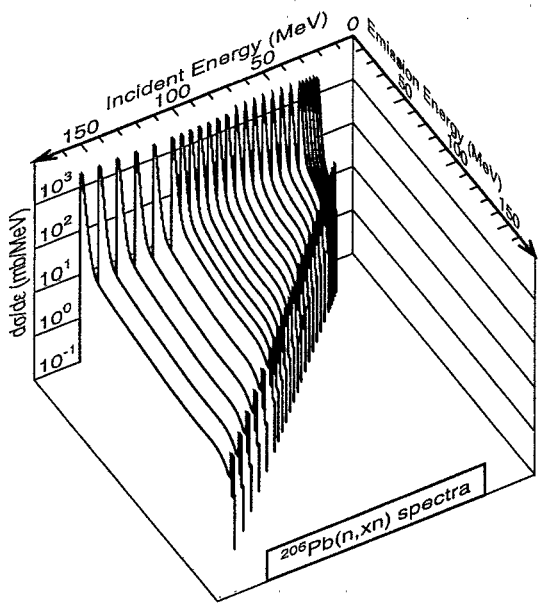
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	2.604E+00	3.240E+00	5.996E+00	2.176E-02	2.810E-03	2.930E-04	0.000E+00	1.038E-03	9.070E+00
2.200E+01	2.591E+00	3.214E+00	6.595E+00	3.223E-02	4.480E-03	5.584E-04	0.000E+00	1.482E-03	9.734E+00
2.400E+01	2.586E+00	3.106E+00	6.847E+00	4.560E-02	6.275E-03	8.643E-04	0.000E+00	1.943E-03	1.108E+01
2.600E+01	2.594E+00	2.937E+00	6.971E+00	6.292E-02	8.185E-03	1.178E-03	0.000E+00	2.408E-03	1.239E+01
2.800E+01	2.577E+00	2.760E+00	7.142E+00	8.395E-02	1.015E-02	1.474E-03	0.000E+00	2.849E-03	1.248E+01
3.000E+01	2.558E+00	2.569E+00	7.483E+00	1.088E-01	1.221E-02	1.758E-03	0.000E+00	3.281E-03	1.137E+01
3.500E+01	2.541E+00	2.109E+00	8.062E+00	1.867E-01	1.732E-02	2.301E-03	0.000E+00	4.297E-03	1.039E+01
4.000E+01	2.502E+00	1.858E+00	8.274E+00	2.775E-01	2.203E-02	2.654E-03	0.000E+00	5.151E-03	1.099E+01
4.500E+01	2.433E+00	1.821E+00	8.597E+00	3.423E-01	2.475E-02	2.903E-03	0.000E+00	6.069E-03	1.155E+01
5.000E+01	2.383E+00	1.907E+00	8.836E+00	4.027E-01	2.692E-02	3.087E-03	0.000E+00	7.086E-03	1.169E+01
5.500E+01	2.323E+00	2.074E+00	9.079E+00	4.553E-01	2.852E-02	3.233E-03	0.000E+00	8.134E-03	1.114E+01
6.000E+01	2.274E+00	2.208E+00	9.262E+00	5.050E-01	2.990E-02	3.366E-03	0.000E+00	9.284E-03	1.109E+01
6.500E+01	2.200E+00	2.402E+00	9.342E+00	5.440E-01	3.080E-02	3.478E-03	0.000E+00	1.040E-02	1.113E+01
7.000E+01	2.125E+00	2.573E+00	9.254E+00	5.768E-01	3.171E-02	3.609E-03	0.000E+00	1.159E-02	9.793E+00
7.500E+01	2.050E+00	2.700E+00	9.224E+00	6.056E-01	3.233E-02	3.745E-03	0.000E+00	1.271E-02	9.459E+00
8.000E+01	1.976E+00	2.830E+00	9.174E+00	6.293E-01	3.266E-02	3.876E-03	0.000E+00	1.391E-02	8.866E+00
8.500E+01	1.923E+00	2.883E+00	9.198E+00	6.549E-01	3.299E-02	4.036E-03	0.000E+00	1.530E-02	8.501E+00
9.000E+01	1.893E+00	2.853E+00	9.319E+00	6.848E-01	3.356E-02	4.269E-03	0.000E+00	1.704E-02	8.429E+00
9.500E+01	1.855E+00	2.808E+00	9.378E+00	7.083E-01	3.385E-02	4.508E-03	0.000E+00	1.965E-02	8.487E+00
1.000E+02	1.822E+00	2.768E+00	9.449E+00	7.304E-01	3.419E-02	4.792E-03	0.000E+00	2.631E-02	8.240E+00
1.100E+02	1.780E+00	2.594E+00	9.663E+00	7.772E-01	3.459E-02	5.489E-03	0.000E+00	5.493E-02	8.162E+00
1.200E+02	1.742E+00	2.416E+00	9.861E+00	8.167E-01	3.441E-02	6.337E-03	0.000E+00	5.002E-02	7.793E+00
1.300E+02	1.704E+00	2.249E+00	1.001E+01	8.484E-01	3.423E-02	7.334E-03	0.000E+00	5.944E-02	7.638E+00
1.400E+02	1.666E+00	2.072E+00	1.012E+01	8.744E-01	3.386E-02	8.438E-03	0.000E+00	7.177E-02	7.529E+00
1.500E+02	1.630E+00	1.928E+00	1.028E+01	8.918E-01	3.339E-02	9.921E-03	0.000E+00	8.013E-02	7.556E+00

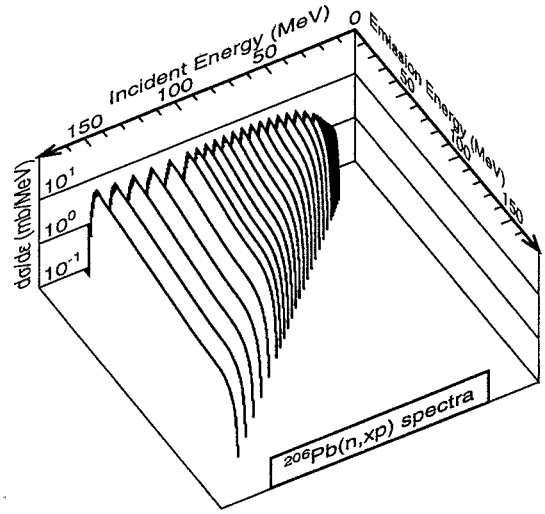
82206 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

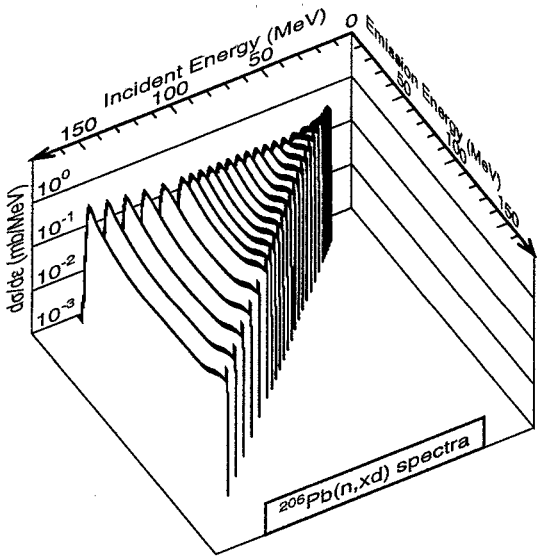
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	1.389E-02	1.664E-03	1.511E-04	0.000E+00	1.014E-03	1.423E-02	2.732E-03	3.368E-02
2.200E+01	2.191E-02	2.930E-03	3.167E-04	0.000E+00	1.510E-03	1.559E-02	2.295E-03	4.455E-02
2.400E+01	3.273E-02	4.488E-03	5.324E-04	0.000E+00	2.053E-03	1.693E-02	2.305E-03	5.903E-02
2.600E+01	4.740E-02	6.341E-03	7.814E-04	0.000E+00	2.625E-03	1.822E-02	2.331E-03	7.770E-02
2.800E+01	6.623E-02	8.450E-03	1.046E-03	0.000E+00	3.193E-03	1.931E-02	2.368E-03	1.006E-01
3.000E+01	8.977E-02	1.087E-02	1.326E-03	0.000E+00	3.771E-03	2.035E-02	2.393E-03	1.285E-01
3.500E+01	1.717E-01	1.790E-02	1.976E-03	0.000E+00	5.212E-03	2.287E-02	2.361E-03	2.220E-01
4.000E+01	2.826E-01	2.602E-02	2.537E-03	0.000E+00	6.534E-03	2.495E-02	2.301E-03	3.449E-01
4.500E+01	3.807E-01	3.284E-02	3.050E-03	0.000E+00	7.907E-03	2.655E-02	2.538E-03	4.535E-01
5.000E+01	4.832E-01	3.946E-02	3.514E-03	0.000E+00	9.382E-03	2.809E-02	2.723E-03	5.664E-01
5.500E+01	5.840E-01	4.555E-02	3.937E-03	0.000E+00	1.087E-02	2.926E-02	2.850E-03	6.765E-01
6.000E+01	6.873E-01	5.152E-02	4.330E-03	0.000E+00	1.245E-02	3.029E-02	2.828E-03	7.887E-01
6.500E+01	7.814E-01	5.681E-02	4.676E-03	0.000E+00	1.395E-02	3.077E-02	2.818E-03	8.904E-01
7.000E+01	8.715E-01	6.243E-02	5.025E-03	0.000E+00	1.546E-02	3.119E-02	2.617E-03	9.882E-01
7.500E+01	9.599E-01	6.750E-02	5.361E-03	0.000E+00	1.687E-02	3.121E-02	2.406E-03	1.083E+00
8.000E+01	1.044E+00	7.197E-02	5.644E-03	0.000E+00	1.827E-02	3.105E-02	2.257E-03	1.174E+00
8.500E+01	1.136E+00	7.645E-02	5.916E-03	0.000E+00	1.986E-02	3.114E-02	2.096E-03	1.271E+00
9.000E+01	1.239E+00	8.143E-02	6.239E-03	0.000E+00	2.178E-02	3.144E-02	1.922E-03	1.382E+00
9.500E+01	1.335E+00	8.577E-02	6.526E-03	0.000E+00	2.389E-02	3.156E-02	1.776E-03	1.485E+00
1.000E+02	1.432E+00	9.031E-02	6.822E-03	0.000E+00	2.723E-02	3.163E-02	1.662E-03	1.590E+00
1.100E+02	1.642E+00	9.798E-02	7.433E-03	0.000E+00	3.855E-02	3.205E-02	1.476E-03	1.819E+00
1.200E+02	1.849E+00	1.029E-01	8.025E-03	0.000E+00	4.112E-02	3.215E-02	1.332E-03	2.034E+00
1.300E+02	2.047E+00	1.074E-01	8.663E-03	0.000E+00	4.865E-02	3.305E-02	1.222E-03	2.246E+00
1.400E+02	2.239E+00	1.107E-01	9.313E-03	0.000E+00	5.825E-02	3.457E-02	1.125E-03	2.453E+00
1.500E+02	2.409E+00	1.126E-01	1.014E-02	0.000E+00	6.584E-02	3.619E-02	1.055E-03	2.635E+00

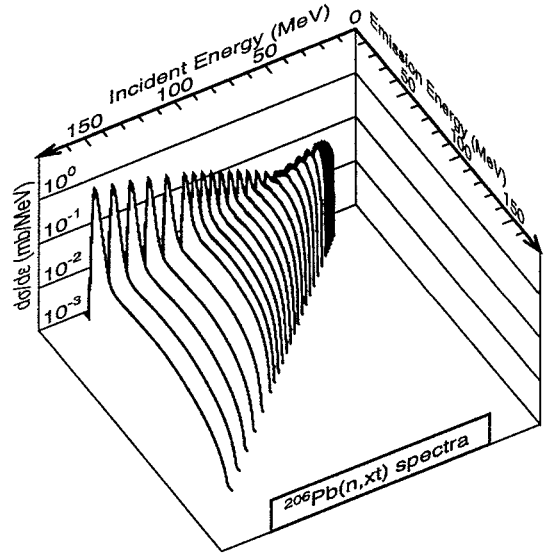

n + 206Pb nonelastic and production cross sections
Production Cross Section (mb)
10^5
10^4
10^3
10^2
10^1
n
γ
p
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
0
50
100
150
Incident Energy (MeV)

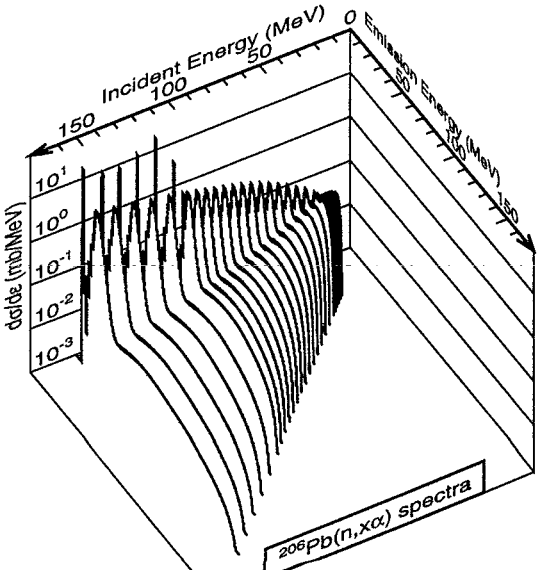
n + ^{206}Pb angle-integrated emission spectra

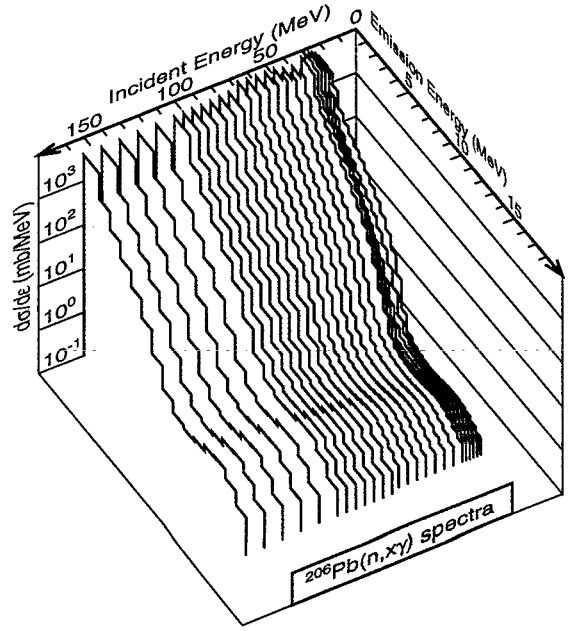












scattering and reaction cross section data for Ni-58, we have employed the following combination of proton potentials:

0 to 5 MeV	:	Harper potential (Ha82b)
6 to 47 MeV	:	Koning and Delaroche (Ko97)
48 to 260 MeV	:	Present OMP

For deuterons, the Lohr-Haeberli (Lo74) global potential was used; for alpha particles the McFadden-Satchler (Mc66) potential was used; and for tritons the Becchetti-Greenlees (Be71) potential was used. The He-3 channel was ignored.

The direct collective inelastic scattering to the following level in Ni-60 was considered by the DWBA-mode calculation of ECIS95 (Ra96):

Jpi	Ex(MeV)	Deformation length
2+	1.331	0.8535

The deformation length was determined to much the ENDF/B-VI value at 20 MeV.

Certain nuclear level densities were modified from the default values in accordance with experimental level-density information as follows. The level density of 57Fe was matched to the observed D-0 value by modifying the pairing energy to 0.15 MeV; the level density of the main competition channel, neutron emission to 60Ni, was adjusted to match Fischer et al.'s (Fi86) value of 3.85e3+-25% at 11 MeV excitation energy, but then increased slightly (a total density increase of 11%) by using a pairing energy of 1.1 MeV, since Haight's alpha production at 14 MeV is approx. 11% smaller than Fischer et al.'s measurements. Production of residual nuclei 59Ni and 56Fe, through (n,2n) and (n,na) reactions, become particularly important above 14 MeV. Pairing energies were adjusted to match the level density for 59Ni at the neutron binding energy (D0=12.9 keV), and Fischer et al.'s result for the 56Fe level density at 11 MeV.

The new Haight et al. (Ha97) LANL/WNR 60Ni(n,x alpha) data up to 50 MeV was used to benchmark our model calculations (Ch97) - agreement with experiment was good.

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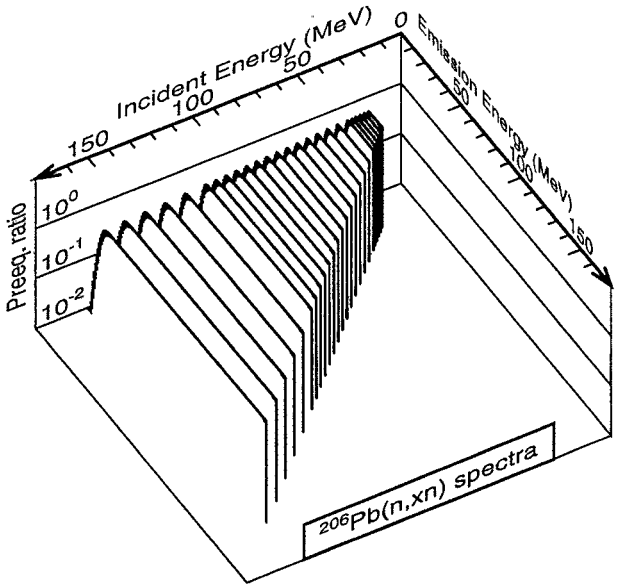
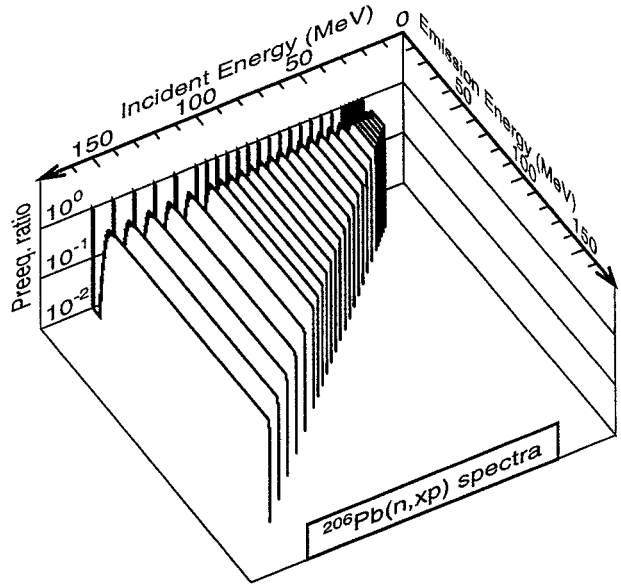
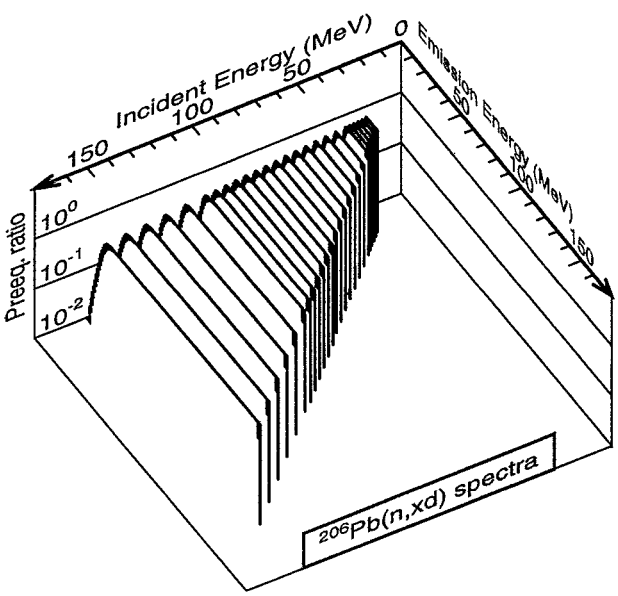
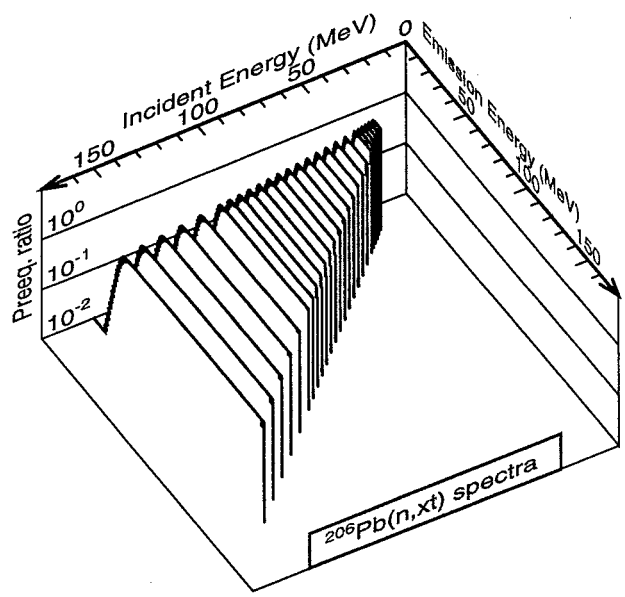
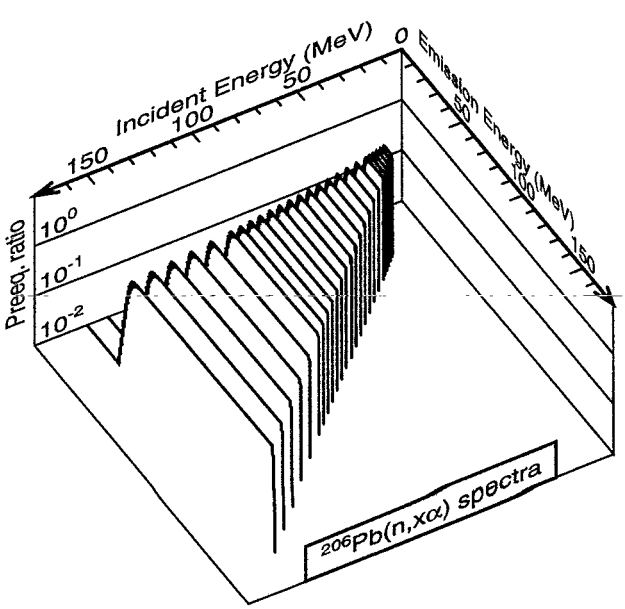
n + ^{206}Pb Kalbach preequilibrium ratios

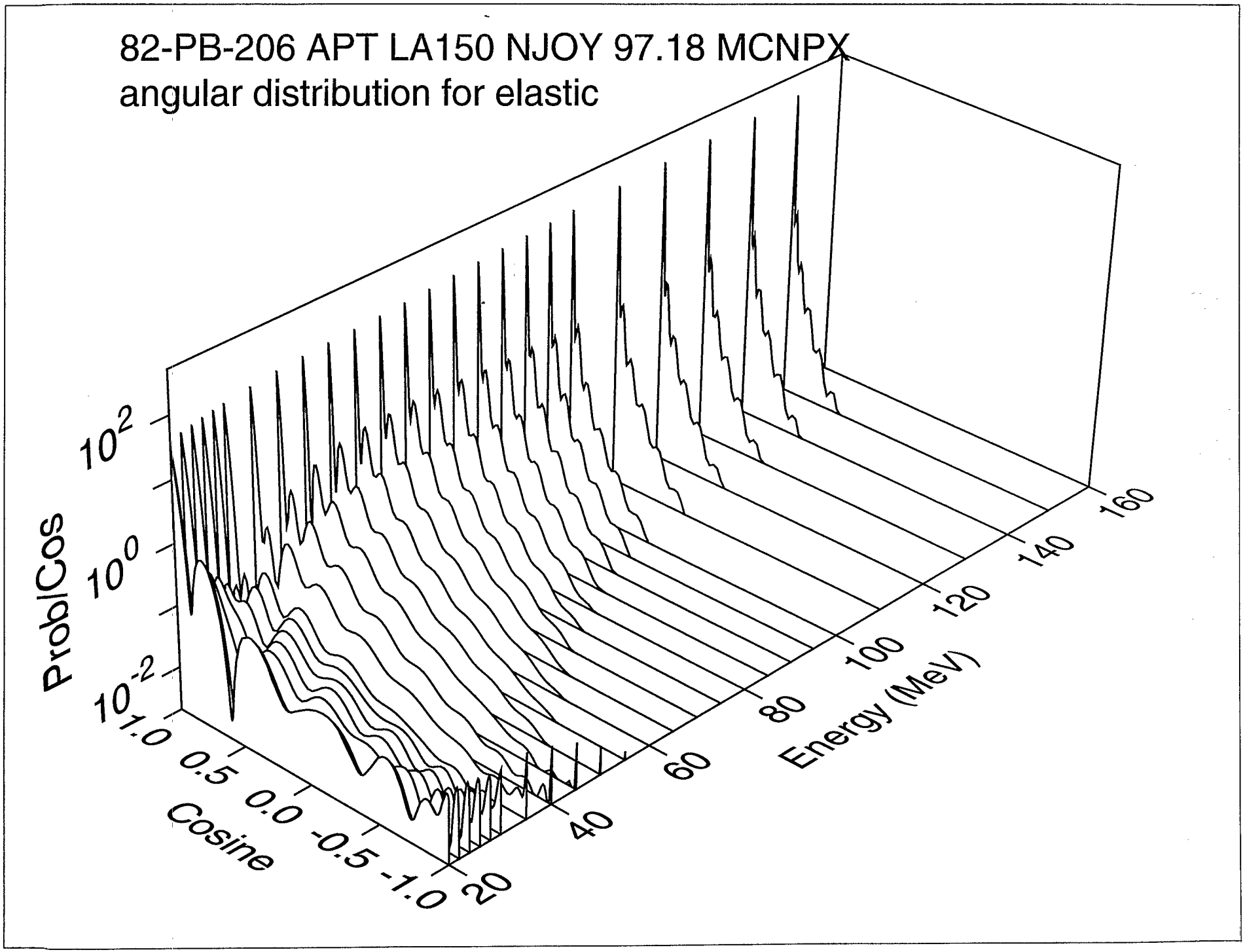


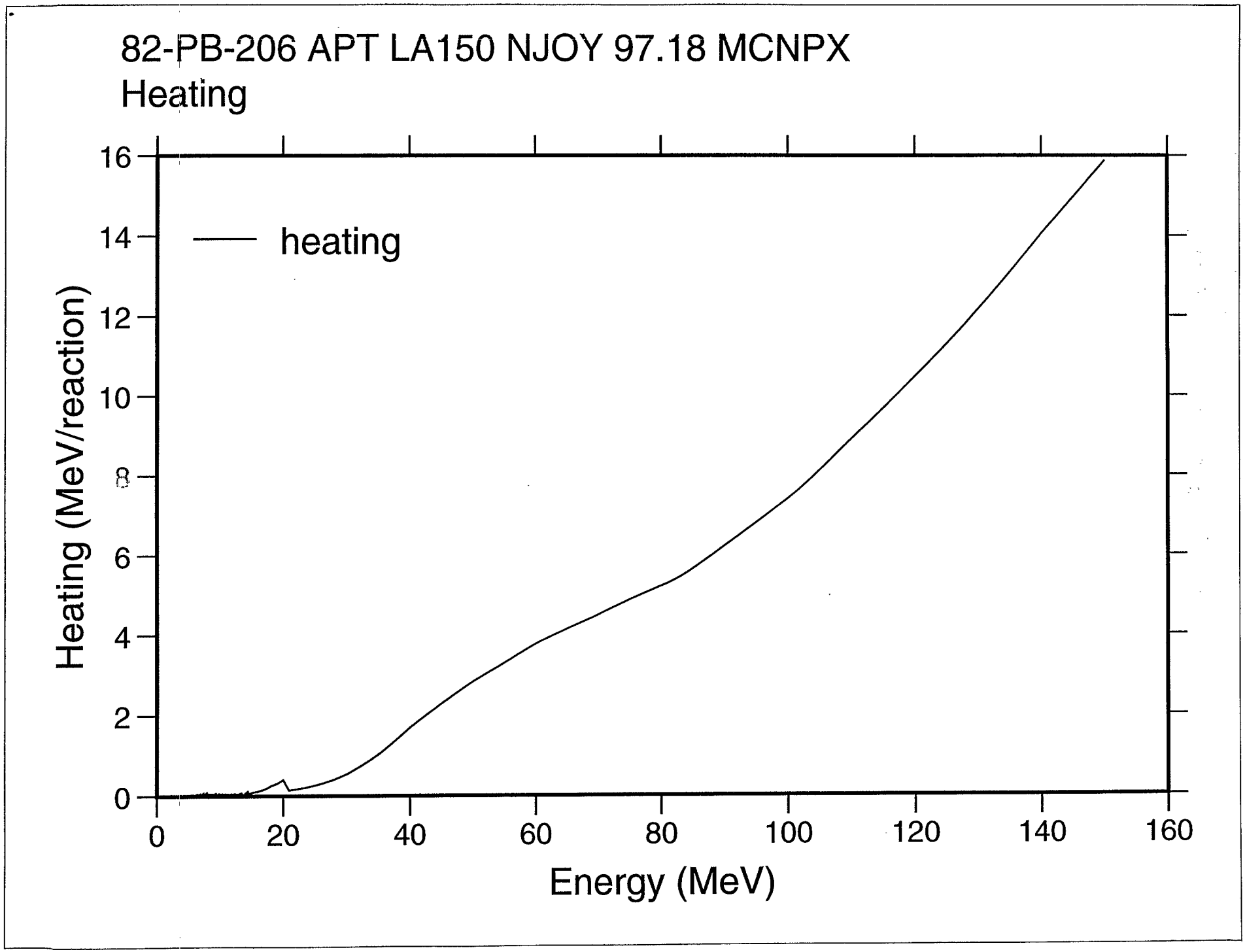


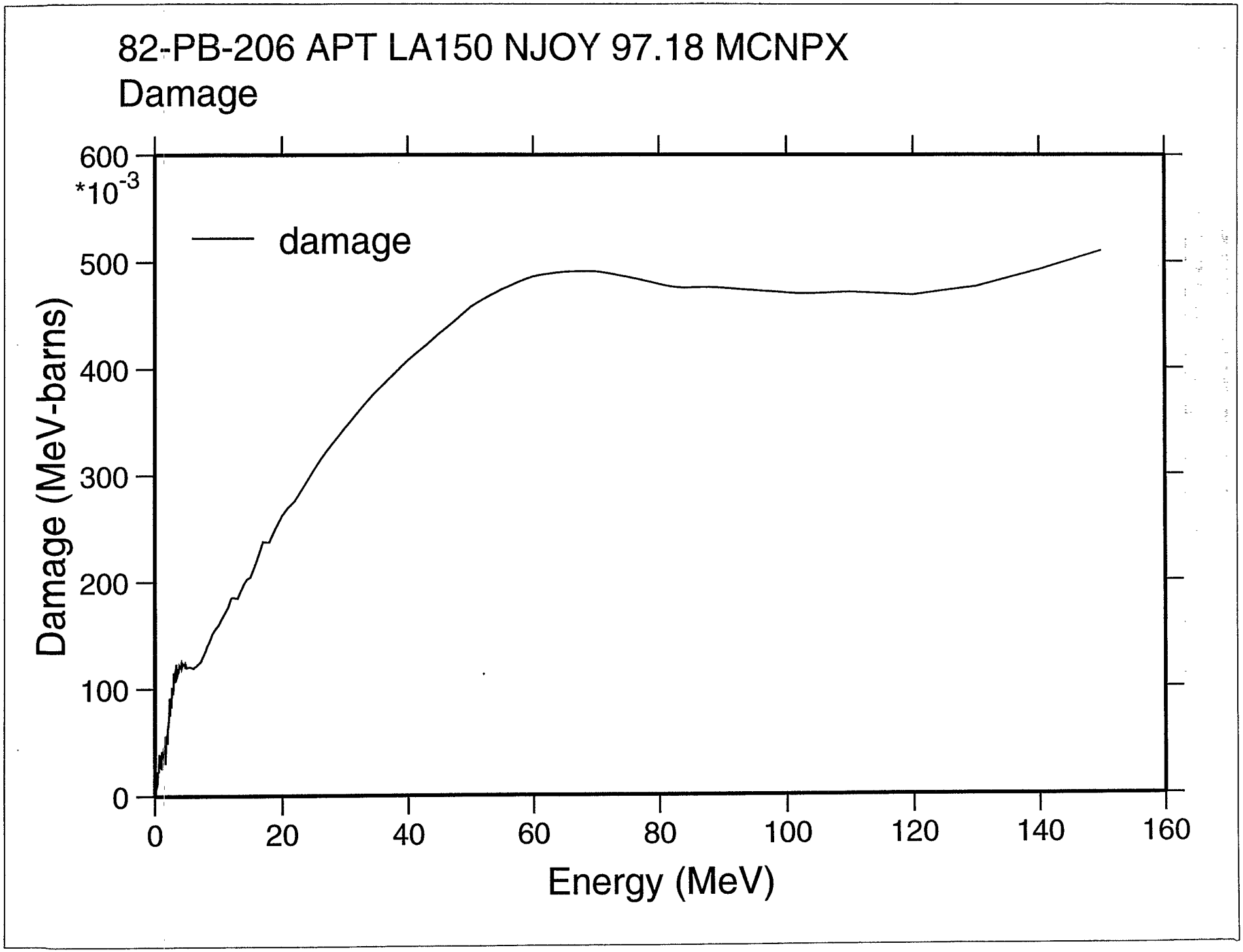







82-PB-206 APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
20
40
60
80
100
120
140
160


82-PB-206 APT LA150 NJOY 97.18 MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
2
4
6
8
10
12
14
16
0
20
40
60
80
100
120
140
160


82-PB-206 APT LA150 NJOY 97.18 MCNPX
Damage
damage
Damage (MeV-barns)
*10^-3
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140
160
Energy (MeV)

all recoil nuclei in the GNASH calculations (Ch96b). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. Note that all other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation requires a modification of the original ENDF-6 format.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

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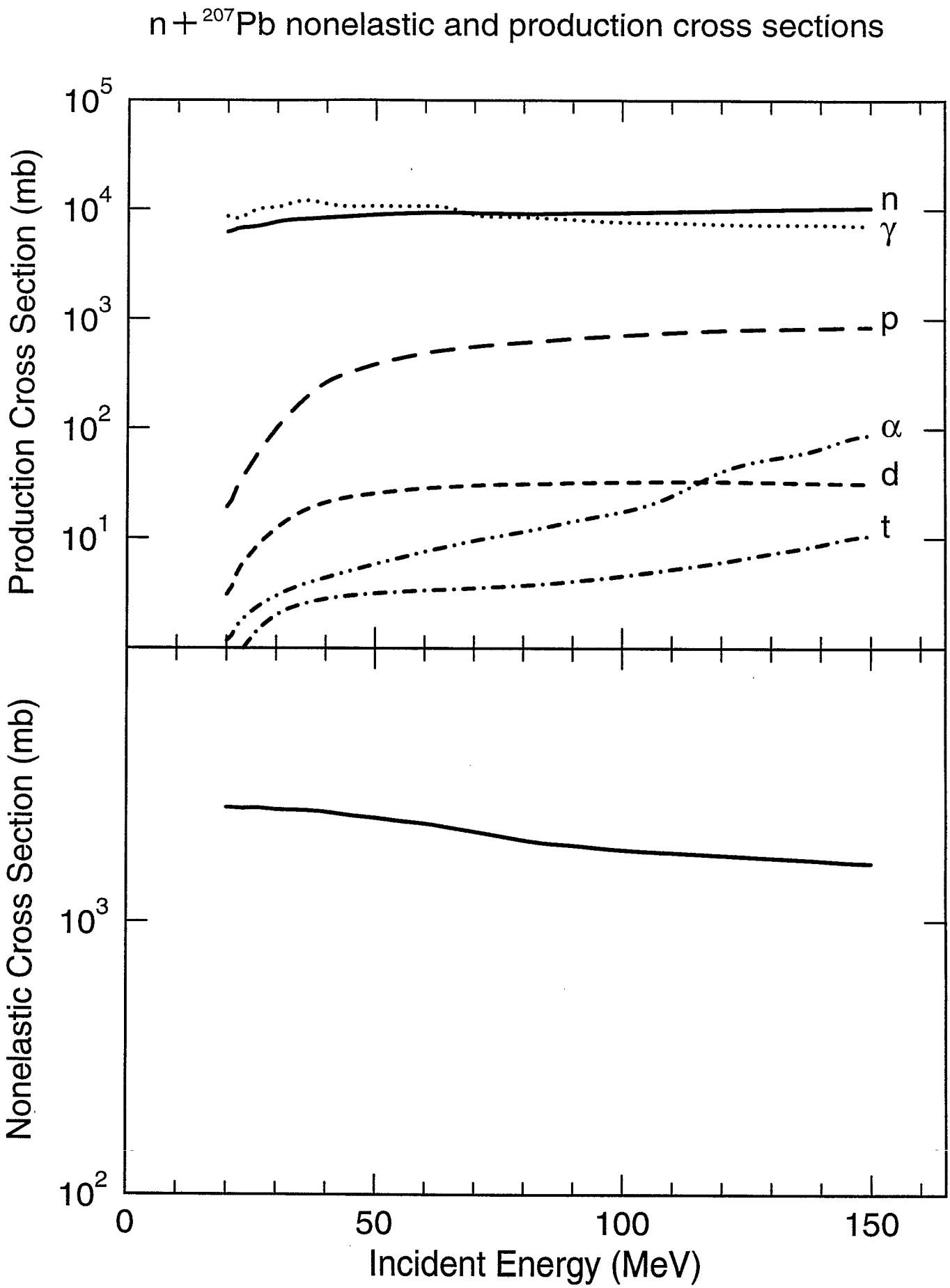
82207 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

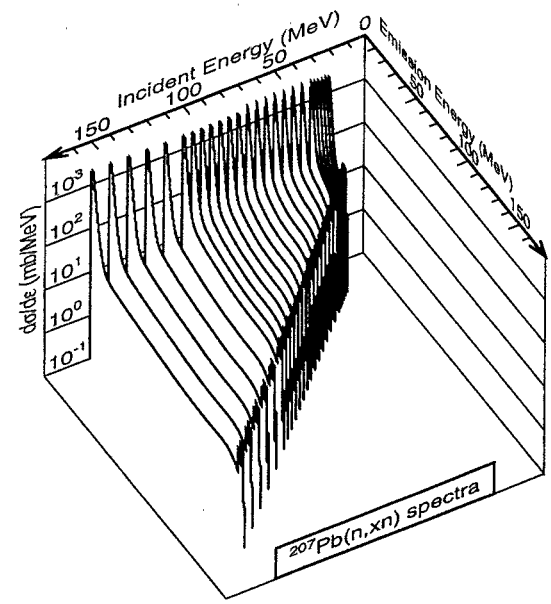
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	2.604E+00	3.240E+00	6.203E+00	1.925E-02	3.060E-03	4.317E-04	0.000E+00	1.164E-03	8.590E+00
2.200E+01	2.591E+00	3.214E+00	6.639E+00	2.860E-02	4.715E-03	7.470E-04	0.000E+00	1.570E-03	8.219E+00
2.400E+01	2.586E+00	3.106E+00	6.816E+00	4.072E-02	6.482E-03	1.085E-03	0.000E+00	1.960E-03	9.005E+00
2.600E+01	2.594E+00	2.937E+00	6.994E+00	5.669E-02	8.356E-03	1.414E-03	0.000E+00	2.330E-03	9.949E+00
2.800E+01	2.577E+00	2.760E+00	7.289E+00	7.641E-02	1.028E-02	1.712E-03	0.000E+00	2.663E-03	1.031E+01
3.000E+01	2.558E+00	2.569E+00	7.679E+00	9.991E-02	1.231E-02	1.989E-03	0.000E+00	2.983E-03	1.047E+01
3.500E+01	2.541E+00	2.109E+00	8.122E+00	1.742E-01	1.730E-02	2.488E-03	0.000E+00	3.726E-03	1.194E+01
4.000E+01	2.502E+00	1.858E+00	8.385E+00	2.627E-01	2.117E-02	2.804E-03	0.000E+00	4.369E-03	1.121E+01
4.500E+01	2.433E+00	1.821E+00	8.641E+00	3.265E-01	2.380E-02	3.005E-03	0.000E+00	5.040E-03	1.060E+01
5.000E+01	2.383E+00	1.907E+00	8.936E+00	3.860E-01	2.557E-02	3.143E-03	0.000E+00	5.808E-03	1.073E+01
5.500E+01	2.323E+00	2.074E+00	9.155E+00	4.381E-01	2.718E-02	3.246E-03	0.000E+00	6.633E-03	1.067E+01
6.000E+01	2.274E+00	2.208E+00	9.320E+00	4.874E-01	2.858E-02	3.339E-03	0.000E+00	7.563E-03	1.072E+01
6.500E+01	2.200E+00	2.402E+00	9.371E+00	5.263E-01	2.950E-02	3.413E-03	0.000E+00	8.489E-03	1.029E+01
7.000E+01	2.125E+00	2.573E+00	9.259E+00	5.593E-01	3.035E-02	3.506E-03	0.000E+00	9.505E-03	8.893E+00
7.500E+01	2.050E+00	2.700E+00	9.193E+00	5.881E-01	3.098E-02	3.612E-03	0.000E+00	1.048E-02	8.602E+00
8.000E+01	1.976E+00	2.830E+00	9.132E+00	6.118E-01	3.131E-02	3.714E-03	0.000E+00	1.154E-02	8.518E+00
8.500E+01	1.923E+00	2.883E+00	9.155E+00	6.372E-01	3.165E-02	3.850E-03	0.000E+00	1.279E-02	8.303E+00
9.000E+01	1.893E+00	2.853E+00	9.270E+00	6.666E-01	3.220E-02	4.056E-03	0.000E+00	1.430E-02	8.098E+00
9.500E+01	1.855E+00	2.808E+00	9.321E+00	6.898E-01	3.250E-02	4.276E-03	0.000E+00	1.584E-02	7.846E+00
1.000E+02	1.822E+00	2.768E+00	9.383E+00	7.117E-01	3.273E-02	4.540E-03	0.000E+00	1.754E-02	7.676E+00
1.100E+02	1.780E+00	2.594E+00	9.592E+00	7.573E-01	3.315E-02	5.211E-03	0.000E+00	2.448E-02	7.594E+00
1.200E+02	1.742E+00	2.416E+00	9.794E+00	7.938E-01	3.308E-02	6.080E-03	0.000E+00	4.083E-02	7.370E+00
1.300E+02	1.704E+00	2.249E+00	1.003E+01	8.150E-01	3.266E-02	7.334E-03	0.000E+00	5.366E-02	7.267E+00
1.400E+02	1.666E+00	2.072E+00	1.022E+01	8.324E-01	3.215E-02	8.812E-03	0.000E+00	6.670E-02	7.277E+00
1.500E+02	1.630E+00	1.928E+00	1.038E+01	8.479E-01	3.167E-02	1.050E-02	0.000E+00	8.775E-02	7.123E+00

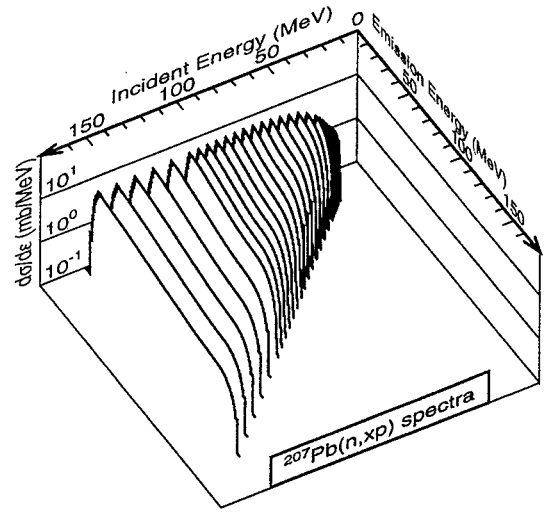
82207 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

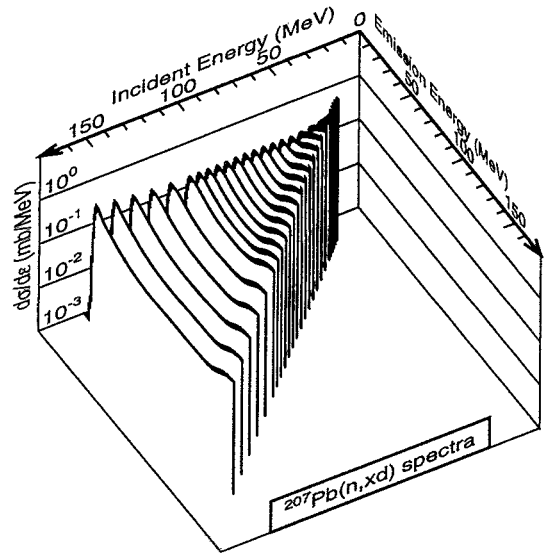
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	1.207E-02	1.834E-03	2.296E-04	0.000E+00	1.193E-03	1.427E-02	2.705E-03	3.230E-02
2.200E+01	1.919E-02	3.122E-03	4.352E-04	0.000E+00	1.679E-03	1.560E-02	2.273E-03	4.230E-02
2.400E+01	2.893E-02	4.684E-03	6.848E-04	0.000E+00	2.178E-03	1.689E-02	2.283E-03	5.565E-02
2.600E+01	4.234E-02	6.528E-03	9.595E-04	0.000E+00	2.680E-03	1.815E-02	2.308E-03	7.297E-02
2.800E+01	5.979E-02	8.622E-03	1.241E-03	0.000E+00	3.160E-03	1.920E-02	2.345E-03	9.436E-02
3.000E+01	8.179E-02	1.102E-02	1.533E-03	0.000E+00	3.641E-03	2.023E-02	2.369E-03	1.206E-01
3.500E+01	1.590E-01	1.795E-02	2.178E-03	0.000E+00	4.831E-03	2.268E-02	2.338E-03	2.090E-01
4.000E+01	2.658E-01	2.477E-02	2.736E-03	0.000E+00	5.941E-03	2.470E-02	2.279E-03	3.262E-01
4.500E+01	3.611E-01	3.128E-02	3.225E-03	0.000E+00	7.055E-03	2.622E-02	2.513E-03	4.314E-01
5.000E+01	4.609E-01	3.689E-02	3.662E-03	0.000E+00	8.260E-03	2.775E-02	2.697E-03	5.402E-01
5.500E+01	5.594E-01	4.275E-02	4.054E-03	0.000E+00	9.498E-03	2.885E-02	2.823E-03	6.474E-01
6.000E+01	6.607E-01	4.850E-02	4.417E-03	0.000E+00	1.083E-02	2.984E-02	2.801E-03	7.571E-01
6.500E+01	7.533E-01	5.362E-02	4.732E-03	0.000E+00	1.209E-02	3.024E-02	2.790E-03	8.567E-01
7.000E+01	8.424E-01	5.887E-02	5.043E-03	0.000E+00	1.340E-02	3.061E-02	2.591E-03	9.529E-01
7.500E+01	9.298E-01	6.370E-02	5.353E-03	0.000E+00	1.461E-02	3.052E-02	2.383E-03	1.046E+00
8.000E+01	1.013E+00	6.798E-02	5.608E-03	0.000E+00	1.584E-02	3.036E-02	2.235E-03	1.135E+00
8.500E+01	1.104E+00	7.226E-02	5.854E-03	0.000E+00	1.725E-02	3.038E-02	2.076E-03	1.232E+00
9.000E+01	1.205E+00	7.702E-02	6.151E-03	0.000E+00	1.893E-02	3.063E-02	1.903E-03	1.340E+00
9.500E+01	1.300E+00	8.118E-02	6.416E-03	0.000E+00	2.059E-02	3.068E-02	1.758E-03	1.441E+00
1.000E+02	1.396E+00	8.515E-02	6.687E-03	0.000E+00	2.239E-02	3.073E-02	1.646E-03	1.543E+00
1.100E+02	1.603E+00	9.262E-02	7.256E-03	0.000E+00	2.733E-02	3.096E-02	1.462E-03	1.763E+00
1.200E+02	1.803E+00	9.807E-02	7.825E-03	0.000E+00	3.536E-02	3.113E-02	1.319E-03	1.977E+00
1.300E+02	1.976E+00	1.016E-01	8.543E-03	0.000E+00	4.348E-02	3.227E-02	1.211E-03	2.164E+00
1.400E+02	2.143E+00	1.041E-01	9.354E-03	0.000E+00	5.251E-02	3.397E-02	1.114E-03	2.344E+00
1.500E+02	2.306E+00	1.060E-01	1.028E-02	0.000E+00	6.460E-02	3.563E-02	1.045E-03	2.524E+00

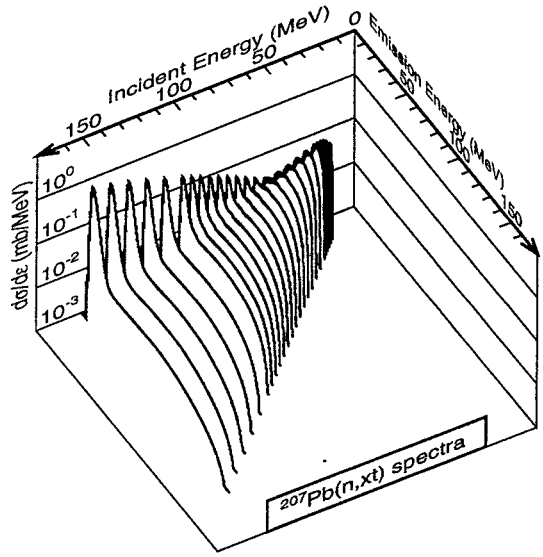

n + 207Pb nonelastic and production cross sections
Production Cross Section (mb)
10^5
10^4
10^3
10^2
10^1
n
γ
p
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
0
50
100
150
Incident Energy (MeV)

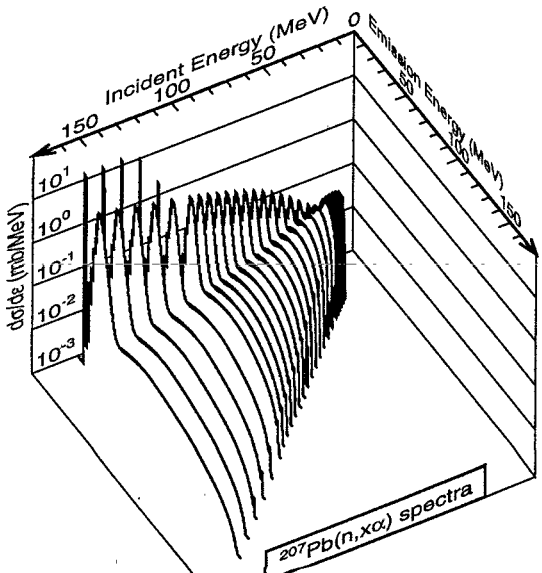
n + ^{207}Pb angle-integrated emission spectra

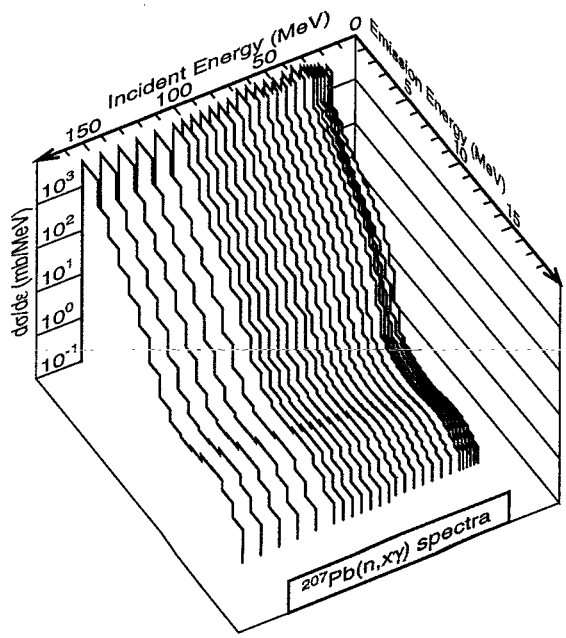




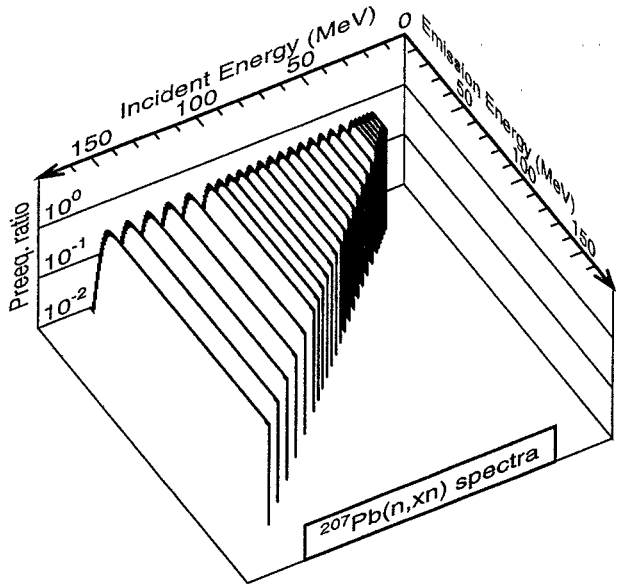


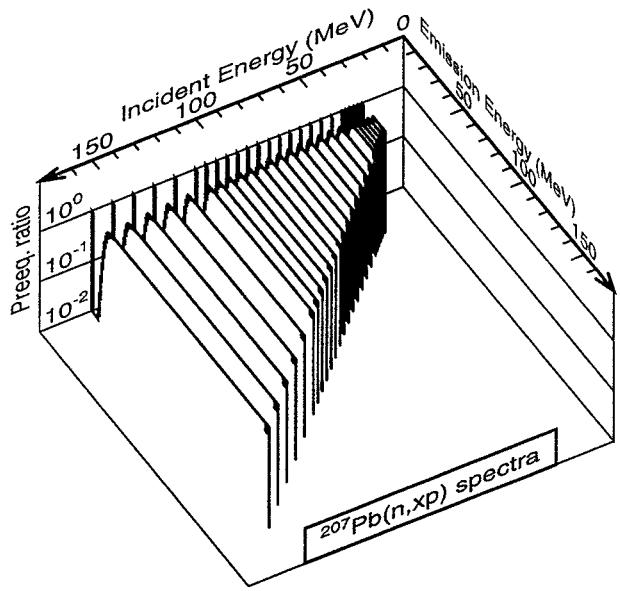


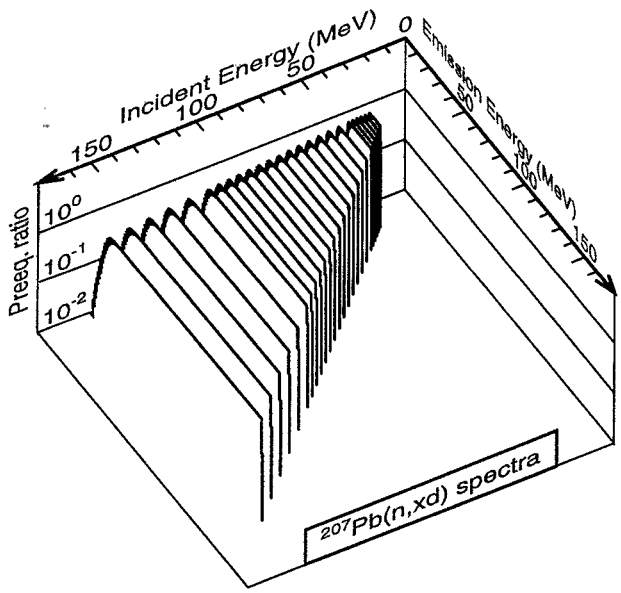


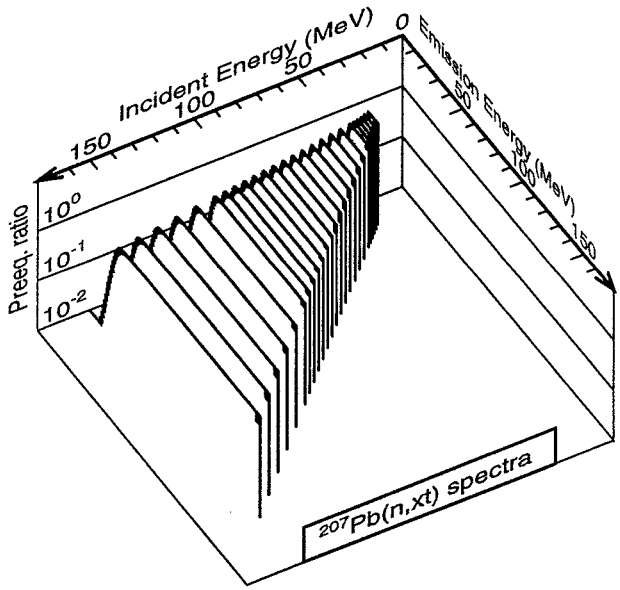


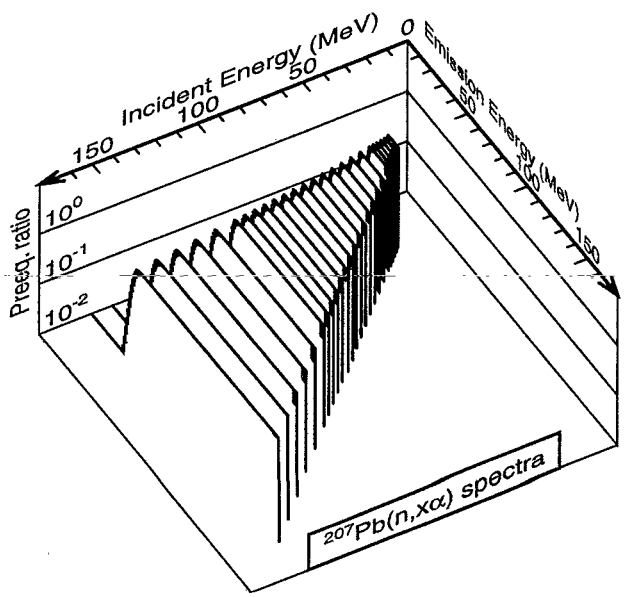
n + ^{207}Pb Kalbach preequilibrium ratios

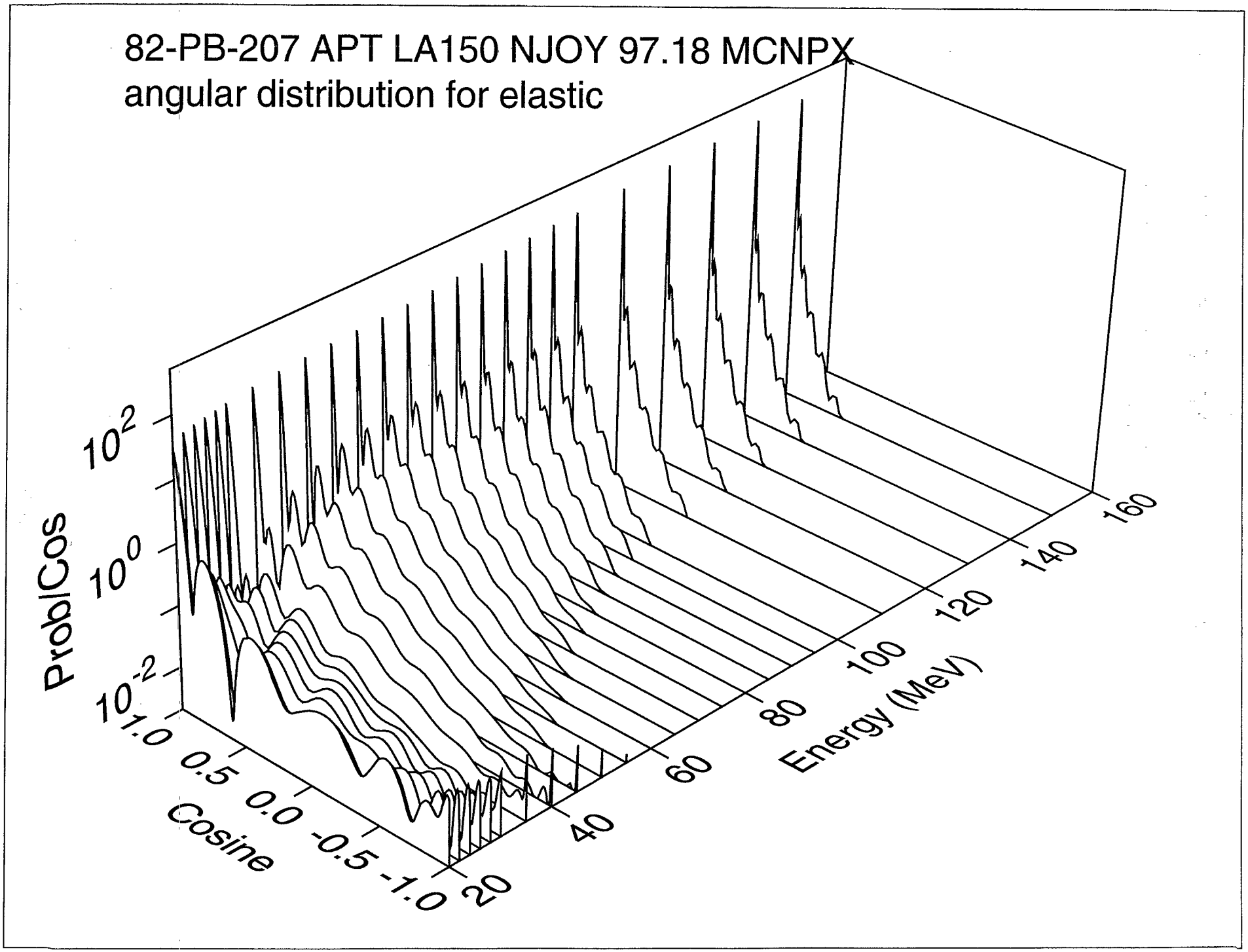


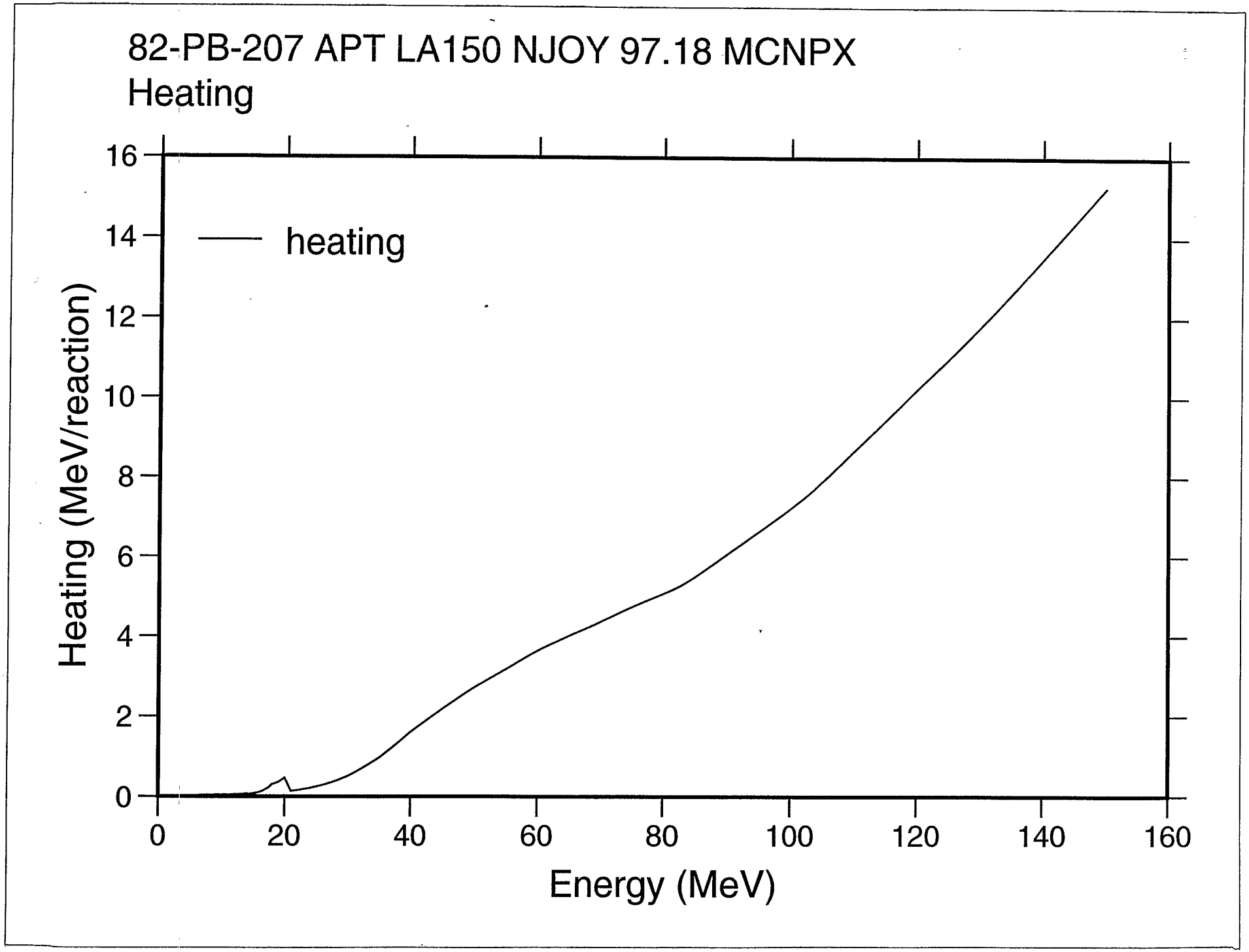


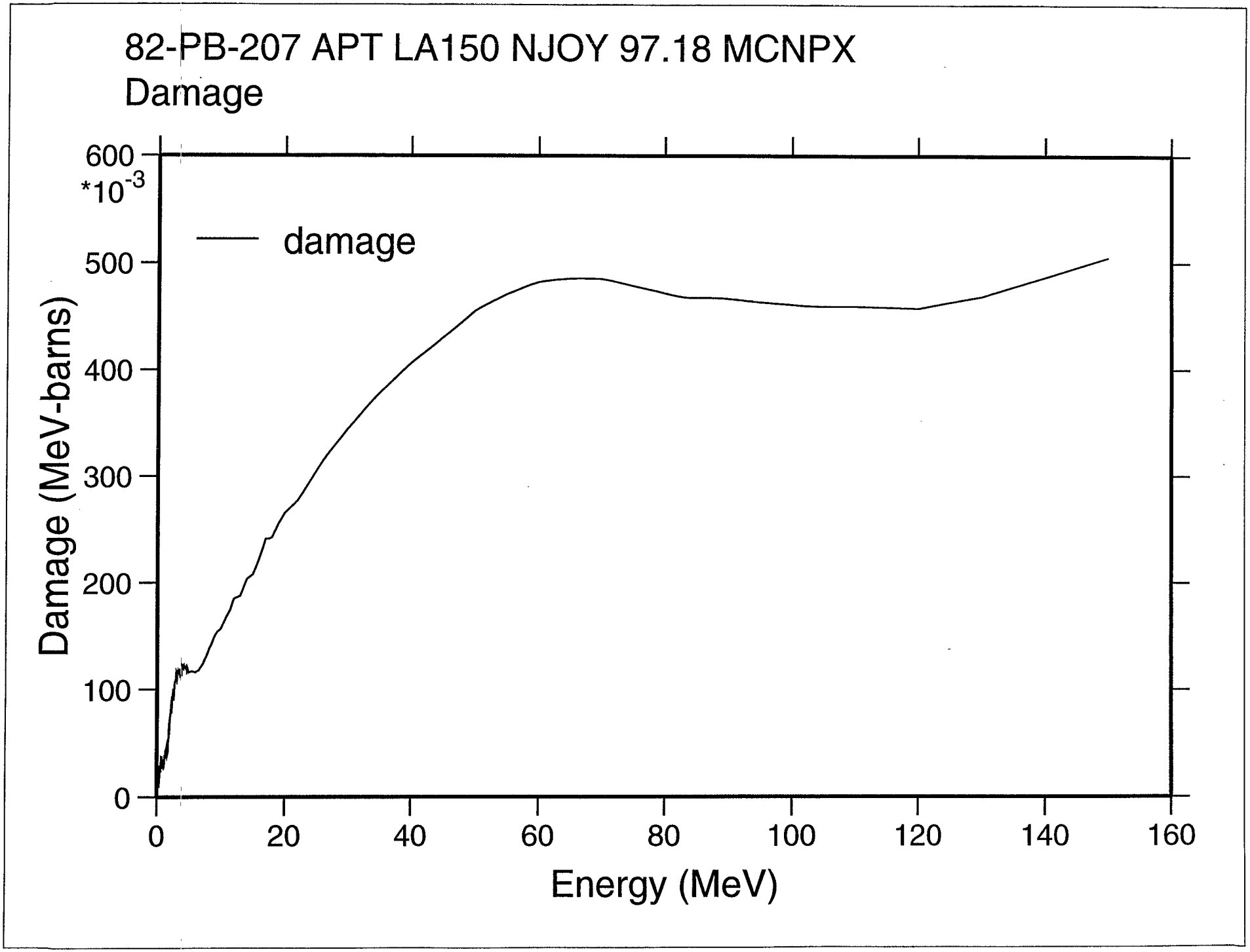







82-PB-207 APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
20
40
60
80
100
120
140
160


82-PB-207 APT LA150 NJOY 97.18 MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
2
4
6
8
10
12
14
16
0
20
40
60
80
100
120
140
160


82-PB-207 APT LA150 NJOY 97.18 MCNPX
Damage
damage
Damage (MeV-barns)
*10^-3
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF n + 208Pb CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

M. B. Chadwick, P. G. Young, and A. J. Koning
23 August 1996

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 30 MeV.

INCIDENT NEUTRON ENERGIES < 30 MeV

Below 30 MeV the evaluation is based completely on a new evaluation by Young and Chadwick that will be submitted to ENDF/B for a future release of ENDF/B-VI. The only change made to the Young-Chadwick evaluation was to remove the covariance data file (MF=3), which had been carried over from an earlier ENDF/B-VI evaluation.

INCIDENT NEUTRON ENERGIES > 30 MeV

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above En = 20 MeV are:

MF=3	MT= 1	Total Cross Section
	MT= 2	Elastic Scattering Cross Section
	MT= 3	Nonelastic Cross Section
	MT= 5	Sum of Binary (n,n') and (n,x) Reactions
MF=4	MT= 2	Elastic Angular Distributions
MF=6	MT= 5	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Pb and p + Pb208 reactions (Ch96a). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Coupled-channel and spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96b). The recoil

energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. Note that all other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation requires a modification of the original ENDF-6 format.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

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Distributions: Extensions to Higher Energies," Phys.Rev.C 37, 2350 (1988); see also C. Kalbach and F. M. Mann, "Phenomenology of Continuum Angular Distributions. I. Systematics and Parameterization," Phys.Rev.C 23, 112 (1981).

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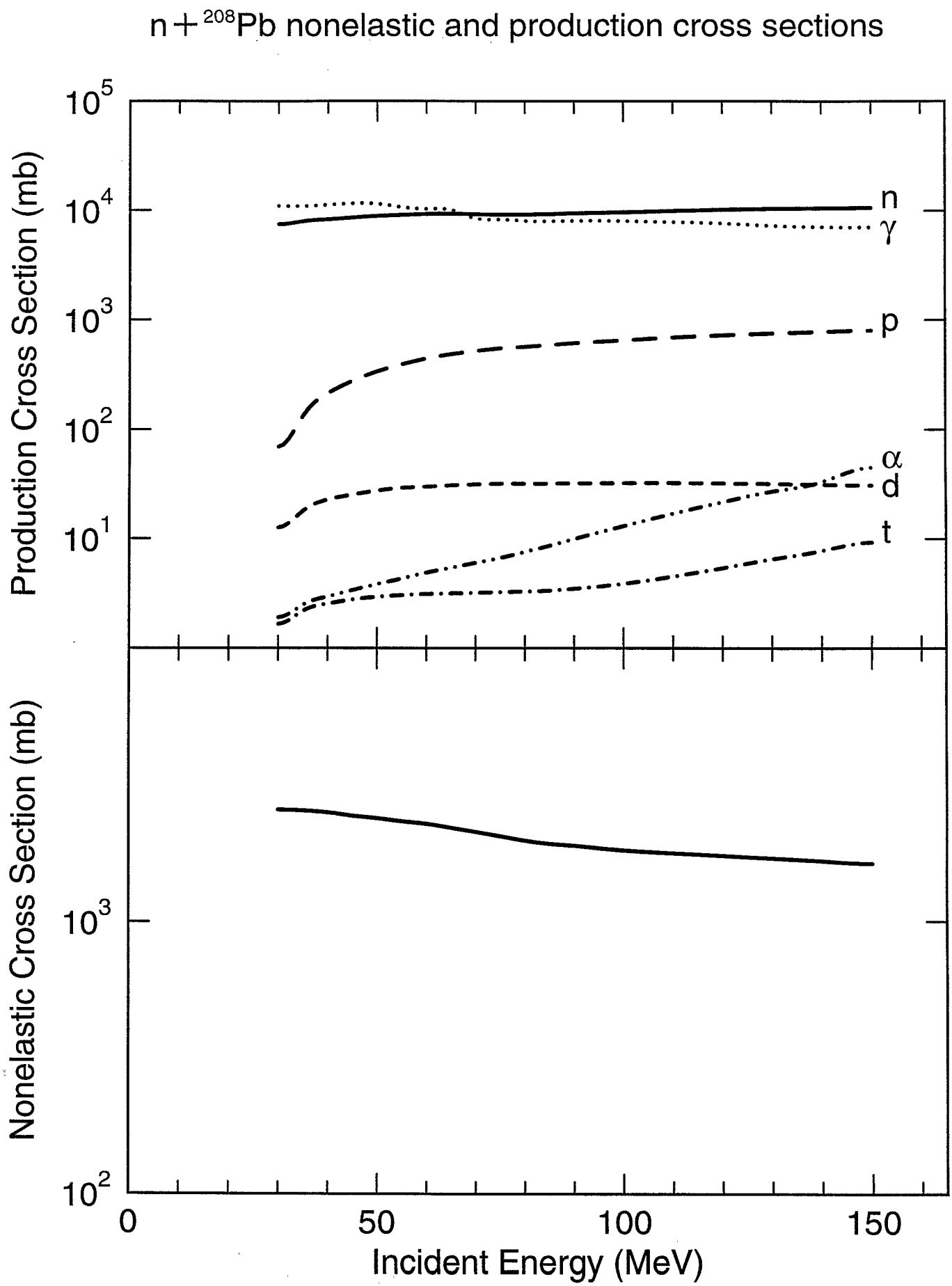
[Yo92]. P.G. Young, E.D. Arthur, and M.B. Chadwick, "Comprehensive Nuclear Model Calculations: Introduction to the Theory and Use of the GNASH Code," LA-12343-MS (1992).

82208 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

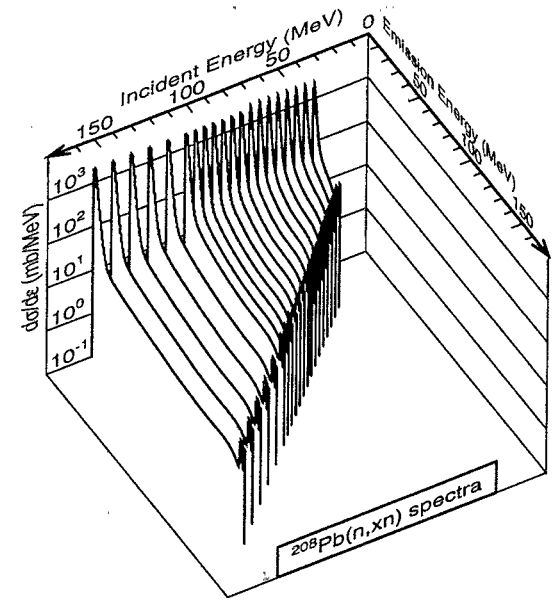
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
3.000E+01	2.558E+00	2.569E+00	7.414E+00	6.930E-02	1.261E-02	1.661E-03	0.000E+00	1.906E-03	1.089E+01
3.500E+01	2.541E+00	2.109E+00	7.920E+00	1.340E-01	1.797E-02	2.191E-03	0.000E+00	2.485E-03	1.089E+01
4.000E+01	2.502E+00	1.858E+00	8.272E+00	2.133E-01	2.283E-02	2.541E-03	0.000E+00	2.935E-03	1.121E+01
4.500E+01	2.433E+00	1.821E+00	8.582E+00	2.760E-01	2.528E-02	2.768E-03	0.000E+00	3.361E-03	1.155E+01
5.000E+01	2.383E+00	1.907E+00	8.873E+00	3.368E-01	2.748E-02	2.921E-03	0.000E+00	3.813E-03	1.144E+01
5.500E+01	2.323E+00	2.074E+00	9.080E+00	3.911E-01	2.909E-02	3.023E-03	0.000E+00	4.290E-03	1.068E+01
6.000E+01	2.274E+00	2.208E+00	9.275E+00	4.423E-01	2.984E-02	3.101E-03	0.000E+00	4.842E-03	1.032E+01
6.500E+01	2.200E+00	2.402E+00	9.314E+00	4.835E-01	3.072E-02	3.142E-03	0.000E+00	5.377E-03	1.008E+01
7.000E+01	2.125E+00	2.573E+00	9.201E+00	5.171E-01	3.133E-02	3.183E-03	0.000E+00	5.979E-03	8.440E+00
7.500E+01	2.050E+00	2.700E+00	9.140E+00	5.464E-01	3.185E-02	3.230E-03	0.000E+00	6.626E-03	8.256E+00
8.000E+01	1.976E+00	2.830E+00	9.173E+00	5.647E-01	3.184E-02	3.266E-03	0.000E+00	7.526E-03	8.001E+00
8.500E+01	1.923E+00	2.883E+00	9.246E+00	5.870E-01	3.196E-02	3.336E-03	0.000E+00	8.589E-03	7.935E+00
9.000E+01	1.893E+00	2.853E+00	9.425E+00	6.111E-01	3.224E-02	3.476E-03	0.000E+00	9.955E-03	8.016E+00
9.500E+01	1.855E+00	2.808E+00	9.537E+00	6.299E-01	3.229E-02	3.646E-03	0.000E+00	1.144E-02	8.048E+00
1.000E+02	1.822E+00	2.768E+00	9.636E+00	6.492E-01	3.237E-02	3.867E-03	0.000E+00	1.307E-02	7.984E+00
1.100E+02	1.780E+00	2.594E+00	9.927E+00	6.887E-01	3.248E-02	4.498E-03	0.000E+00	1.701E-02	7.823E+00
1.200E+02	1.742E+00	2.416E+00	1.018E+01	7.227E-01	3.223E-02	5.365E-03	0.000E+00	2.172E-02	7.610E+00
1.300E+02	1.704E+00	2.249E+00	1.039E+01	7.497E-01	3.183E-02	6.492E-03	0.000E+00	2.711E-02	7.226E+00
1.400E+02	1.666E+00	2.072E+00	1.051E+01	7.747E-01	3.135E-02	7.767E-03	0.000E+00	3.328E-02	7.048E+00
1.500E+02	1.630E+00	1.928E+00	1.063E+01	7.954E-01	3.085E-02	9.253E-03	0.000E+00	4.504E-02	7.010E+00

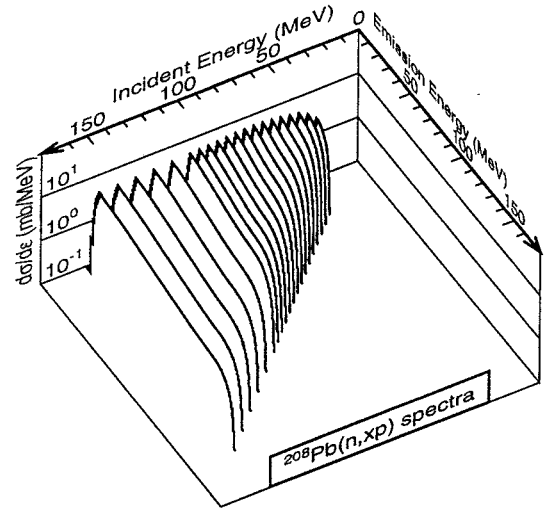
82208 = TARGET 1000Z+A (if A=0 then elemental)
1 = PROJECTILE 1000Z+A
Kerma coefficients in units of f.Gy.m^2:

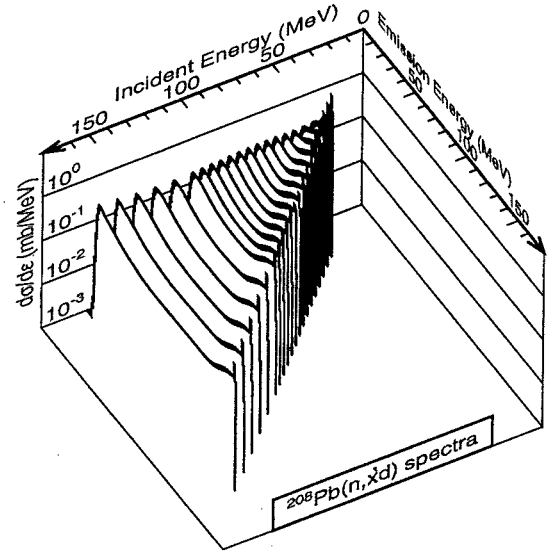
Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
3.000E+01	5.173E-02	1.088E-02	1.235E-03	0.000E+00	2.286E-03	1.983E-02	2.345E-03	8.831E-02
3.500E+01	1.128E-01	1.800E-02	1.857E-03	0.000E+00	3.220E-03	2.221E-02	2.316E-03	1.604E-01
4.000E+01	2.005E-01	2.613E-02	2.403E-03	0.000E+00	4.072E-03	2.426E-02	2.257E-03	2.597E-01
4.500E+01	2.855E-01	3.234E-02	2.884E-03	0.000E+00	4.898E-03	2.581E-02	2.490E-03	3.539E-01
5.000E+01	3.789E-01	3.882E-02	3.314E-03	0.000E+00	5.756E-03	2.730E-02	2.671E-03	4.567E-01
5.500E+01	4.734E-01	4.481E-02	3.698E-03	0.000E+00	6.619E-03	2.833E-02	2.796E-03	5.596E-01
6.000E+01	5.716E-01	4.913E-02	4.047E-03	0.000E+00	7.549E-03	2.928E-02	2.774E-03	6.644E-01
6.500E+01	6.629E-01	5.421E-02	4.342E-03	0.000E+00	8.409E-03	2.966E-02	2.764E-03	7.623E-01
7.000E+01	7.493E-01	5.895E-02	4.620E-03	0.000E+00	9.287E-03	3.003E-02	2.567E-03	8.547E-01
7.500E+01	8.342E-01	6.361E-02	4.891E-03	0.000E+00	1.016E-02	2.991E-02	2.360E-03	9.452E-01
8.000E+01	9.067E-01	6.723E-02	5.080E-03	0.000E+00	1.119E-02	2.977E-02	2.214E-03	1.022E+00
8.500E+01	9.888E-01	7.106E-02	5.273E-03	0.000E+00	1.238E-02	2.987E-02	2.056E-03	1.109E+00
9.000E+01	1.078E+00	7.523E-02	5.505E-03	0.000E+00	1.386E-02	3.029E-02	1.885E-03	1.205E+00
9.500E+01	1.161E+00	7.884E-02	5.720E-03	0.000E+00	1.542E-02	3.045E-02	1.742E-03	1.294E+00
1.000E+02	1.249E+00	8.244E-02	5.954E-03	0.000E+00	1.711E-02	3.056E-02	1.630E-03	1.386E+00
1.100E+02	1.435E+00	8.914E-02	6.474E-03	0.000E+00	2.119E-02	3.105E-02	1.448E-03	1.584E+00
1.200E+02	1.620E+00	9.415E-02	7.033E-03	0.000E+00	2.598E-02	3.134E-02	1.307E-03	1.780E+00
1.300E+02	1.798E+00	9.801E-02	7.704E-03	0.000E+00	3.143E-02	3.230E-02	1.199E-03	1.968E+00
1.400E+02	1.977E+00	1.010E-01	8.430E-03	0.000E+00	3.733E-02	3.378E-02	1.103E-03	2.158E+00
1.500E+02	2.149E+00	1.034E-01	9.252E-03	0.000E+00	4.547E-02	3.523E-02	1.035E-03	2.343E+00

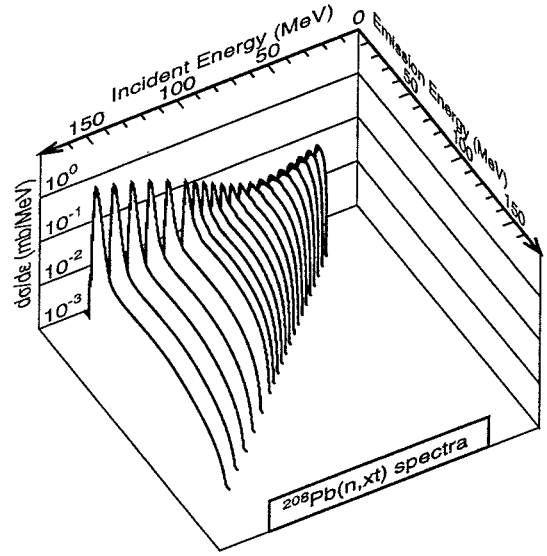

n + 208Pb nonelastic and production cross sections
Production Cross Section (mb)
10^5
10^4
10^3
10^2
10^1
n
γ
p
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
0
50
100
150
Incident Energy (MeV)

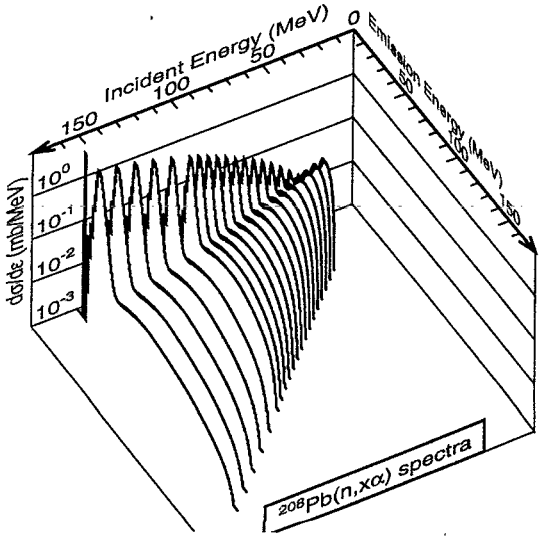
n + ^{208}Pb angle-integrated emission spectra

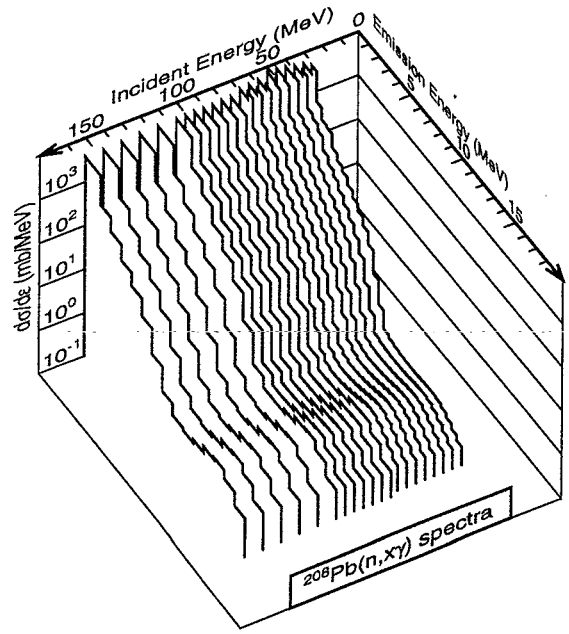




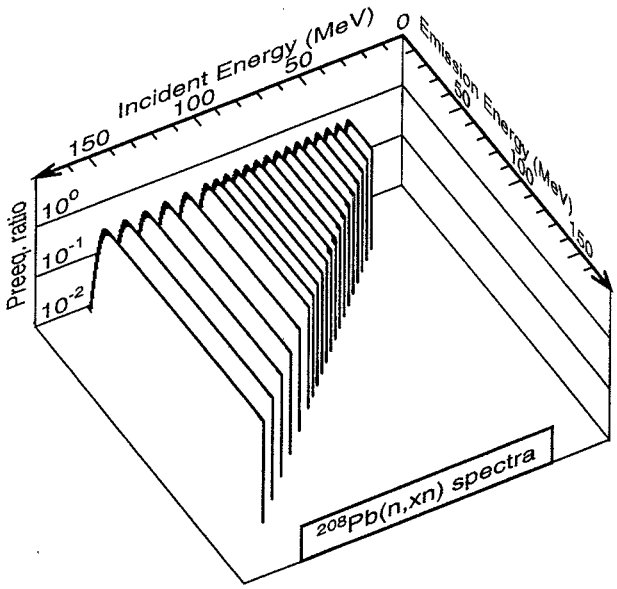


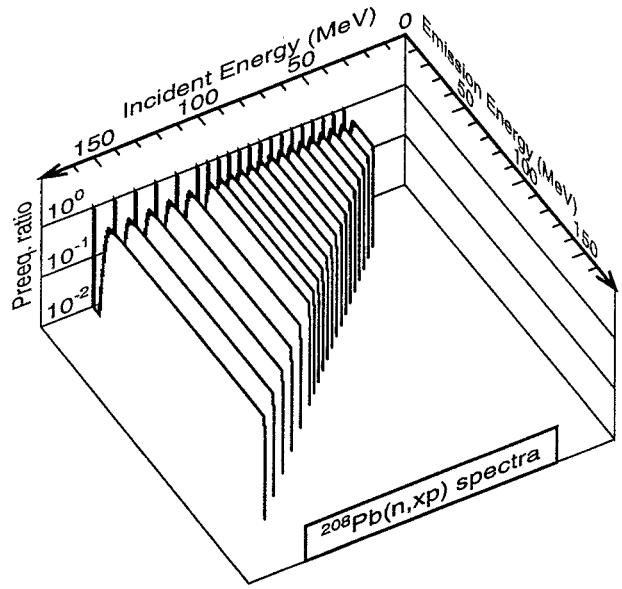


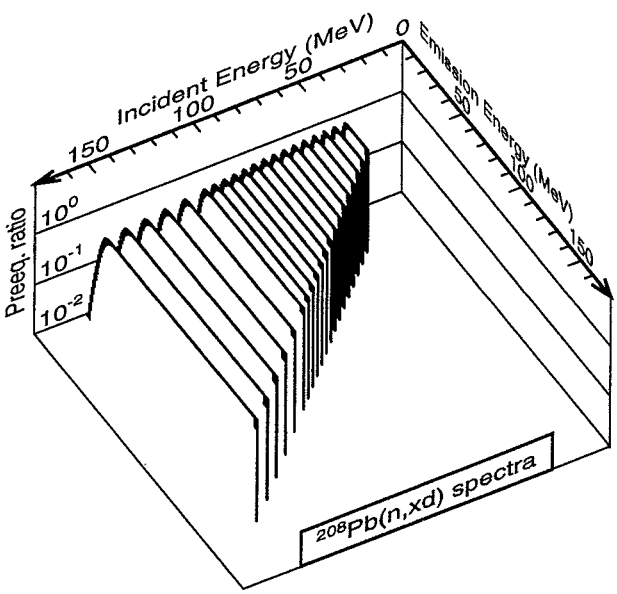


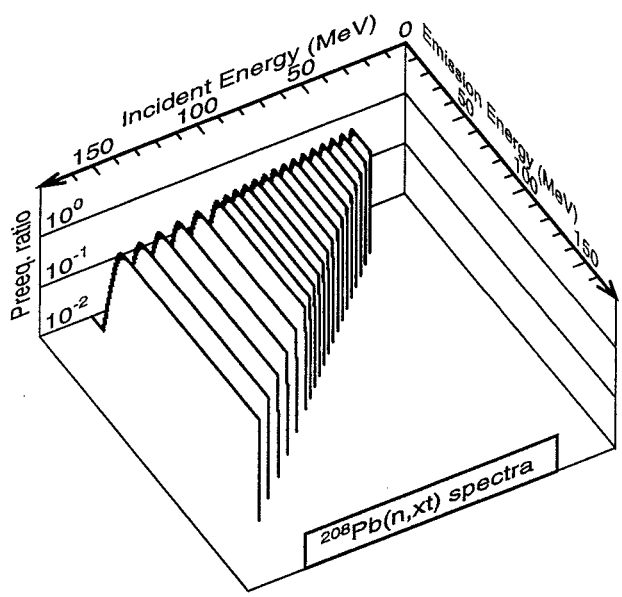


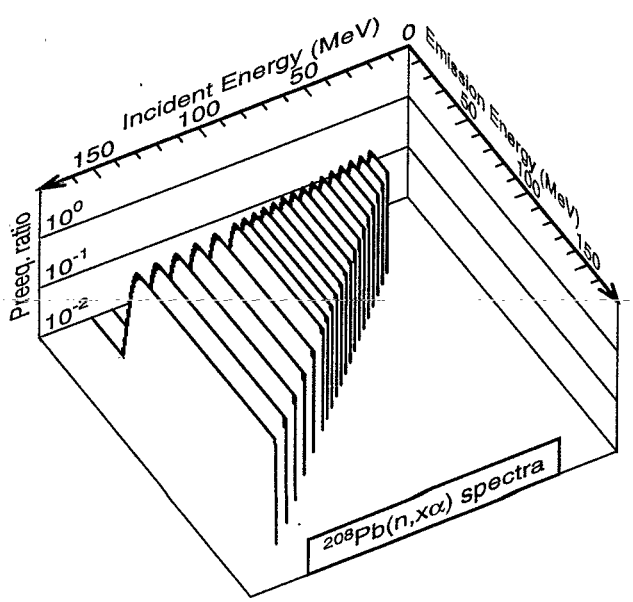
n + ^{208}Pb Kalbach preequilibrium ratios

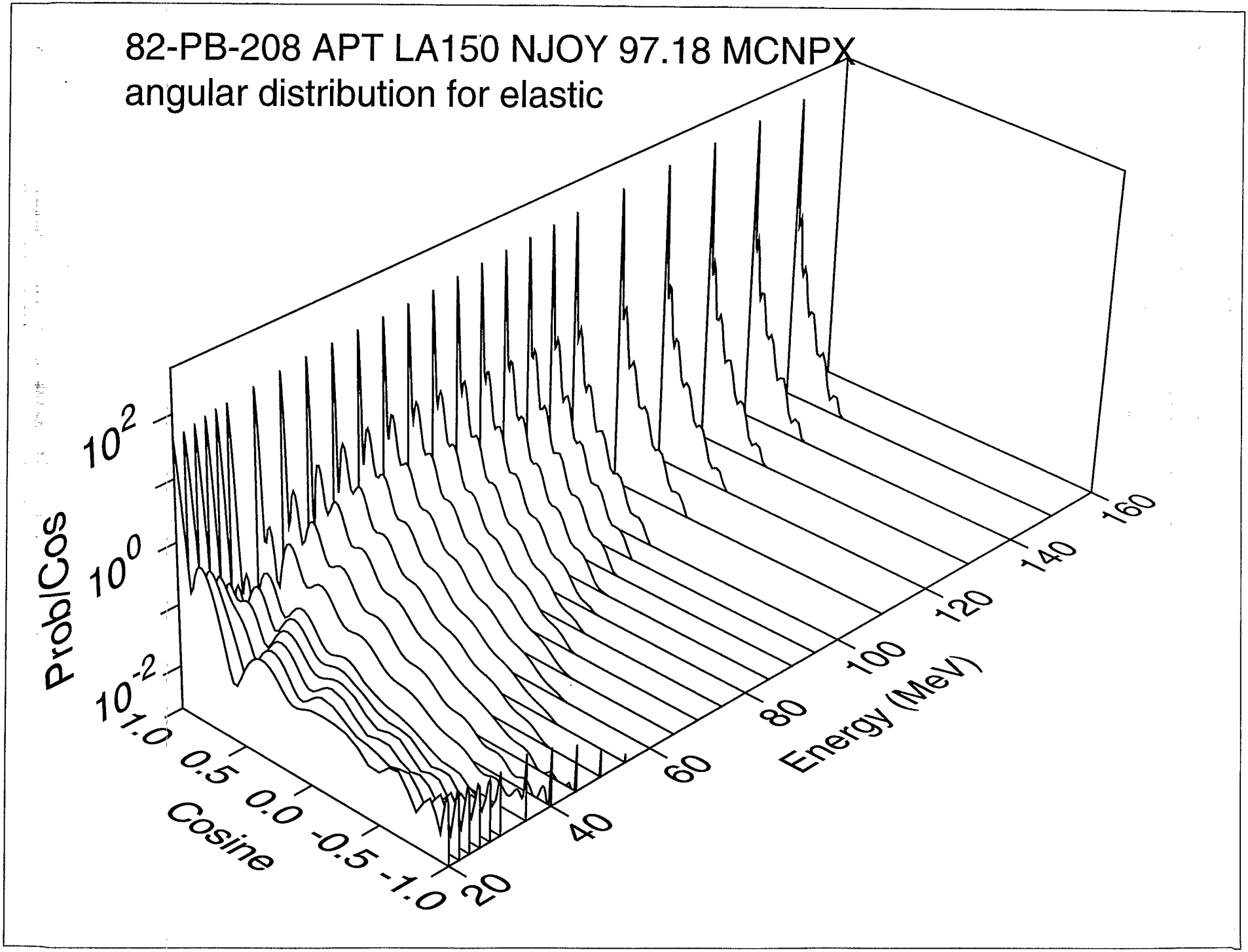


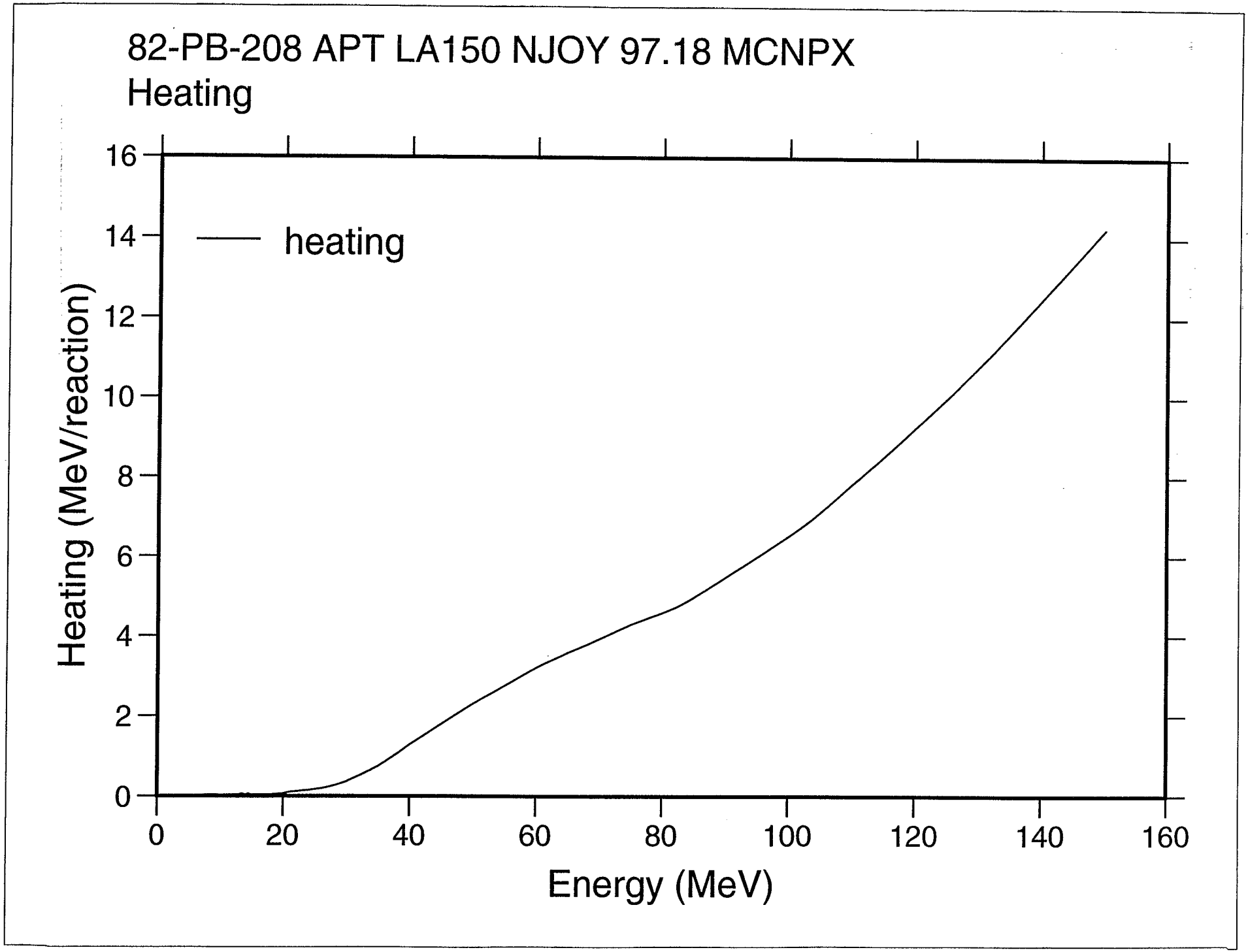


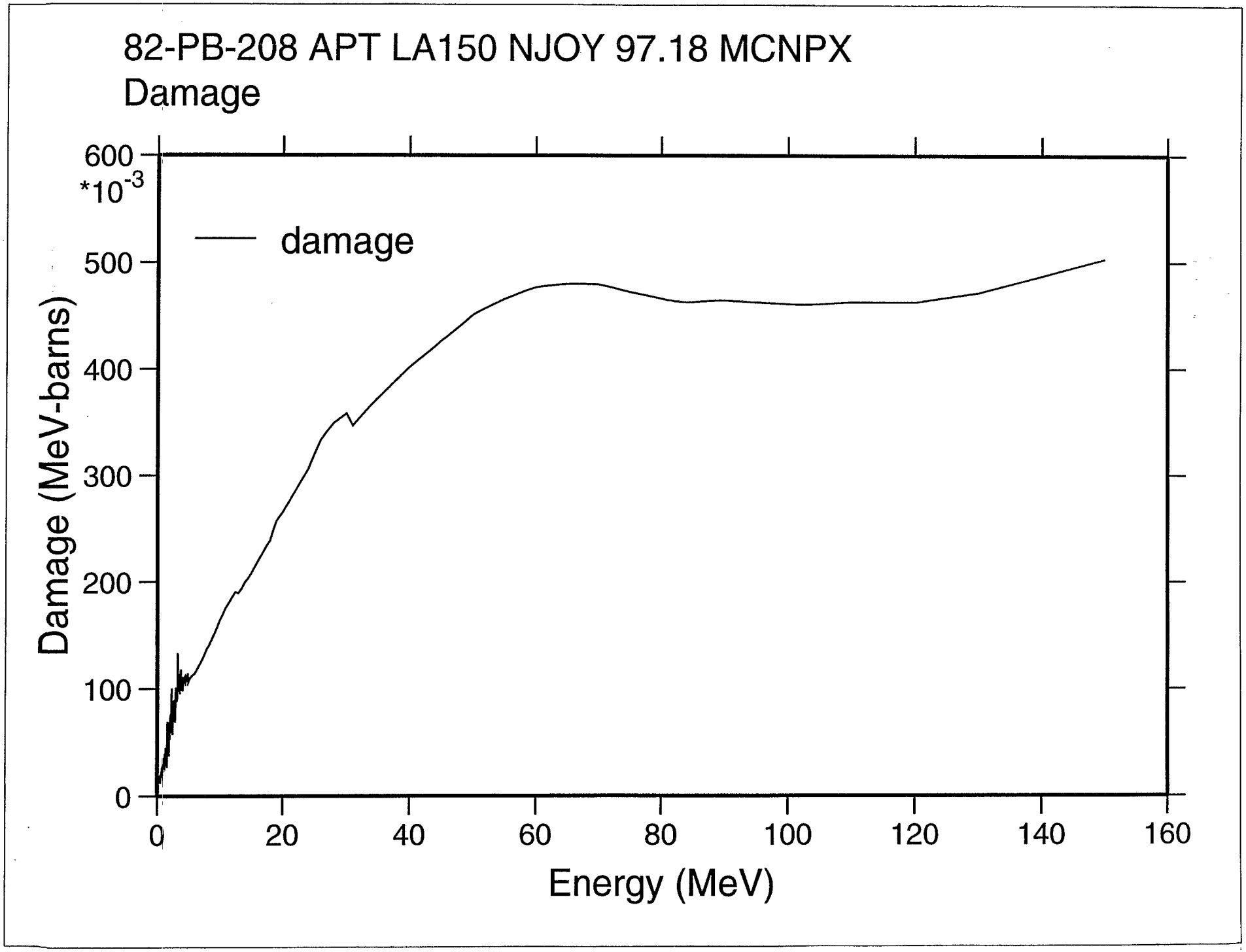







82-PB-208 APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
20
40
60
80
100
120
140
160


82-PB-208 APT LA150 NJOY 97.18 MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
2
4
6
8
10
12
14
16
0
20
40
60
80
100
120
140
160

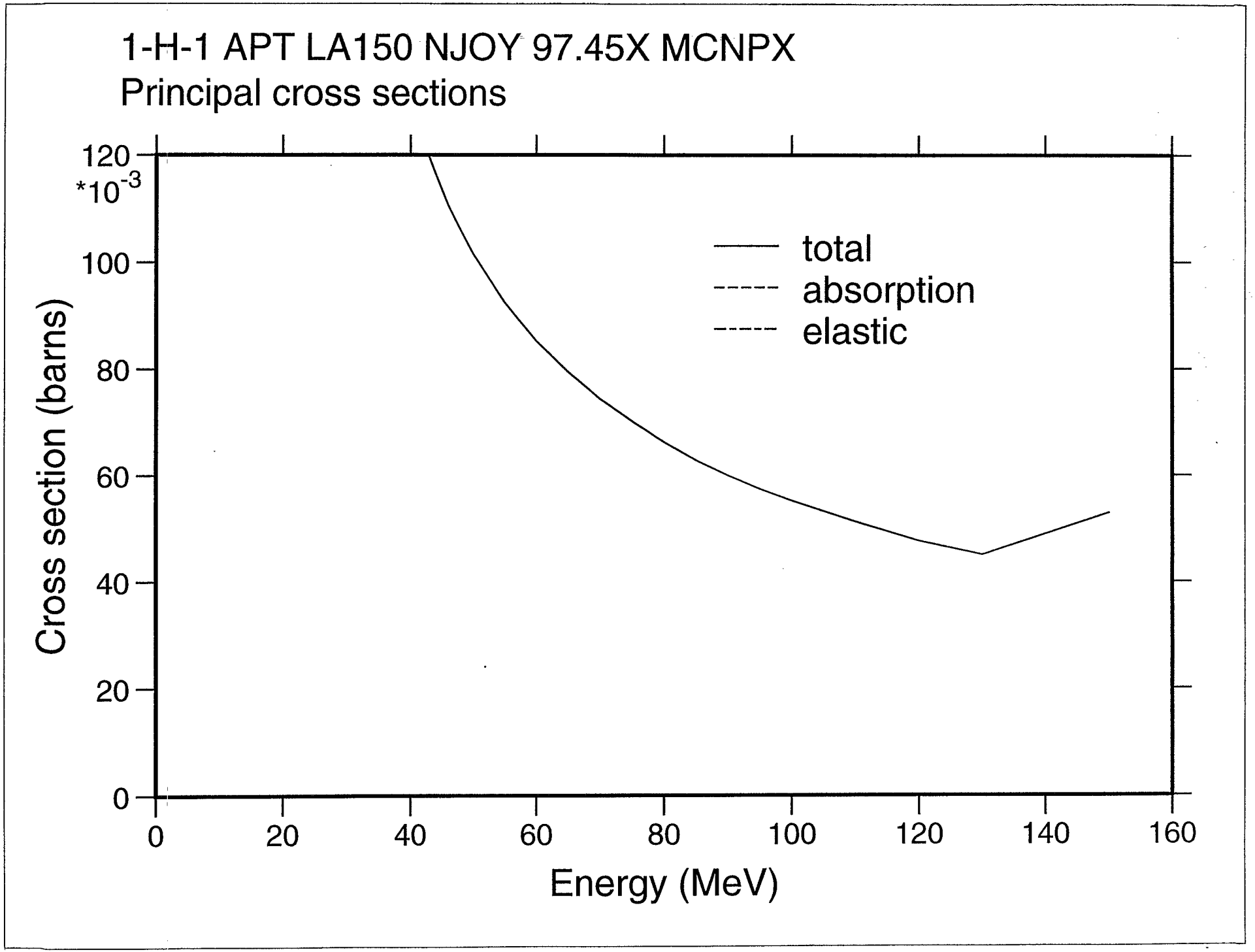

82-PB-208 APT LA150 NJOY 97.18 MCNPX
Damage
damage
Damage (MeV-barns)
*10^-3
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140
160
Energy (MeV)

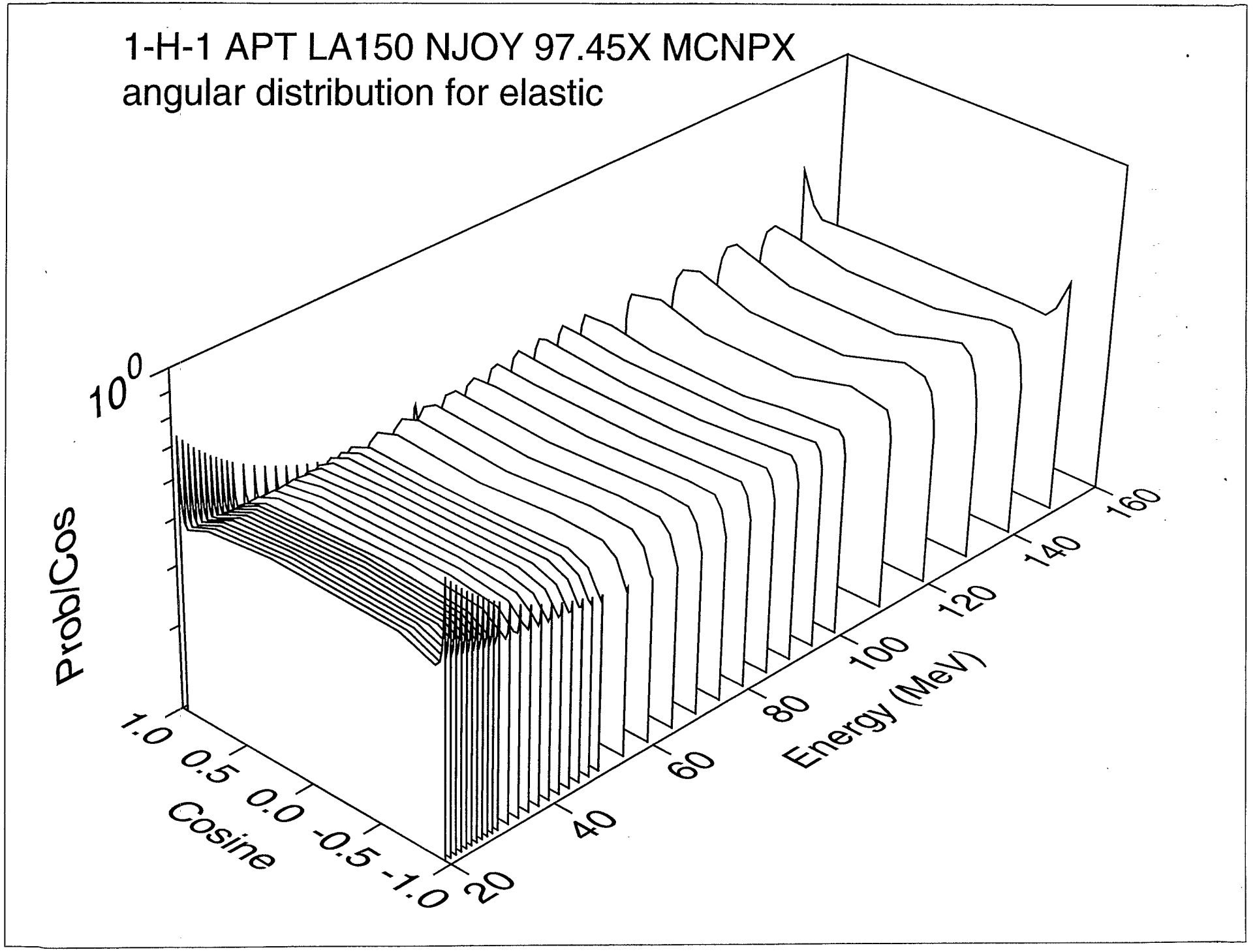
PART B: INCIDENT PROTONS

P + H1 EVALUATION UP TO 150 MEV

G. Hale, LANL, Feb 1998

P-P ELASTIC CROSS SECTIONS CALCULATED FOR EP BETWEEN 0 AND 150 MEV FROM AN R-MATRIX ANALYSIS OF P-P CROSS-SECTION AND POLARIZATION DATA IN THIS ENERGY RANGE. THE MAXIMUM NUCLEAR PARTIAL WAVE ALLOWED IN THE FIT IS L=6, AND THE RESULTING CHI-SQUARED PER DEGREE OF FREEDOM IS 1.8.


1-H-1 APT LA150 NJOY 97.45X MCNPX
Principal cross sections
Cross section (barns)
*10^-3
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
160
Energy (MeV)
total
absorption
elastic


1-H-1 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
10^0
Prob/Cos
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF p + 2H CROSS SECTIONS FOR THE ENERGY RANGE 0.1 to 150 MeV

P. G. Young, M.B. Chadwick, and G. M. Hale

23 March 1997

1. SUMMARY

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 0.1 to 150 MeV.

To summarize, the following ENDF sections are utilized at all energies:

MF=3	MT= 2	Elastic Scattering Cross Section
	MT= 28	2H(p,np)1H Cross Section
	MT=102	Radiative Capture Cross Section (Estimate Only at higher energies)
MF=6	MT= 2	Elastic Proton Angular Distributions
	MT= 28	Production Cross Sections and Energy-Angle Distributions for Emission Neutrons and Protons
	MT=102	Gamma-ray multiplicities from radiative capture and designation of residual nucleus for heating.

2. METHODOLOGY USED IN EVALUATION

Our preliminary evaluation of the 2H(p,n2p) cross section is based on experimental data for both the p + 2H [Ca73] and n + 2H reaction (nonelastic) cross sections, since these appear to be indistinguishable at energies above about 20 MeV. Additionally, we utilize the Faddeev calculations of Sloan [Sl71] for the evaluated cross section at lower energies.

We are utilizing the results of Hale's R-matrix analysis of p + 2H data at proton energies up to 4 MeV and experimental data up to an energy of 65 MeV for the evaluation of elastic scattering. The angular distribution from the 64.8-MeV measurement is used up to 150 MeV.
Experimental data [Gr55] normalized to sigma=4.15e-6 barns at a proton energy of 1 MeV are used for the 2H(p,gamma)3He cross section below 2 MeV; these results are joined smoothly to the ENDF/B-VI evaluated 2H(n,gamma)3H cross section above 4 MeV.

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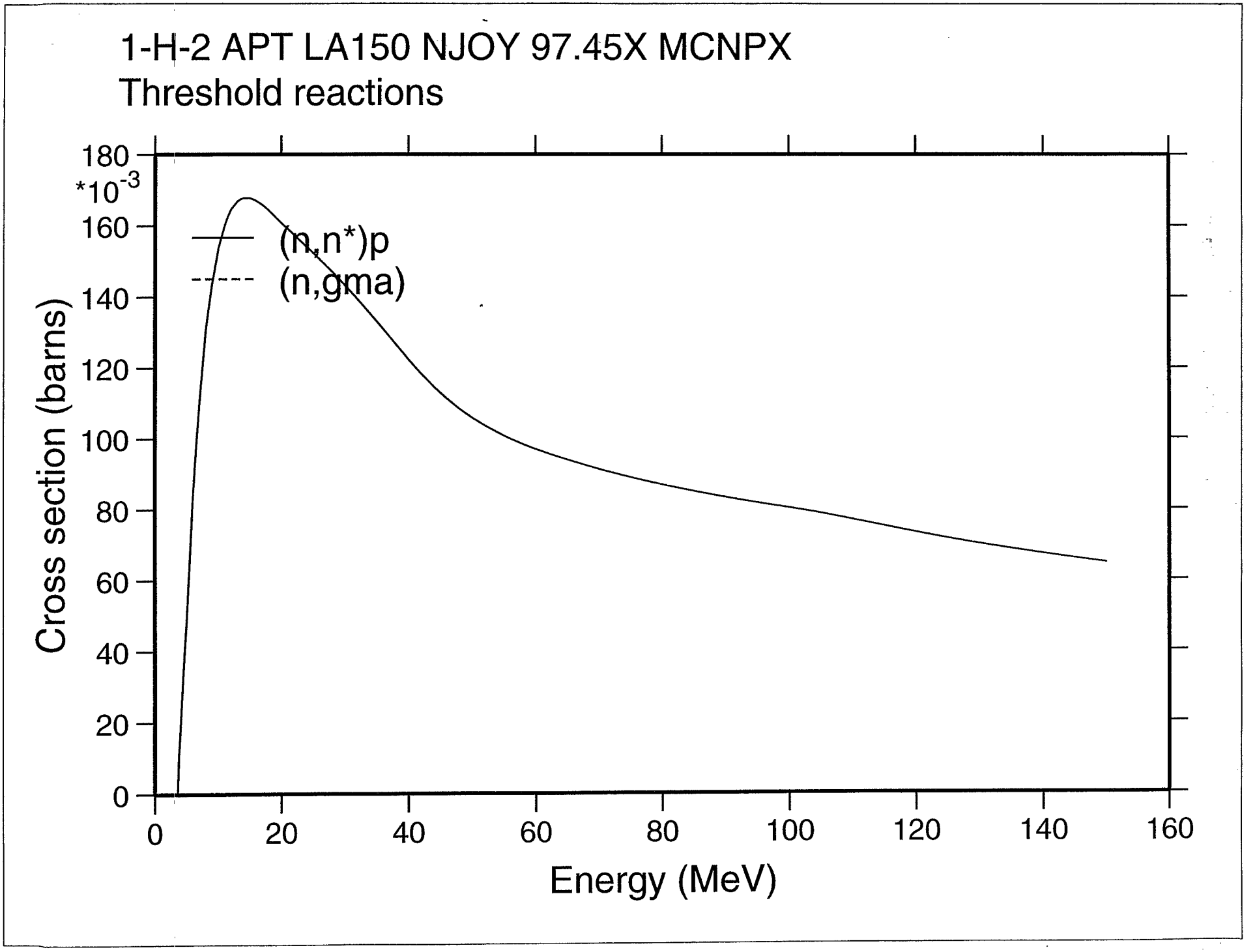
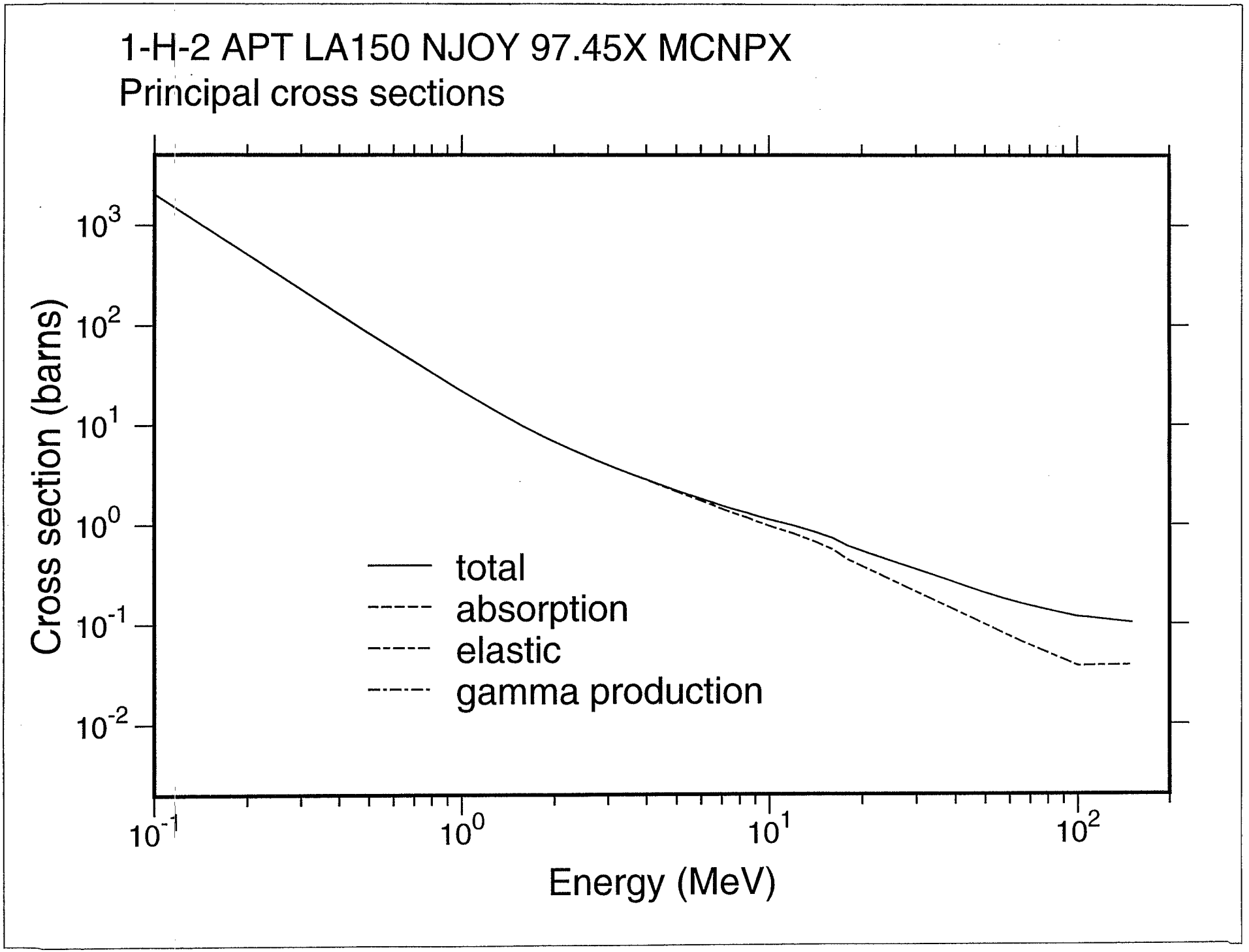
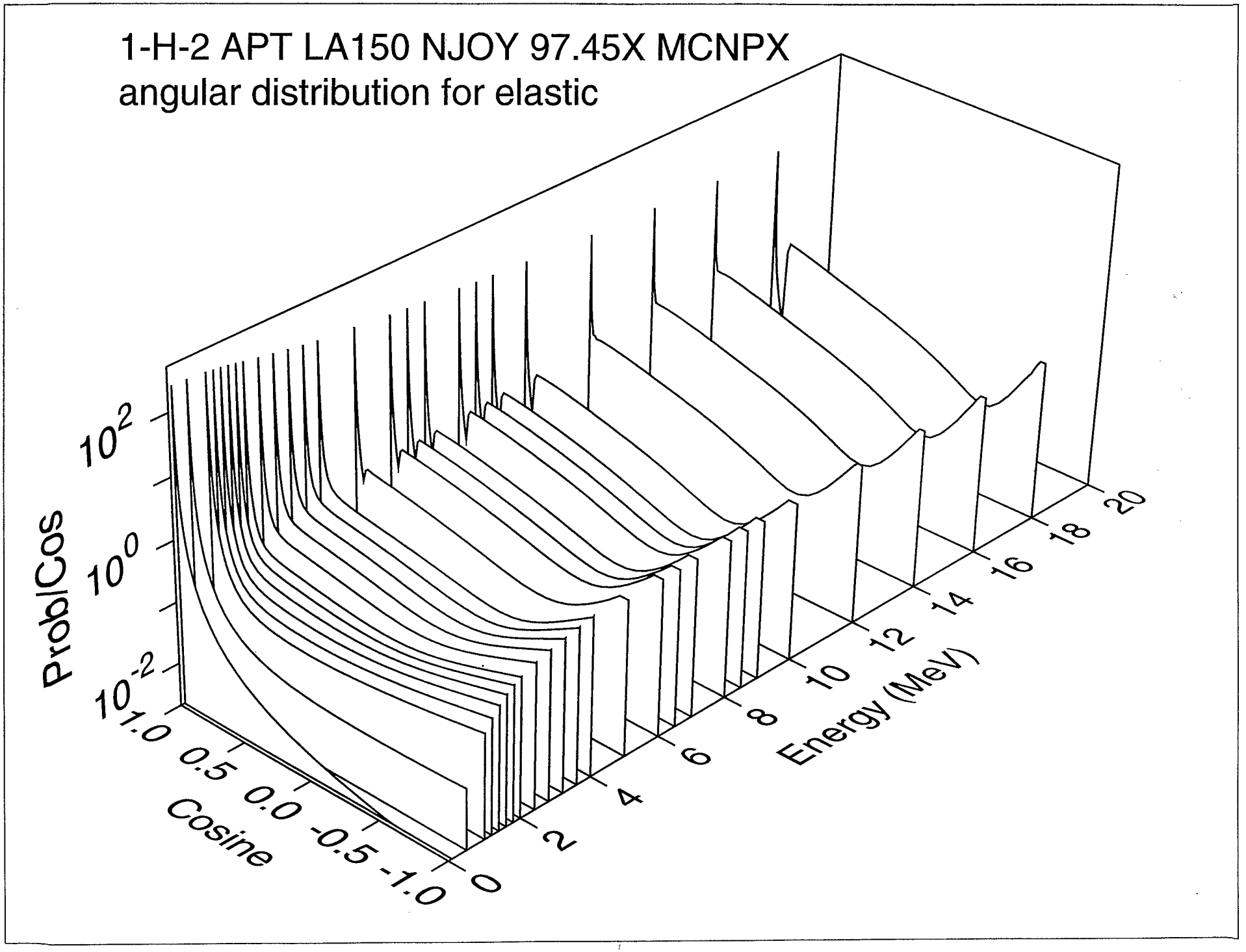
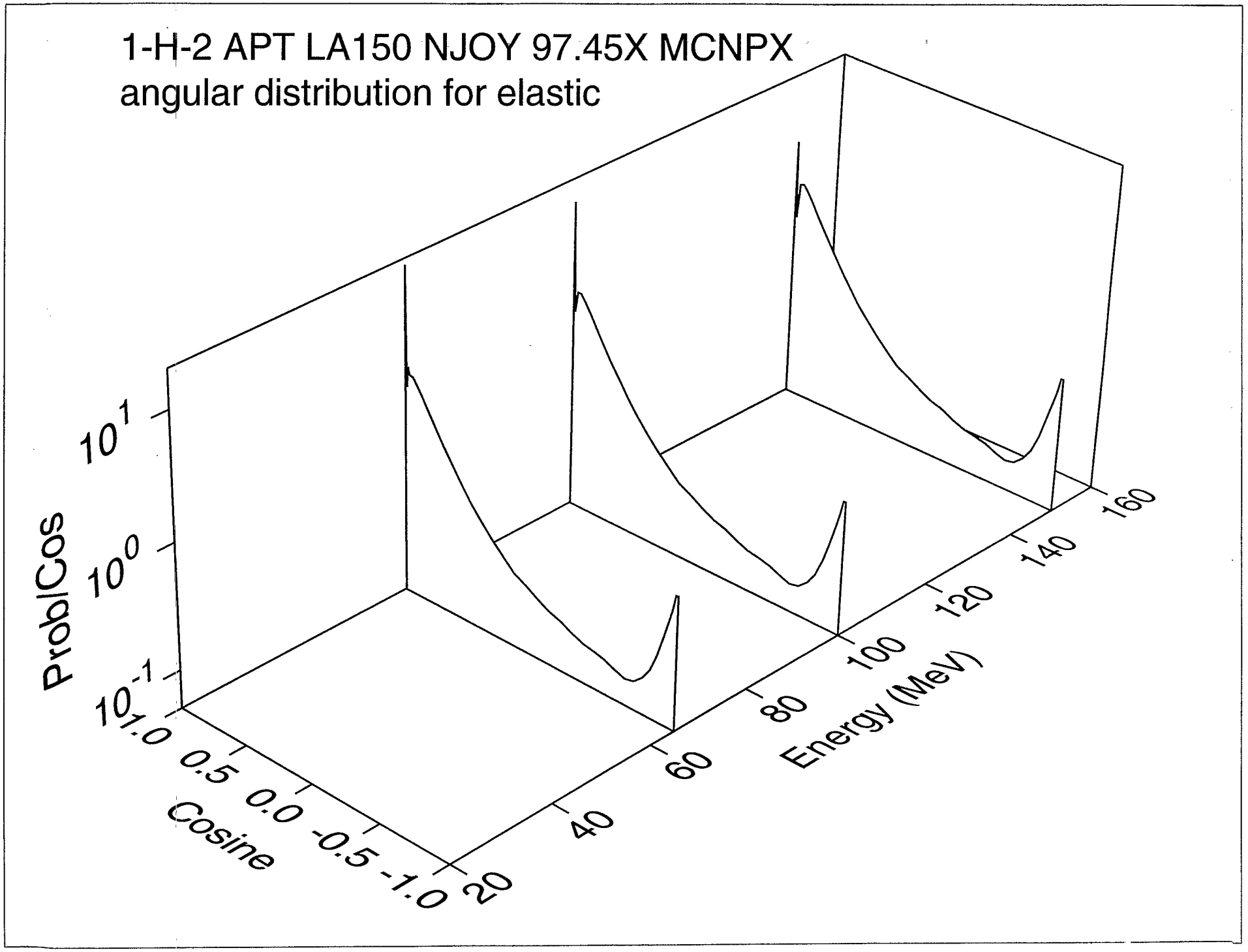
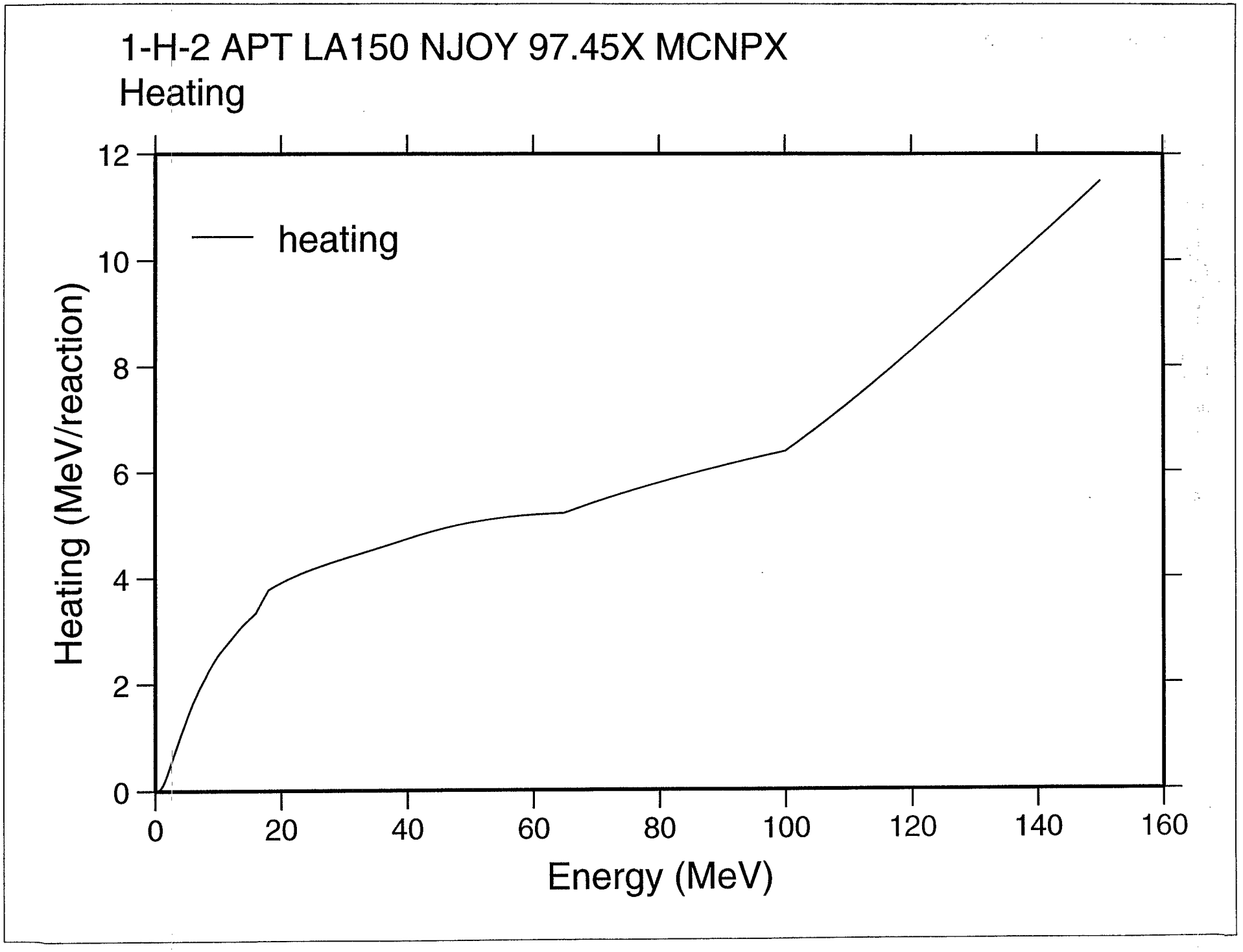

1-H-2 APT LA150 NJOY 97.45X MCNPX
Threshold reactions
*10^-3
(n,n*)p
(n,gma)
Cross section (barns)
Energy (MeV)
0
20
40
60
80
100
120
140
160
180


1-H-2 APT LA150 NJOY 97.45X MCNPX
Principal cross sections
Cross section (barns)
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
total
absorption
elastic
gamma production
10^{-1}
10^0
10^1
10^2
Energy (MeV)


1-H-2 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
ProblCos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
0
2
4
6
8
10
12
14
16
18
20


1-H-2 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^{1}
10^{0}
10^{-1}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
20
40
60
80
100
120
140
160


1-H-2 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
2
4
6
8
10
12
0
20
40
60
80
100
120
140
160

EVALUATION OF P + 12C CROSS SECTIONS FOR THE ENERGY RANGE 1. to 150 MeV

M. B. Chadwick and P. G. Young
16 July 1996

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident proton energy range from 1 to 150 MeV.

The evaluation utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for emission neutrons, protons, deuterons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the following ENDF sections are included:

MF=3	MT= 2	Integral of nuclear plus interference components of the elastic scattering cross section
	MT= 5	Sum of binary (n,n') and (n,x) reactions
MF=6	MT= 2	Elastic angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
	MT= 5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + C12 and p + C12 reactions (Ch96a, Ch96b, Ch96c). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequi-librium and direct-reaction theories. Coupled-channel and spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96b). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. Note that all other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation requires a modification of the original ENDF-6 format.

Preequilibrium corrections were performed in the course of the

GNASH calculations using either Feshbach, Kerman, Koonin (FKK) theory [Ch93d] or the exciton model of Kalbach (Ka77, Ka85). Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

MT=2 elastic scattering data in MF=3 and MF=6 are based on optical model calculations with the SCAT2 code (Be92). We have made use of the "nuclear-plus-interference" option in MF=6, which corresponds to LAW=5, LTP=12, and the appropriate integrated cross section is stored in MF=3. Note that because of the interference effect, the tabulations in both MF=6 and MF=3 can be negative at some energies and angles.

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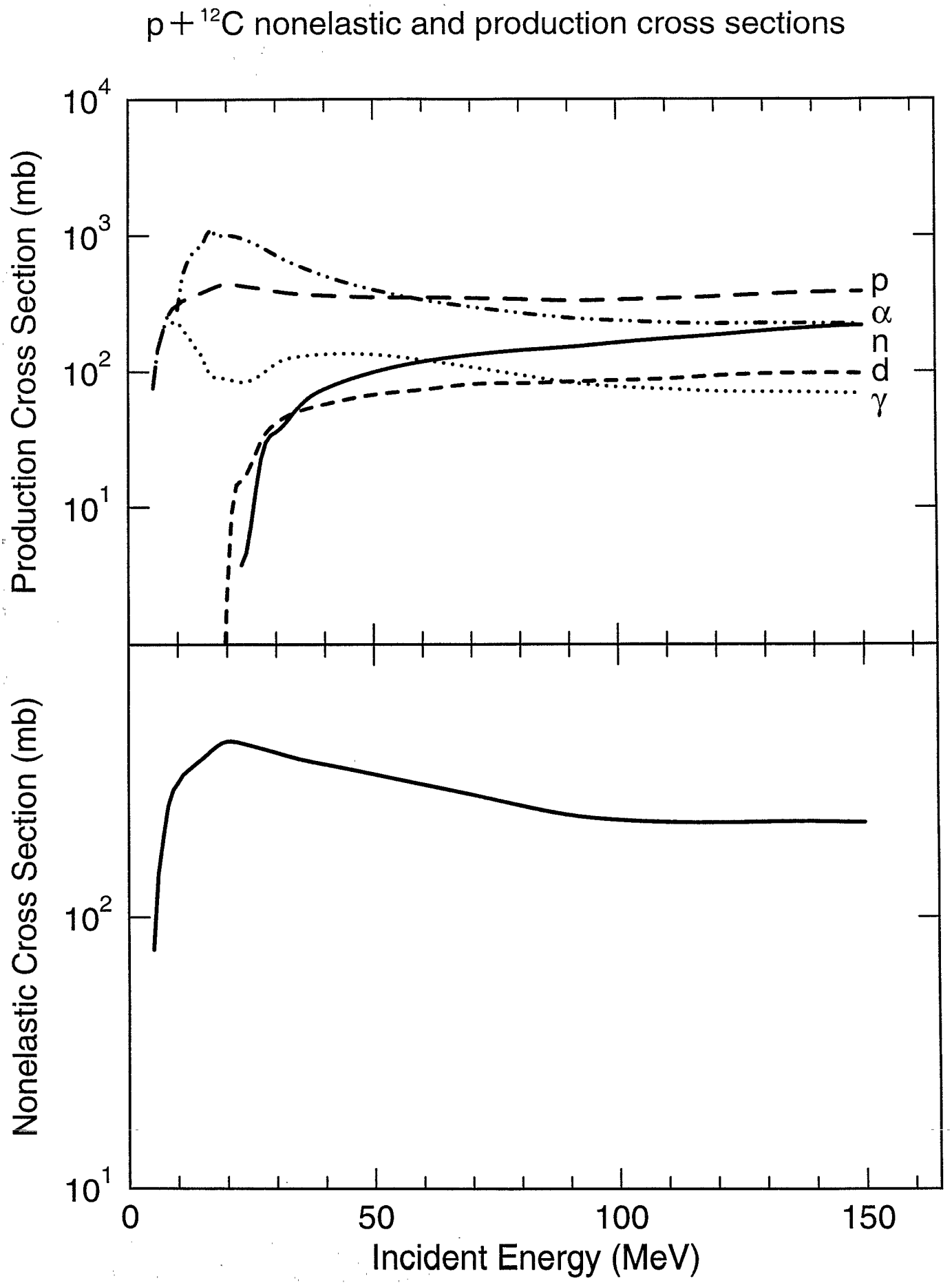
6012 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

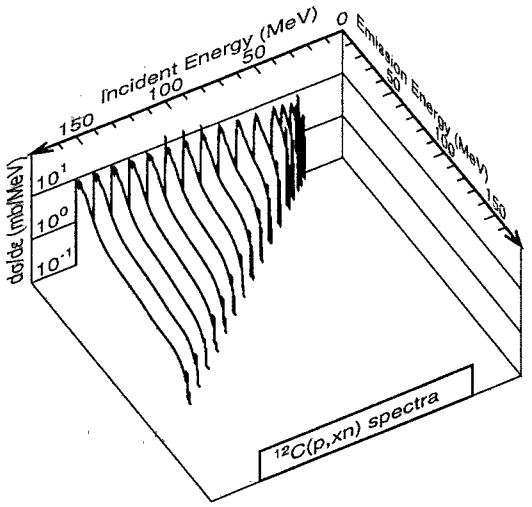
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
5.000E+00	7.557E-02	0.000E+00	0.000E+00	7.557E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	7.556E-02
6.000E+00	1.450E-01	0.000E+00	0.000E+00	1.450E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.450E-01
7.000E+00	1.960E-01	0.000E+00	0.000E+00	1.960E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.960E-01
8.000E+00	2.560E-01	0.000E+00	0.000E+00	2.560E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.560E-01
9.000E+00	2.920E-01	0.000E+00	0.000E+00	2.920E-01	0.000E+00	0.000E+00	0.000E+00	2.237E-01	2.312E-01
1.000E+01	3.100E-01	0.000E+00	0.000E+00	3.100E-01	0.000E+00	0.000E+00	0.000E+00	2.871E-01	2.354E-01
1.100E+01	3.324E-01	0.000E+00	0.000E+00	3.324E-01	0.000E+00	0.000E+00	0.000E+00	5.020E-01	2.092E-01
1.200E+01	3.448E-01	0.000E+00	0.000E+00	3.448E-01	0.000E+00	0.000E+00	0.000E+00	6.326E-01	1.864E-01
1.300E+01	3.572E-01	0.000E+00	0.000E+00	3.570E-01	0.000E+00	0.000E+00	0.000E+00	7.319E-01	1.660E-01
1.400E+01	3.696E-01	0.000E+00	0.000E+00	3.691E-01	0.000E+00	0.000E+00	0.000E+00	8.047E-01	1.449E-01
1.500E+01	3.820E-01	0.000E+00	0.000E+00	3.812E-01	0.000E+00	0.000E+00	0.000E+00	8.364E-01	1.320E-01
1.600E+01	3.959E-01	0.000E+00	0.000E+00	3.951E-01	0.000E+00	0.000E+00	0.000E+00	1.015E+00	1.048E-01
1.700E+01	4.109E-01	0.000E+00	0.000E+00	4.101E-01	0.000E+00	0.000E+00	0.000E+00	1.128E+00	9.254E-02
1.800E+01	4.246E-01	0.000E+00	0.000E+00	4.240E-01	5.783E-05	0.000E+00	0.000E+00	9.779E-01	8.977E-02
1.900E+01	4.357E-01	0.000E+00	0.000E+00	4.356E-01	4.274E-04	0.000E+00	0.000E+00	9.996E-01	8.959E-02
2.000E+01	4.410E-01	0.000E+00	8.509E-09	4.412E-01	2.159E-03	0.000E+00	0.000E+00	1.010E+00	8.844E-02
2.300E+01	4.340E-01	0.000E+00	3.761E-03	4.292E-01	1.571E-02	0.000E+00	0.000E+00	9.618E-01	8.387E-02
2.700E+01	4.149E-01	0.000E+00	2.262E-02	4.084E-01	3.055E-02	0.000E+00	0.000E+00	8.320E-01	9.474E-02
3.000E+01	4.006E-01	0.000E+00	3.572E-02	3.904E-01	4.167E-02	0.000E+00	0.000E+00	7.238E-01	1.145E-01
3.500E+01	3.785E-01	0.000E+00	5.628E-02	3.718E-01	5.143E-02	0.000E+00	0.000E+00	5.956E-01	1.300E-01
4.000E+01	3.630E-01	0.000E+00	7.443E-02	3.635E-01	5.760E-02	0.000E+00	0.000E+00	5.098E-01	1.350E-01
5.000E+01	3.340E-01	0.000E+00	9.890E-02	3.525E-01	6.744E-02	0.000E+00	0.000E+00	4.014E-01	1.340E-01
6.000E+01	3.060E-01	0.000E+00	1.185E-01	3.514E-01	7.338E-02	0.000E+00	0.000E+00	3.387E-01	1.223E-01
7.000E+01	2.810E-01	0.000E+00	1.328E-01	3.469E-01	8.045E-02	0.000E+00	0.000E+00	3.000E-01	1.081E-01
8.000E+01	2.560E-01	0.000E+00	1.437E-01	3.400E-01	8.187E-02	0.000E+00	0.000E+00	2.704E-01	9.459E-02
9.000E+01	2.366E-01	0.000E+00	1.517E-01	3.326E-01	8.385E-02	0.000E+00	0.000E+00	2.477E-01	8.329E-02
1.000E+02	2.270E-01	0.000E+00	1.633E-01	3.371E-01	8.589E-02	0.000E+00	0.000E+00	2.369E-01	7.704E-02
1.100E+02	2.230E-01	0.000E+00	1.747E-01	3.451E-01	8.815E-02	0.000E+00	0.000E+00	2.288E-01	7.416E-02
1.200E+02	2.220E-01	0.000E+00	1.858E-01	3.546E-01	9.283E-02	0.000E+00	0.000E+00	2.253E-01	7.127E-02
1.300E+02	2.234E-01	0.000E+00	1.995E-01	3.696E-01	9.614E-02	0.000E+00	0.000E+00	2.266E-01	7.051E-02
1.400E+02	2.240E-01	0.000E+00	2.112E-01	3.811E-01	9.714E-02	0.000E+00	0.000E+00	2.254E-01	7.001E-02
1.500E+02	2.224E-01	0.000E+00	2.182E-01	3.866E-01	9.691E-02	0.000E+00	0.000E+00	2.238E-01	6.889E-02

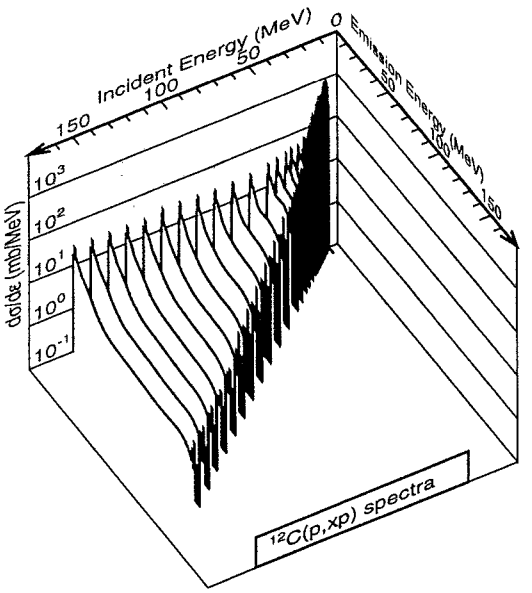
6012 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

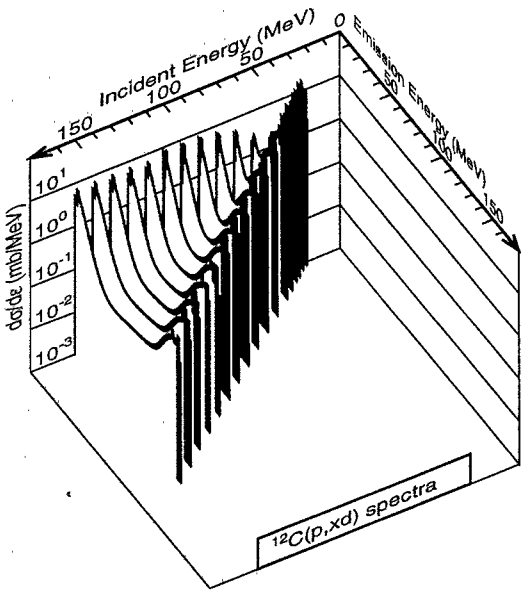
Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
5.000E+00	0.000E+00	2.033E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.500E+00
6.000E+00	0.000E+00	9.586E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.500E+00
7.000E+00	0.000E+00	1.887E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.500E+00
8.000E+00	0.000E+00	2.816E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.500E+00
9.000E+00	0.000E+00	2.937E+00	0.000E+00	0.000E+00	0.000E+00	3.460E-01	4.500E+00
1.000E+01	0.000E+00	3.718E+00	0.000E+00	0.000E+00	0.000E+00	3.719E-01	4.500E+00
1.100E+01	0.000E+00	4.145E+00	0.000E+00	0.000E+00	0.000E+00	4.700E-01	4.500E+00
1.200E+01	0.000E+00	4.842E+00	0.000E+00	0.000E+00	0.000E+00	5.586E-01	4.500E+00
1.300E+01	0.000E+00	5.025E+00	0.000E+00	0.000E+00	0.000E+00	7.053E-01	4.500E+00
1.400E+01	0.000E+00	5.301E+00	0.000E+00	0.000E+00	0.000E+00	8.664E-01	4.495E+00
1.500E+01	0.000E+00	5.672E+00	0.000E+00	0.000E+00	0.000E+00	1.035E+00	4.483E+00
1.600E+01	0.000E+00	5.624E+00	0.000E+00	0.000E+00	0.000E+00	1.205E+00	4.465E+00
1.700E+01	0.000E+00	5.933E+00	0.000E+00	0.000E+00	0.000E+00	1.355E+00	4.452E+00
1.800E+01	0.000E+00	6.344E+00	3.747E-01	0.000E+00	0.000E+00	1.497E+00	4.453E+00
1.900E+01	0.000E+00	6.728E+00	1.074E+00	0.000E+00	0.000E+00	1.647E+00	4.449E+00
2.000E+01	2.931E-01	7.117E+00	1.931E+00	0.000E+00	0.000E+00	1.812E+00	4.451E+00
2.300E+01	1.668E+00	8.335E+00	2.991E+00	0.000E+00	0.000E+00	2.285E+00	4.175E+00
2.700E+01	3.133E+00	9.524E+00	5.496E+00	0.000E+00	0.000E+00	2.765E+00	4.022E+00
3.000E+01	4.250E+00	1.064E+01	6.997E+00	0.000E+00	0.000E+00	3.076E+00	4.107E+00
3.500E+01	5.856E+00	1.247E+01	9.686E+00	0.000E+00	0.000E+00	3.445E+00	4.120E+00
4.000E+01	7.491E+00	1.403E+01	1.229E+01	0.000E+00	0.000E+00	3.818E+00	3.948E+00
5.000E+01	1.035E+01	1.707E+01	1.734E+01	0.000E+00	0.000E+00	4.422E+00	3.764E+00
6.000E+01	1.282E+01	1.936E+01	2.039E+01	0.000E+00	0.000E+00	4.930E+00	3.611E+00
7.000E+01	1.516E+01	2.150E+01	2.295E+01	0.000E+00	0.000E+00	5.390E+00	3.537E+00
8.000E+01	1.721E+01	2.349E+01	2.502E+01	0.000E+00	0.000E+00	5.827E+00	3.488E+00
9.000E+01	1.928E+01	2.529E+01	2.764E+01	0.000E+00	0.000E+00	6.250E+00	3.470E+00
1.000E+02	2.125E+01	2.712E+01	2.971E+01	0.000E+00	0.000E+00	6.664E+00	3.450E+00
1.100E+02	2.325E+01	2.926E+01	3.214E+01	0.000E+00	0.000E+00	7.139E+00	3.408E+00
1.200E+02	2.517E+01	3.136E+01	3.520E+01	0.000E+00	0.000E+00	7.494E+00	3.462E+00
1.300E+02	2.715E+01	3.357E+01	3.704E+01	0.000E+00	0.000E+00	7.873E+00	3.514E+00
1.400E+02	2.920E+01	3.580E+01	3.894E+01	0.000E+00	0.000E+00	8.185E+00	3.588E+00
1.500E+02	3.116E+01	3.826E+01	4.069E+01	0.000E+00	0.000E+00	8.437E+00	3.696E+00

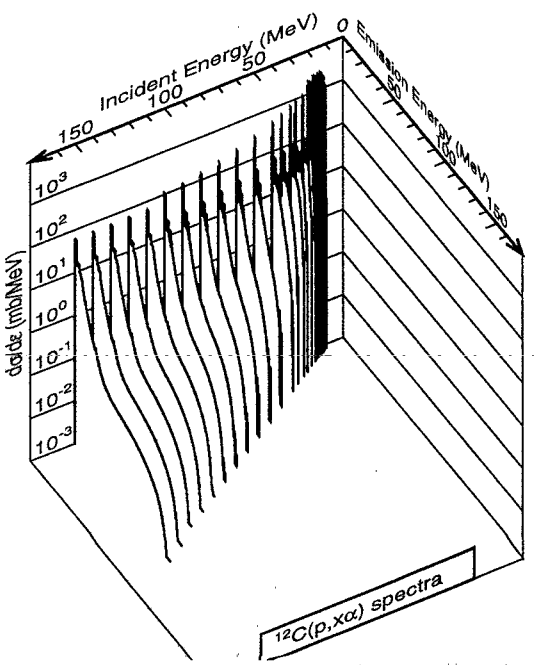

p + 12C nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
p
α
n
d
γ
Nonelastic Cross Section (mb)
10^2
10^1
0
50
100
150
Incident Energy (MeV)

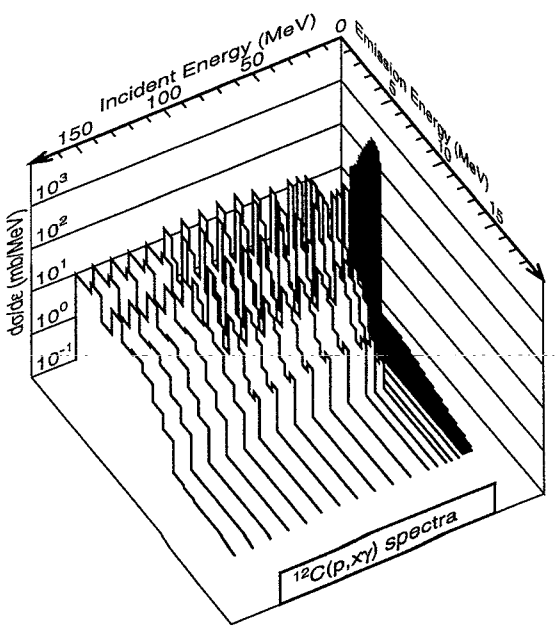
p + ^{12}C angle-integrated emission spectra



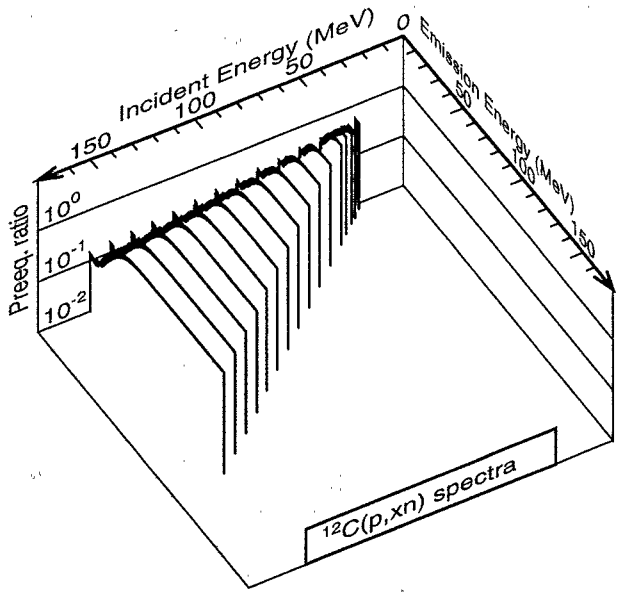


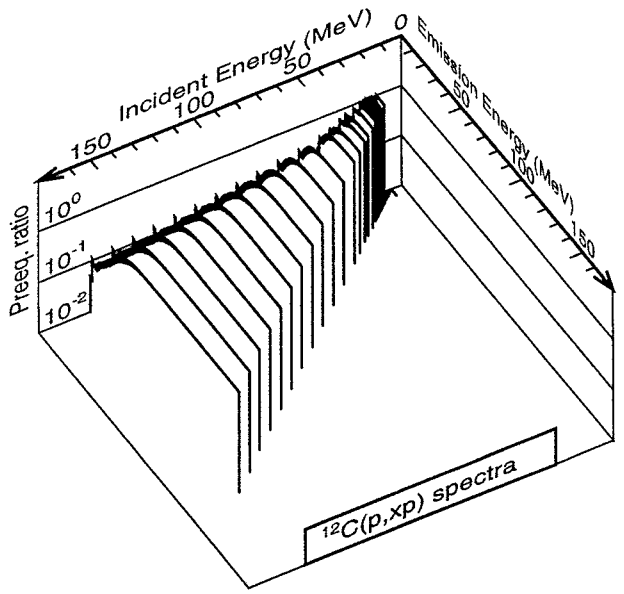


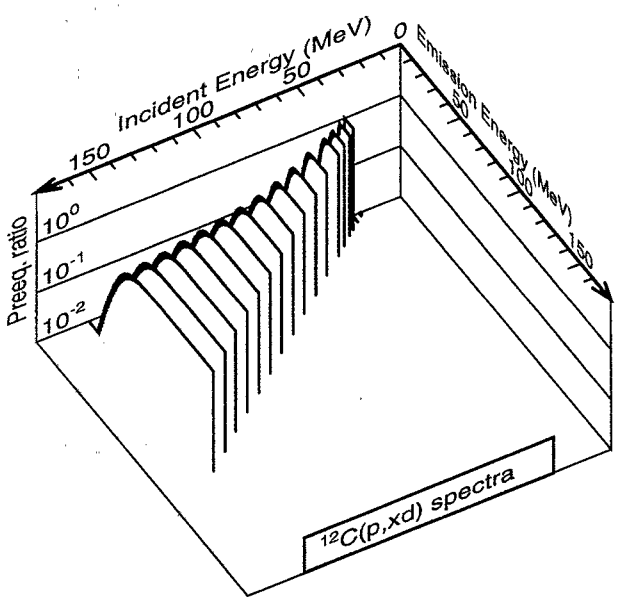


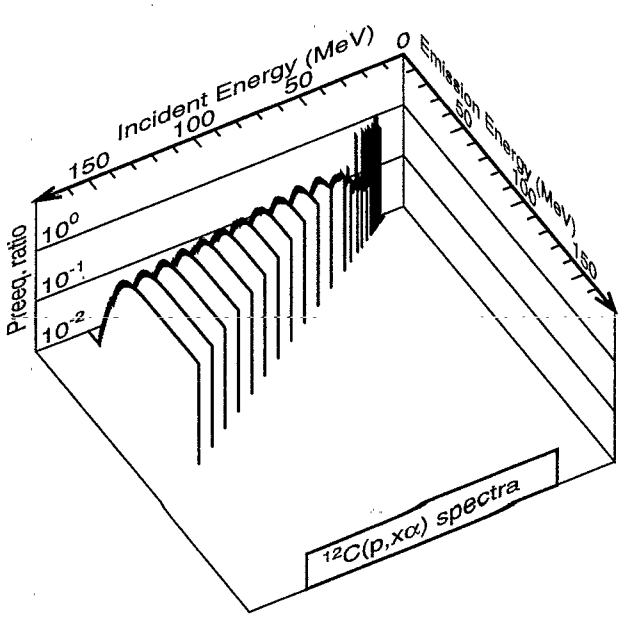


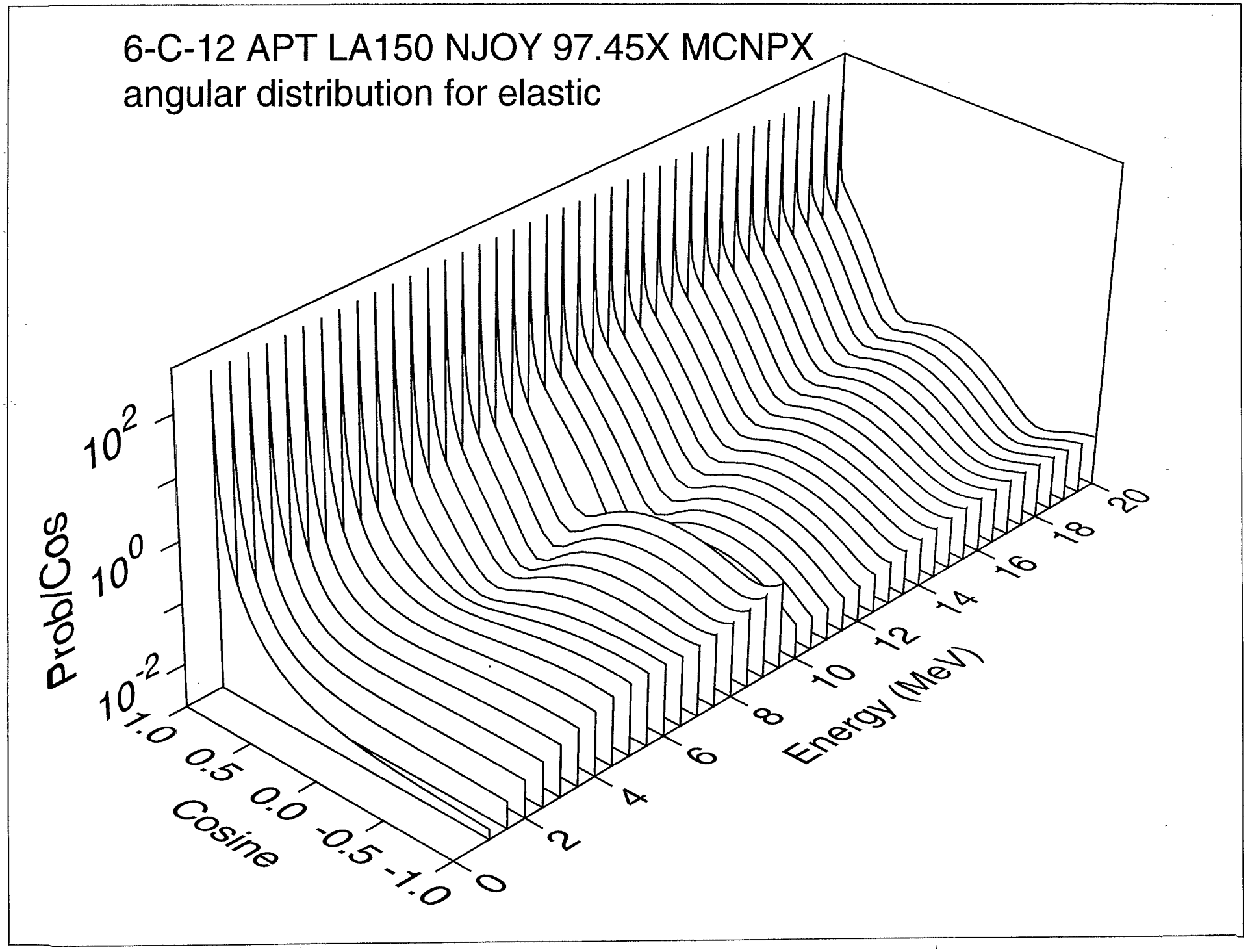
p + ^{12}C Kalbach preequilibrium ratios

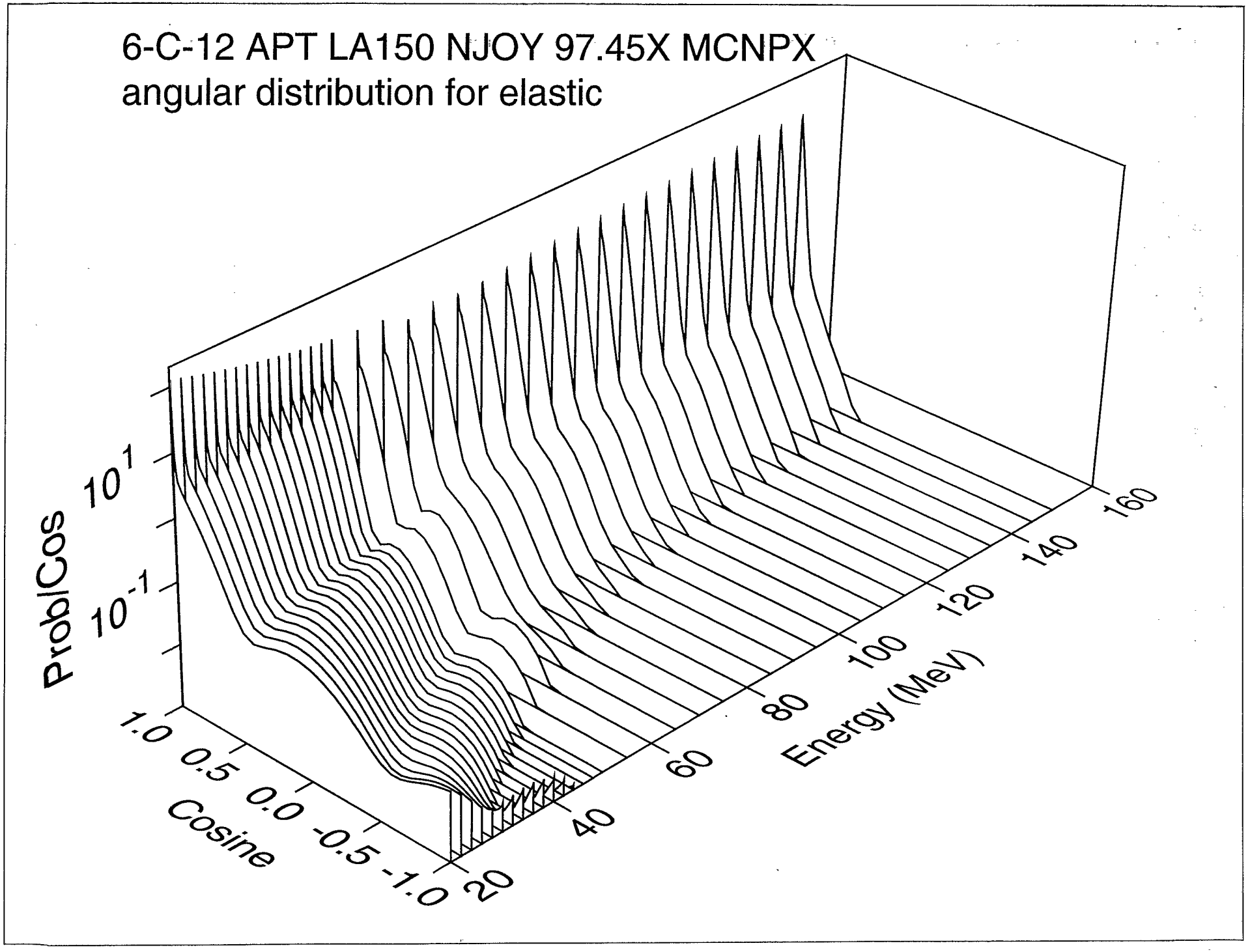


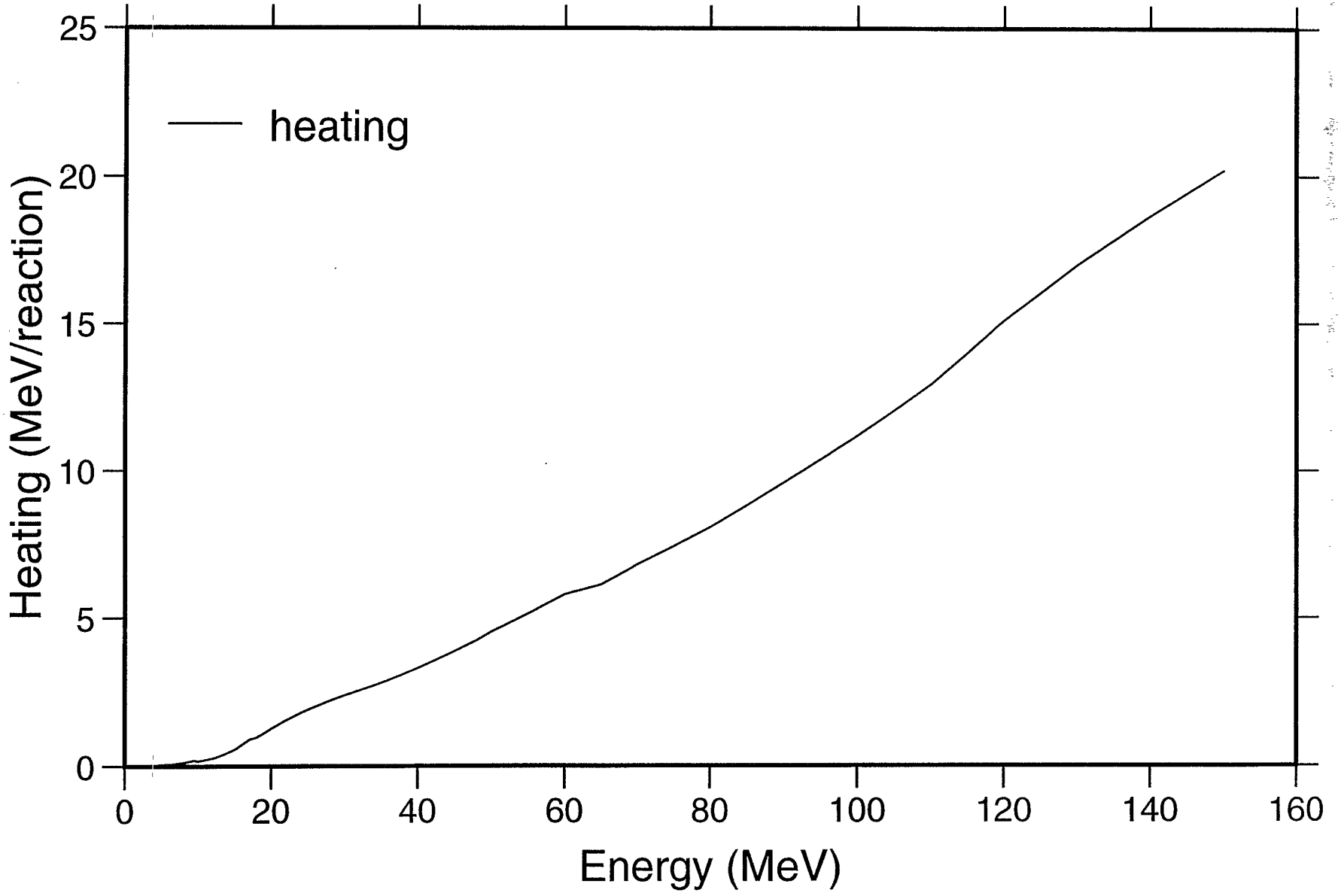







6-C-12 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
0
2
4
6
8
10
12
14
16
18
20


6-C-12 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^{1}
10^{-1}
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


6-C-12 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
5
10
15
20
25
0
20
40
60
80
100
120
140
160

EVALUATION OF p + 14N CROSS SECTIONS FOR THE ENERGY RANGE 1 to 150 MeV

M. B. Chadwick and P. G. Young
1 August 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident proton energy range from 1 to 150 MeV. The evaluation utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above are:

MF=3	MT= 2	Integral of nuclear plus interference components of the elastic scattering cross section
	MT= 5	Sum of binary (p,n') and (p,x) reactions
MF=6	MT= 2	Elastic (p,p) angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
	MT= 5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + 14N and p + 14N reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic proton angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission

coefficients were calculated using the Kopecky-Uhl model (Ko90).

DETAILS OF THE p + N-14 ANALYSIS

GNASH calculations [Yo92] were performed for neutron and proton reactions on nitrogen up to 150 MeV, and the calculated results were benchmarked against experimental data. The present evaluation made extensive use of our previous work [Ch96a,Ch97]. Very minor differences with this earlier work exist due to recent developments in the GNASH code. Additionally, the (angle-integrated) emission spectra of heavy recoils were calculated using our model described in Ref. [Ch96]. Some additional information on this evaluation can be found in Ref. [Ch97].

Between 20 and 150 MeV, the optical models used (the neutron potential of Islam below 60 MeV [Is88]; Madland's potential [Ma88] at higher energies, with Lane transformations for the proton potential) provided a reasonably good description of measured reaction cross section data. But since a very accurate description of the reaction cross section is important for determining secondary particle spectra, we slightly modify the calculated results to better describe the experimental data, and renormalize the calculated transmission coefficients accordingly. Experimental proton-induced nonelastic cross sections from the Bauhoff compilation [Ba86] were used for this purpose. The SCAT2 code [Be92] was used to calculate the transmission coefficients. No measurements for the neutron reaction cross section on nitrogen exist above about 50 MeV. However, systematics have been determined from a number of target elements at 95 MeV by DeJuren [De50], and for 100 MeV protons by Kirby and Link [Ki66] (at this energy the proton and neutron reaction cross sections would be expected to be very similar). We have, therefore, used these systematics to guide our evaluated reaction cross sections. Additionally, below 50 MeV we have also been guided by the proton-induced reaction cross sections of Carlson et al. [Ca75]. Experimental total elastic scattering values of Islam et al. [Is88], Olsson et al. [Ol90], and Petler et al. [Pe85] were obtained by subtracting their angle-integrated elastic data from the evaluated total cross sections (see below).

Preequilibrium spectra were calculated with the exciton model in the GNASH code [Ka77,Ka85]. Nuclear level densities were determined using the Ignatyuk model [Ig75], as implemented by Arthur et al. [Yo92]. Pairing energies were obtained from the Cook systematics with the Los Alamos extensions to light nuclei from [Ar83]. This continuum level density formulation is matched continuously onto discrete low-lying levels at the lower excitation energies. Discrete level information (energy, spin, parity, gamma-ray branching ratios) is tabulated for each nuclide in an input file, which is based on the Ajzenberg-Selove compilations. For each nucleus we performed a level-density analysis and determined the excitation energy at which we judged the level data complete. Gamma-ray transmission coefficients were obtained from the Kopecky-Uhl model [Ko92].

Comparison was made with new (unpublished) data from South Africa (Cowley et al.) for 150 and 200 MeV protons on 14N. The evaluated proton emission spectra were in reasonable agreement with the experimental data. For deuteron and alpha ejectiles, the quality of agreement was poorer. However, modeling cluster emission in these nuclei is difficult, and the cross sections

are small, so the practical impact is low.

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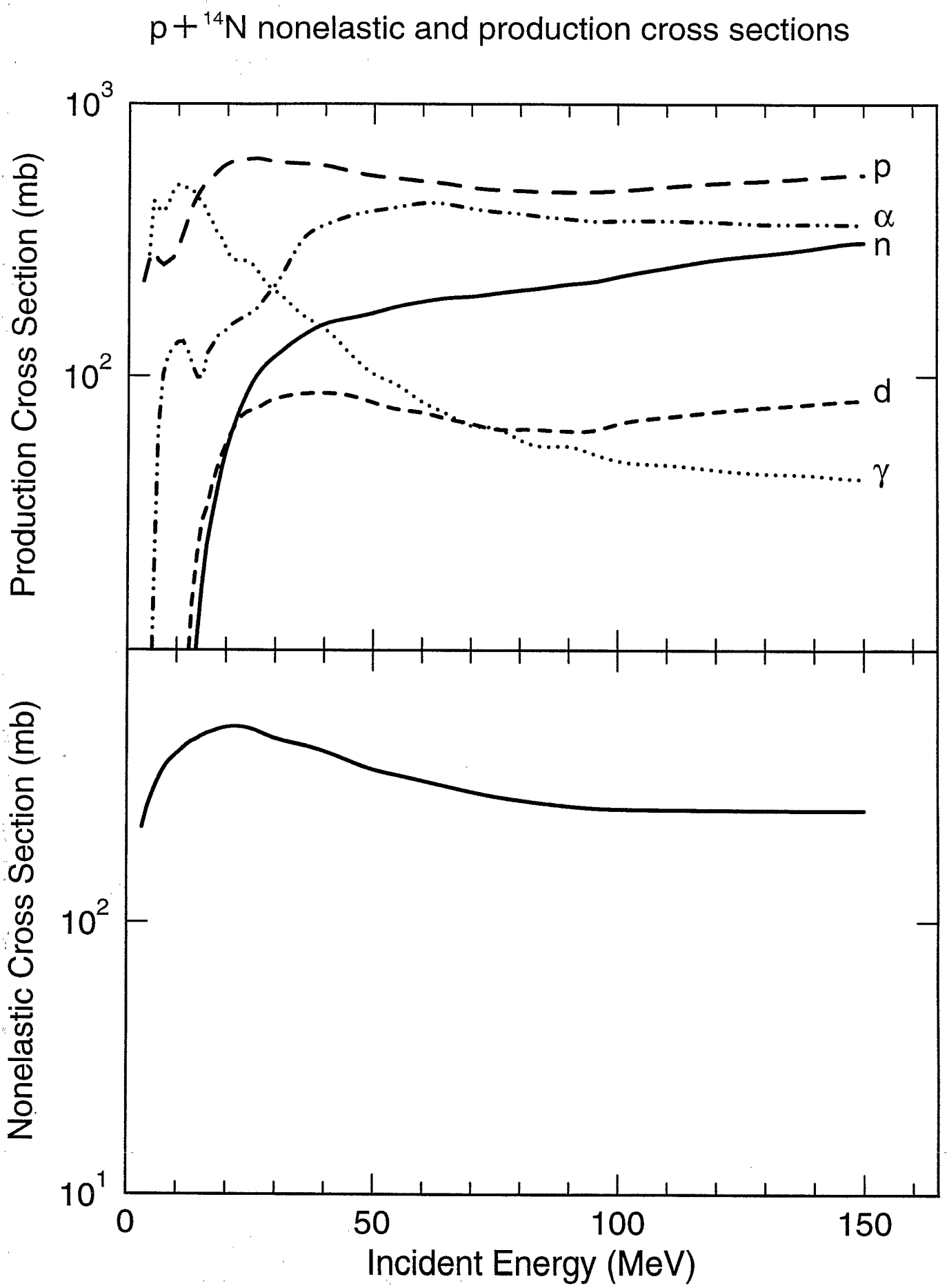
7014 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
3.000E+00	2.221E-01	0.000E+00	0.000E+00	2.221E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.221E-01
4.000E+00	2.621E-01	0.000E+00	0.000E+00	2.620E-01	0.000E+00	0.000E+00	0.000E+00	1.472E-04	2.620E-01
5.000E+00	2.950E-01	0.000E+00	0.000E+00	2.839E-01	0.000E+00	0.000E+00	0.000E+00	1.111E-02	4.382E-01
6.000E+00	3.266E-01	0.000E+00	0.000E+00	2.639E-01	0.000E+00	0.000E+00	0.000E+00	6.268E-02	4.096E-01
7.000E+00	3.560E-01	0.000E+00	1.267E-05	2.546E-01	0.000E+00	0.000E+00	0.000E+00	1.014E-01	3.985E-01
8.000E+00	3.809E-01	0.000E+00	1.268E-04	2.623E-01	0.000E+00	0.000E+00	0.000E+00	1.184E-01	4.308E-01
9.000E+00	3.987E-01	0.000E+00	4.053E-04	2.710E-01	0.000E+00	0.000E+00	0.000E+00	1.273E-01	4.795E-01
1.000E+01	4.150E-01	0.000E+00	8.179E-04	2.942E-01	8.807E-05	0.000E+00	0.000E+00	1.328E-01	5.019E-01
1.100E+01	4.309E-01	0.000E+00	1.421E-03	3.322E-01	2.382E-03	0.000E+00	0.000E+00	1.338E-01	4.883E-01
1.200E+01	4.478E-01	0.000E+00	2.916E-03	3.767E-01	7.946E-03	0.000E+00	0.000E+00	1.231E-01	4.901E-01
1.300E+01	4.604E-01	0.000E+00	5.324E-03	4.247E-01	1.478E-02	0.000E+00	0.000E+00	1.082E-01	4.767E-01
1.400E+01	4.693E-01	0.000E+00	1.078E-02	4.618E-01	2.188E-02	0.000E+00	0.000E+00	9.896E-02	4.482E-01
1.500E+01	4.812E-01	0.000E+00	1.682E-02	4.934E-01	2.954E-02	0.000E+00	0.000E+00	9.913E-02	4.290E-01
1.600E+01	4.915E-01	0.000E+00	2.409E-02	5.131E-01	3.324E-02	0.000E+00	0.000E+00	1.217E-01	3.910E-01
1.700E+01	4.989E-01	0.000E+00	3.052E-02	5.373E-01	3.977E-02	0.000E+00	0.000E+00	1.294E-01	3.628E-01
1.800E+01	5.063E-01	0.000E+00	3.774E-02	5.608E-01	4.595E-02	0.000E+00	0.000E+00	1.399E-01	3.297E-01
1.900E+01	5.139E-01	0.000E+00	4.634E-02	5.835E-01	5.196E-02	0.000E+00	0.000E+00	1.425E-01	3.151E-01
2.000E+01	5.190E-01	0.000E+00	5.460E-02	5.989E-01	5.745E-02	0.000E+00	0.000E+00	1.489E-01	2.831E-01
2.200E+01	5.229E-01	0.000E+00	7.044E-02	6.196E-01	6.796E-02	0.000E+00	0.000E+00	1.590E-01	2.642E-01
2.400E+01	5.176E-01	0.000E+00	8.585E-02	6.231E-01	7.394E-02	0.000E+00	0.000E+00	1.670E-01	2.631E-01
2.600E+01	5.050E-01	0.000E+00	1.001E-01	6.280E-01	7.604E-02	0.000E+00	0.000E+00	1.767E-01	2.449E-01
2.800E+01	4.868E-01	0.000E+00	1.105E-01	6.190E-01	8.002E-02	0.000E+00	0.000E+00	1.968E-01	2.169E-01
3.000E+01	4.718E-01	0.000E+00	1.189E-01	6.100E-01	8.280E-02	0.000E+00	0.000E+00	2.180E-01	2.036E-01
3.500E+01	4.491E-01	0.000E+00	1.390E-01	6.016E-01	8.606E-02	0.000E+00	0.000E+00	3.098E-01	1.689E-01
4.000E+01	4.236E-01	0.000E+00	1.553E-01	5.903E-01	8.669E-02	0.000E+00	0.000E+00	3.585E-01	1.484E-01
4.500E+01	3.903E-01	0.000E+00	1.631E-01	5.629E-01	8.492E-02	0.000E+00	0.000E+00	3.860E-01	1.212E-01
5.000E+01	3.624E-01	0.000E+00	1.708E-01	5.411E-01	7.995E-02	0.000E+00	0.000E+00	4.036E-01	1.017E-01
5.500E+01	3.457E-01	0.000E+00	1.804E-01	5.303E-01	7.562E-02	0.000E+00	0.000E+00	4.170E-01	9.230E-02
6.000E+01	3.301E-01	0.000E+00	1.878E-01	5.181E-01	7.358E-02	0.000E+00	0.000E+00	4.310E-01	8.042E-02
6.500E+01	3.147E-01	0.000E+00	1.937E-01	5.076E-01	7.000E-02	0.000E+00	0.000E+00	4.276E-01	7.285E-02
7.000E+01	3.002E-01	0.000E+00	1.964E-01	4.914E-01	6.715E-02	0.000E+00	0.000E+00	4.118E-01	6.594E-02
7.500E+01	2.884E-01	0.000E+00	2.015E-01	4.824E-01	6.405E-02	0.000E+00	0.000E+00	4.009E-01	6.472E-02
8.000E+01	2.794E-01	0.000E+00	2.066E-01	4.787E-01	6.400E-02	0.000E+00	0.000E+00	3.939E-01	5.851E-02
8.500E+01	2.721E-01	0.000E+00	2.115E-01	4.743E-01	6.367E-02	0.000E+00	0.000E+00	3.837E-01	5.535E-02
9.000E+01	2.661E-01	0.000E+00	2.177E-01	4.732E-01	6.298E-02	0.000E+00	0.000E+00	3.770E-01	5.546E-02
9.500E+01	2.616E-01	0.000E+00	2.222E-01	4.742E-01	6.348E-02	0.000E+00	0.000E+00	3.702E-01	5.205E-02
1.000E+02	2.595E-01	0.000E+00	2.318E-01	4.789E-01	6.706E-02	0.000E+00	0.000E+00	3.712E-01	4.903E-02
1.100E+02	2.584E-01	0.000E+00	2.499E-01	4.954E-01	7.104E-02	0.000E+00	0.000E+00	3.711E-01	4.740E-02
1.200E+02	2.577E-01	0.000E+00	2.677E-01	5.098E-01	7.424E-02	0.000E+00	0.000E+00	3.678E-01	4.550E-02
1.300E+02	2.570E-01	0.000E+00	2.798E-01	5.204E-01	7.687E-02	0.000E+00	0.000E+00	3.611E-01	4.411E-02
1.400E+02	2.566E-01	0.000E+00	2.946E-01	5.350E-01	7.935E-02	0.000E+00	0.000E+00	3.615E-01	4.346E-02
1.500E+02	2.567E-01	0.000E+00	3.088E-01	5.467E-01	8.140E-02	0.000E+00	0.000E+00	3.591E-01	4.213E-02

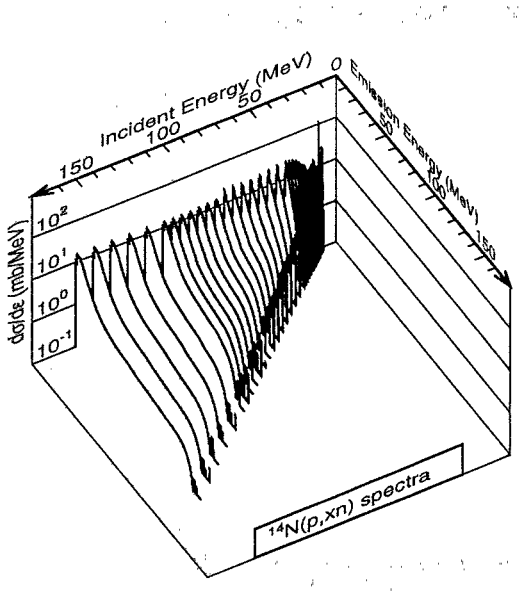
7014 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

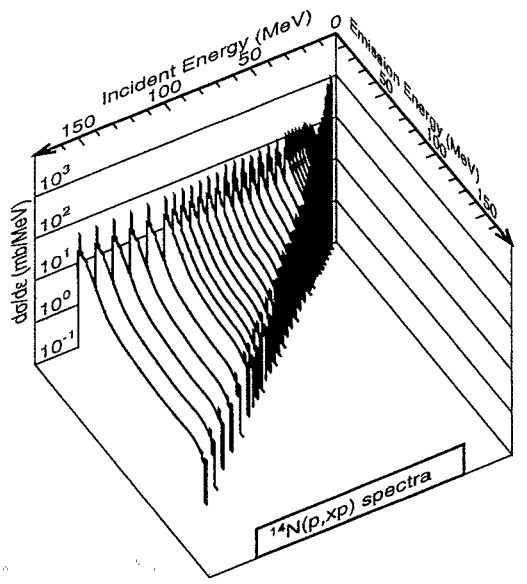
Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
3.000E+00	0.000E+00	4.949E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.250E+00
4.000E+00	0.000E+00	1.452E+00	0.000E+00	0.000E+00	0.000E+00	6.426E-01	2.250E+00
5.000E+00	0.000E+00	1.367E+00	0.000E+00	0.000E+00	0.000E+00	1.411E+00	2.099E+00
6.000E+00	0.000E+00	1.884E+00	0.000E+00	0.000E+00	0.000E+00	2.083E+00	2.434E+00
7.000E+00	5.344E-01	2.249E+00	0.000E+00	0.000E+00	0.000E+00	2.512E+00	2.794E+00
8.000E+00	1.485E+00	2.724E+00	0.000E+00	0.000E+00	0.000E+00	2.993E+00	2.909E+00
9.000E+00	2.433E+00	3.275E+00	0.000E+00	0.000E+00	0.000E+00	3.417E+00	2.957E+00
1.000E+01	3.383E+00	3.758E+00	1.030E+00	0.000E+00	0.000E+00	3.803E+00	3.029E+00
1.100E+01	4.168E+00	4.060E+00	1.939E+00	0.000E+00	0.000E+00	4.088E+00	3.102E+00
1.200E+01	2.851E+00	4.469E+00	2.364E+00	0.000E+00	0.000E+00	4.469E+00	3.192E+00
1.300E+01	2.346E+00	4.803E+00	2.887E+00	0.000E+00	0.000E+00	4.771E+00	3.272E+00
1.400E+01	2.333E+00	5.159E+00	3.294E+00	0.000E+00	0.000E+00	4.994E+00	3.312E+00
1.500E+01	2.477E+00	5.430E+00	3.884E+00	0.000E+00	0.000E+00	5.074E+00	3.351E+00
1.600E+01	2.417E+00	5.397E+00	4.328E+00	0.000E+00	0.000E+00	5.086E+00	3.404E+00
1.700E+01	2.677E+00	5.615E+00	4.778E+00	0.000E+00	0.000E+00	4.910E+00	3.391E+00
1.800E+01	2.874E+00	5.830E+00	5.106E+00	0.000E+00	0.000E+00	4.823E+00	3.363E+00
1.900E+01	3.083E+00	6.108E+00	5.572E+00	0.000E+00	0.000E+00	4.890E+00	3.322E+00
2.000E+01	3.149E+00	6.306E+00	6.064E+00	0.000E+00	0.000E+00	4.987E+00	3.314E+00
2.200E+01	3.573E+00	6.847E+00	6.927E+00	0.000E+00	0.000E+00	5.176E+00	3.184E+00
2.400E+01	3.936E+00	7.476E+00	7.585E+00	0.000E+00	0.000E+00	5.321E+00	3.151E+00
2.600E+01	4.162E+00	7.926E+00	8.618E+00	0.000E+00	0.000E+00	5.248E+00	3.079E+00
2.800E+01	4.564E+00	8.310E+00	9.633E+00	0.000E+00	0.000E+00	5.051E+00	3.001E+00
3.000E+01	5.028E+00	8.817E+00	1.059E+01	0.000E+00	0.000E+00	4.839E+00	2.993E+00
3.500E+01	5.952E+00	9.809E+00	1.246E+01	0.000E+00	0.000E+00	4.512E+00	3.000E+00

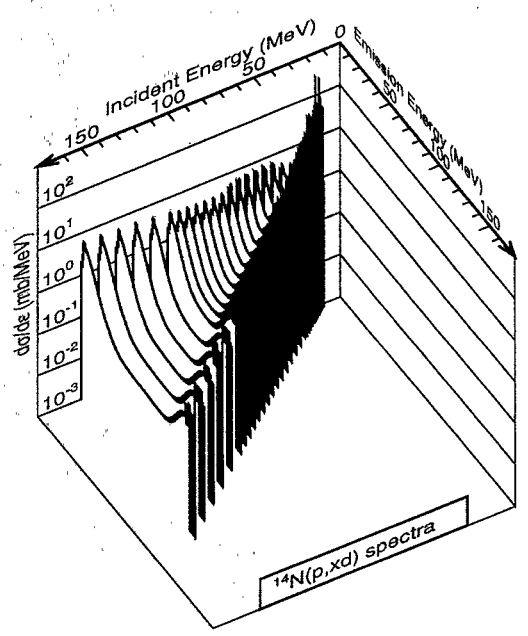
4.000E+01	7.051E+00	1.109E+01	1.444E+01	0.000E+00	0.000E+00	4.375E+00	3.111E+00
4.500E+01	8.135E+00	1.217E+01	1.676E+01	0.000E+00	0.000E+00	4.428E+00	3.153E+00
5.000E+01	9.188E+00	1.319E+01	1.909E+01	0.000E+00	0.000E+00	4.543E+00	3.243E+00
5.500E+01	1.031E+01	1.436E+01	2.108E+01	0.000E+00	0.000E+00	4.724E+00	3.334E+00
6.000E+01	1.135E+01	1.524E+01	2.292E+01	0.000E+00	0.000E+00	5.011E+00	3.365E+00
6.500E+01	1.244E+01	1.619E+01	2.494E+01	0.000E+00	0.000E+00	5.226E+00	3.438E+00
7.000E+01	1.363E+01	1.739E+01	2.644E+01	0.000E+00	0.000E+00	5.628E+00	3.310E+00
7.500E+01	1.468E+01	1.845E+01	2.811E+01	0.000E+00	0.000E+00	5.768E+00	3.376E+00
8.000E+01	1.584E+01	1.931E+01	2.964E+01	0.000E+00	0.000E+00	5.954E+00	3.392E+00
8.500E+01	1.695E+01	2.042E+01	2.999E+01	0.000E+00	0.000E+00	6.197E+00	3.378E+00
9.000E+01	1.790E+01	2.149E+01	3.075E+01	0.000E+00	0.000E+00	6.295E+00	3.416E+00
9.500E+01	1.924E+01	2.260E+01	3.233E+01	0.000E+00	0.000E+00	6.335E+00	3.428E+00
1.000E+02	1.979E+01	2.339E+01	3.068E+01	0.000E+00	0.000E+00	6.736E+00	3.401E+00
1.100E+02	2.159E+01	2.534E+01	3.091E+01	0.000E+00	0.000E+00	6.969E+00	3.440E+00
1.200E+02	2.341E+01	2.750E+01	2.985E+01	0.000E+00	0.000E+00	7.236E+00	3.441E+00
1.300E+02	2.557E+01	2.998E+01	2.943E+01	0.000E+00	0.000E+00	7.468E+00	3.448E+00
1.400E+02	2.729E+01	3.197E+01	2.849E+01	0.000E+00	0.000E+00	7.648E+00	3.489E+00
1.500E+02	2.904E+01	3.412E+01	2.665E+01	0.000E+00	0.000E+00	7.889E+00	3.503E+00

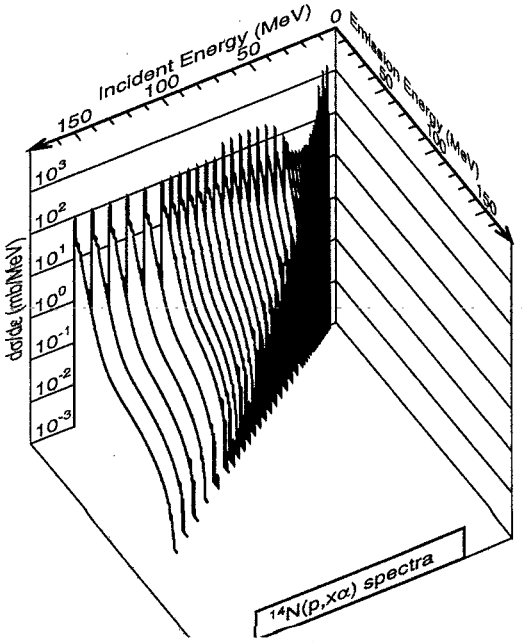

p + 14N nonelastic and production cross sections
Production Cross Section (mb)
10^3
10^2
p
α
n
d
γ
Nonelastic Cross Section (mb)
10^2
10^1
0
50
100
150
Incident Energy (MeV)

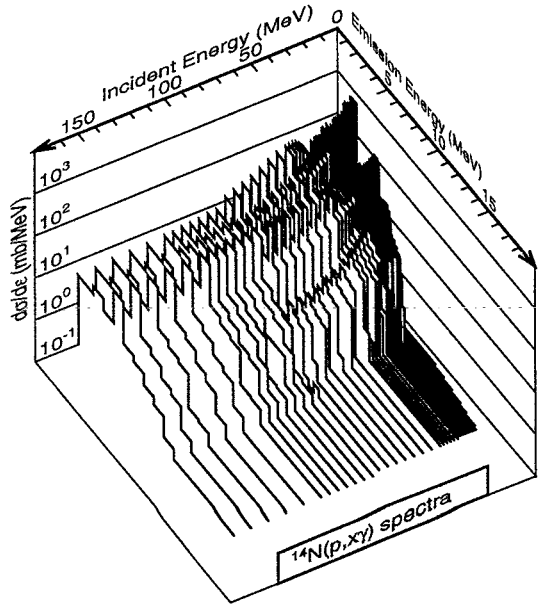
p + ^{14}N angle-integrated emission spectra



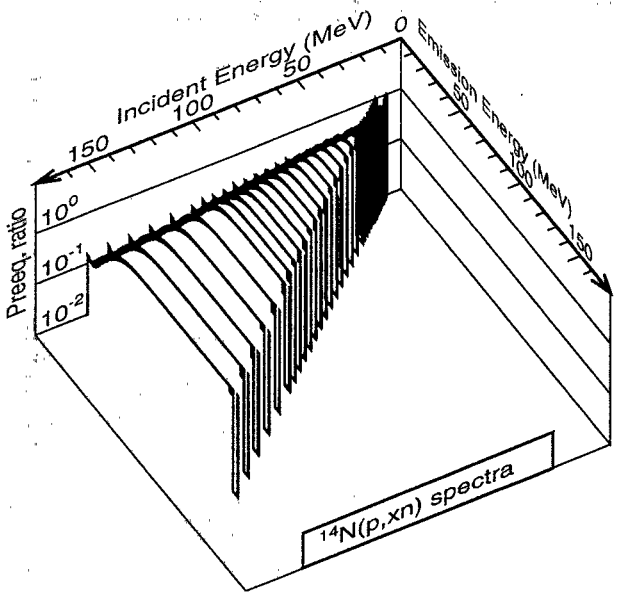


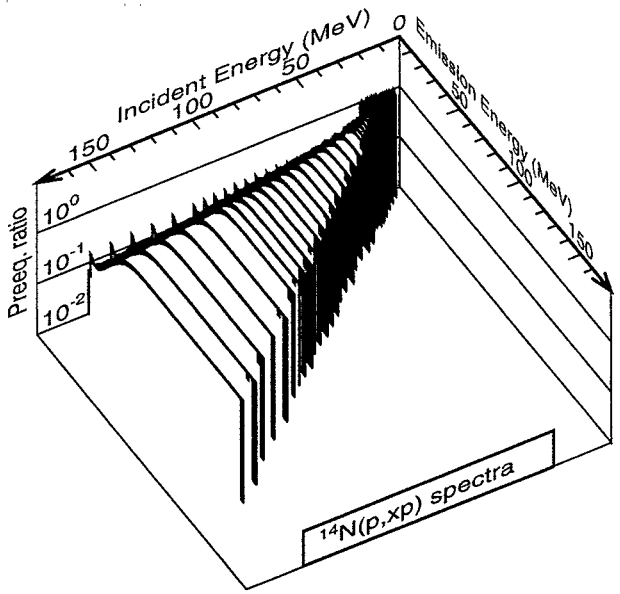


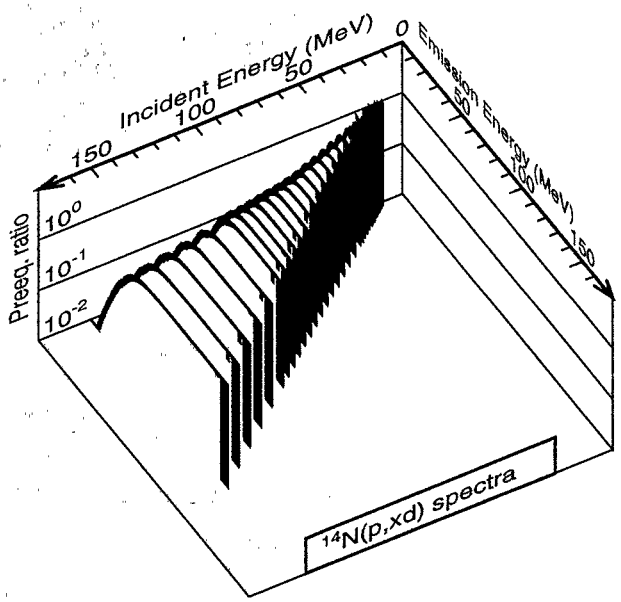


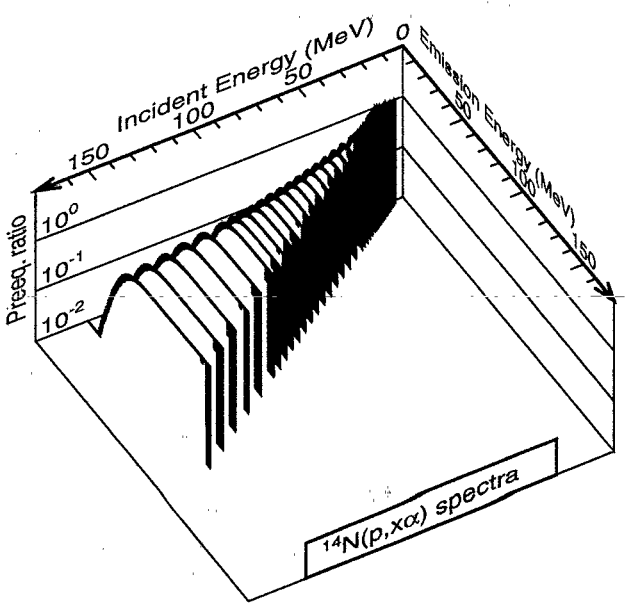


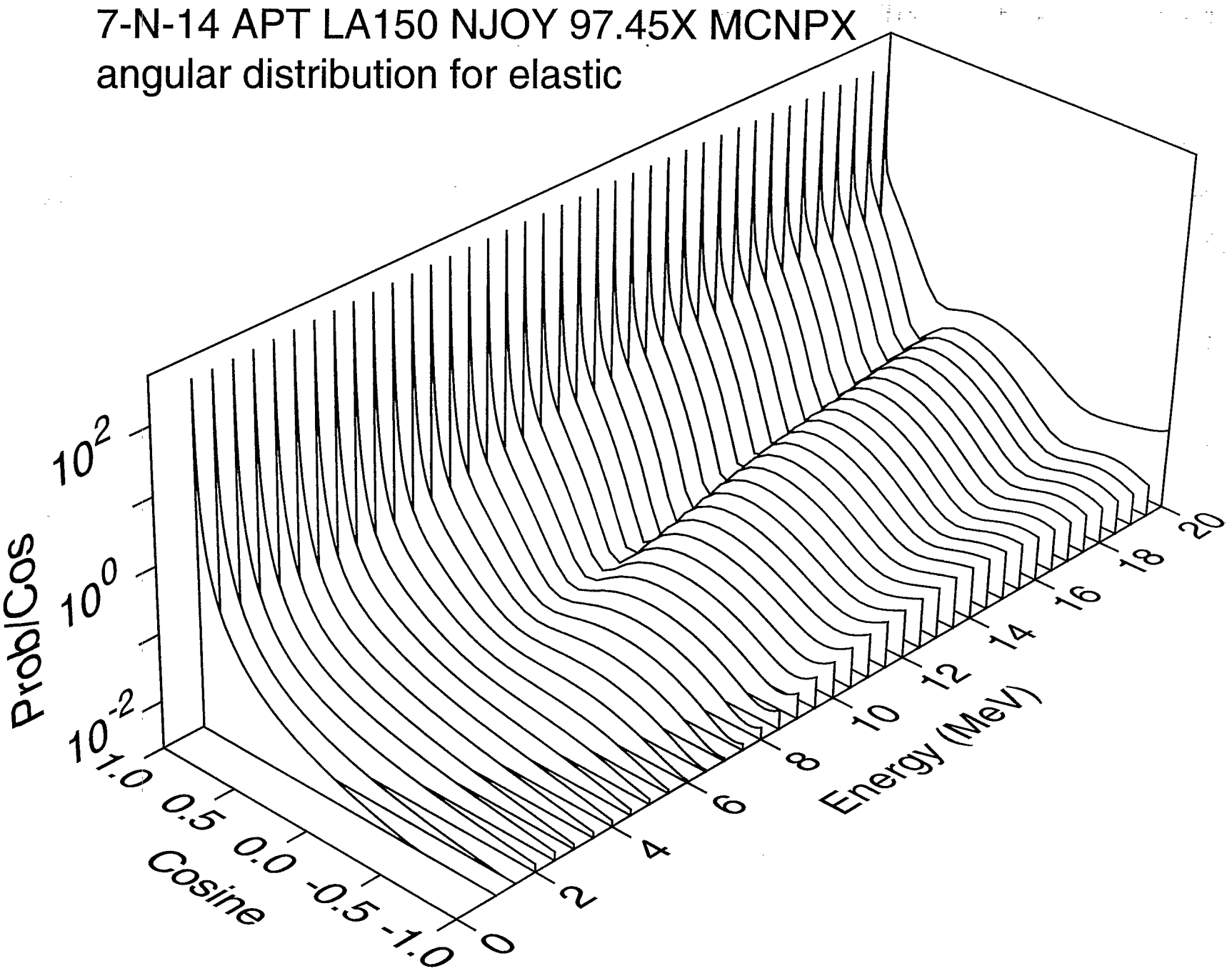
p + ^{14}N Kalbach preequilibrium ratios

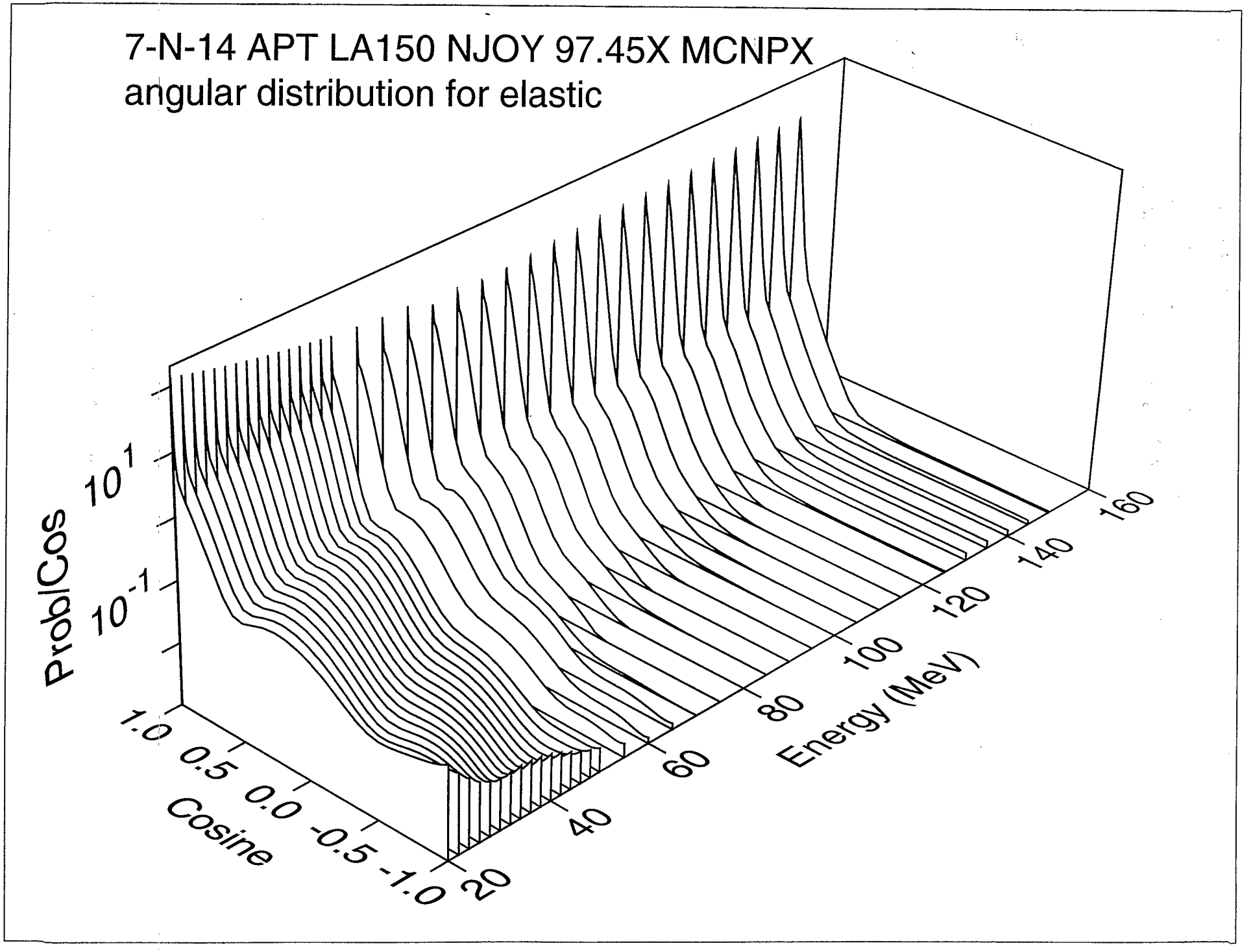


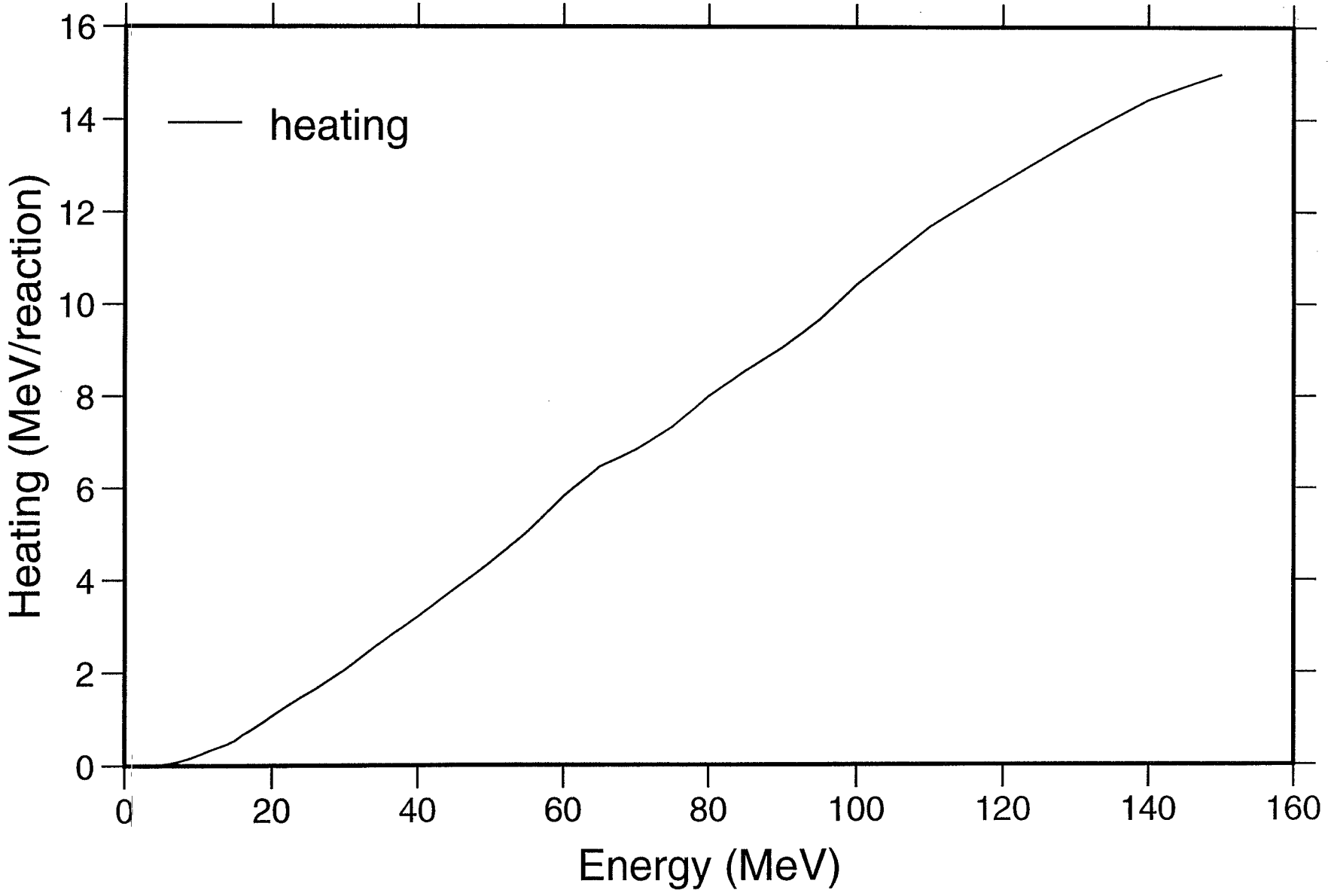







7-N-14 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
ProblCos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
0
2
4
6
8
10
12
14
16
18
20


7-N-14 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^{1}
10^{-1}
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


7-N-14 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
2
4
6
8
10
12
14
16
0
20
40
60
80
100
120
140
160

EVALUATION OF P + 16O CROSS SECTIONS FOR THE ENERGY RANGE 1. to 150 MeV

M. B. Chadwick and P. G. Young
16 July 1996

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident proton energy range from 1 to 150 MeV.

The evaluation utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for emission neutrons, protons, deuterons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the following ENDF sections are included:

MF=3	MT= 2	Integral of nuclear plus interference components of the elastic scattering cross section
	MT= 5	Sum of binary (n,n') and (n,x) reactions
MF=6	MT= 2	Elastic angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
	MT= 5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + O16 and p + O16 reactions (Ch96a, Ch96b, Ch96c). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequi-librium and direct-reaction theories. Coupled-channel and spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96b). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. Note that all other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation requires a modification of the original ENDF-6 format.

Preequilibrium corrections were performed in the course of the

GNASH calculations using either Feshbach, Kerman, Koonin (FKK) theory [Ch93d] or the exciton model of Kalbach (Ka77, Ka85). Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

MT=2 elastic scattering data in MF=3 and MF=6 are based on optical model calculations with the SCAT2 code (Be92). We have made use of the "nuclear-plus-interference" option in MF=6, which corresponds to LAW=5, LTP=12, and the appropriate integrated cross section is stored in MF=3. Note that because of the interference effect, the tabulations in both MF=6 and MF=3 can be negative at some energies and angles.

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REFERENCES

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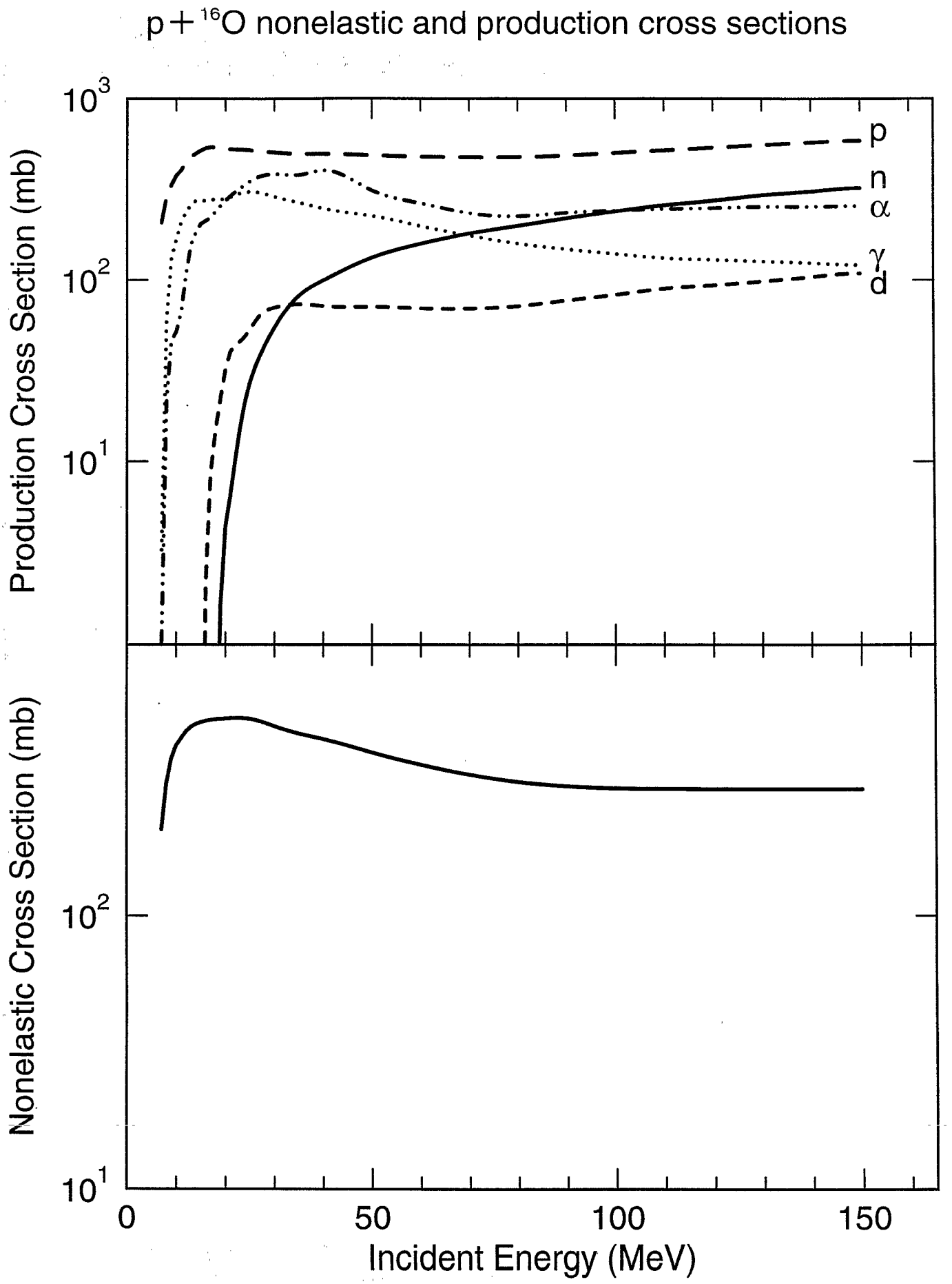
8016 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

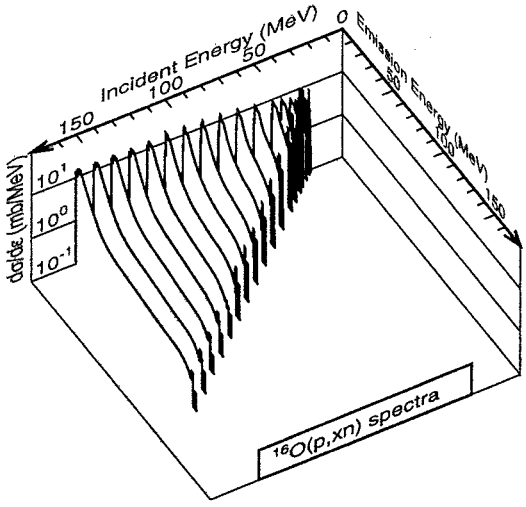
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
7.000E+00	2.083E-01	0.000E+00	0.000E+00	2.073E-01	0.000E+00	0.000E+00	0.000E+00	1.030E-03	3.290E-03
8.000E+00	3.075E-01	0.000E+00	0.000E+00	2.853E-01	0.000E+00	0.000E+00	0.000E+00	2.213E-02	5.947E-02
9.000E+00	3.806E-01	0.000E+00	0.000E+00	3.348E-01	0.000E+00	0.000E+00	0.000E+00	4.607E-02	1.306E-01
1.000E+01	4.248E-01	0.000E+00	0.000E+00	3.759E-01	0.000E+00	0.000E+00	0.000E+00	5.193E-02	1.679E-01
1.100E+01	4.518E-01	0.000E+00	0.000E+00	4.039E-01	0.000E+00	0.000E+00	0.000E+00	6.668E-02	2.088E-01
1.200E+01	4.786E-01	0.000E+00	0.000E+00	4.446E-01	0.000E+00	0.000E+00	0.000E+00	1.082E-01	2.374E-01
1.300E+01	4.980E-01	0.000E+00	0.000E+00	4.770E-01	0.000E+00	0.000E+00	0.000E+00	1.568E-01	2.600E-01
1.400E+01	5.105E-01	0.000E+00	0.000E+00	4.990E-01	0.000E+00	0.000E+00	0.000E+00	1.831E-01	2.737E-01
1.500E+01	5.182E-01	0.000E+00	0.000E+00	5.177E-01	1.846E-05	0.000E+00	0.000E+00	2.041E-01	2.751E-01
1.600E+01	5.241E-01	0.000E+00	0.000E+00	5.329E-01	2.236E-03	0.000E+00	0.000E+00	2.119E-01	2.731E-01
1.700E+01	5.284E-01	0.000E+00	0.000E+00	5.401E-01	8.577E-03	0.000E+00	0.000E+00	2.209E-01	2.745E-01
1.800E+01	5.311E-01	0.000E+00	1.763E-04	5.393E-01	1.499E-02	0.000E+00	0.000E+00	2.377E-01	2.795E-01
1.900E+01	5.330E-01	0.000E+00	1.648E-03	5.357E-01	2.225E-02	0.000E+00	0.000E+00	2.568E-01	2.775E-01
2.000E+01	5.346E-01	0.000E+00	4.372E-03	5.297E-01	3.201E-02	0.000E+00	0.000E+00	2.736E-01	2.796E-01
2.300E+01	5.370E-01	0.000E+00	1.535E-02	5.244E-01	4.566E-02	0.000E+00	0.000E+00	3.209E-01	3.005E-01
2.700E+01	5.227E-01	0.000E+00	3.787E-02	5.136E-01	6.332E-02	0.000E+00	0.000E+00	3.717E-01	3.029E-01
3.000E+01	5.006E-01	0.000E+00	5.446E-02	5.052E-01	7.017E-02	0.000E+00	0.000E+00	3.834E-01	2.873E-01
3.500E+01	4.706E-01	0.000E+00	8.151E-02	4.967E-01	7.338E-02	0.000E+00	0.000E+00	3.789E-01	2.676E-01
4.000E+01	4.490E-01	0.000E+00	9.948E-02	4.956E-01	7.160E-02	0.000E+00	0.000E+00	4.021E-01	2.480E-01
5.000E+01	4.010E-01	0.000E+00	1.329E-01	4.862E-01	7.092E-02	0.000E+00	0.000E+00	3.120E-01	2.255E-01
6.000E+01	3.620E-01	0.000E+00	1.586E-01	4.787E-01	6.957E-02	0.000E+00	0.000E+00	2.653E-01	1.987E-01
7.000E+01	3.330E-01	0.000E+00	1.808E-01	4.752E-01	6.937E-02	0.000E+00	0.000E+00	2.339E-01	1.762E-01
8.000E+01	3.130E-01	0.000E+00	1.994E-01	4.764E-01	7.153E-02	0.000E+00	0.000E+00	2.250E-01	1.590E-01
9.000E+01	3.021E-01	0.000E+00	2.193E-01	4.860E-01	7.687E-02	0.000E+00	0.000E+00	2.351E-01	1.478E-01
1.000E+02	2.970E-01	0.000E+00	2.395E-01	5.024E-01	8.263E-02	0.000E+00	0.000E+00	2.418E-01	1.394E-01
1.100E+02	2.956E-01	0.000E+00	2.595E-01	5.186E-01	8.954E-02	0.000E+00	0.000E+00	2.476E-01	1.322E-01
1.200E+02	2.950E-01	0.000E+00	2.742E-01	5.363E-01	9.332E-02	0.000E+00	0.000E+00	2.497E-01	1.292E-01
1.300E+02	2.950E-01	0.000E+00	2.934E-01	5.546E-01	9.811E-02	0.000E+00	0.000E+00	2.539E-01	1.265E-01
1.400E+02	2.950E-01	0.000E+00	3.082E-01	5.734E-01	1.038E-01	0.000E+00	0.000E+00	2.543E-01	1.237E-01
1.500E+02	2.950E-01	0.000E+00	3.221E-01	5.862E-01	1.088E-01	0.000E+00	0.000E+00	2.565E-01	1.209E-01

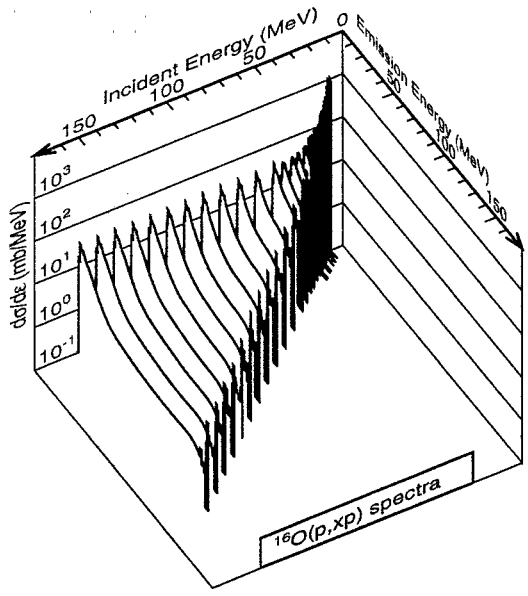
8016 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

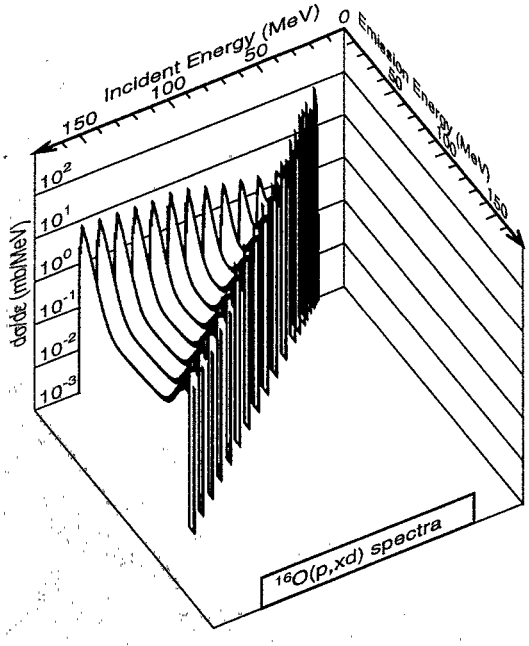
Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
7.000E+00	0.000E+00	4.950E-01	0.000E+00	0.000E+00	0.000E+00	1.054E+00	6.245E+00
8.000E+00	0.000E+00	1.417E+00	0.000E+00	0.000E+00	0.000E+00	1.833E+00	6.334E+00
9.000E+00	0.000E+00	2.201E+00	0.000E+00	0.000E+00	0.000E+00	2.602E+00	6.477E+00
1.000E+01	0.000E+00	2.892E+00	0.000E+00	0.000E+00	0.000E+00	3.282E+00	6.461E+00
1.100E+01	0.000E+00	3.558E+00	0.000E+00	0.000E+00	0.000E+00	3.603E+00	6.215E+00
1.200E+01	0.000E+00	3.880E+00	0.000E+00	0.000E+00	0.000E+00	3.169E+00	5.887E+00
1.300E+01	0.000E+00	4.075E+00	0.000E+00	0.000E+00	0.000E+00	3.082E+00	5.760E+00
1.400E+01	0.000E+00	4.477E+00	0.000E+00	0.000E+00	0.000E+00	3.183E+00	5.713E+00
1.500E+01	0.000E+00	5.093E+00	7.667E-01	0.000E+00	0.000E+00	3.340E+00	5.746E+00
1.600E+01	0.000E+00	5.579E+00	1.435E+00	0.000E+00	0.000E+00	3.728E+00	5.783E+00
1.700E+01	0.000E+00	5.993E+00	2.324E+00	0.000E+00	0.000E+00	3.523E+00	5.762E+00
1.800E+01	4.796E-01	6.483E+00	3.212E+00	0.000E+00	0.000E+00	3.883E+00	5.685E+00
1.900E+01	1.134E+00	6.855E+00	4.101E+00	0.000E+00	0.000E+00	4.085E+00	5.521E+00
2.000E+01	1.817E+00	7.189E+00	4.453E+00	0.000E+00	0.000E+00	4.055E+00	5.348E+00
2.300E+01	2.598E+00	7.858E+00	5.290E+00	0.000E+00	0.000E+00	4.797E+00	5.096E+00
2.700E+01	4.051E+00	9.258E+00	7.107E+00	0.000E+00	0.000E+00	4.427E+00	5.075E+00
3.000E+01	4.956E+00	1.017E+01	8.782E+00	0.000E+00	0.000E+00	4.156E+00	5.100E+00
3.500E+01	6.350E+00	1.184E+01	1.178E+01	0.000E+00	0.000E+00	4.144E+00	5.078E+00
4.000E+01	7.583E+00	1.302E+01	1.471E+01	0.000E+00	0.000E+00	4.377E+00	4.978E+00
5.000E+01	9.998E+00	1.565E+01	2.020E+01	0.000E+00	0.000E+00	5.027E+00	4.818E+00
6.000E+01	1.193E+01	1.745E+01	2.460E+01	0.000E+00	0.000E+00	5.822E+00	4.647E+00
7.000E+01	1.369E+01	1.933E+01	2.823E+01	0.000E+00	0.000E+00	6.211E+00	4.518E+00
8.000E+01	1.554E+01	2.125E+01	3.069E+01	0.000E+00	0.000E+00	6.476E+00	4.442E+00
9.000E+01	1.721E+01	2.296E+01	3.164E+01	0.000E+00	0.000E+00	6.779E+00	4.400E+00
1.000E+02	1.894E+01	2.474E+01	3.323E+01	0.000E+00	0.000E+00	7.033E+00	4.375E+00
1.100E+02	2.065E+01	2.659E+01	3.518E+01	0.000E+00	0.000E+00	7.374E+00	4.279E+00
1.200E+02	2.280E+01	2.873E+01	3.713E+01	0.000E+00	0.000E+00	7.519E+00	4.262E+00
1.300E+02	2.453E+01	3.067E+01	3.741E+01	0.000E+00	0.000E+00	7.869E+00	4.266E+00
1.400E+02	2.628E+01	3.226E+01	3.896E+01	0.000E+00	0.000E+00	8.125E+00	4.246E+00
1.500E+02	2.797E+01	3.428E+01	3.946E+01	0.000E+00	0.000E+00	8.450E+00	4.248E+00

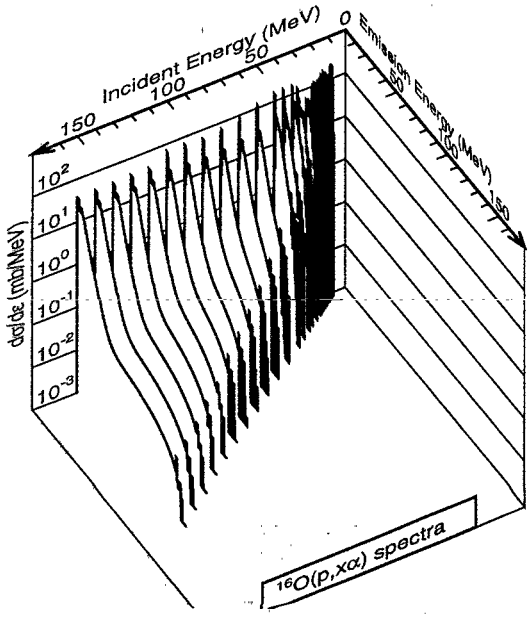

p + 16O nonelastic and production cross sections
Production Cross Section (mb)
10^3
10^2
10^1
p
n
α
γ
d
Nonelastic Cross Section (mb)
10^2
10^1
0
50
100
150
Incident Energy (MeV)

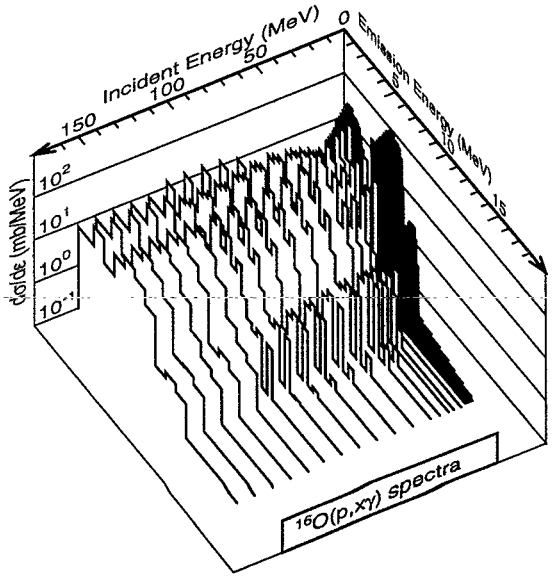
p + ^{16}O angle-integrated emission spectra



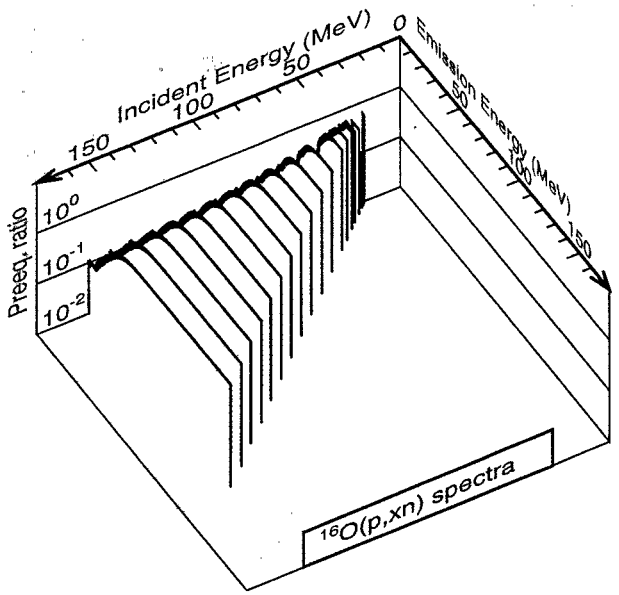


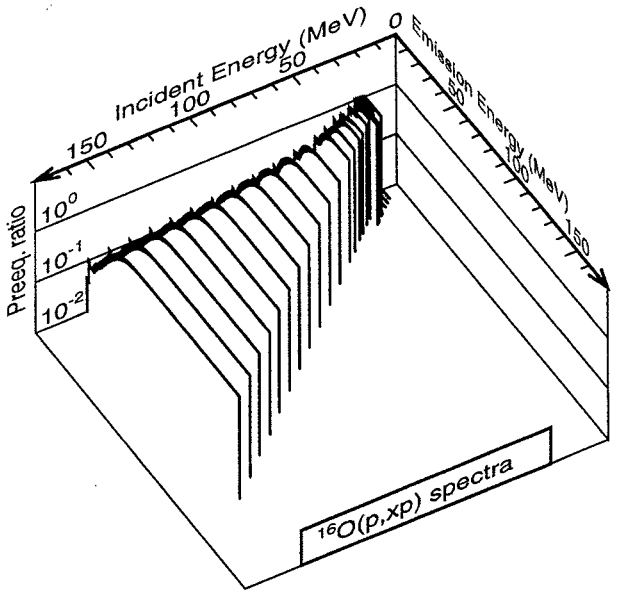


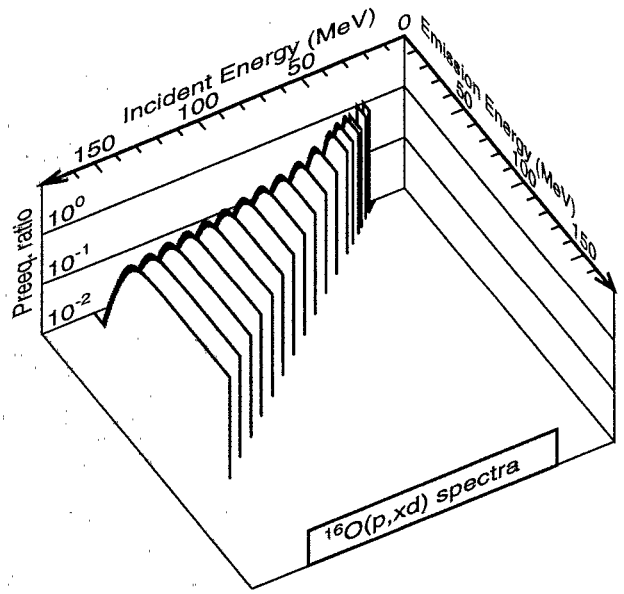


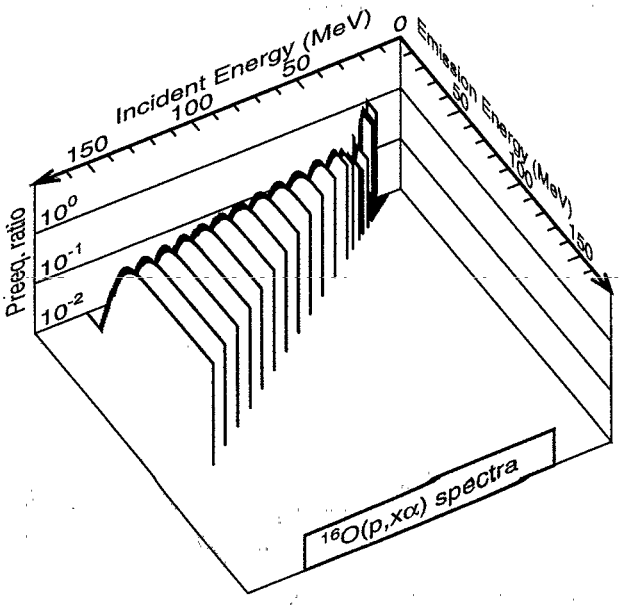


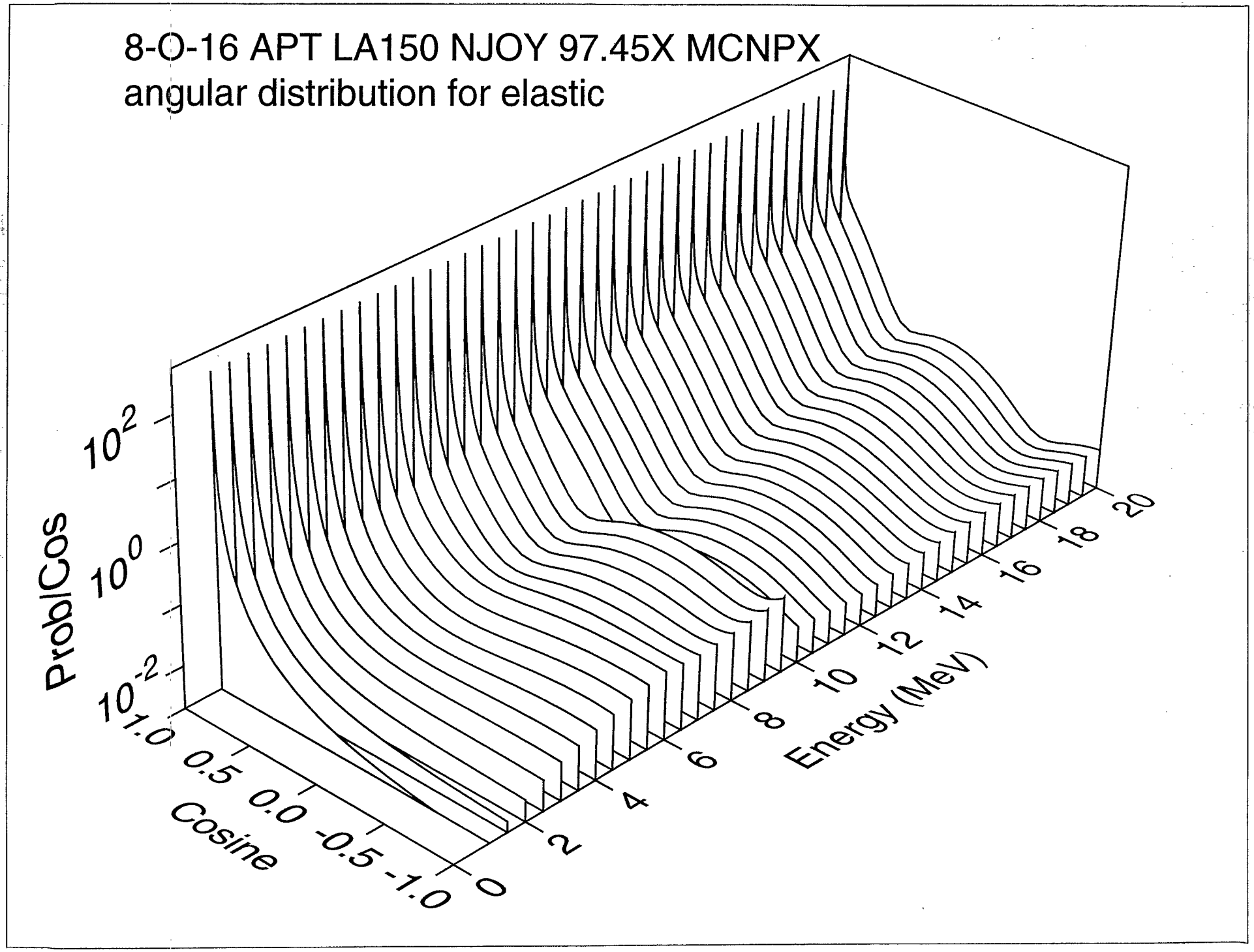
p + ^{16}O Kalbach preequilibrium ratios

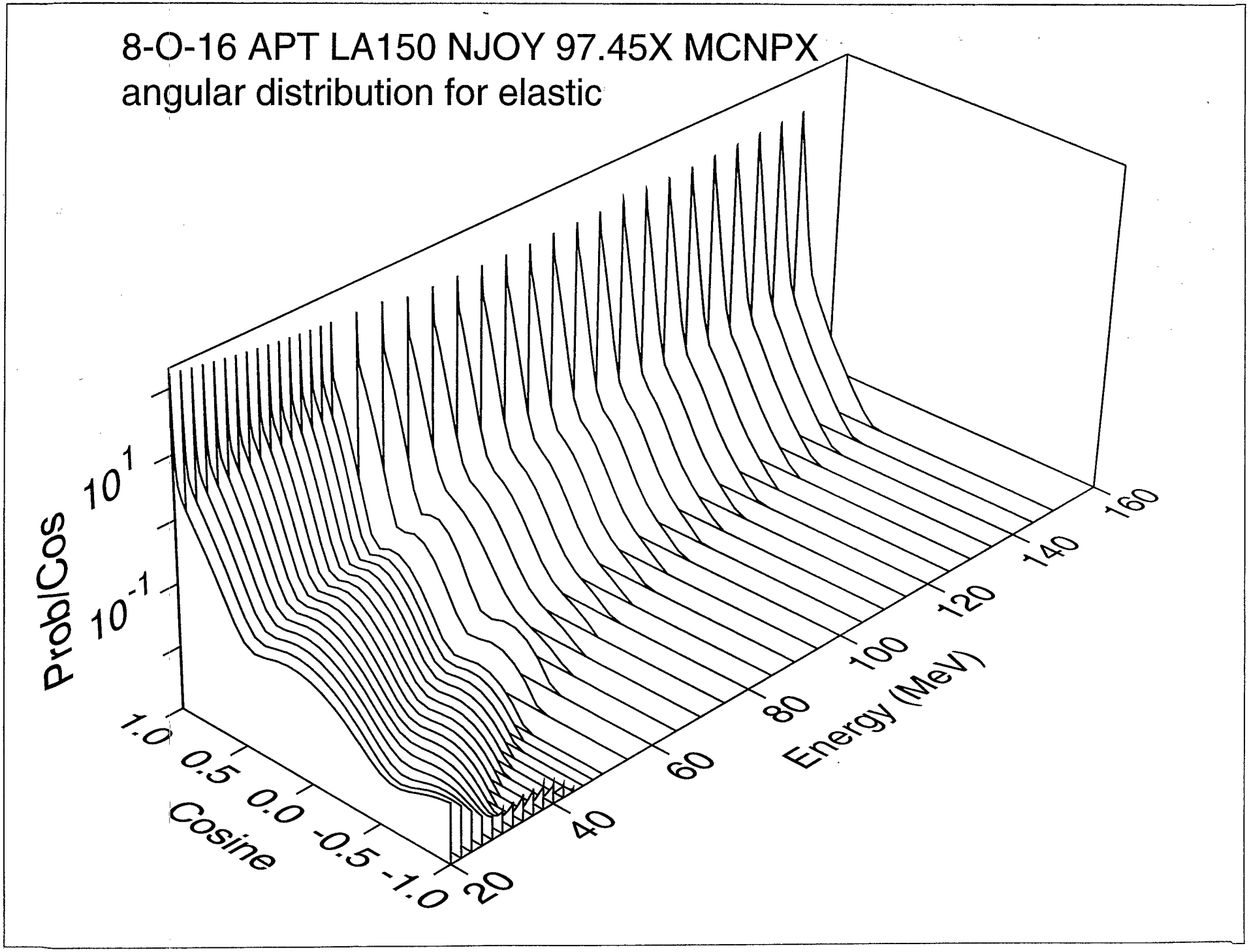


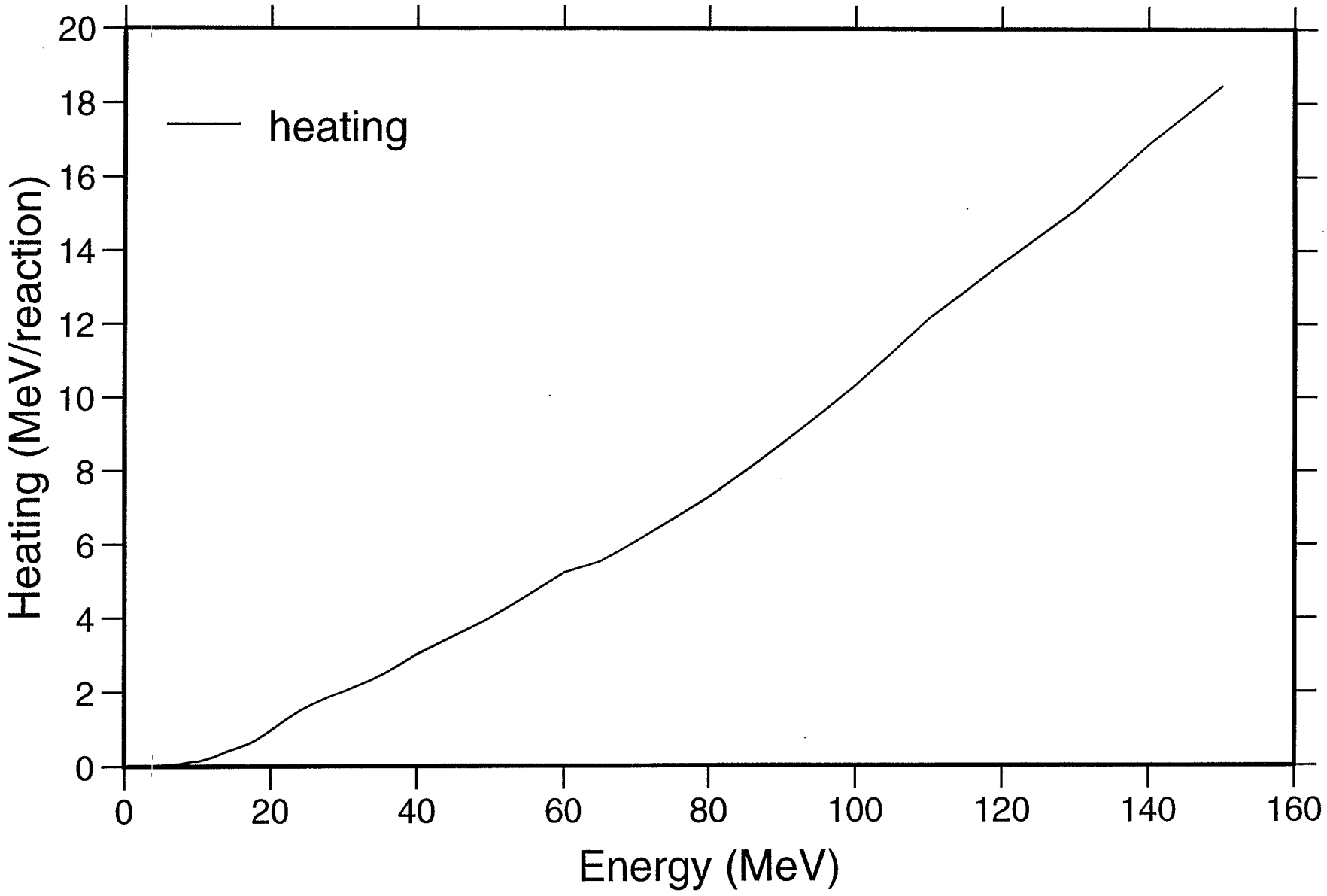







8-O-16 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
0
2
4
6
8
10
12
14
16
18
20


8-O-16 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
ProbCos
10^{1}
10^{-1}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
20
40
60
80
100
120
140
160


8-O-16 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
2
4
6
8
10
12
14
16
18
20
0
20
40
60
80
100
120
140
160

EVALUATION OF p + 27Al CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

M. B. Chadwick and P. G. Young
12 February 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident proton energy range from 1 to 150 MeV. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains.

To summarize, the ENDF sections with non-zero data are:

MF=3	MT= 2	Integral of nuclear plus interference components of the elastic scattering cross section
	MT= 5	Sum of binary (n,n') and (n,x) reactions
MF=6	MT= 2	Elastic angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
	MT= 5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Al27 and p + Al27 reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting..

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission

coefficients were calculated using the Kopecky-Uhl model (Ko90).

The optical potential of Petler (Pe85), specially developed for n+Al elastic scattering, was used for neutrons up to 60 MeV, and above this energy the Madland global potential (Ma88) was used. For incident protons, the Petler neutron potential was modified to account for proton scattering up to 60 MeV, and again the Madland global potential was used at higher energies. For deuterons, the potential of Perey and Perey (Pe63) was used at all energies, and for tritons the Becchetti and Greenlees potential (Be71) was adopted. Finally, the potential of Arthur and Young (Ar80), based on the work of Lemos (Le72), was used for alpha particles at all energies. DWBA calculations were performed for inelastic scattering to low-lying states using the DWUCK code.

While the above optical potentials did describe the experimental neutron and proton nonelastic cross section data fairly well, we modified these theoretical predictions slightly to better agree with the measurements, and renormalized the transmission coefficients accordingly.

Both proton- and neutron-induced measurements were utilized in validating our model and parameters used in the GNASH calculations. Of great importance were Benck et al.'s (Be97) measurements of charged-particle producing reactions on Al for incident neutrons at 63 MeV at Louvain-la-Neuve, Belgium. Since these data represent the only neutron-induced emission spectra above 20 MeV, they have been invaluable for guiding, and testing, our calculations. The proton, triton, and alpha emission spectra in the Benck et al. measurements are described very well. However, our deuteron emission calculations compare poorly with the measurements. Fortunately this has only a small practical impact since deuteron emission is small compared to proton emission, and our calculated emission spectrum approximates the measured deuteron energy deposition (production cross section times average energy) reasonably well, which is important for heating calculations. The combination of equilibrium and preequilibrium reaction mechanisms included in the GNASH code account for the measured data rather well.

As an independent validation of our GNASH calculations using the exciton model, we have also performed FKK calculations. This was done by implementing a multistep reaction theory recently developed by Koning and Chadwick, which is particularly suited to the simultaneous calculation of neutron and proton emission. The FKK theory describes the forward-peaking very well, as do our exciton model calculations using the phenomenological Kalbach angular distribution systematics.

As part of our evaluation, extensive comparisons were made to higher energy proton-induced measurements. In particular, the neutron and charged-particle emission spectra measured at the University of Maryland (Kalend et al. and Wu et al.) for 90-MeV protons, by Meier at Los Alamos for 113-MeV protons, and Bertrand and Peelle for 61-MeV protons are all reproduced reasonably by the present analysis (Ch97).

Another useful test of our model calculations, particularly for radionuclide production, was made by comparing our theoretical predictions of discrete gamma-ray emission in Al27(n,xngamma) reactions with the recent LANSCE/WNR data taken by Vonach, Haight, and collaborators (Vo94) using the white neutron source. Preliminary comparisons show reasonably good agreement.

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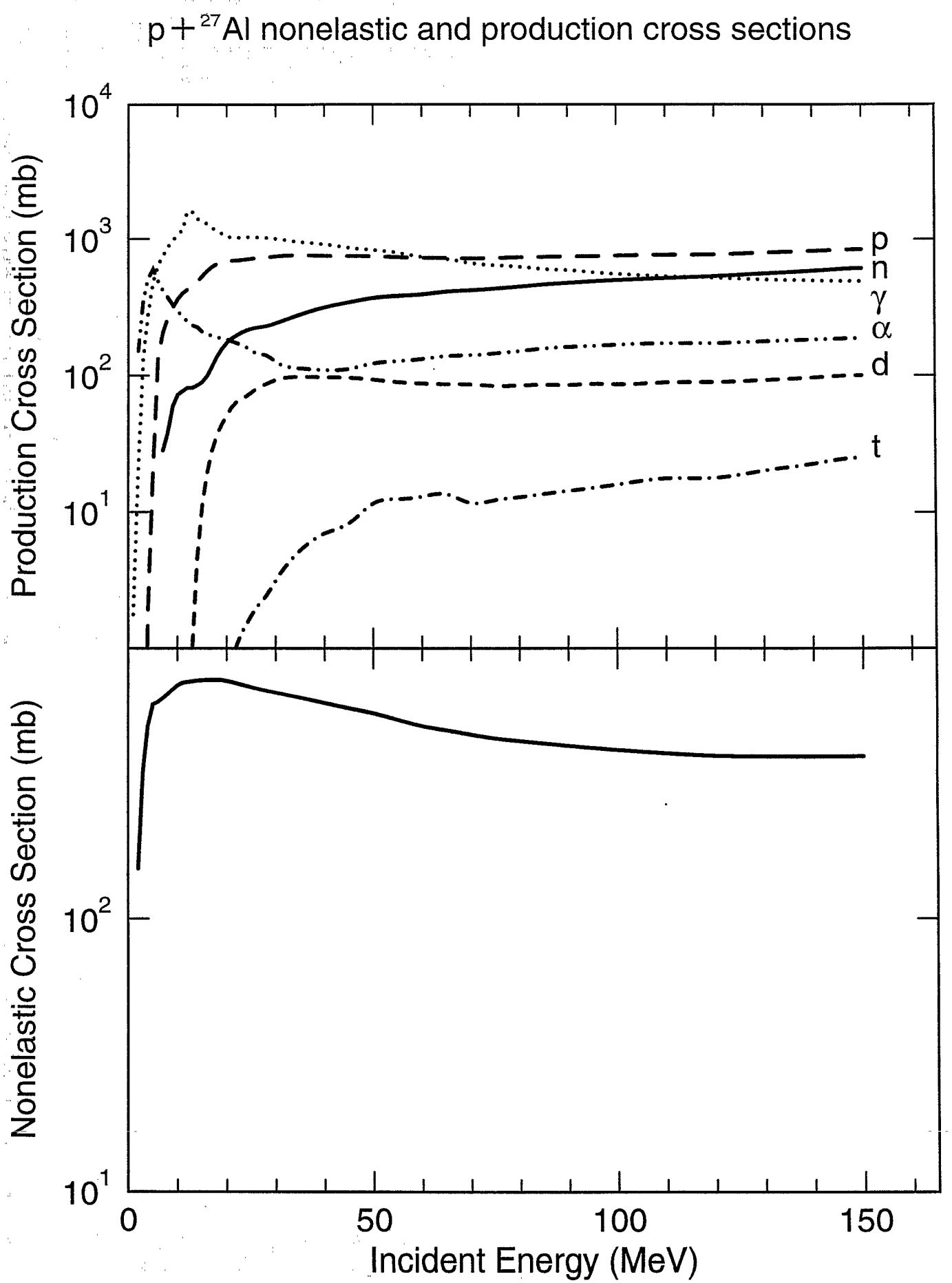
13027 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
1.000E+00	1.352E-02	0.000E+00	0.000E+00	6.488E-07	0.000E+00	0.000E+00	0.000E+00	1.343E-02	1.774E-03
2.000E+00	1.526E-01	0.000E+00	0.000E+00	7.321E-06	0.000E+00	0.000E+00	0.000E+00	1.516E-01	2.002E-02
3.000E+00	3.545E-01	0.000E+00	0.000E+00	1.474E-05	0.000E+00	0.000E+00	0.000E+00	3.537E-01	1.319E-01
4.000E+00	5.189E-01	0.000E+00	0.000E+00	1.910E-03	0.000E+00	0.000E+00	0.000E+00	5.163E-01	2.848E-01
5.000E+00	6.190E-01	0.000E+00	0.000E+00	1.939E-02	0.000E+00	0.000E+00	0.000E+00	5.990E-01	4.787E-01
6.000E+00	6.329E-01	0.000E+00	5.747E-03	1.342E-01	0.000E+00	0.000E+00	0.000E+00	4.923E-01	6.411E-01
7.000E+00	6.531E-01	0.000E+00	2.814E-02	2.059E-01	0.000E+00	0.000E+00	0.000E+00	4.185E-01	7.506E-01
8.000E+00	6.780E-01	0.000E+00	3.811E-02	2.659E-01	0.000E+00	0.000E+00	0.000E+00	3.733E-01	8.684E-01
9.000E+00	7.062E-01	0.000E+00	5.928E-02	3.152E-01	0.000E+00	0.000E+00	0.000E+00	3.309E-01	9.729E-01
1.000E+01	7.325E-01	0.000E+00	7.233E-02	3.630E-01	0.000E+00	0.000E+00	0.000E+00	2.964E-01	1.076E+00
1.100E+01	7.477E-01	0.000E+00	7.694E-02	4.001E-01	0.000E+00	0.000E+00	0.000E+00	2.705E-01	1.162E+00
1.200E+01	7.535E-01	0.000E+00	8.131E-02	4.264E-01	3.358E-06	0.000E+00	0.000E+00	2.500E-01	1.603E+00
1.300E+01	7.578E-01	0.000E+00	8.151E-02	4.583E-01	8.491E-04	0.000E+00	0.000E+00	2.335E-01	1.577E+00
1.400E+01	7.616E-01	0.000E+00	8.493E-02	4.851E-01	4.486E-03	0.000E+00	0.000E+00	2.264E-01	1.404E+00
1.500E+01	7.642E-01	0.000E+00	8.973E-02	5.335E-01	1.089E-02	0.000E+00	0.000E+00	2.093E-01	1.364E+00
1.600E+01	7.657E-01	0.000E+00	9.911E-02	5.827E-01	1.910E-02	0.000E+00	0.000E+00	2.015E-01	1.294E+00
1.700E+01	7.666E-01	0.000E+00	1.162E-01	6.242E-01	2.795E-02	0.000E+00	0.000E+00	1.956E-01	1.213E+00
1.800E+01	7.667E-01	0.000E+00	1.371E-01	6.540E-01	3.673E-02	3.909E-05	0.000E+00	1.909E-01	1.141E+00
1.900E+01	7.649E-01	0.000E+00	1.565E-01	6.751E-01	4.369E-02	2.261E-04	0.000E+00	1.871E-01	1.095E+00
2.000E+01	7.599E-01	0.000E+00	1.736E-01	6.865E-01	5.102E-02	5.018E-04	0.000E+00	1.842E-01	1.046E+00
2.200E+01	7.444E-01	0.000E+00	1.967E-01	6.941E-01	6.377E-02	1.038E-03	0.000E+00	1.731E-01	1.021E+00
2.400E+01	7.283E-01	0.000E+00	2.139E-01	7.077E-01	7.034E-02	1.491E-03	0.000E+00	1.613E-01	1.030E+00
2.600E+01	7.126E-01	0.000E+00	2.241E-01	7.226E-01	7.965E-02	1.982E-03	0.000E+00	1.455E-01	1.029E+00
2.800E+01	6.986E-01	0.000E+00	2.300E-01	7.313E-01	8.643E-02	2.409E-03	0.000E+00	1.409E-01	1.019E+00
3.000E+01	6.859E-01	0.000E+00	2.422E-01	7.445E-01	9.262E-02	3.135E-03	0.000E+00	1.261E-01	1.002E+00
3.500E+01	6.554E-01	0.000E+00	2.799E-01	7.585E-01	9.769E-02	5.221E-03	0.000E+00	1.129E-01	9.487E-01
4.000E+01	6.262E-01	0.000E+00	3.163E-01	7.515E-01	9.713E-02	6.974E-03	0.000E+00	1.096E-01	9.147E-01
4.500E+01	5.992E-01	0.000E+00	3.452E-01	7.505E-01	9.618E-02	8.260E-03	0.000E+00	1.121E-01	8.632E-01
5.000E+01	5.748E-01	0.000E+00	3.714E-01	7.476E-01	9.334E-02	1.154E-02	0.000E+00	1.228E-01	8.303E-01
5.500E+01	5.440E-01	0.000E+00	3.841E-01	7.376E-01	8.943E-02	1.245E-02	0.000E+00	1.276E-01	7.941E-01
6.000E+01	5.150E-01	0.000E+00	3.940E-01	7.286E-01	8.735E-02	1.295E-02	0.000E+00	1.322E-01	7.403E-01
6.500E+01	4.970E-01	0.000E+00	4.122E-01	7.281E-01	8.634E-02	1.351E-02	0.000E+00	1.389E-01	7.146E-01
7.000E+01	4.796E-01	0.000E+00	4.216E-01	7.212E-01	8.587E-02	1.163E-02	0.000E+00	1.409E-01	6.672E-01
7.500E+01	4.642E-01	0.000E+00	4.332E-01	7.265E-01	8.359E-02	1.221E-02	0.000E+00	1.453E-01	6.425E-01
8.000E+01	4.539E-01	0.000E+00	4.472E-01	7.336E-01	8.427E-02	1.283E-02	0.000E+00	1.511E-01	6.255E-01
8.500E+01	4.448E-01	0.000E+00	4.633E-01	7.388E-01	8.520E-02	1.356E-02	0.000E+00	1.575E-01	6.016E-01
9.000E+01	4.358E-01	0.000E+00	4.762E-01	7.438E-01	8.490E-02	1.427E-02	0.000E+00	1.618E-01	5.909E-01
9.500E+01	4.278E-01	0.000E+00	4.886E-01	7.463E-01	8.656E-02	1.503E-02	0.000E+00	1.646E-01	5.707E-01
1.000E+02	4.207E-01	0.000E+00	4.990E-01	7.543E-01	8.584E-02	1.587E-02	0.000E+00	1.679E-01	5.545E-01
1.100E+02	4.090E-01	0.000E+00	5.171E-01	7.654E-01	8.863E-02	1.760E-02	0.000E+00	1.720E-01	5.328E-01
1.200E+02	4.006E-01	0.000E+00	5.346E-01	7.697E-01	8.917E-02	1.778E-02	0.000E+00	1.723E-01	5.193E-01
1.300E+02	3.985E-01	0.000E+00	5.584E-01	7.932E-01	9.217E-02	2.008E-02	0.000E+00	1.776E-01	5.036E-01
1.400E+02	3.985E-01	0.000E+00	5.842E-01	8.160E-01	9.623E-02	2.258E-02	0.000E+00	1.829E-01	4.951E-01
1.500E+02	3.991E-01	0.000E+00	6.096E-01	8.378E-01	9.999E-02	2.508E-02	0.000E+00	1.870E-01	4.898E-01

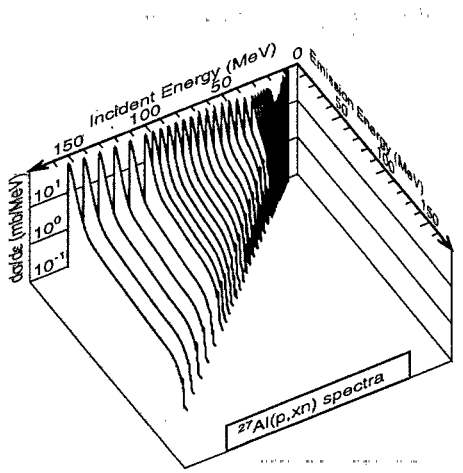
13027 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

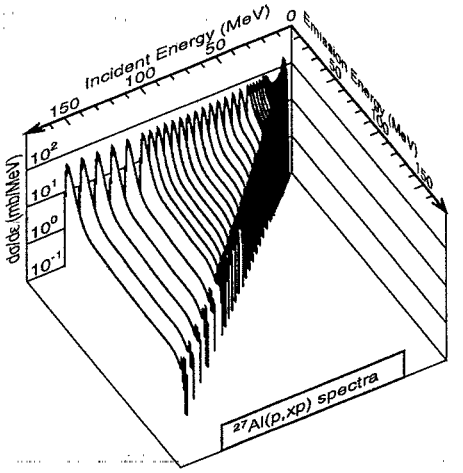
Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
1.000E+00	0.000E+00	1.297E-03	0.000E+00	0.000E+00	0.000E+00	5.188E-03	5.000E-12
2.000E+00	0.000E+00	9.775E-01	0.000E+00	0.000E+00	0.000E+00	2.942E+00	1.762E+00
3.000E+00	0.000E+00	1.135E+00	0.000E+00	0.000E+00	0.000E+00	3.479E+00	1.314E+00
4.000E+00	0.000E+00	1.720E+00	0.000E+00	0.000E+00	0.000E+00	4.133E+00	1.304E+00
5.000E+00	0.000E+00	2.603E+00	0.000E+00	0.000E+00	0.000E+00	4.677E+00	1.426E+00
6.000E+00	1.885E-01	3.415E+00	0.000E+00	0.000E+00	0.000E+00	5.120E+00	1.654E+00
7.000E+00	1.004E+00	4.045E+00	0.000E+00	0.000E+00	0.000E+00	5.427E+00	1.900E+00
8.000E+00	1.628E+00	4.498E+00	0.000E+00	0.000E+00	0.000E+00	5.734E+00	2.137E+00
9.000E+00	1.759E+00	4.870E+00	0.000E+00	0.000E+00	0.000E+00	6.076E+00	2.383E+00
1.000E+01	2.272E+00	5.240E+00	0.000E+00	0.000E+00	0.000E+00	6.275E+00	2.634E+00
1.100E+01	2.601E+00	5.555E+00	0.000E+00	0.000E+00	0.000E+00	6.534E+00	2.850E+00
1.200E+01	2.899E+00	5.874E+00	7.261E-01	0.000E+00	0.000E+00	6.729E+00	2.654E+00
1.300E+01	3.254E+00	6.135E+00	1.547E+00	0.000E+00	0.000E+00	6.924E+00	2.872E+00
1.400E+01	3.441E+00	6.279E+00	2.284E+00	0.000E+00	0.000E+00	7.012E+00	3.284E+00
1.500E+01	3.633E+00	6.375E+00	2.921E+00	0.000E+00	0.000E+00	7.121E+00	3.354E+00
1.600E+01	3.661E+00	6.403E+00	3.455E+00	0.000E+00	0.000E+00	7.093E+00	3.329E+00
1.700E+01	3.537E+00	6.501E+00	4.046E+00	0.000E+00	0.000E+00	7.027E+00	3.229E+00
1.800E+01	3.444E+00	6.706E+00	4.602E+00	1.406E+00	0.000E+00	6.999E+00	3.064E+00
1.900E+01	3.481E+00	6.959E+00	5.136E+00	1.984E+00	0.000E+00	6.974E+00	2.899E+00
2.000E+01	3.510E+00	7.201E+00	5.647E+00	2.713E+00	0.000E+00	7.029E+00	2.789E+00
2.200E+01	3.881E+00	7.830E+00	6.873E+00	3.650E+00	0.000E+00	7.183E+00	2.479E+00
2.400E+01	4.386E+00	8.404E+00	7.967E+00	4.350E+00	0.000E+00	7.461E+00	2.360E+00

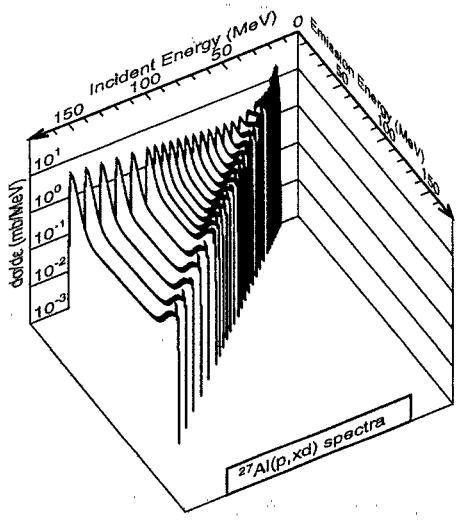
2.600E+01	4.930E+00	8.950E+00	9.168E+00	5.078E+00	0.000E+00	7.700E+00	2.301E+00
2.800E+01	5.504E+00	9.496E+00	1.033E+01	5.760E+00	0.000E+00	7.974E+00	2.277E+00
3.000E+01	5.932E+00	1.004E+01	1.152E+01	6.338E+00	0.000E+00	8.336E+00	2.253E+00
3.500E+01	6.933E+00	1.118E+01	1.451E+01	7.664E+00	0.000E+00	8.721E+00	2.183E+00
4.000E+01	7.849E+00	1.256E+01	1.782E+01	8.970E+00	0.000E+00	8.838E+00	2.173E+00
4.500E+01	8.675E+00	1.365E+01	2.118E+01	1.015E+01	0.000E+00	8.896E+00	2.144E+00
5.000E+01	9.317E+00	1.471E+01	2.407E+01	1.029E+01	0.000E+00	8.829E+00	2.127E+00
5.500E+01	1.008E+01	1.576E+01	2.691E+01	1.131E+01	0.000E+00	8.807E+00	2.127E+00
6.000E+01	1.074E+01	1.659E+01	2.971E+01	1.223E+01	0.000E+00	8.822E+00	2.101E+00
6.500E+01	1.136E+01	1.751E+01	3.225E+01	1.302E+01	0.000E+00	8.824E+00	2.091E+00
7.000E+01	1.217E+01	1.854E+01	3.514E+01	1.463E+01	0.000E+00	8.861E+00	2.083E+00
7.500E+01	1.286E+01	1.935E+01	3.705E+01	1.512E+01	0.000E+00	8.907E+00	2.099E+00
8.000E+01	1.347E+01	2.012E+01	3.935E+01	1.546E+01	0.000E+00	8.975E+00	2.102E+00
8.500E+01	1.405E+01	2.091E+01	4.143E+01	1.559E+01	0.000E+00	8.969E+00	2.091E+00
9.000E+01	1.473E+01	2.171E+01	4.294E+01	1.563E+01	0.000E+00	9.040E+00	2.126E+00
9.500E+01	1.538E+01	2.240E+01	4.499E+01	1.557E+01	0.000E+00	9.122E+00	2.103E+00
1.000E+02	1.611E+01	2.322E+01	4.602E+01	1.549E+01	0.000E+00	9.225E+00	2.129E+00
1.100E+02	1.741E+01	2.471E+01	4.957E+01	1.514E+01	0.000E+00	9.396E+00	2.150E+00
1.200E+02	1.899E+01	2.670E+01	5.306E+01	1.462E+01	0.000E+00	9.587E+00	2.169E+00
1.300E+02	2.042E+01	2.820E+01	5.519E+01	1.413E+01	0.000E+00	9.790E+00	2.190E+00
1.400E+02	2.162E+01	2.978E+01	5.758E+01	1.365E+01	0.000E+00	9.955E+00	2.203E+00
1.500E+02	2.291E+01	3.135E+01	5.927E+01	1.328E+01	0.000E+00	1.014E+01	2.212E+00

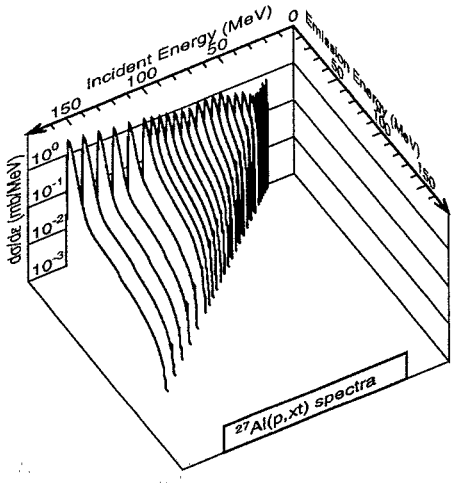

p + 27Al nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
p
n
γ
α
d
t
Nonelastic Cross Section (mb)
10^2
10^1
0
50
100
150
Incident Energy (MeV)

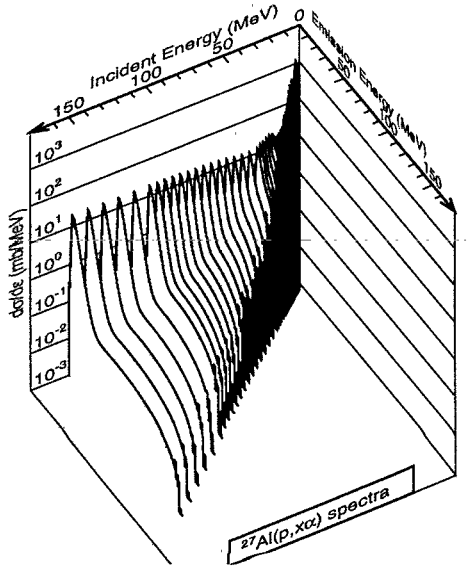
p + ^{27}Al angle-integrated emission spectra

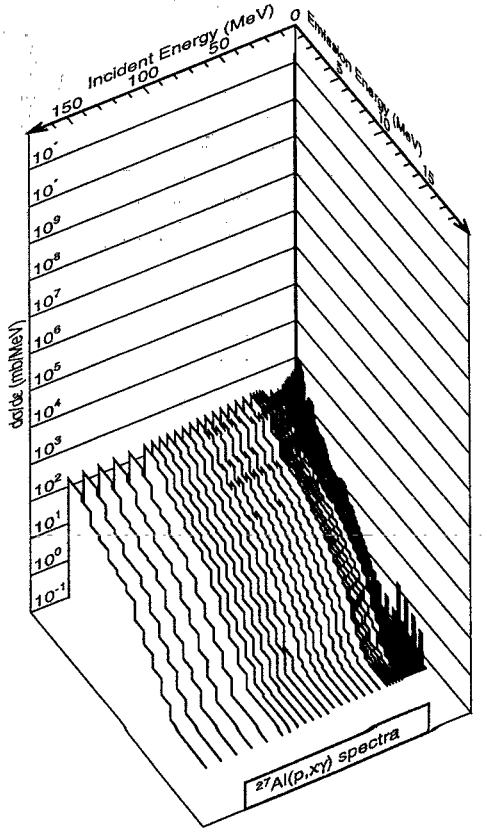




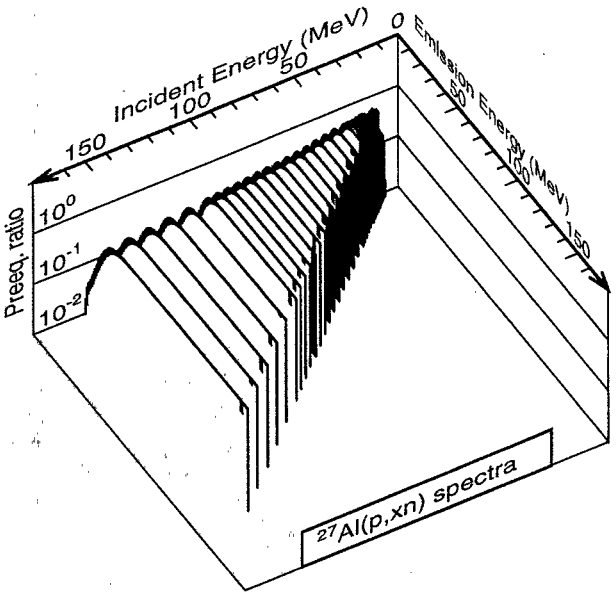


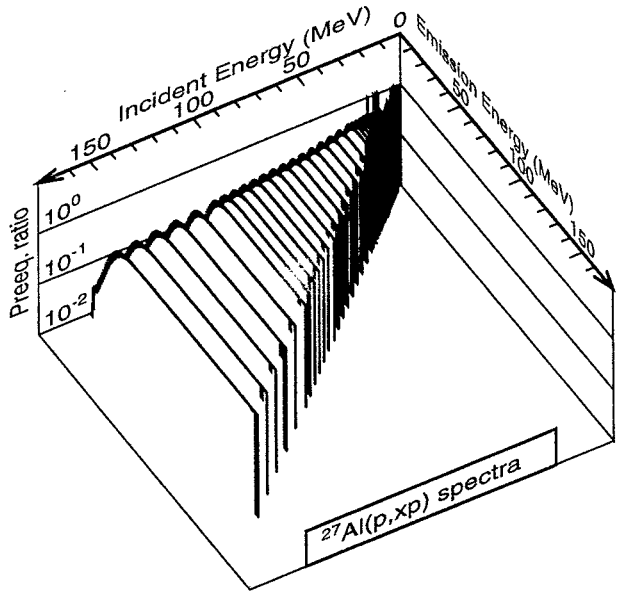


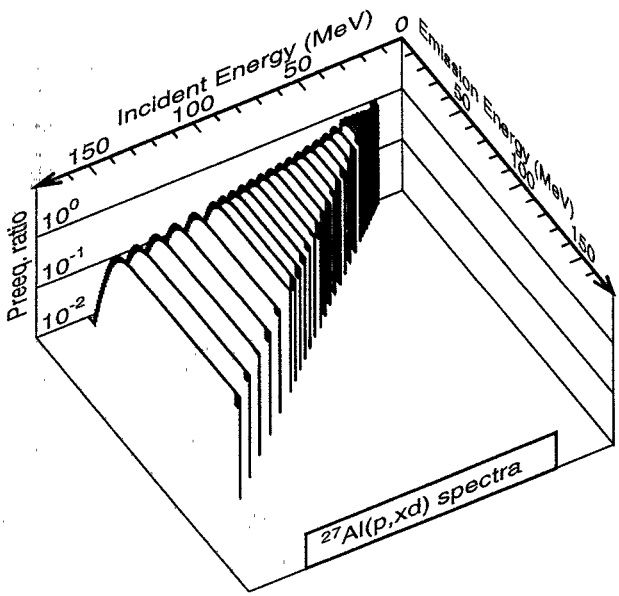


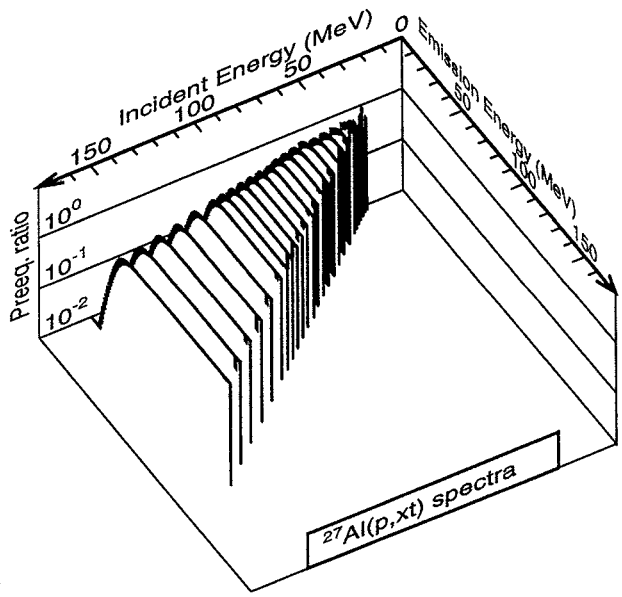


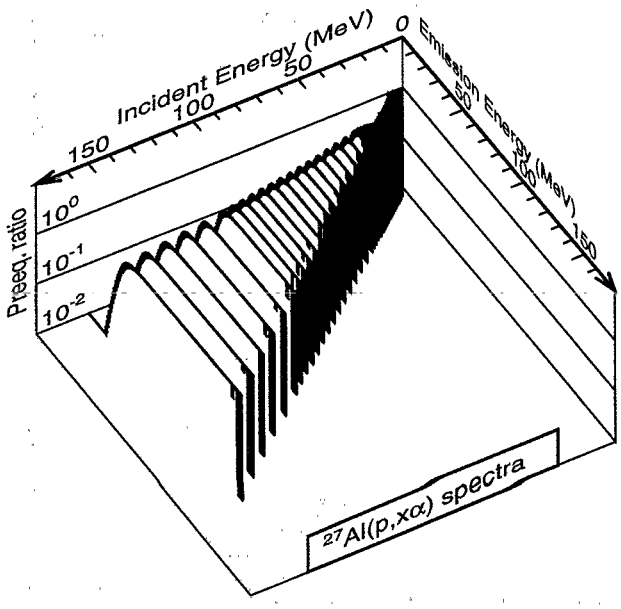
p + ^{27}Al Kalbach preequilibrium ratios

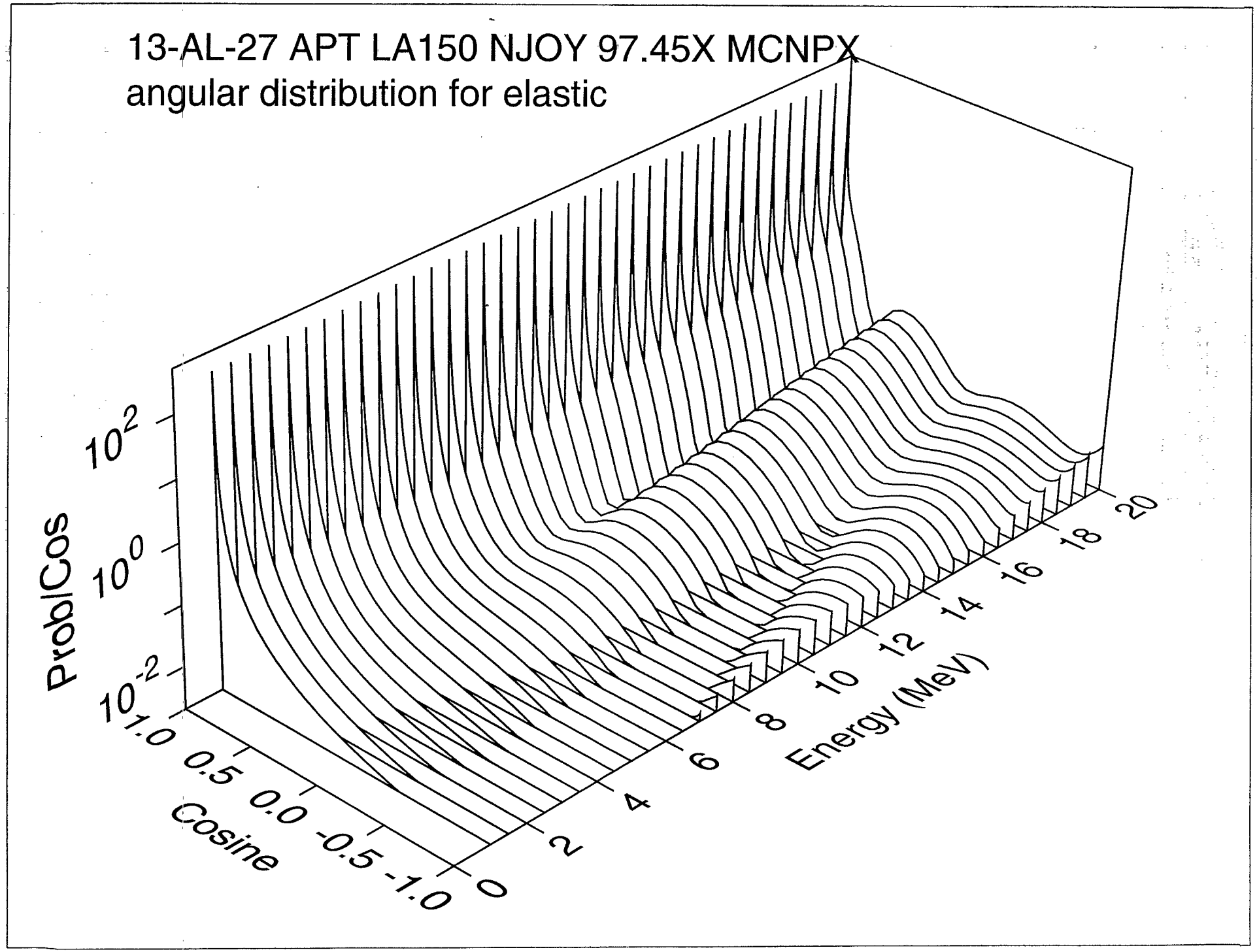


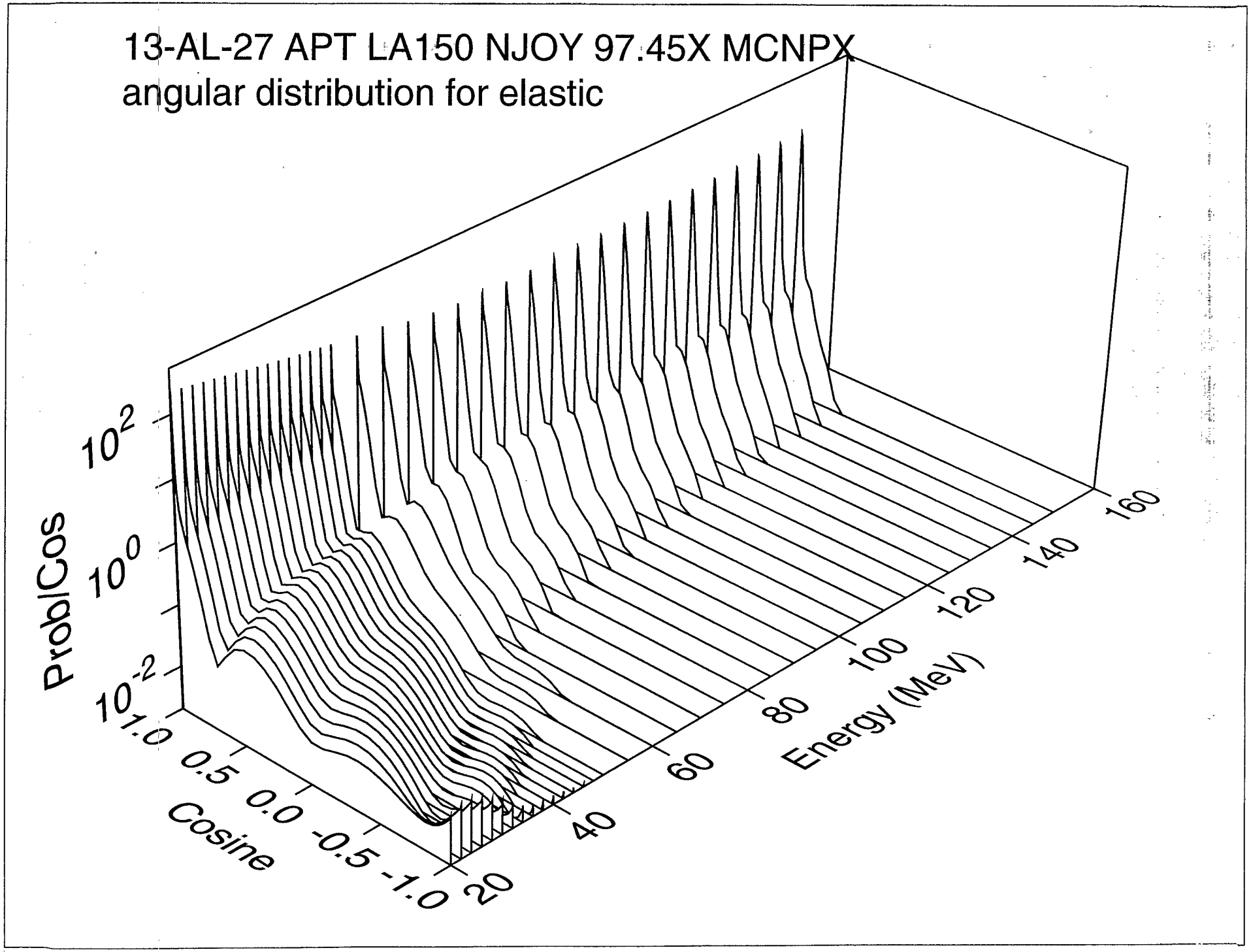


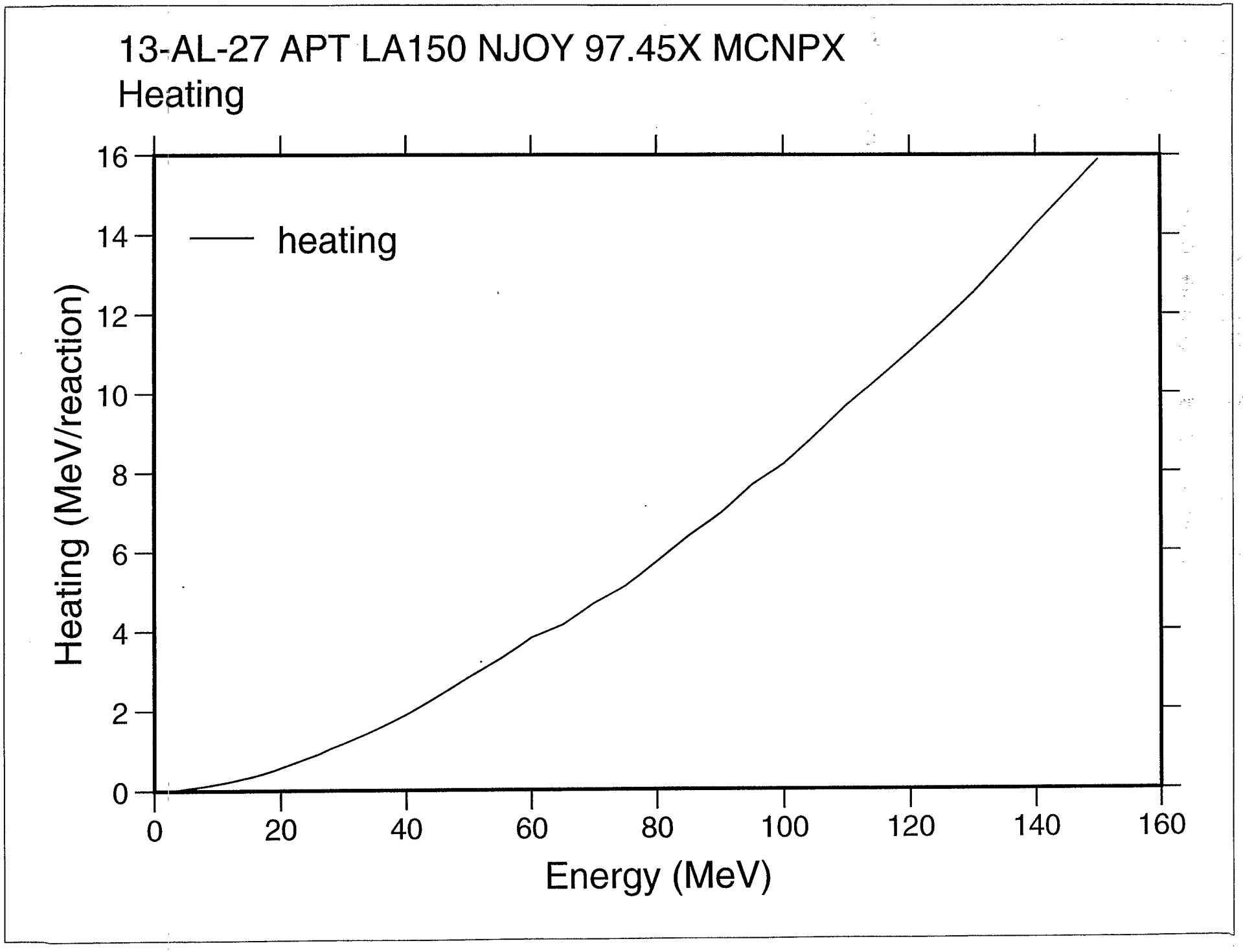







13-AL-27 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
ProblCos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
0
2
4
6
8
10
12
14
16
18
20


13-AL-27 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
ProblCos
10^2
10^0
10^{-2}
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


13-AL-27 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
2
4
6
8
10
12
14
16
0
20
40
60
80
100
120
140
160

EVALUATION OF p + 28Si CROSS SECTIONS FOR THE ENERGY RANGE 1 to 150 MeV

M. B. Chadwick and P. G. Young
1 July 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident proton energy range from 1 to 150 MeV. The evaluation utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above are:

MF=3	MT= 2	Integral of nuclear plus interference components of the elastic scattering cross section
	MT= 5	Sum of binary (p,n') and (p,x) reactions
MF=6	MT= 2	Elastic (p,p) angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
	MT= 5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Si28 and p + Si28 reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic proton angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission

coefficients were calculated using the Kopecky-Uhl model (Ko90).

DETAILS OF THE p + SI-28 ANALYSIS

The Madland global medium-energy optical potential (Ma88) was used for neutrons above 46 MeV, and the Wilmore-Hodgson potential was used for lower neutron energies. The Madland global medium-energy optical potential was used for protons above 28 MeV, and the Beccheti-Greenlees potential was used for lower proton energies. In both cases the transition region to the Madland potential was chosen to approximately give continuity in the reaction cross section. For deuterons, the Perey global potential was used; for alpha particles the Moyen potential was used; and for tritons the Beccheti-Greenlees potential was used.

While the above optical potentials did describe the experimental proton nonelastic cross section data fairly well, we modified the theoretical predictions slightly to better agree with the measurements, and renormalized the transmission coefficients accordingly. In addition to using Si nonelastic proton cross section measurements, we also were guided by p+Al nonelastic data, scaled by A**2/3.

Coupled-channel optical model calculations were performed to determine inelastic scattering on 28Si, for the 0+, 2+, and 4+ states, as well as a DWBA calculation of the inelastic scattering to the 3- vibrational state, all performed with the ECIS code. Near 20 MeV neutron energy, neutron inelastic scattering to these states has been measured by Alarcon and Rapaport, and Finlay et al., from Ohio University, and the inelastic cross sections to these collective states is in good agreement with the ORNL ENDF evaluation for 28Si. We performed a rotational band (0+, 2+, 4+) coupled channel calculation using the Madland medium energy potential at higher energies and Beccheti-Greenlees at lower energies (with their imaginary potentials reduced by 20%, to approximately account for the coupling). Deformation parameters were chosen to reproduce the ENDF/B-VI neutron cross sections at 20 MeV, resulting in values of beta-2=-0.365, beta-4=+0.22, in good agreement with Rapaport's values of -0.37, 0.17 respectively. A vibrational DWBA calculation (using ECIS) was performed for the 3- state resulting in beta-3=0.235 (Rapaport obtained 0.23). These same beta values were used for the proton-inelastic scattering calculations.

The calculated emission spectra were indirectly benchmarked by comparing neutron-induced calculations with neutron-induced data. Only 2 measurements exist for neutron-induced emission spectra above 20 MeV for 28Si. New data have been published by the Louvain group at the 1997 Trieste conference for 63 MeV Si(n,xz) double-differential spectra (z=p,d,a ejectiles). Additionally, Haight et al. of Los Alamos have preliminary data for Si(n,xp), for neutrons up to 50 MeV, including emission spectra at four angles. Our calculations agree reasonably well with these measurements. While default level density parameters (using the Ignatyuk model) were utilized, in the case of 28Al the level density parameter was slightly modified to optimize agreement with the Abfalterer total level density measurements based on fluctuation analyses (Ab93).

As an independent validation of our GNASH calculations using the exciton model, we have also performed FKK calculations. This was done by implementing a multistep reaction theory recently

developed by Koning and Chadwick, which is particularly suited to the simultaneous calculation of neutron and proton emission. The FKK theory describes the forward-peaking very well, as do our exciton model calculations using the phenomenological Kalbach angular distribution systematics.

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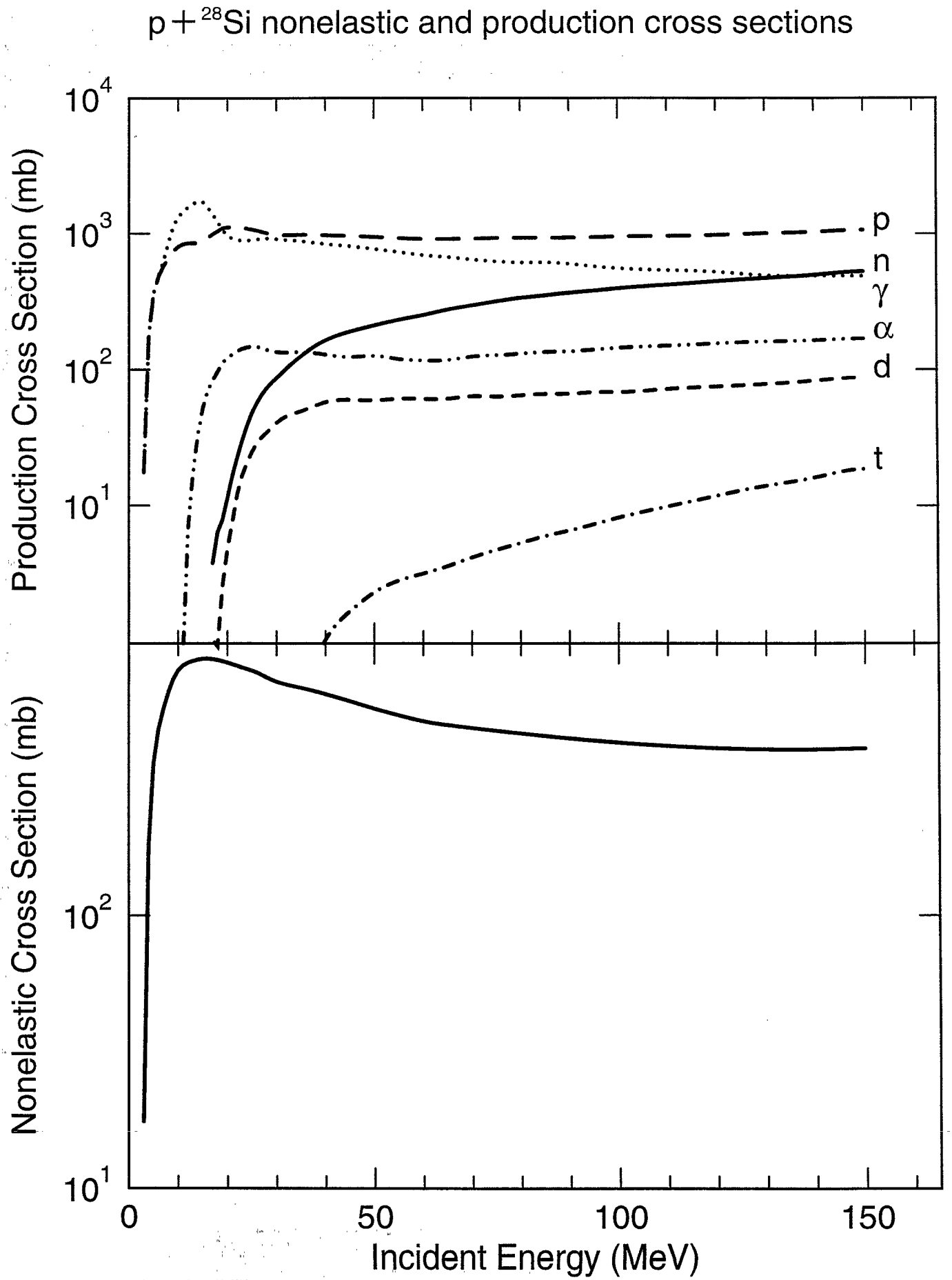
14028 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
3.000E+00	1.751E-02	0.000E+00	0.000E+00	1.751E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.751E-02
4.000E+00	1.813E-01	0.000E+00	0.000E+00	1.813E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.813E-01
5.000E+00	3.639E-01	0.000E+00	0.000E+00	3.639E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.639E-01
6.000E+00	4.831E-01	0.000E+00	0.000E+00	4.831E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.855E-01
7.000E+00	5.731E-01	0.000E+00	0.000E+00	5.731E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	6.268E-01
8.000E+00	6.603E-01	0.000E+00	0.000E+00	6.603E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	8.494E-01
9.000E+00	7.421E-01	0.000E+00	0.000E+00	7.421E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.127E+00
1.000E+01	7.967E-01	0.000E+00	0.000E+00	7.966E-01	0.000E+00	0.000E+00	0.000E+00	1.264E-05	1.318E+00
1.100E+01	8.319E-01	0.000E+00	0.000E+00	8.311E-01	0.000E+00	0.000E+00	0.000E+00	7.743E-04	1.452E+00
1.200E+01	8.507E-01	0.000E+00	0.000E+00	8.438E-01	0.000E+00	0.000E+00	0.000E+00	6.848E-03	1.556E+00
1.300E+01	8.632E-01	0.000E+00	0.000E+00	8.460E-01	0.000E+00	0.000E+00	0.000E+00	1.748E-02	1.651E+00
1.400E+01	8.723E-01	0.000E+00	0.000E+00	8.448E-01	0.000E+00	0.000E+00	0.000E+00	3.345E-02	1.716E+00
1.500E+01	8.779E-01	0.000E+00	0.000E+00	8.671E-01	0.000E+00	0.000E+00	0.000E+00	5.230E-02	1.704E+00
1.600E+01	8.786E-01	0.000E+00	1.641E-03	9.231E-01	6.560E-10	0.000E+00	0.000E+00	6.989E-02	1.564E+00
1.700E+01	8.752E-01	0.000E+00	3.818E-03	9.867E-01	9.884E-05	0.000E+00	0.000E+00	8.364E-02	1.383E+00
1.800E+01	8.689E-01	0.000E+00	6.367E-03	1.037E+00	9.545E-04	0.000E+00	0.000E+00	9.655E-02	1.222E+00
1.900E+01	8.601E-01	0.000E+00	7.874E-03	1.092E+00	2.592E-03	0.000E+00	0.000E+00	1.120E-01	1.062E+00
2.000E+01	8.501E-01	0.000E+00	1.130E-02	1.107E+00	4.799E-03	0.000E+00	0.000E+00	1.216E-01	9.622E-01
2.200E+01	8.279E-01	0.000E+00	2.254E-02	1.108E+00	1.201E-02	0.000E+00	0.000E+00	1.369E-01	8.918E-01
2.400E+01	8.053E-01	0.000E+00	3.867E-02	1.085E+00	2.061E-02	2.034E-07	0.000E+00	1.453E-01	8.829E-01
2.600E+01	7.822E-01	0.000E+00	5.673E-02	1.050E+00	2.879E-02	1.175E-05	0.000E+00	1.470E-01	8.991E-01
2.800E+01	7.502E-01	0.000E+00	7.280E-02	1.004E+00	3.432E-02	5.065E-05	0.000E+00	1.392E-01	9.149E-01
3.000E+01	7.240E-01	0.000E+00	8.655E-02	9.758E-01	4.049E-02	1.166E-04	0.000E+00	1.342E-01	9.041E-01
3.500E+01	6.860E-01	0.000E+00	1.256E-01	9.764E-01	4.918E-02	4.319E-04	0.000E+00	1.344E-01	8.748E-01
4.000E+01	6.503E-01	0.000E+00	1.639E-01	9.705E-01	5.773E-02	1.063E-03	0.000E+00	1.290E-01	8.343E-01
4.500E+01	6.126E-01	0.000E+00	1.905E-01	9.589E-01	6.005E-02	1.710E-03	0.000E+00	1.239E-01	8.043E-01
5.000E+01	5.753E-01	0.000E+00	2.117E-01	9.420E-01	5.956E-02	2.347E-03	0.000E+00	1.262E-01	7.682E-01
5.500E+01	5.437E-01	0.000E+00	2.327E-01	9.239E-01	6.103E-02	2.853E-03	0.000E+00	1.196E-01	7.313E-01
6.000E+01	5.171E-01	0.000E+00	2.522E-01	9.105E-01	6.084E-02	3.208E-03	0.000E+00	1.166E-01	6.934E-01
6.500E+01	5.007E-01	0.000E+00	2.768E-01	9.096E-01	6.108E-02	3.635E-03	0.000E+00	1.175E-01	6.714E-01
7.000E+01	4.882E-01	0.000E+00	2.972E-01	9.161E-01	6.366E-02	4.184E-03	0.000E+00	1.247E-01	6.442E-01
7.500E+01	4.764E-01	0.000E+00	3.181E-01	9.268E-01	6.322E-02	4.761E-03	0.000E+00	1.277E-01	6.240E-01
8.000E+01	4.656E-01	0.000E+00	3.369E-01	9.292E-01	6.458E-02	5.337E-03	0.000E+00	1.309E-01	6.112E-01
8.500E+01	4.555E-01	0.000E+00	3.509E-01	9.287E-01	6.609E-02	5.991E-03	0.000E+00	1.347E-01	6.123E-01
9.000E+01	4.464E-01	0.000E+00	3.670E-01	9.322E-01	6.630E-02	6.574E-03	0.000E+00	1.360E-01	5.978E-01
9.500E+01	4.383E-01	0.000E+00	3.800E-01	9.395E-01	6.805E-02	7.318E-03	0.000E+00	1.400E-01	5.733E-01
1.000E+02	4.311E-01	0.000E+00	3.953E-01	9.506E-01	6.821E-02	8.175E-03	0.000E+00	1.441E-01	5.542E-01
1.100E+02	4.194E-01	0.000E+00	4.196E-01	9.589E-01	7.191E-02	9.850E-03	0.000E+00	1.493E-01	5.352E-01
1.200E+02	4.112E-01	0.000E+00	4.453E-01	9.756E-01	7.501E-02	1.181E-02	0.000E+00	1.551E-01	5.207E-01
1.300E+02	4.070E-01	0.000E+00	4.704E-01	1.004E+00	7.822E-02	1.395E-02	0.000E+00	1.604E-01	4.903E-01
1.400E+02	4.068E-01	0.000E+00	4.955E-01	1.030E+00	8.302E-02	1.612E-02	0.000E+00	1.640E-01	4.880E-01
1.500E+02	4.102E-01	0.000E+00	5.248E-01	1.066E+00	8.761E-02	1.858E-02	0.000E+00	1.689E-01	4.873E-01

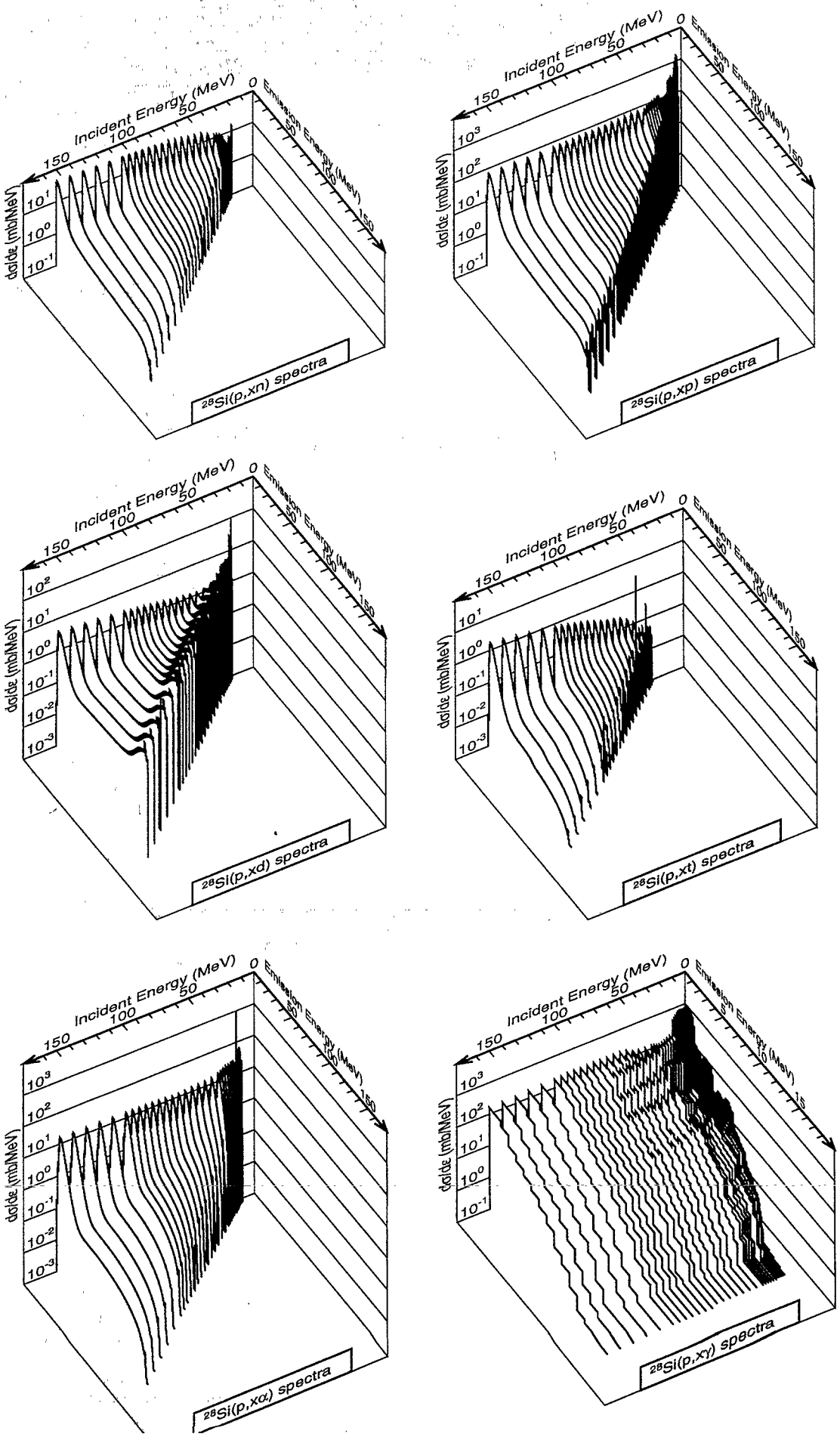
14028 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
3.000E+00	0.000E+00	9.689E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.750E+00
4.000E+00	0.000E+00	1.936E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.750E+00
5.000E+00	0.000E+00	2.903E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.750E+00
6.000E+00	0.000E+00	3.858E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.755E+00
7.000E+00	0.000E+00	4.574E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.852E+00
8.000E+00	0.000E+00	4.887E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.075E+00
9.000E+00	0.000E+00	4.740E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.514E+00
1.000E+01	0.000E+00	4.739E+00	0.000E+00	0.000E+00	0.000E+00	1.623E+00	2.841E+00
1.100E+01	0.000E+00	4.764E+00	0.000E+00	0.000E+00	0.000E+00	2.505E+00	3.174E+00
1.200E+01	0.000E+00	4.998E+00	0.000E+00	0.000E+00	0.000E+00	3.222E+00	3.377E+00
1.300E+01	0.000E+00	5.332E+00	0.000E+00	0.000E+00	0.000E+00	3.916E+00	3.516E+00
1.400E+01	0.000E+00	5.727E+00	0.000E+00	0.000E+00	0.000E+00	4.069E+00	3.616E+00
1.500E+01	0.000E+00	5.999E+00	0.000E+00	0.000E+00	0.000E+00	3.890E+00	3.657E+00
1.600E+01	1.784E-01	6.104E+00	4.409E-01	0.000E+00	0.000E+00	3.823E+00	3.655E+00
1.700E+01	9.800E-01	6.215E+00	1.364E+00	0.000E+00	0.000E+00	3.903E+00	3.611E+00
1.800E+01	1.416E+00	6.392E+00	2.140E+00	0.000E+00	0.000E+00	4.043E+00	3.509E+00
1.900E+01	1.686E+00	6.490E+00	2.804E+00	0.000E+00	0.000E+00	3.990E+00	3.387E+00
2.000E+01	2.072E+00	6.772E+00	3.111E+00	0.000E+00	0.000E+00	4.374E+00	3.384E+00
2.200E+01	2.561E+00	7.479E+00	4.417E+00	0.000E+00	0.000E+00	4.914E+00	3.113E+00
2.400E+01	3.037E+00	8.106E+00	5.578E+00	9.749E-01	0.000E+00	5.306E+00	2.933E+00
2.600E+01	3.577E+00	8.763E+00	6.714E+00	2.713E+00	0.000E+00	5.627E+00	2.848E+00
2.800E+01	4.162E+00	9.399E+00	7.888E+00	3.473E+00	0.000E+00	6.119E+00	2.853E+00
3.000E+01	4.726E+00	9.988E+00	9.073E+00	4.360E+00	0.000E+00	6.493E+00	2.869E+00
3.500E+01	5.889E+00	1.073E+01	1.192E+01	6.596E+00	0.000E+00	7.135E+00	2.797E+00

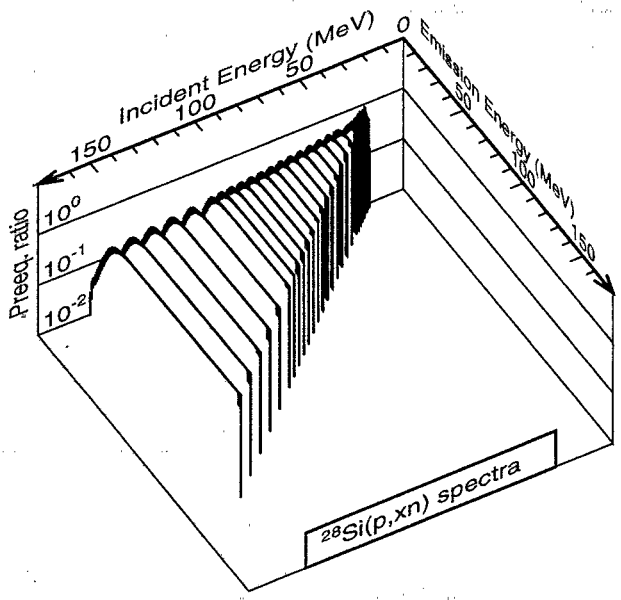
4.000E+01	7.028E+00	1.158E+01	1.509E+01	7.613E+00	0.000E+00	7.487E+00	2.573E+00
4.500E+01	8.162E+00	1.239E+01	1.813E+01	8.612E+00	0.000E+00	7.898E+00	2.412E+00
5.000E+01	9.133E+00	1.307E+01	2.119E+01	9.517E+00	0.000E+00	8.335E+00	2.330E+00
5.500E+01	1.010E+01	1.388E+01	2.434E+01	1.051E+01	0.000E+00	8.632E+00	2.277E+00
6.000E+01	1.095E+01	1.469E+01	2.711E+01	1.141E+01	0.000E+00	8.937E+00	2.225E+00
6.500E+01	1.167E+01	1.550E+01	2.985E+01	1.214E+01	0.000E+00	9.166E+00	2.208E+00
7.000E+01	1.234E+01	1.604E+01	3.254E+01	1.245E+01	0.000E+00	9.322E+00	2.168E+00
7.500E+01	1.305E+01	1.672E+01	3.455E+01	1.271E+01	0.000E+00	9.454E+00	2.151E+00
8.000E+01	1.375E+01	1.739E+01	3.686E+01	1.278E+01	0.000E+00	9.598E+00	2.115E+00
8.500E+01	1.456E+01	1.813E+01	3.897E+01	1.282E+01	0.000E+00	9.724E+00	2.129E+00
9.000E+01	1.540E+01	1.886E+01	4.059E+01	1.292E+01	0.000E+00	9.797E+00	2.129E+00
9.500E+01	1.612E+01	1.949E+01	4.259E+01	1.279E+01	0.000E+00	9.871E+00	2.086E+00
1.000E+02	1.681E+01	2.011E+01	4.359E+01	1.256E+01	0.000E+00	9.940E+00	2.073E+00
1.100E+02	1.823E+01	2.144E+01	4.687E+01	1.214E+01	0.000E+00	1.017E+01	2.074E+00
1.200E+02	1.964E+01	2.268E+01	4.889E+01	1.177E+01	0.000E+00	1.039E+01	2.104E+00
1.300E+02	2.101E+01	2.390E+01	5.059E+01	1.145E+01	0.000E+00	1.059E+01	2.070E+00
1.400E+02	2.239E+01	2.520E+01	5.296E+01	1.122E+01	0.000E+00	1.084E+01	2.083E+00
1.500E+02	2.378E+01	2.643E+01	5.419E+01	1.106E+01	0.000E+00	1.107E+01	2.116E+00

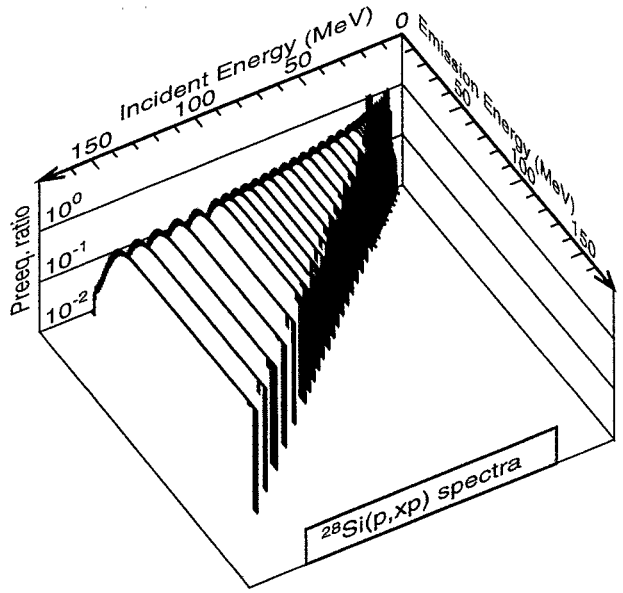

p + 28Si nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
p
n
γ
α
d
t
Nonelastic Cross Section (mb)
10^2
10^1
0
50
100
150
Incident Energy (MeV)

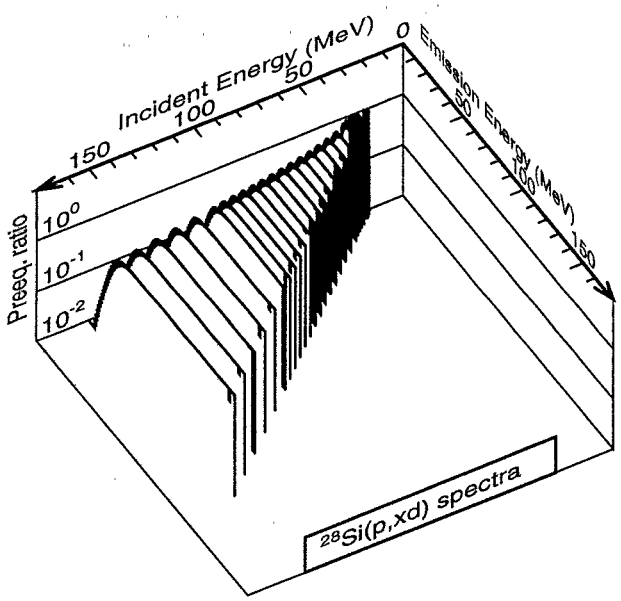
p + ^{28}Si angle-integrated emission spectra

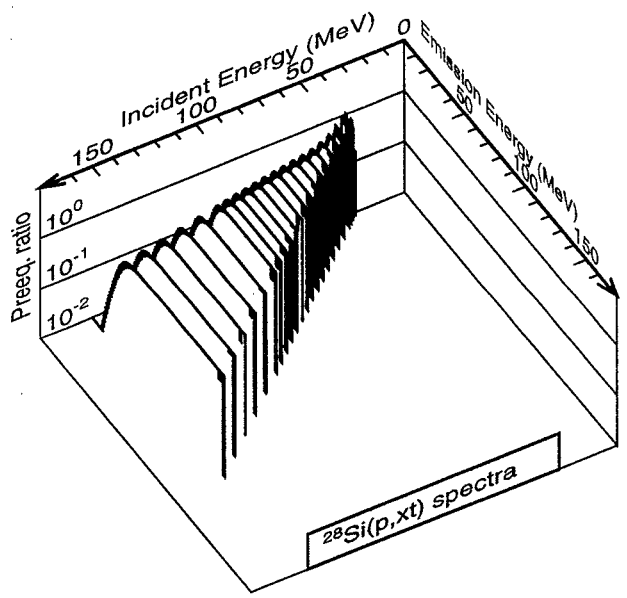


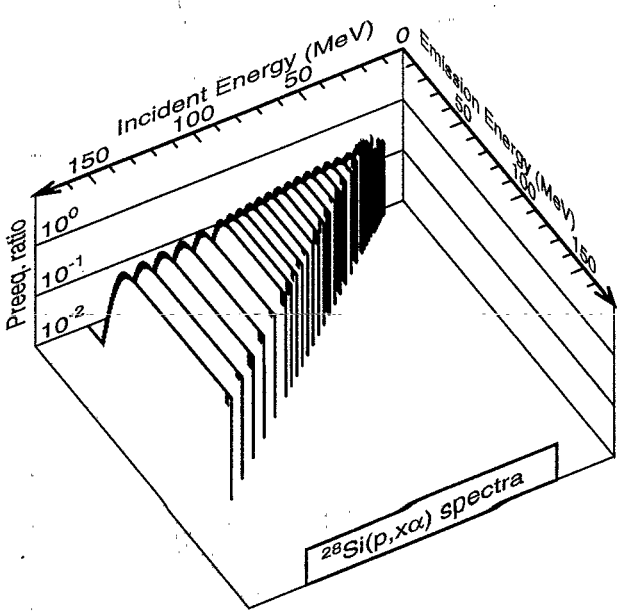
p + ^{28}Si Kalbach preequilibrium ratios

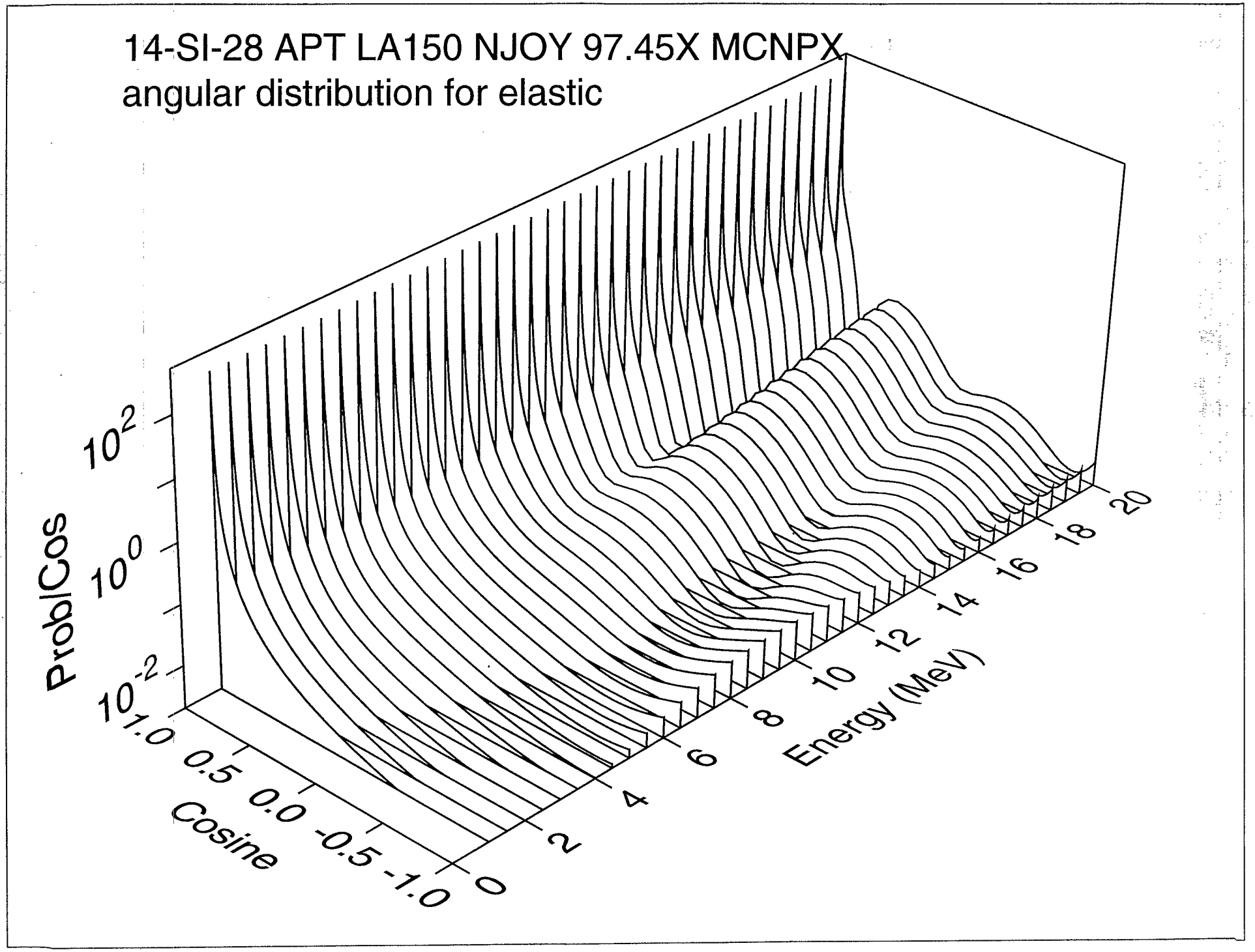


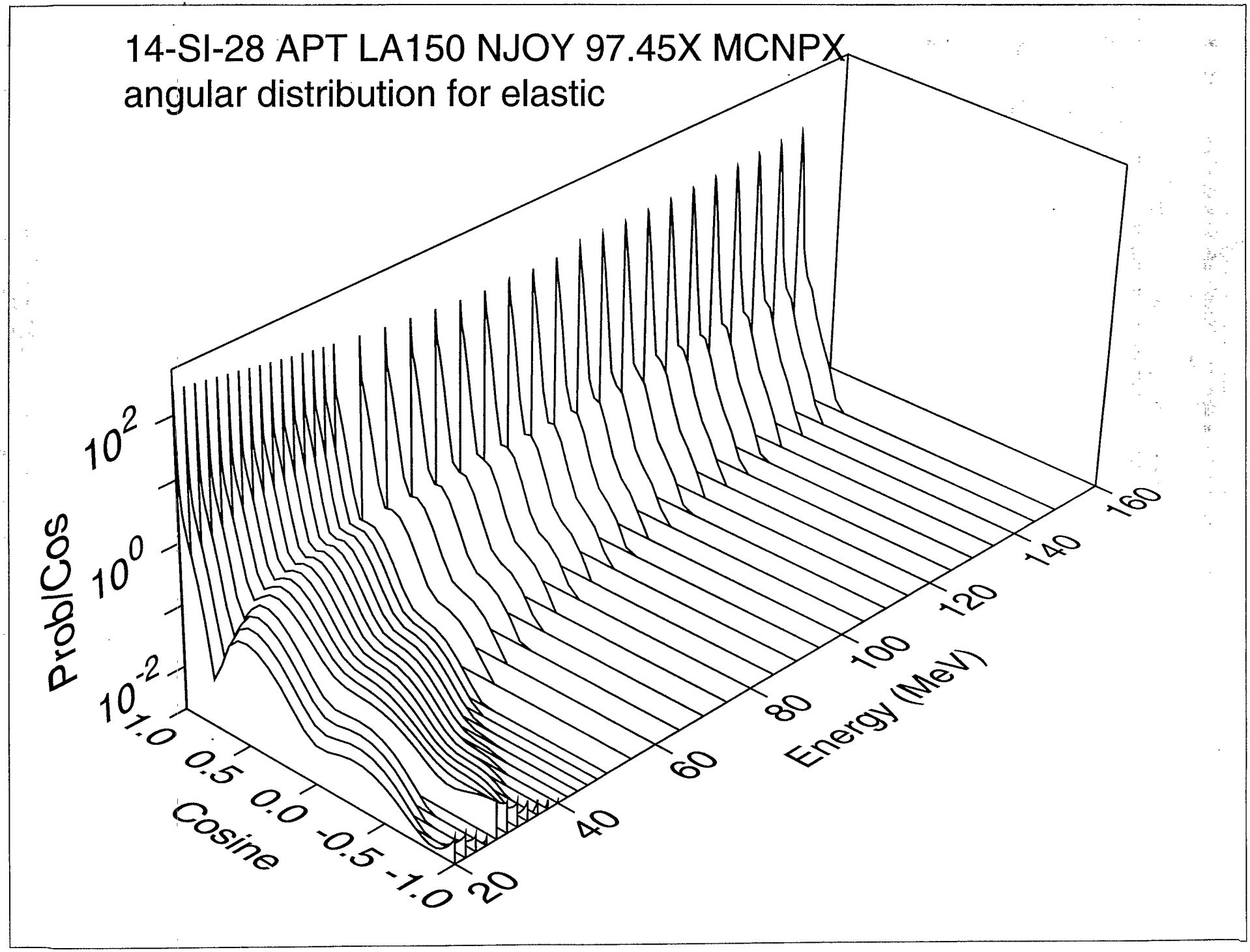


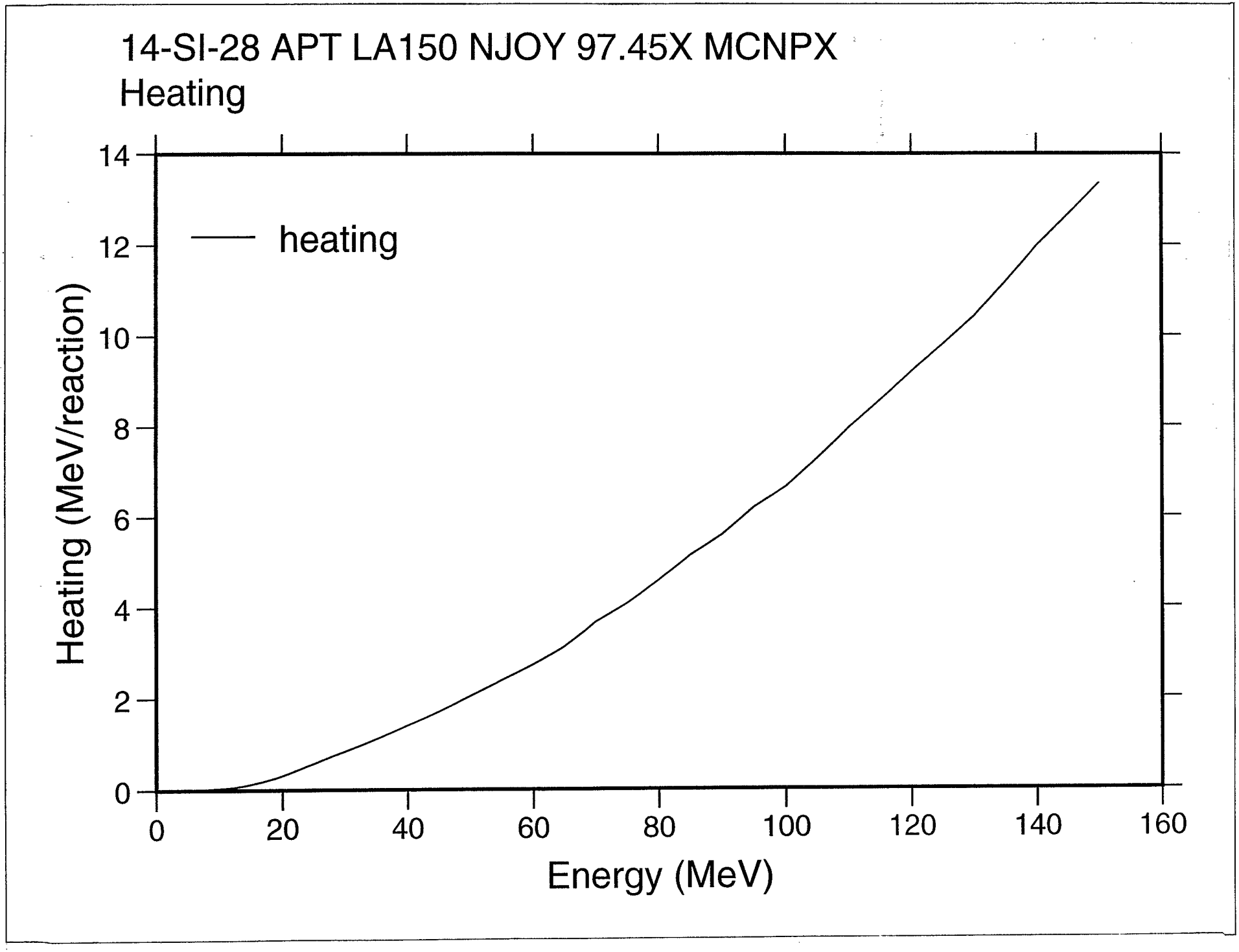







14-SI-28 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
ProblCos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
0
2
4
6
8
10
12
14
16
18
20


14-SI-28 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
ProblCos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
20
40
60
80
100
120
140
160


14-SI-28 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
2
4
6
8
10
12
14
0
20
40
60
80
100
120
140
160

EVALUATION OF p + 29Si CROSS SECTIONS FOR THE ENERGY RANGE 1 to 150 MeV

M. B. Chadwick and P. G. Young
1 July 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident proton energy range from 1 to 150 MeV. The evaluation utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above are:

MF=3	MT= 2	Integral of nuclear plus interference components of the elastic scattering cross section
	MT= 5	Sum of binary (p,n') and (p,x) reactions
MF=6	MT= 2	Elastic (p,p) angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
	MT= 5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Si28 and p + Si28 reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic proton angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77,

Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

DETAILS OF THE p + SI-29 ANALYSIS

The Madland global medium-energy optical potential (Ma88) was used for neutrons above 46 MeV, and the Wilmore-Hodgson (Wi64) potential was used for lower neutron energies. The Madland global medium-energy optical potential was used for protons above 28 MeV, and the Beccheti-Greenlees (Be69) potential was used for lower proton energies. In both cases the transition region to the Madland potential was chosen to approximately give continuity in the reaction cross section. For deuterons, the Perey global potential was used; for alpha particles the MacFadden (Ma66) potential was used; and for tritons the Beccheti-Greenlees (Be71) potential was used.

While the above optical potentials did describe the experimental proton nonelastic cross section data fairly well, we modified the theoretical predictions slightly to better agree with the measurements, and renormalized the transmission coefficients accordingly. In addition to using Si nonelastic proton cross section measurements, we also were guided by p+Al nonelastic data, scaled by A**2/3. The Si-29 nonelastic cross section was taken by scaling the evaluated Si-28 value by 1.02036 (an A**2/3 factor).

Above 20 MeV, the same proton inelastic cross sections were used as for n+Si29 (the 3/2+ and 5/2+ levels - this is a reasonable approximation for energies well above the Coulomb barrier) - see our n+29Si ENDF file-1 documentation. At lower energies the 20-MeV cross sections were modified according to the shape obtained from our coupled-channel calculations for p+28Si. This approximate treatment is sufficiently accurate for most applications due to the small relative abundance of 29-Si.

The same preequilibrium input parameters were used as for Si-28, which was benchmarked, indirectly, by comparing neutron-induced calculated cross sections against (n,xz) data from the Louvain group at 63 MeV, and against unpublished (n,xp) data by Haight et al. for neutrons up to 50 MeV. See our ENDF file-1 for p+28Si for more details.

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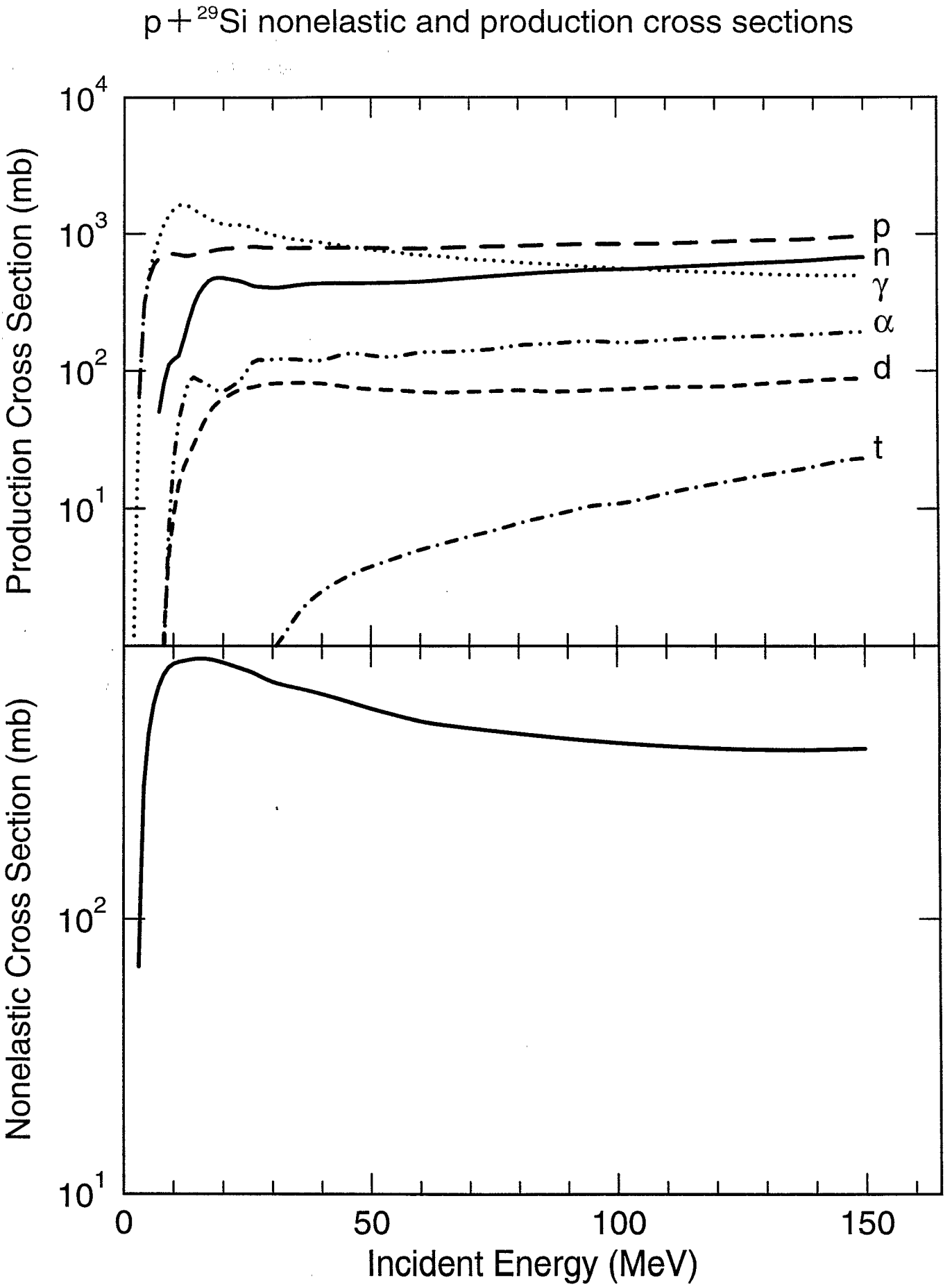
14029 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+00	1.189E-03	0.000E+00	0.000E+00	1.189E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.189E-03
3.000E+00	6.729E-02	0.000E+00	0.000E+00	6.728E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	6.731E-02
4.000E+00	3.013E-01	0.000E+00	0.000E+00	3.013E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.022E-01
5.000E+00	4.763E-01	0.000E+00	0.000E+00	4.762E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	5.069E-01
6.000E+00	6.092E-01	0.000E+00	1.297E-02	5.962E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	7.288E-01
7.000E+00	7.106E-01	0.000E+00	5.032E-02	6.602E-01	1.144E-07	0.000E+00	0.000E+00	1.009E-05	9.289E-01
8.000E+00	7.869E-01	0.000E+00	8.188E-02	7.033E-01	1.118E-03	0.000E+00	0.000E+00	6.082E-04	1.170E+00
9.000E+00	8.351E-01	0.000E+00	1.113E-01	7.124E-01	4.443E-03	0.000E+00	0.000E+00	6.937E-03	1.370E+00
1.000E+01	8.625E-01	0.000E+00	1.216E-01	7.091E-01	9.074E-03	0.000E+00	0.000E+00	2.312E-02	1.517E+00
1.100E+01	8.759E-01	0.000E+00	1.293E-01	6.997E-01	1.498E-02	0.000E+00	0.000E+00	4.387E-02	1.621E+00
1.200E+01	8.831E-01	0.000E+00	1.702E-01	6.879E-01	1.994E-02	0.000E+00	0.000E+00	6.234E-02	1.639E+00
1.300E+01	8.904E-01	0.000E+00	2.305E-01	6.865E-01	2.430E-02	0.000E+00	0.000E+00	8.454E-02	1.590E+00
1.400E+01	8.973E-01	0.000E+00	2.991E-01	7.012E-01	2.912E-02	0.000E+00	0.000E+00	8.984E-02	1.513E+00
1.500E+01	9.011E-01	0.000E+00	3.624E-01	7.170E-01	3.512E-02	0.000E+00	0.000E+00	8.588E-02	1.431E+00
1.600E+01	9.009E-01	0.000E+00	4.094E-01	7.273E-01	4.180E-02	0.000E+00	0.000E+00	8.295E-02	1.367E+00
1.700E+01	8.967E-01	0.000E+00	4.497E-01	7.373E-01	4.889E-02	0.000E+00	0.000E+00	7.886E-02	1.294E+00
1.800E+01	8.900E-01	0.000E+00	4.694E-01	7.518E-01	5.498E-02	0.000E+00	0.000E+00	7.400E-02	1.241E+00
1.900E+01	8.806E-01	0.000E+00	4.757E-01	7.644E-01	5.931E-02	6.317E-06	0.000E+00	7.130E-02	1.203E+00
2.000E+01	8.703E-01	0.000E+00	4.718E-01	7.730E-01	6.252E-02	8.360E-05	0.000E+00	7.127E-02	1.168E+00
2.200E+01	8.476E-01	0.000E+00	4.579E-01	7.819E-01	6.933E-02	3.064E-04	0.000E+00	7.854E-02	1.158E+00
2.400E+01	8.244E-01	0.000E+00	4.405E-01	7.911E-01	7.401E-02	4.949E-04	0.000E+00	9.036E-02	1.150E+00
2.600E+01	8.007E-01	0.000E+00	4.129E-01	8.006E-01	7.623E-02	5.579E-04	0.000E+00	1.156E-01	1.098E+00
2.800E+01	7.680E-01	0.000E+00	4.050E-01	7.909E-01	7.953E-02	7.764E-04	0.000E+00	1.200E-01	1.032E+00
3.000E+01	7.412E-01	0.000E+00	4.009E-01	7.857E-01	8.095E-02	9.402E-04	0.000E+00	1.212E-01	9.800E-01
3.500E+01	7.022E-01	0.000E+00	4.201E-01	7.854E-01	8.211E-02	1.684E-03	0.000E+00	1.210E-01	9.030E-01
4.000E+01	6.657E-01	0.000E+00	4.327E-01	7.871E-01	8.099E-02	2.495E-03	0.000E+00	1.196E-01	8.609E-01
4.500E+01	6.271E-01	0.000E+00	4.346E-01	7.910E-01	7.666E-02	3.188E-03	0.000E+00	1.332E-01	8.081E-01
5.000E+01	5.889E-01	0.000E+00	4.350E-01	7.879E-01	7.364E-02	3.780E-03	0.000E+00	1.293E-01	7.642E-01
5.500E+01	5.566E-01	0.000E+00	4.391E-01	7.821E-01	7.235E-02	4.374E-03	0.000E+00	1.273E-01	7.325E-01
6.000E+01	5.293E-01	0.000E+00	4.460E-01	7.806E-01	7.029E-02	5.012E-03	0.000E+00	1.363E-01	6.981E-01
6.500E+01	5.125E-01	0.000E+00	4.606E-01	7.897E-01	6.964E-02	5.615E-03	0.000E+00	1.372E-01	6.810E-01
7.000E+01	4.998E-01	0.000E+00	4.757E-01	8.020E-01	7.054E-02	6.271E-03	0.000E+00	1.403E-01	6.512E-01
7.500E+01	4.877E-01	0.000E+00	4.904E-01	8.085E-01	7.129E-02	6.940E-03	0.000E+00	1.443E-01	6.392E-01
8.000E+01	4.766E-01	0.000E+00	5.049E-01	8.156E-01	7.229E-02	7.824E-03	0.000E+00	1.532E-01	6.169E-01
8.500E+01	4.663E-01	0.000E+00	5.193E-01	8.262E-01	7.098E-02	8.639E-03	0.000E+00	1.566E-01	6.051E-01
9.000E+01	4.569E-01	0.000E+00	5.316E-01	8.354E-01	7.087E-02	9.514E-03	0.000E+00	1.613E-01	5.906E-01
9.500E+01	4.487E-01	0.000E+00	5.442E-01	8.425E-01	7.238E-02	1.047E-02	0.000E+00	1.646E-01	5.735E-01
1.000E+02	4.413E-01	0.000E+00	5.488E-01	8.428E-01	7.336E-02	1.086E-02	0.000E+00	1.611E-01	5.625E-01
1.100E+02	4.293E-01	0.000E+00	5.684E-01	8.511E-01	7.630E-02	1.290E-02	0.000E+00	1.679E-01	5.383E-01
1.200E+02	4.210E-01	0.000E+00	5.925E-01	8.744E-01	7.701E-02	1.522E-02	0.000E+00	1.749E-01	5.222E-01
1.300E+02	4.166E-01	0.000E+00	6.175E-01	8.969E-01	8.101E-02	1.764E-02	0.000E+00	1.797E-01	5.063E-01
1.400E+02	4.164E-01	0.000E+00	6.445E-01	9.202E-01	8.554E-02	2.033E-02	0.000E+00	1.851E-01	4.961E-01
1.500E+02	4.200E-01	0.000E+00	6.771E-01	9.608E-01	8.826E-02	2.330E-02	0.000E+00	1.920E-01	4.949E-01

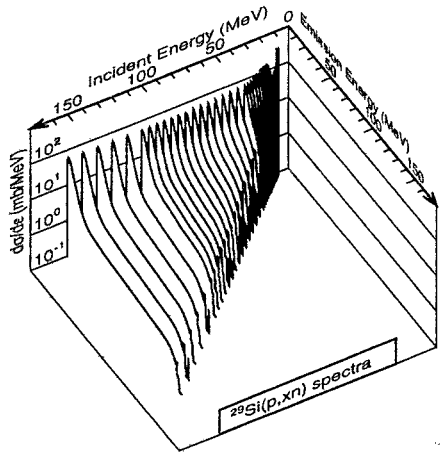
14029 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

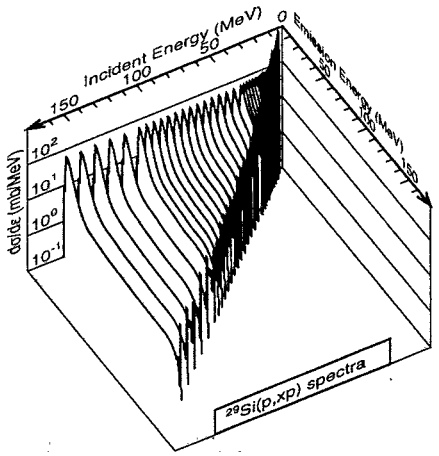
Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+00	0.000E+00	2.260E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	5.000E-12
3.000E+00	0.000E+00	1.645E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.292E+00
4.000E+00	0.000E+00	2.239E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.452E+00
5.000E+00	0.000E+00	2.918E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.675E+00
6.000E+00	4.179E-02	3.546E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.713E+00
7.000E+00	9.335E-01	4.102E+00	4.320E-01	0.000E+00	0.000E+00	1.518E+00	1.791E+00
8.000E+00	1.144E+00	4.482E+00	1.353E+00	0.000E+00	0.000E+00	2.414E+00	1.907E+00
9.000E+00	1.508E+00	4.822E+00	2.261E+00	0.000E+00	0.000E+00	3.220E+00	2.024E+00
1.000E+01	1.975E+00	5.225E+00	2.798E+00	0.000E+00	0.000E+00	3.869E+00	2.127E+00
1.100E+01	2.215E+00	5.525E+00	3.160E+00	0.000E+00	0.000E+00	4.407E+00	2.226E+00
1.200E+01	2.013E+00	5.869E+00	3.774E+00	0.000E+00	0.000E+00	4.769E+00	2.239E+00
1.300E+01	1.852E+00	6.130E+00	4.300E+00	0.000E+00	0.000E+00	5.110E+00	2.203E+00
1.400E+01	1.803E+00	6.374E+00	4.693E+00	0.000E+00	0.000E+00	5.518E+00	2.177E+00
1.500E+01	1.946E+00	6.665E+00	5.100E+00	0.000E+00	0.000E+00	5.877E+00	2.165E+00
1.600E+01	2.166E+00	6.986E+00	5.492E+00	0.000E+00	0.000E+00	6.186E+00	2.175E+00
1.700E+01	2.387E+00	7.258E+00	5.992E+00	0.000E+00	0.000E+00	6.442E+00	2.176E+00
1.800E+01	2.622E+00	7.543E+00	6.435E+00	0.000E+00	0.000E+00	6.626E+00	2.191E+00
1.900E+01	2.758E+00	7.850E+00	6.995E+00	1.106E+00	0.000E+00	6.701E+00	2.219E+00
2.000E+01	2.971E+00	8.185E+00	7.620E+00	1.777E+00	0.000E+00	6.662E+00	2.391E+00
2.200E+01	3.425E+00	8.675E+00	8.653E+00	3.158E+00	0.000E+00	6.574E+00	2.497E+00
2.400E+01	3.769E+00	9.078E+00	9.784E+00	4.027E+00	0.000E+00	6.548E+00	2.583E+00
2.600E+01	4.273E+00	9.407E+00	1.093E+01	4.810E+00	0.000E+00	6.667E+00	2.565E+00
2.800E+01	4.723E+00	9.807E+00	1.208E+01	5.631E+00	0.000E+00	6.816E+00	2.588E+00

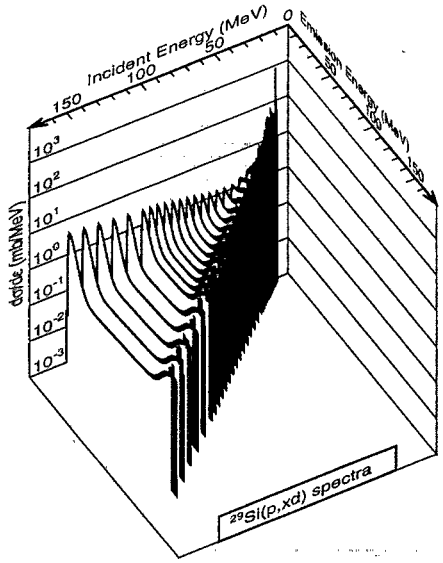
3.000E+01	5.115E+00	1.031E+01	1.324E+01	6.602E+00	0.000E+00	7.021E+00	2.602E+00
3.500E+01	6.201E+00	1.174E+01	1.653E+01	8.355E+00	0.000E+00	7.429E+00	2.625E+00
4.000E+01	7.148E+00	1.284E+01	1.997E+01	9.620E+00	0.000E+00	7.936E+00	2.674E+00
4.500E+01	8.051E+00	1.347E+01	2.313E+01	1.049E+01	0.000E+00	8.230E+00	2.646E+00
5.000E+01	9.027E+00	1.443E+01	2.631E+01	1.143E+01	0.000E+00	8.329E+00	2.630E+00
5.500E+01	9.820E+00	1.537E+01	2.936E+01	1.203E+01	0.000E+00	8.514E+00	2.608E+00
6.000E+01	1.052E+01	1.604E+01	3.196E+01	1.227E+01	0.000E+00	8.645E+00	2.545E+00
6.500E+01	1.129E+01	1.691E+01	3.455E+01	1.264E+01	0.000E+00	8.723E+00	2.546E+00
7.000E+01	1.199E+01	1.767E+01	3.698E+01	1.280E+01	0.000E+00	8.785E+00	2.491E+00
7.500E+01	1.268E+01	1.845E+01	3.933E+01	1.290E+01	0.000E+00	8.898E+00	2.483E+00
8.000E+01	1.329E+01	1.905E+01	4.133E+01	1.274E+01	0.000E+00	9.029E+00	2.442E+00
8.500E+01	1.398E+01	1.983E+01	4.284E+01	1.267E+01	0.000E+00	9.126E+00	2.452E+00
9.000E+01	1.467E+01	2.059E+01	4.402E+01	1.250E+01	0.000E+00	9.137E+00	2.465E+00
9.500E+01	1.521E+01	2.134E+01	4.587E+01	1.228E+01	0.000E+00	9.171E+00	2.471E+00
1.000E+02	1.610E+01	2.237E+01	4.831E+01	1.230E+01	0.000E+00	9.145E+00	2.480E+00
1.100E+02	1.739E+01	2.385E+01	5.150E+01	1.183E+01	0.000E+00	9.372E+00	2.452E+00
1.200E+02	1.864E+01	2.531E+01	5.262E+01	1.143E+01	0.000E+00	9.520E+00	2.483E+00
1.300E+02	1.980E+01	2.669E+01	5.520E+01	1.110E+01	0.000E+00	9.633E+00	2.510E+00
1.400E+02	2.101E+01	2.810E+01	5.740E+01	1.085E+01	0.000E+00	9.880E+00	2.491E+00
1.500E+02	2.222E+01	2.954E+01	5.740E+01	1.069E+01	0.000E+00	1.005E+01	2.529E+00

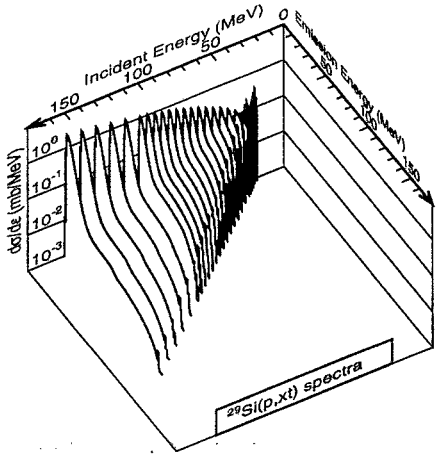

p + 29Si nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
p
n
γ
α
d
t
Nonelastic Cross Section (mb)
10^2
10^1
0
50
100
150
Incident Energy (MeV)

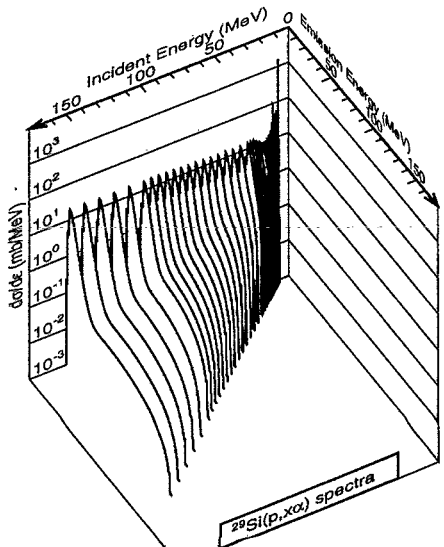
p + ^{29}Si angle-integrated emission spectra

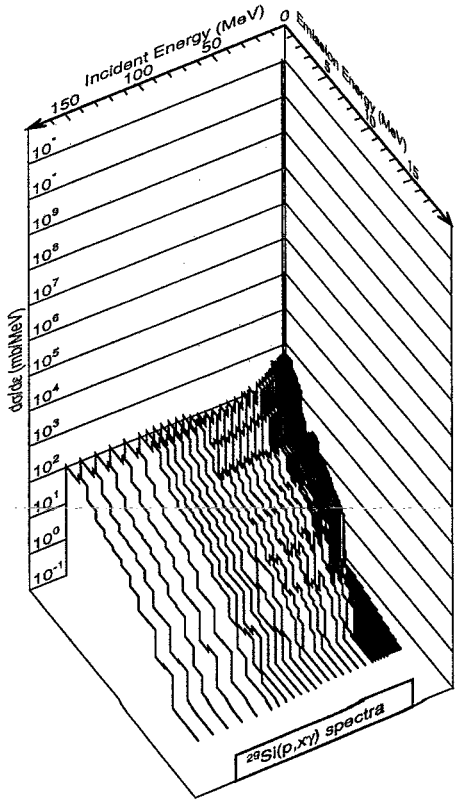




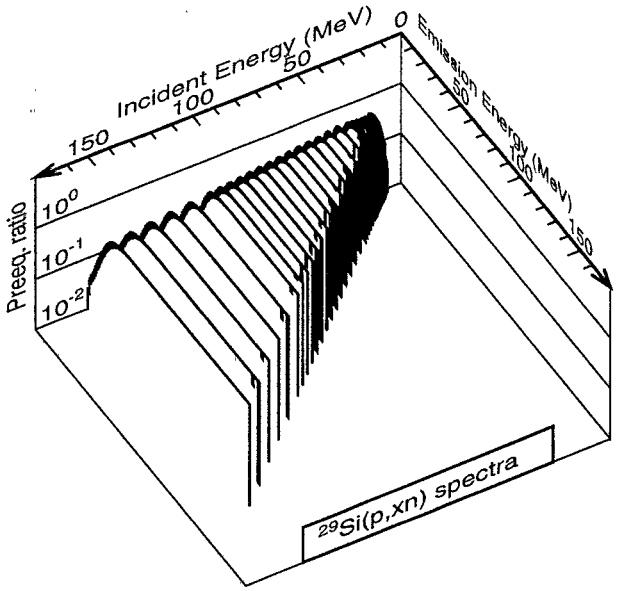


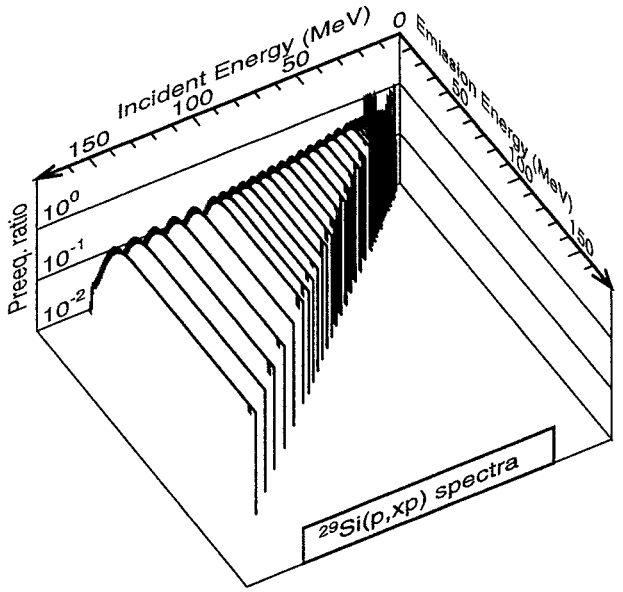


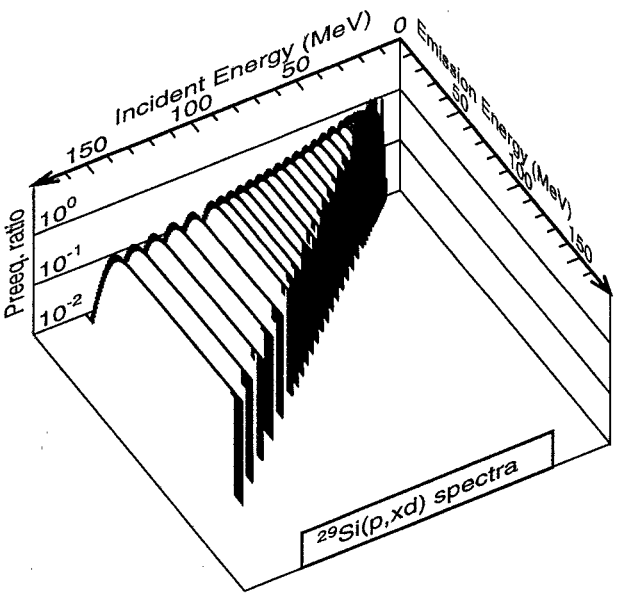


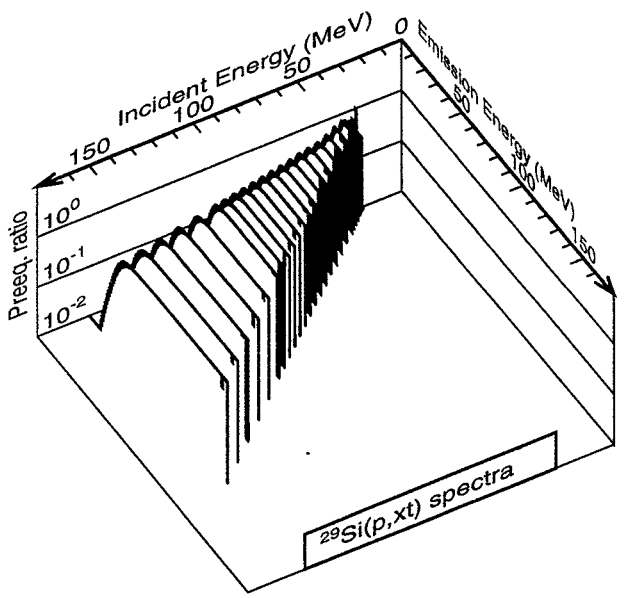


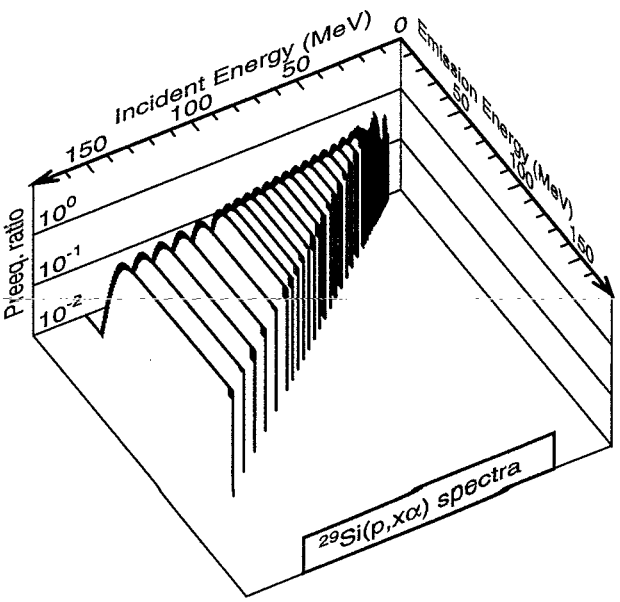
p + ^{29}Si Kalbach preequilibrium ratios

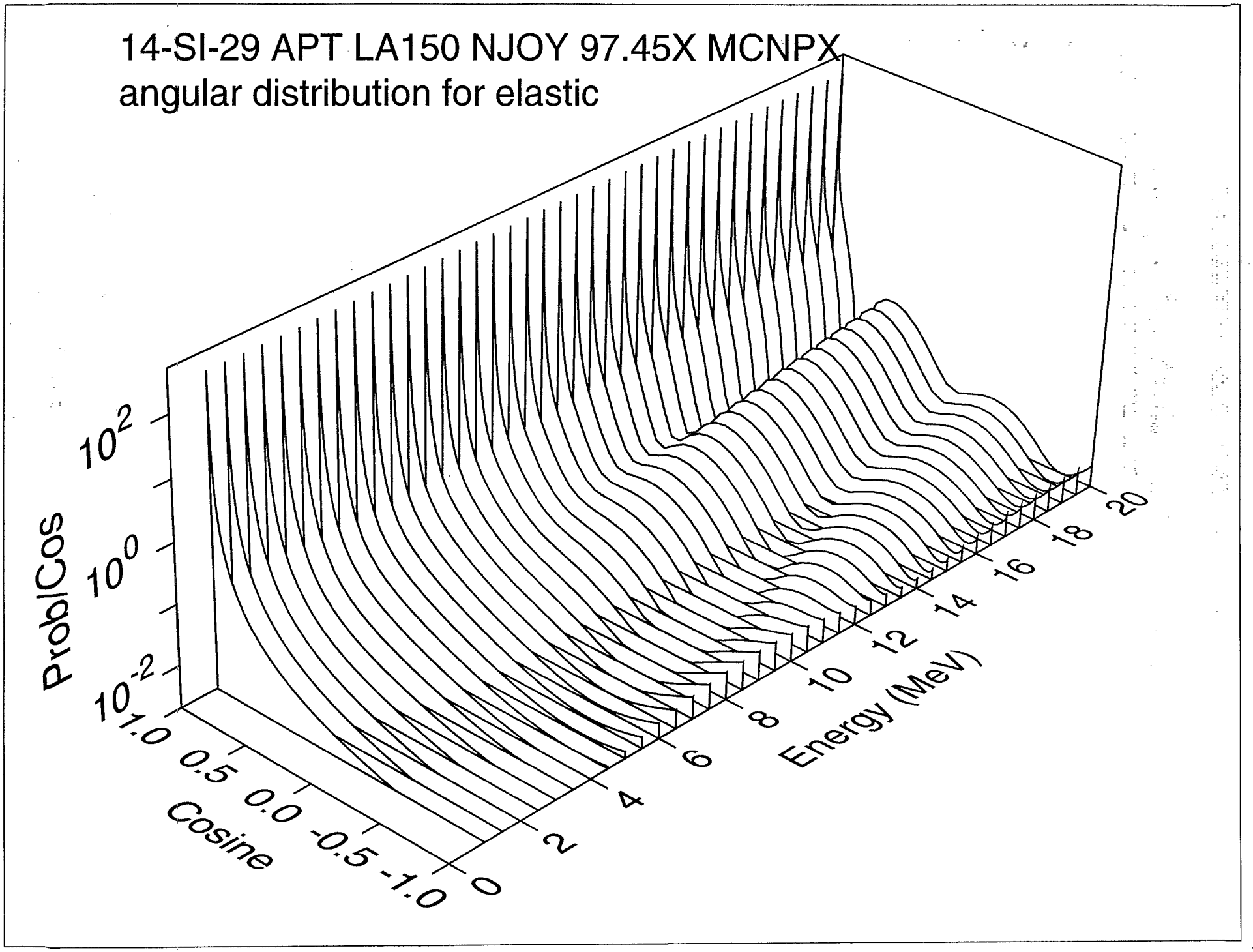


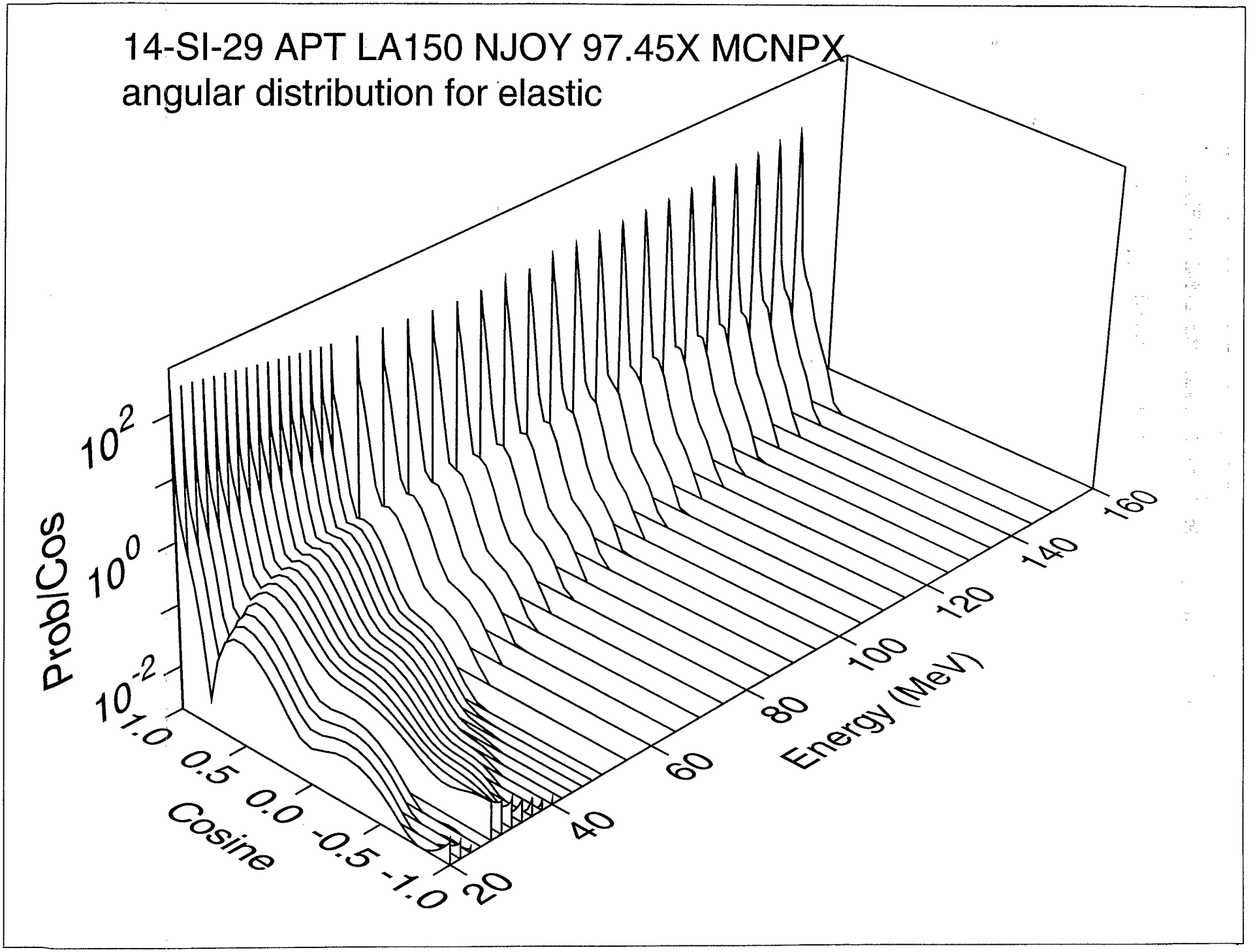


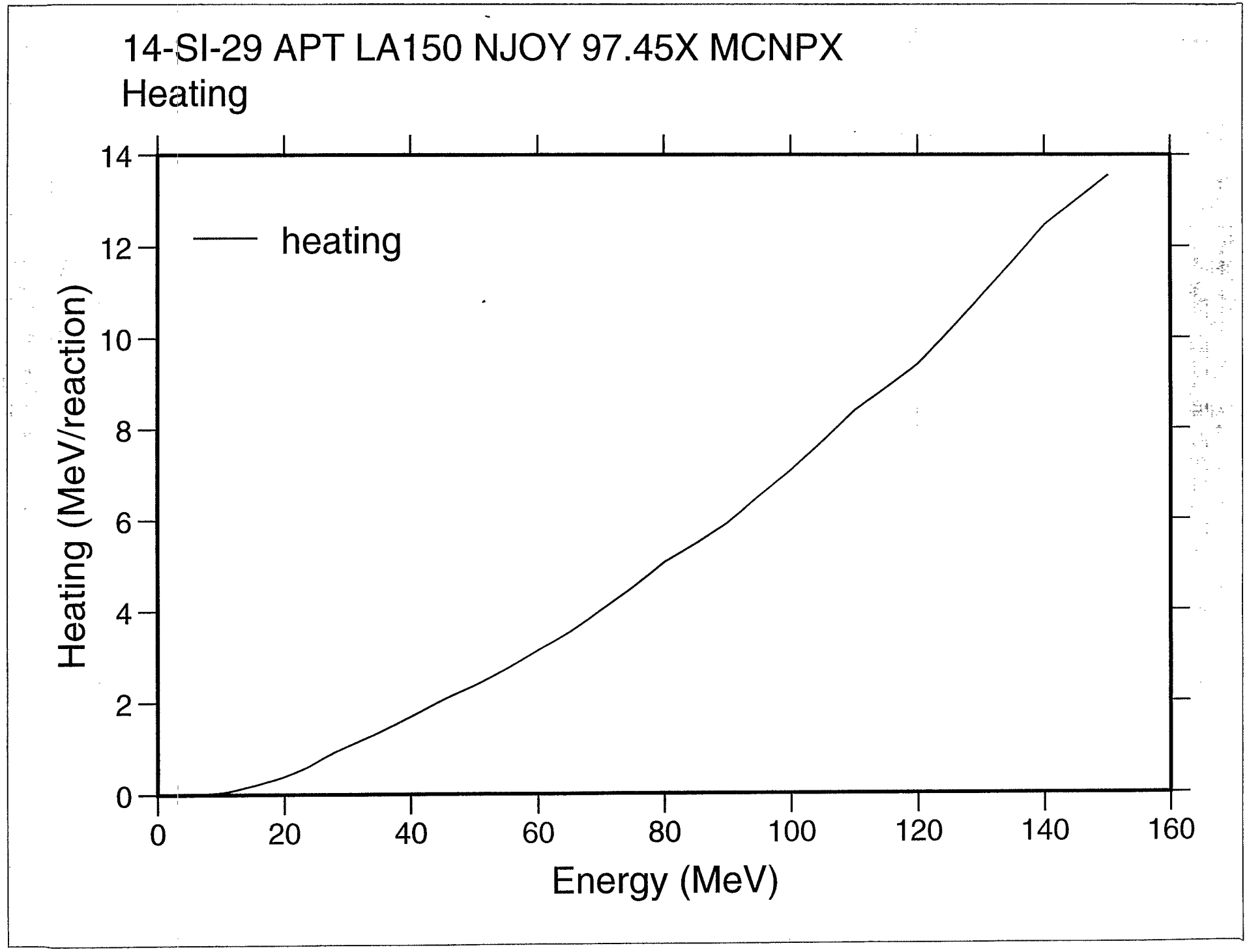







14-SI-29 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
ProblCos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
0
2
4
6
8
10
12
14
16
18
20


14-SI-29 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
ProbCos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
20
40
60
80
100
120
140
160


14-SI-29 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
2
4
6
8
10
12
14
0
20
40
60
80
100
120
140
160

EVALUATION OF p + 30Si CROSS SECTIONS FOR THE ENERGY RANGE 1 to 150 MeV

M. B. Chadwick and P. G. Young

1 July 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident proton energy range from 1 to 150 MeV. The evaluation utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above are:

MF=3	MT= 2	Integral of nuclear plus interference components of the elastic scattering cross section
	MT= 5	Sum of binary (p,n') and (p,x) reactions
MF=6	MT= 2	Elastic (p,p) angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
	MT= 5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Si28 and p + Si28 reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic proton angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach,

Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

DETAILS OF THE p + SI-30 ANALYSIS

The Madland global medium-energy optical potential (Ma88) was used for neutrons above 46 MeV, and the Wilmore-Hodgson (Wi64) potential was used for lower neutron energies. The Madland global medium-energy optical potential was used for protons above 28 MeV, and the Beccheti-Greenlees (Be69) potential was used for lower proton energies. In both cases the transition region to the Madland potential was chosen to approximately give continuity in the reaction cross section. For deuterons, the Perey global potential was used; for alpha particles the MacFadden (Ma66) potential was used; and for tritons the Beccheti-Greenlees (Be71) potential was used.

While the above optical potentials did describe the experimental proton nonelastic cross section data fairly well, we modified the theoretical predictions slightly to better agree with the measurements, and renormalized the transmission coefficients accordingly. In addition to using Si nonelastic proton cross section measurements, we also were guided by p+Al nonelastic data, scaled by A**2/3. The Si-30 nonelastic cross section was taken by scaling the evaluated Si-28 value by 1.047 (an A**2/3 factor).

Inelastic scattering to the 2+ (2.24 MeV) and 4+ (5.95 MeV) states in 30-Si was determined using a coupled-channel ECIS [Ra72] calculation. To produce continuity in the calculated inelastic cross sections up to 150 MeV, we performed an oblate rotational band (0+, 2+, 4+) coupled channel calculation using the Madland medium energy potential (with its imaginary potential reduced by 20%, to approximately account for the coupling). Deformation parameters were chosen, in a neutron-induced calculation, to reproduce the JENDL-3 (neutron-induced) evaluation at 20 MeV (H.KITAZAWA et al.). The resulting deformation parameters (beta-2=-0.33, beta-4=0.20) were close to those used for Si-28. These same beta values were used for the proton-inelastic scattering calculations.

The same preequilibrium input parameters were used as for Si-28, which was benchmarked, indirectly, by comparing neutron-induced calculated cross sections against (n,xz) data from the Louvain group at 63 MeV, and against unpublished (n,xp) data by Haight et al. for neutrons up to 50 MeV. See our ENDF file-1 for p+28Si for more details.

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14030 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

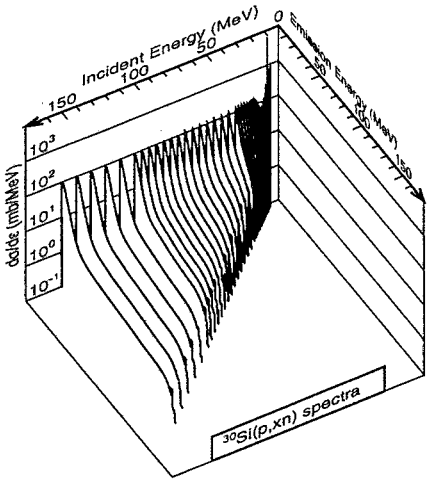
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
3.000E+00	2.012E-03	0.000E+00	0.000E+00	2.009E-03	0.000E+00	0.000E+00	0.000E+00	1.385E-06	2.011E-03
4.000E+00	9.716E-02	0.000E+00	0.000E+00	9.703E-02	0.000E+00	0.000E+00	0.000E+00	6.689E-05	9.715E-02
5.000E+00	3.291E-01	0.000E+00	0.000E+00	3.267E-01	0.000E+00	0.000E+00	0.000E+00	2.271E-03	3.394E-01
6.000E+00	6.280E-01	0.000E+00	2.035E-01	3.953E-01	0.000E+00	0.000E+00	0.000E+00	2.914E-02	5.177E-01
7.000E+00	7.566E-01	0.000E+00	2.656E-01	4.116E-01	0.000E+00	0.000E+00	0.000E+00	7.941E-02	7.792E-01
8.000E+00	8.316E-01	0.000E+00	2.802E-01	4.331E-01	0.000E+00	0.000E+00	0.000E+00	1.183E-01	1.019E+00
9.000E+00	8.728E-01	0.000E+00	3.138E-01	4.301E-01	0.000E+00	0.000E+00	0.000E+00	1.290E-01	1.227E+00
1.000E+01	8.955E-01	0.000E+00	3.197E-01	4.444E-01	3.222E-04	0.000E+00	0.000E+00	1.310E-01	1.408E+00
1.100E+01	9.035E-01	0.000E+00	3.266E-01	4.410E-01	2.484E-03	0.000E+00	0.000E+00	1.334E-01	1.531E+00
1.200E+01	9.077E-01	0.000E+00	3.245E-01	4.625E-01	6.459E-03	8.653E-06	0.000E+00	1.272E-01	1.629E+00
1.300E+01	9.133E-01	0.000E+00	3.246E-01	5.132E-01	1.269E-02	5.314E-04	0.000E+00	1.268E-01	1.621E+00
1.400E+01	9.193E-01	0.000E+00	3.443E-01	5.748E-01	2.012E-02	1.247E-03	0.000E+00	1.224E-01	1.538E+00
1.500E+01	9.227E-01	0.000E+00	3.888E-01	6.187E-01	2.721E-02	2.246E-03	0.000E+00	1.155E-01	1.435E+00
1.600E+01	9.221E-01	0.000E+00	4.335E-01	6.532E-01	3.401E-02	2.946E-03	0.000E+00	1.081E-01	1.345E+00
1.700E+01	9.176E-01	0.000E+00	4.726E-01	6.809E-01	3.943E-02	2.874E-03	0.000E+00	1.012E-01	1.280E+00
1.800E+01	9.106E-01	0.000E+00	5.024E-01	7.016E-01	4.502E-02	2.812E-03	0.000E+00	9.478E-02	1.246E+00
1.900E+01	9.009E-01	0.000E+00	5.152E-01	7.189E-01	4.892E-02	2.774E-03	0.000E+00	8.563E-02	1.235E+00
2.000E+01	8.903E-01	0.000E+00	5.165E-01	7.315E-01	5.057E-02	2.812E-03	0.000E+00	8.002E-02	1.224E+00
2.200E+01	8.670E-01	0.000E+00	5.580E-01	7.194E-01	5.832E-02	3.535E-03	0.000E+00	7.892E-02	1.241E+00
2.400E+01	8.432E-01	0.000E+00	5.973E-01	6.976E-01	6.402E-02	3.830E-03	0.000E+00	8.201E-02	1.239E+00
2.600E+01	8.191E-01	0.000E+00	6.222E-01	6.680E-01	6.790E-02	4.034E-03	0.000E+00	1.032E-01	1.194E+00
2.800E+01	7.855E-01	0.000E+00	6.366E-01	6.432E-01	7.104E-02	4.323E-03	0.000E+00	1.006E-01	1.148E+00
3.000E+01	7.581E-01	0.000E+00	6.442E-01	6.291E-01	7.355E-02	4.668E-03	0.000E+00	9.902E-02	1.108E+00
3.500E+01	7.183E-01	0.000E+00	6.596E-01	6.402E-01	7.420E-02	5.620E-03	0.000E+00	1.019E-01	1.042E+00
4.000E+01	6.809E-01	0.000E+00	6.574E-01	6.478E-01	7.458E-02	6.319E-03	0.000E+00	1.201E-01	9.782E-01
4.500E+01	6.414E-01	0.000E+00	6.665E-01	6.527E-01	7.410E-02	6.636E-03	0.000E+00	1.165E-01	8.944E-01
5.000E+01	6.024E-01	0.000E+00	6.721E-01	6.544E-01	7.011E-02	6.972E-03	0.000E+00	1.151E-01	8.406E-01
5.500E+01	5.693E-01	0.000E+00	6.785E-01	6.559E-01	6.977E-02	7.280E-03	0.000E+00	1.138E-01	7.906E-01
6.000E+01	5.414E-01	0.000E+00	6.899E-01	6.597E-01	6.909E-02	7.953E-03	0.000E+00	1.203E-01	7.388E-01
6.500E+01	5.243E-01	0.000E+00	7.053E-01	6.753E-01	6.815E-02	8.595E-03	0.000E+00	1.228E-01	7.239E-01
7.000E+01	5.112E-01	0.000E+00	7.138E-01	6.843E-01	7.100E-02	9.300E-03	0.000E+00	1.251E-01	6.960E-01
7.500E+01	4.988E-01	0.000E+00	7.338E-01	7.022E-01	6.992E-02	1.004E-02	0.000E+00	1.297E-01	6.741E-01
8.000E+01	4.875E-01	0.000E+00	7.498E-01	7.165E-01	7.015E-02	1.104E-02	0.000E+00	1.383E-01	6.659E-01
8.500E+01	4.770E-01	0.000E+00	7.658E-01	7.282E-01	7.089E-02	1.194E-02	0.000E+00	1.417E-01	6.478E-01
9.000E+01	4.674E-01	0.000E+00	7.779E-01	7.336E-01	7.226E-02	1.281E-02	0.000E+00	1.452E-01	6.324E-01
9.500E+01	4.590E-01	0.000E+00	7.857E-01	7.434E-01	7.389E-02	1.377E-02	0.000E+00	1.491E-01	6.111E-01
1.000E+02	4.514E-01	0.000E+00	7.930E-01	7.502E-01	7.530E-02	1.474E-02	0.000E+00	1.509E-01	6.033E-01
1.100E+02	4.391E-01	0.000E+00	8.132E-01	7.697E-01	7.594E-02	1.658E-02	0.000E+00	1.562E-01	5.842E-01
1.200E+02	4.306E-01	0.000E+00	8.351E-01	7.837E-01	7.869E-02	1.848E-02	0.000E+00	1.601E-01	5.628E-01
1.300E+02	4.261E-01	0.000E+00	8.558E-01	8.059E-01	8.281E-02	2.104E-02	0.000E+00	1.653E-01	5.483E-01
1.400E+02	4.259E-01	0.000E+00	8.917E-01	8.390E-01	8.545E-02	2.389E-02	0.000E+00	1.728E-01	5.377E-01
1.500E+02	4.295E-01	0.000E+00	9.312E-01	8.730E-01	9.023E-02	2.701E-02	0.000E+00	1.792E-01	5.368E-01

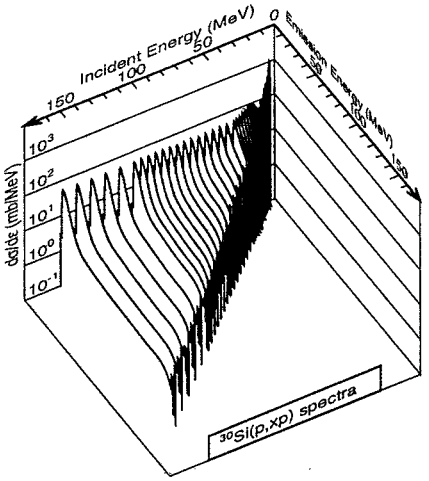
14030 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

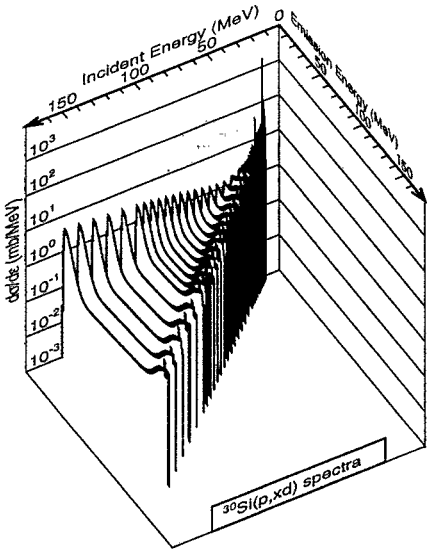
Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
3.000E+00	0.000E+00	3.176E-03	0.000E+00	0.000E+00	0.000E+00	1.270E-02	5.000E-12
4.000E+00	0.000E+00	1.698E+00	0.000E+00	0.000E+00	0.000E+00	1.268E+00	2.255E+00
5.000E+00	0.000E+00	2.341E+00	0.000E+00	0.000E+00	0.000E+00	2.109E+00	2.252E+00
6.000E+00	5.891E-01	2.952E+00	0.000E+00	0.000E+00	0.000E+00	2.950E+00	2.132E+00
7.000E+00	1.058E+00	3.499E+00	0.000E+00	0.000E+00	0.000E+00	3.699E+00	1.896E+00
8.000E+00	1.614E+00	3.936E+00	0.000E+00	0.000E+00	0.000E+00	4.307E+00	1.910E+00
9.000E+00	1.922E+00	4.431E+00	0.000E+00	0.000E+00	0.000E+00	4.869E+00	1.983E+00
1.000E+01	2.244E+00	4.824E+00	1.158E+00	0.000E+00	0.000E+00	5.299E+00	2.131E+00
1.100E+01	2.561E+00	5.269E+00	2.004E+00	0.000E+00	0.000E+00	5.660E+00	2.296E+00
1.200E+01	2.818E+00	5.439E+00	2.643E+00	8.889E-01	0.000E+00	5.994E+00	2.453E+00
1.300E+01	3.031E+00	5.393E+00	3.169E+00	1.783E+00	0.000E+00	6.191E+00	2.603E+00
1.400E+01	3.051E+00	5.389E+00	3.701E+00	2.580E+00	0.000E+00	6.418E+00	2.709E+00
1.500E+01	3.012E+00	5.504E+00	4.161E+00	2.902E+00	0.000E+00	6.639E+00	2.733E+00
1.600E+01	2.956E+00	5.629E+00	4.723E+00	3.355E+00	0.000E+00	6.819E+00	2.700E+00
1.700E+01	3.010E+00	5.839E+00	5.268E+00	4.032E+00	0.000E+00	7.008E+00	2.635E+00
1.800E+01	3.123E+00	6.081E+00	5.797E+00	4.460E+00	0.000E+00	7.195E+00	2.546E+00
1.900E+01	3.282E+00	6.584E+00	6.300E+00	4.817E+00	0.000E+00	7.334E+00	2.441E+00
2.000E+01	3.376E+00	7.109E+00	6.839E+00	5.004E+00	0.000E+00	7.529E+00	2.369E+00
2.200E+01	3.676E+00	7.675E+00	8.015E+00	5.395E+00	0.000E+00	7.635E+00	2.284E+00
2.400E+01	3.940E+00	8.412E+00	9.172E+00	6.217E+00	0.000E+00	7.601E+00	2.233E+00
2.600E+01	4.199E+00	9.166E+00	1.033E+01	7.101E+00	0.000E+00	7.544E+00	2.169E+00
2.800E+01	4.451E+00	9.929E+00	1.158E+01	7.835E+00	0.000E+00	7.841E+00	2.186E+00
3.000E+01	4.790E+00	1.065E+01	1.280E+01	8.619E+00	0.000E+00	8.122E+00	2.208E+00
3.500E+01	5.604E+00	1.204E+01	1.577E+01	1.020E+01	0.000E+00	8.520E+00	2.270E+00

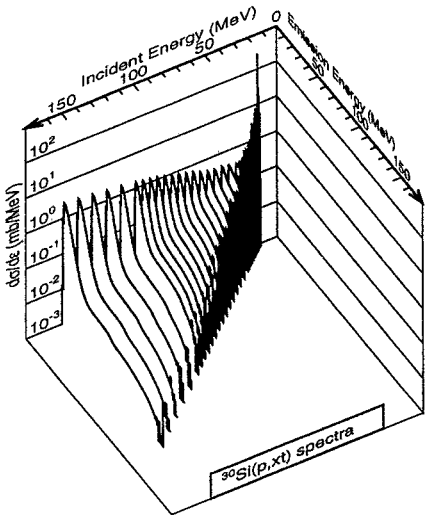
4.000E+01	6.388E+00	1.311E+01	1.920E+01	1.125E+01	0.000E+00	8.648E+00	2.277E+00
4.500E+01	7.039E+00	1.427E+01	2.261E+01	1.250E+01	0.000E+00	8.877E+00	2.271E+00
5.000E+01	7.623E+00	1.537E+01	2.540E+01	1.340E+01	0.000E+00	9.029E+00	2.288E+00
5.500E+01	8.225E+00	1.634E+01	2.844E+01	1.395E+01	0.000E+00	9.104E+00	2.279E+00
6.000E+01	8.661E+00	1.711E+01	3.112E+01	1.395E+01	0.000E+00	9.187E+00	2.248E+00
6.500E+01	9.212E+00	1.798E+01	3.333E+01	1.407E+01	0.000E+00	9.232E+00	2.248E+00
7.000E+01	9.892E+00	1.880E+01	3.613E+01	1.407E+01	0.000E+00	9.267E+00	2.154E+00
7.500E+01	1.039E+01	1.957E+01	3.782E+01	1.402E+01	0.000E+00	9.293E+00	2.150E+00
8.000E+01	1.090E+01	2.022E+01	3.923E+01	1.357E+01	0.000E+00	9.340E+00	2.150E+00
8.500E+01	1.139E+01	2.098E+01	4.087E+01	1.333E+01	0.000E+00	9.357E+00	2.141E+00
9.000E+01	1.188E+01	2.182E+01	4.277E+01	1.309E+01	0.000E+00	9.391E+00	2.140E+00
9.500E+01	1.246E+01	2.251E+01	4.450E+01	1.282E+01	0.000E+00	9.397E+00	2.124E+00
1.000E+02	1.303E+01	2.333E+01	4.627E+01	1.255E+01	0.000E+00	9.495E+00	2.141E+00
1.100E+02	1.416E+01	2.499E+01	4.823E+01	1.213E+01	0.000E+00	9.564E+00	2.160E+00
1.200E+02	1.521E+01	2.674E+01	5.108E+01	1.178E+01	0.000E+00	9.654E+00	2.168E+00
1.300E+02	1.632E+01	2.819E+01	5.365E+01	1.141E+01	0.000E+00	9.810E+00	2.184E+00
1.400E+02	1.729E+01	2.968E+01	5.410E+01	1.109E+01	0.000E+00	9.938E+00	2.197E+00
1.500E+02	1.823E+01	3.118E+01	5.564E+01	1.086E+01	0.000E+00	1.007E+01	2.220E+00

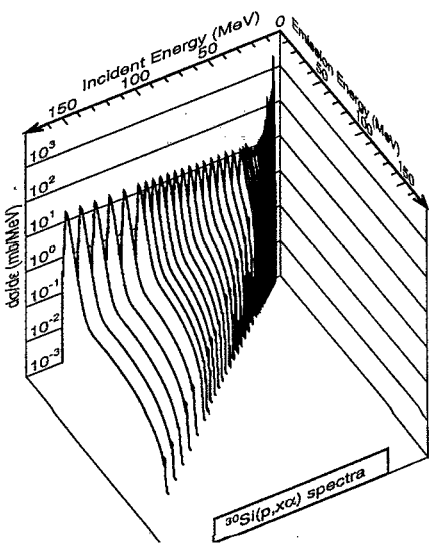
p + ^{30}Si angle-integrated emission spectra

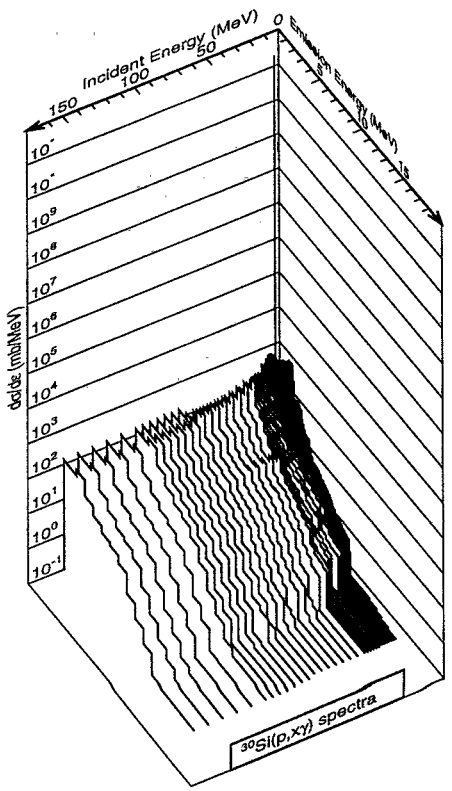




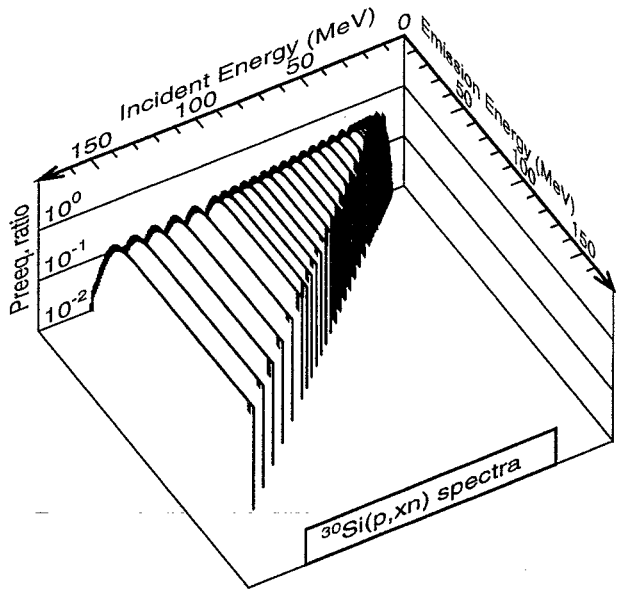


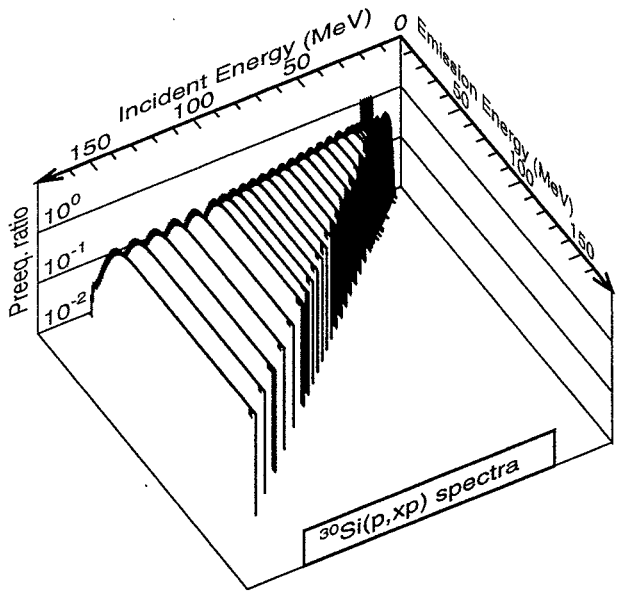


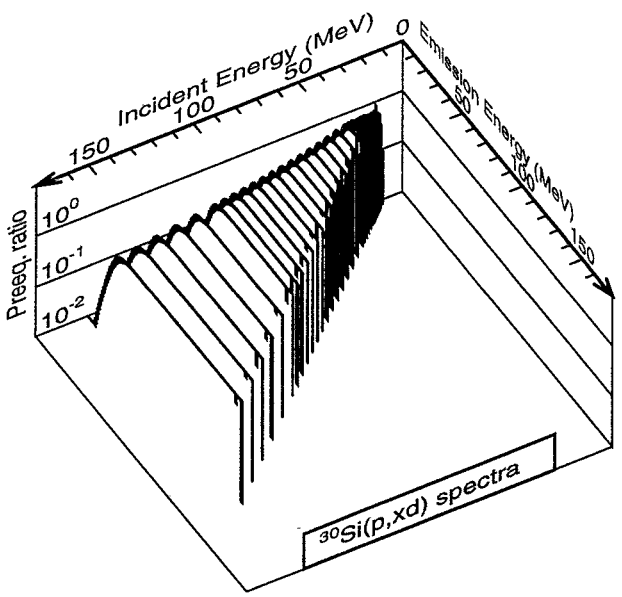


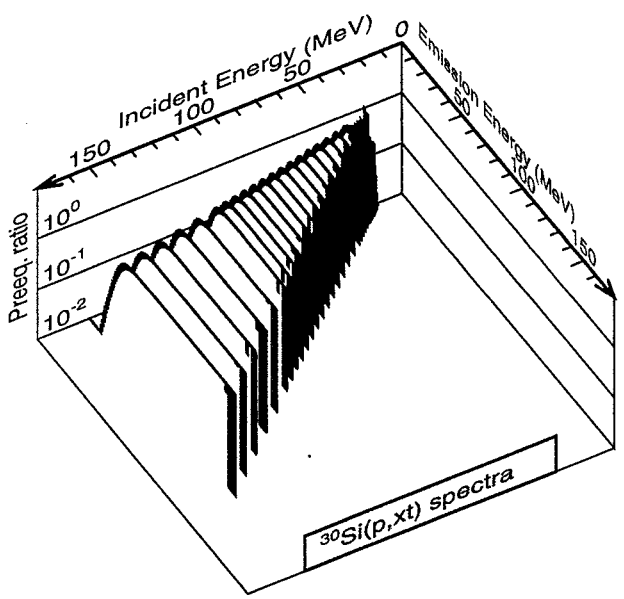


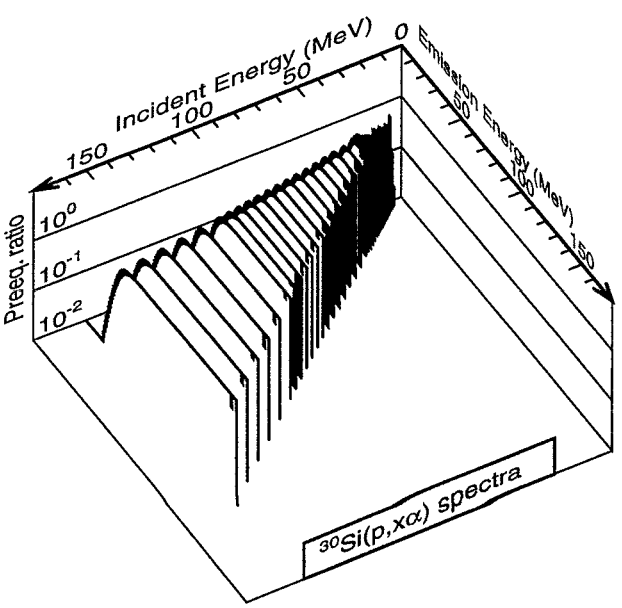
p + ^{30}Si Kalbach preequilibrium ratios

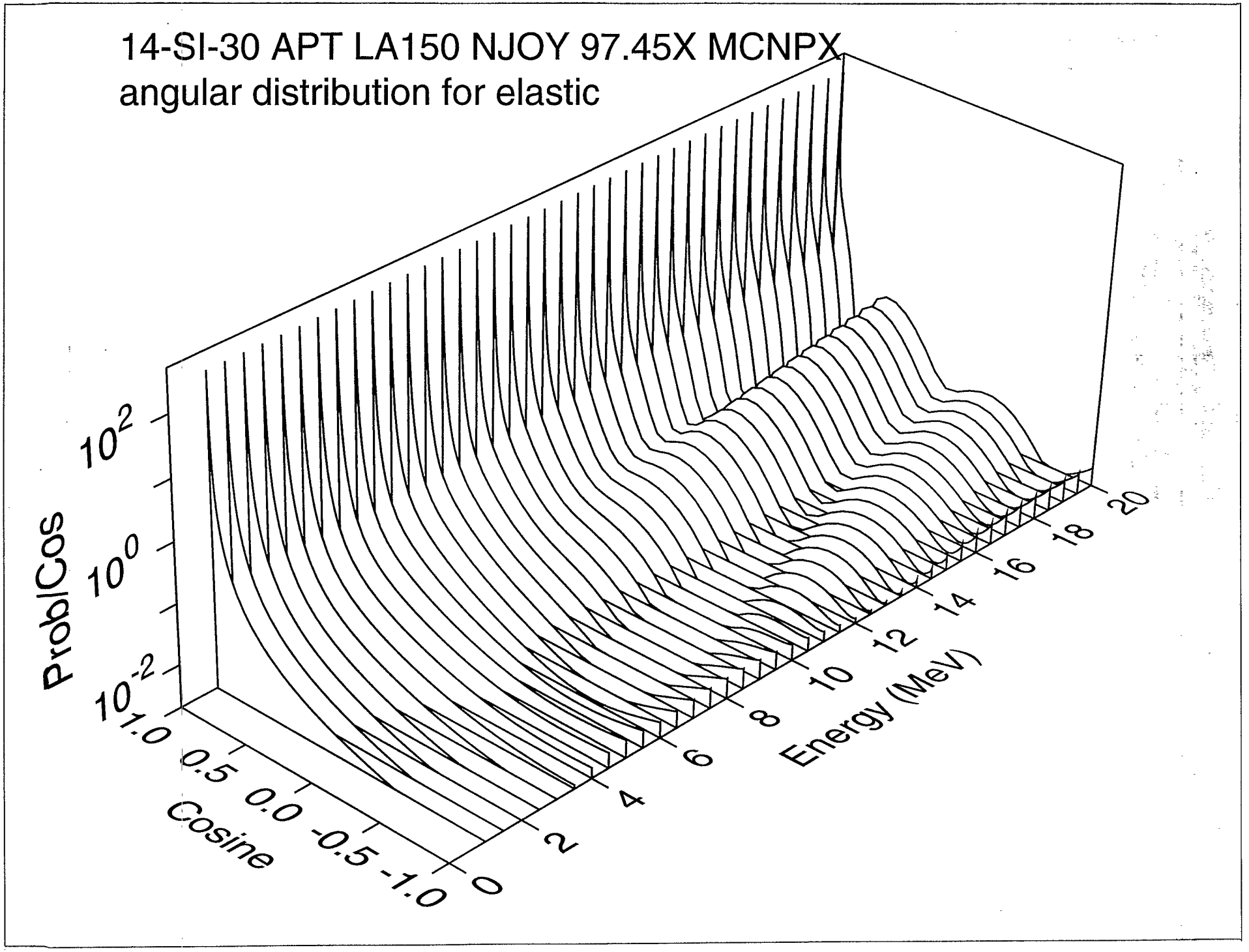








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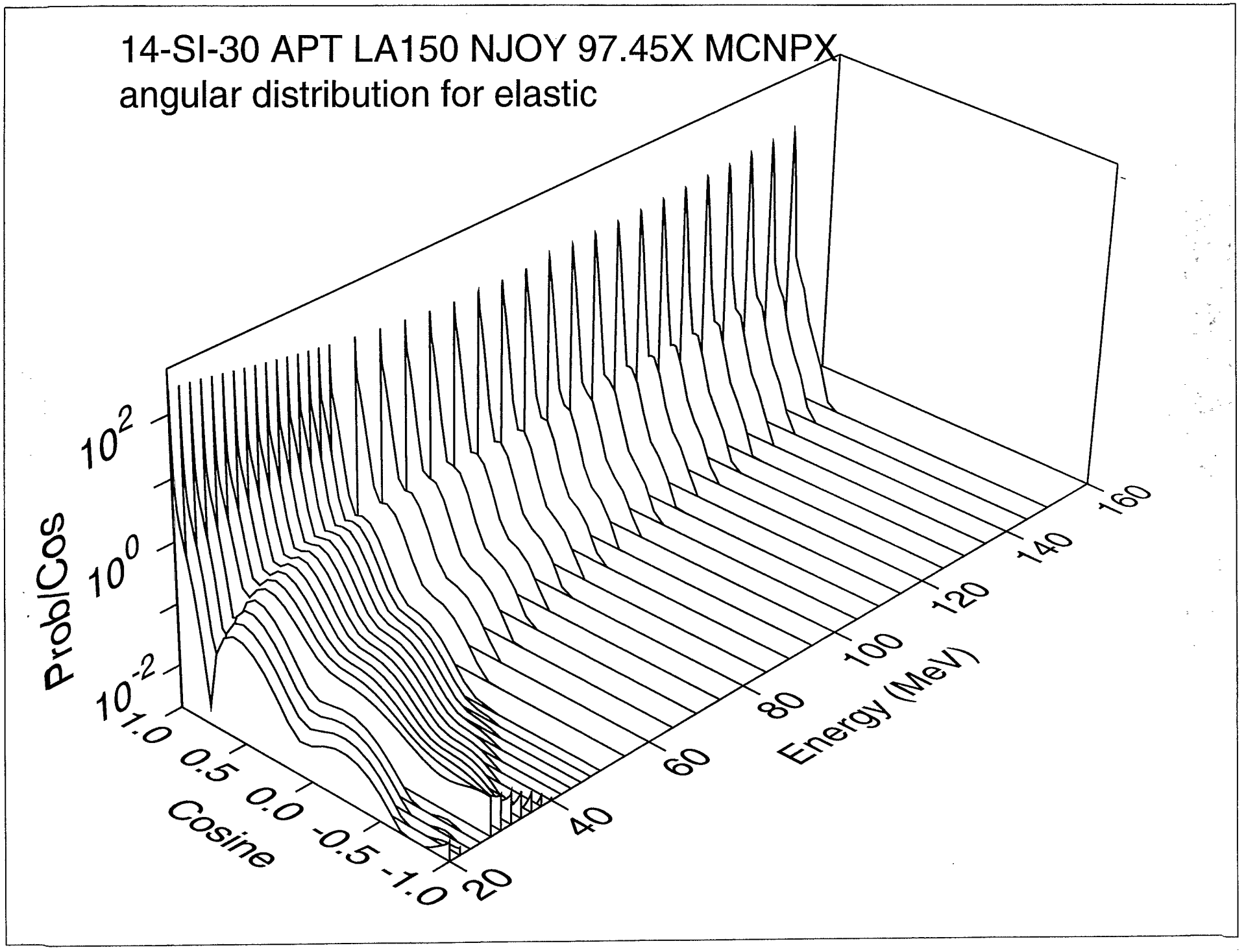
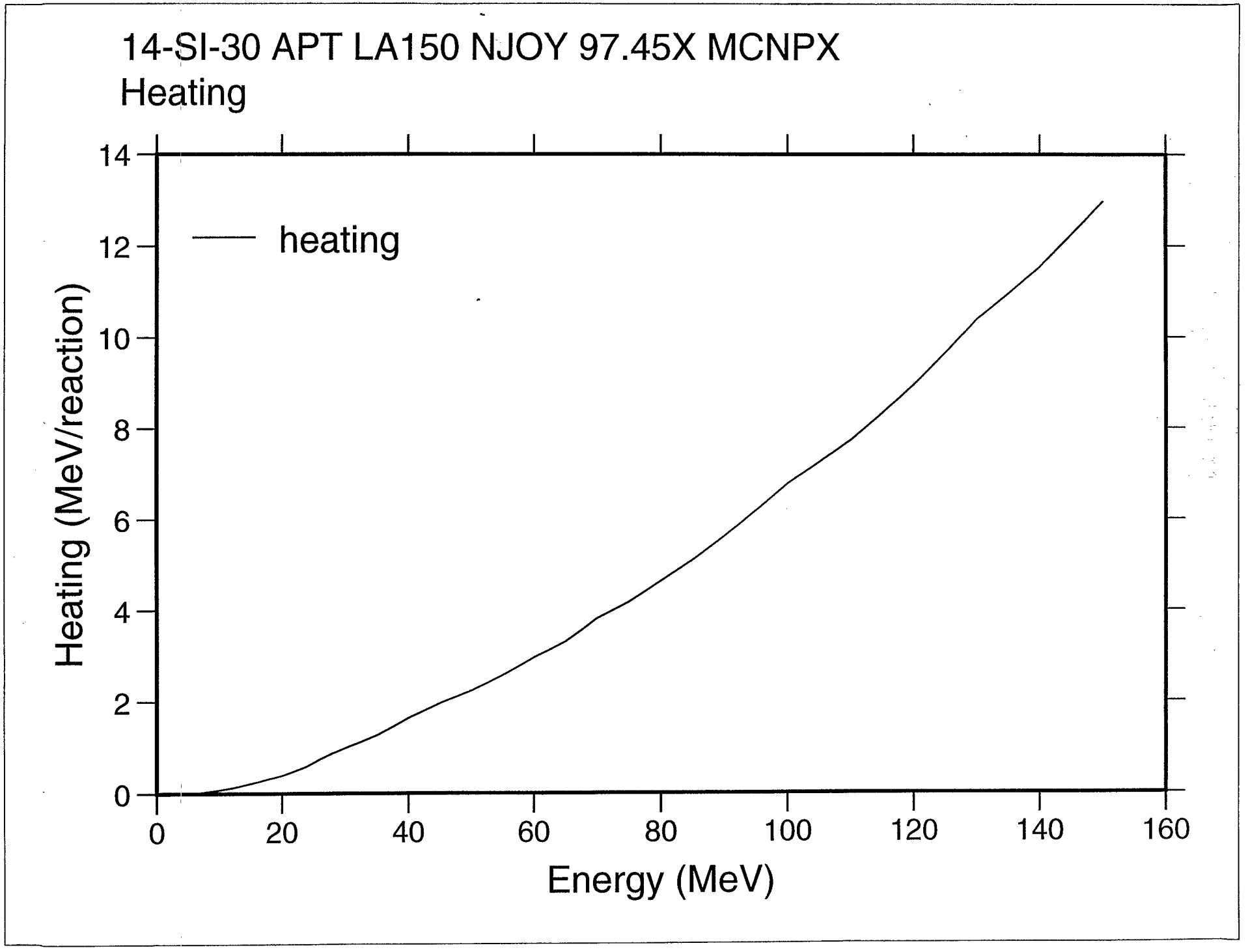
angular distribution for elastic
ProblCos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
0
2
4
6
8
10
12
14
16
18
20


14-SI-30 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
ProblCos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
20
40
60
80
100
120
140
160


14-SI-30 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
2
4
6
8
10
12
14
0
20
40
60
80
100
120
140
160

EVALUATION OF p + 31P CROSS SECTIONS FOR THE ENERGY RANGE 1 to 150 MeV

M. B. Chadwick, and P. G. Young
10 December 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident proton energy range from 1 to 150 MeV. The evaluation utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above are:

MF=3	MT= 2	Integral of nuclear plus interference components of the elastic scattering cross section
	MT= 5	Sum of binary (p,n') and (p,x) reactions
MF=6	MT= 2	Elastic (p,p) angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
	MT= 5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + P31 and p + P31 reactions (Ch98). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic proton angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96a). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk et al. (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged- particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission

coefficients were calculated using the Kopecky-Uhl model (Ko90).

SPECIFIC INFORMATION CONCERNING THE P-31 EVALUATION

For incident neutrons the Wilmore-Hodgson [Wi64] optical potential was used below 20 MeV and the Madland medium [Ma88] energy potential was used at higher energies. Above 130 MeV the reaction cross section, and corresponding transmission coefficients, were renormalized to agree with the evaluated reaction cross section of [Ch96b]. For incident protons the Becchetti-Greenlees [Be69] potential was used below 20 MeV, and the Madland potential at higher energies. Above 6 MeV the reaction cross section (and trans. coeff.) was renormalized to values predicted by the systematics of Wellisch [We96]. The potential of Lohr (Lo74) was used for deuterons, and Mcfadden-Satchler (Mc66) for alpha particles. We followed ref. [Ch96b] in ignoring He-3 emission.

Nuclear level densities were obtained using the Ignatyuk model (Ig75), and low-lying levels were obtained after first determining the upper limit for which the experimental level information is complete.

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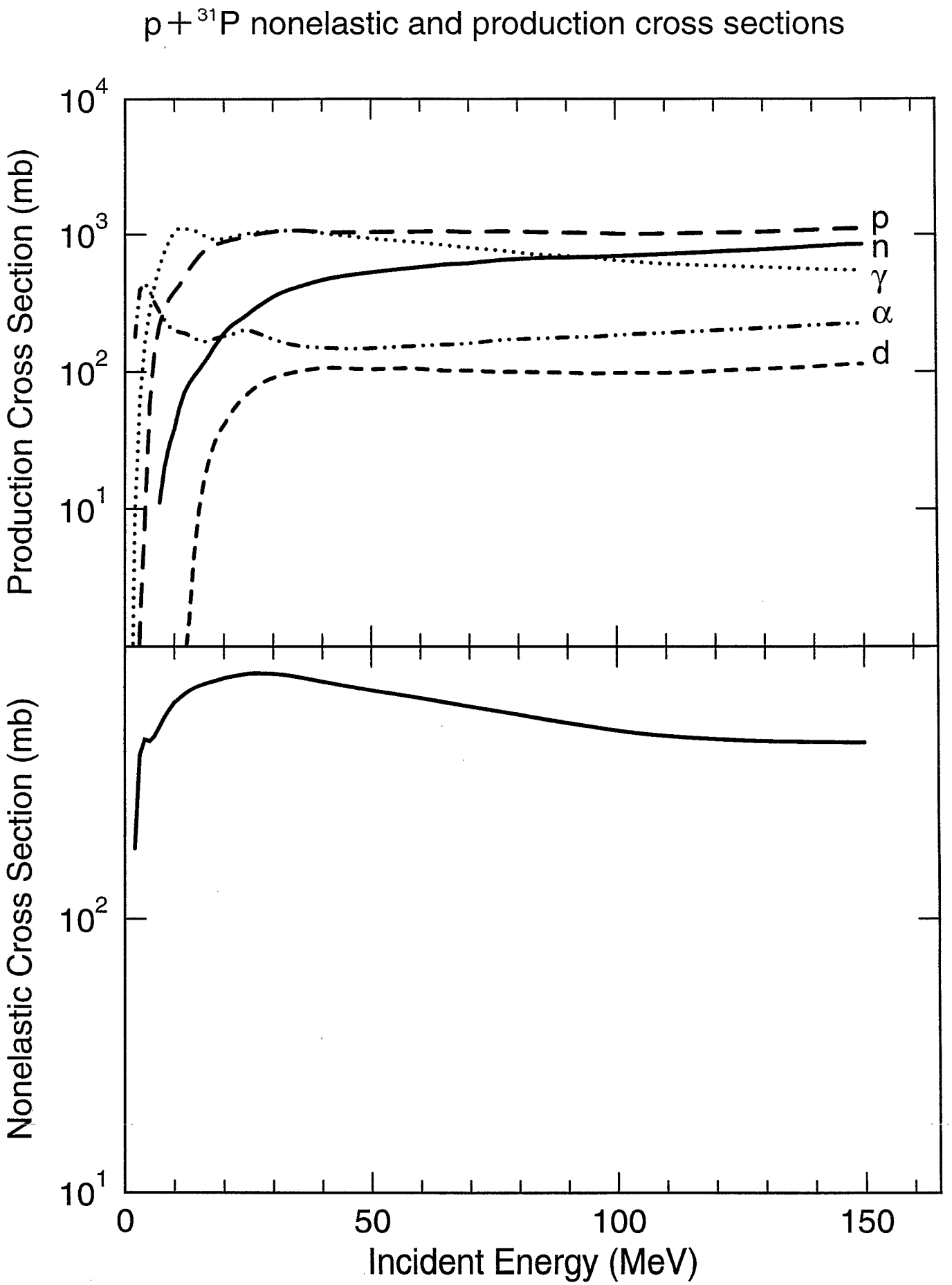
15031 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
1.000E+00	2.012E-03	0.000E+00	0.000E+00	1.230E-07	0.000E+00	0.000E+00	0.000E+00	2.012E-03	9.335E-05
1.307E+00	5.354E-02	0.000E+00	0.000E+00	3.273E-06	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
2.000E+00	1.802E-01	0.000E+00	0.000E+00	1.102E-05	0.000E+00	0.000E+00	0.000E+00	1.802E-01	8.359E-03
3.000E+00	3.960E-01	0.000E+00	0.000E+00	1.314E-03	0.000E+00	0.000E+00	0.000E+00	3.946E-01	6.159E-02
4.000E+00	4.517E-01	0.000E+00	0.000E+00	7.791E-03	0.000E+00	0.000E+00	0.000E+00	4.438E-01	1.612E-01
5.000E+00	4.454E-01	0.000E+00	0.000E+00	5.818E-02	0.000E+00	0.000E+00	0.000E+00	3.872E-01	2.795E-01
6.000E+00	4.655E-01	0.000E+00	0.000E+00	1.487E-01	0.000E+00	0.000E+00	0.000E+00	3.168E-01	4.330E-01
7.000E+00	5.057E-01	0.000E+00	1.111E-02	2.222E-01	0.000E+00	0.000E+00	0.000E+00	2.723E-01	5.865E-01
8.000E+00	5.467E-01	0.000E+00	2.019E-02	2.900E-01	0.000E+00	0.000E+00	0.000E+00	2.365E-01	7.504E-01
9.000E+00	5.849E-01	0.000E+00	2.944E-02	3.429E-01	0.000E+00	0.000E+00	0.000E+00	2.126E-01	9.048E-01
1.000E+01	6.196E-01	0.000E+00	3.847E-02	3.846E-01	0.000E+00	0.000E+00	0.000E+00	2.011E-01	1.047E+00
1.100E+01	6.425E-01	0.000E+00	5.487E-02	4.269E-01	2.318E-08	0.000E+00	0.000E+00	1.948E-01	1.109E+00
1.200E+01	6.659E-01	0.000E+00	7.047E-02	4.907E-01	1.212E-04	0.000E+00	0.000E+00	1.922E-01	1.103E+00
1.300E+01	6.860E-01	0.000E+00	8.289E-02	5.586E-01	1.552E-03	0.000E+00	0.000E+00	1.847E-01	1.084E+00
1.400E+01	7.035E-01	0.000E+00	9.350E-02	6.257E-01	4.688E-03	0.000E+00	0.000E+00	1.762E-01	1.070E+00
1.500E+01	7.164E-01	0.000E+00	1.036E-01	6.932E-01	9.820E-03	0.000E+00	0.000E+00	1.686E-01	1.033E+00
1.600E+01	7.281E-01	0.000E+00	1.170E-01	7.525E-01	1.601E-02	0.000E+00	0.000E+00	1.659E-01	9.822E-01
1.700E+01	7.381E-01	0.000E+00	1.322E-01	8.004E-01	2.256E-02	0.000E+00	0.000E+00	1.690E-01	9.370E-01
1.800E+01	7.470E-01	0.000E+00	1.512E-01	8.321E-01	2.945E-02	0.000E+00	0.000E+00	1.735E-01	9.174E-01
1.900E+01	7.562E-01	0.000E+00	1.701E-01	8.554E-01	3.600E-02	0.000E+00	0.000E+00	1.787E-01	9.230E-01
2.000E+01	7.662E-01	0.000E+00	1.906E-01	8.788E-01	4.074E-02	0.000E+00	0.000E+00	1.829E-01	9.259E-01
2.200E+01	7.791E-01	0.000E+00	2.226E-01	9.162E-01	5.325E-02	0.000E+00	0.000E+00	1.897E-01	9.647E-01
2.400E+01	7.914E-01	0.000E+00	2.483E-01	9.560E-01	6.451E-02	0.000E+00	0.000E+00	2.012E-01	1.001E+00
2.600E+01	7.984E-01	0.000E+00	2.826E-01	9.948E-01	7.481E-02	0.000E+00	0.000E+00	1.962E-01	1.027E+00
2.800E+01	7.972E-01	0.000E+00	3.159E-01	1.023E+00	8.386E-02	0.000E+00	0.000E+00	1.847E-01	1.044E+00
3.000E+01	7.946E-01	0.000E+00	3.510E-01	1.047E+00	9.038E-02	0.000E+00	0.000E+00	1.731E-01	1.055E+00
3.500E+01	7.731E-01	0.000E+00	4.139E-01	1.066E+00	1.003E-01	0.000E+00	0.000E+00	1.550E-01	1.066E+00
4.000E+01	7.431E-01	0.000E+00	4.653E-01	1.043E+00	1.063E-01	0.000E+00	0.000E+00	1.501E-01	1.023E+00
4.500E+01	7.145E-01	0.000E+00	5.010E-01	1.037E+00	1.058E-01	0.000E+00	0.000E+00	1.472E-01	9.780E-01
5.000E+01	6.883E-01	0.000E+00	5.286E-01	1.043E+00	1.042E-01	0.000E+00	0.000E+00	1.484E-01	9.334E-01
5.500E+01	6.656E-01	0.000E+00	5.546E-01	1.048E+00	1.057E-01	0.000E+00	0.000E+00	1.517E-01	9.006E-01
6.000E+01	6.434E-01	0.000E+00	5.781E-01	1.050E+00	1.049E-01	0.000E+00	0.000E+00	1.547E-01	8.702E-01
6.500E+01	6.212E-01	0.000E+00	6.036E-01	1.057E+00	1.018E-01	0.000E+00	0.000E+00	1.579E-01	8.332E-01
7.000E+01	5.993E-01	0.000E+00	6.185E-01	1.043E+00	1.020E-01	0.000E+00	0.000E+00	1.608E-01	7.984E-01
7.500E+01	5.788E-01	0.000E+00	6.448E-01	1.052E+00	9.976E-02	0.000E+00	0.000E+00	1.685E-01	7.697E-01
8.000E+01	5.584E-01	0.000E+00	6.626E-01	1.048E+00	9.954E-02	0.000E+00	0.000E+00	1.729E-01	7.368E-01
8.500E+01	5.381E-01	0.000E+00	6.729E-01	1.039E+00	9.862E-02	0.000E+00	0.000E+00	1.750E-01	7.084E-01
9.000E+01	5.205E-01	0.000E+00	6.794E-01	1.031E+00	9.811E-02	0.000E+00	0.000E+00	1.784E-01	6.947E-01
9.500E+01	5.040E-01	0.000E+00	6.854E-01	1.025E+00	9.694E-02	0.000E+00	0.000E+00	1.799E-01	6.756E-01
1.000E+02	4.879E-01	0.000E+00	6.948E-01	1.013E+00	9.780E-02	0.000E+00	0.000E+00	1.848E-01	6.500E-01
1.100E+02	4.658E-01	0.000E+00	7.186E-01	1.015E+00	9.790E-02	0.000E+00	0.000E+00	1.923E-01	6.115E-01
1.200E+02	4.534E-01	0.000E+00	7.453E-01	1.028E+00	1.009E-01	0.000E+00	0.000E+00	2.000E-01	5.912E-01
1.300E+02	4.457E-01	0.000E+00	7.749E-01	1.045E+00	1.048E-01	0.000E+00	0.000E+00	2.080E-01	5.765E-01
1.400E+02	4.428E-01	0.000E+00	8.147E-01	1.078E+00	1.086E-01	0.000E+00	0.000E+00	2.176E-01	5.591E-01
1.500E+02	4.406E-01	0.000E+00	8.475E-01	1.105E+00	1.137E-01	0.000E+00	0.000E+00	2.243E-01	5.495E-01

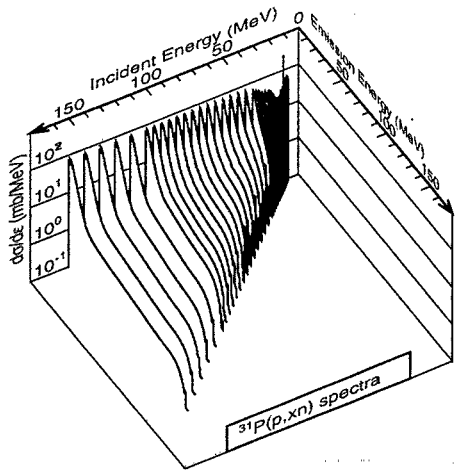
15031 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

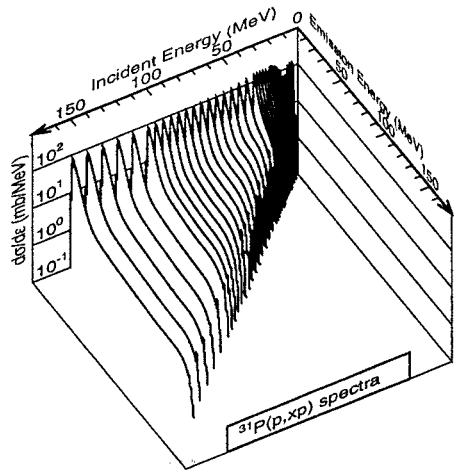
Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
1.000E+00	0.000E+00	9.935E-04	0.000E+00	0.000E+00	0.000E+00	3.974E-03	5.000E-12
1.307E+00	0.000E+00	1.299E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
2.000E+00	0.000E+00	7.360E-01	0.000E+00	0.000E+00	0.000E+00	3.262E+00	1.782E+00
3.000E+00	0.000E+00	1.692E+00	0.000E+00	0.000E+00	0.000E+00	3.991E+00	1.745E+00
4.000E+00	0.000E+00	2.301E+00	0.000E+00	0.000E+00	0.000E+00	4.593E+00	1.739E+00
5.000E+00	0.000E+00	2.818E+00	0.000E+00	0.000E+00	0.000E+00	5.142E+00	1.778E+00
6.000E+00	0.000E+00	3.160E+00	0.000E+00	0.000E+00	0.000E+00	5.607E+00	1.947E+00
7.000E+00	4.799E-01	3.458E+00	0.000E+00	0.000E+00	0.000E+00	6.075E+00	2.104E+00
8.000E+00	9.497E-01	3.787E+00	0.000E+00	0.000E+00	0.000E+00	6.448E+00	2.268E+00
9.000E+00	1.457E+00	4.143E+00	0.000E+00	0.000E+00	0.000E+00	6.638E+00	2.450E+00
1.000E+01	1.824E+00	4.448E+00	0.000E+00	0.000E+00	0.000E+00	6.777E+00	2.627E+00
1.100E+01	1.898E+00	4.512E+00	4.799E-01	0.000E+00	0.000E+00	6.892E+00	2.732E+00
1.200E+01	2.148E+00	4.425E+00	1.381E+00	0.000E+00	0.000E+00	7.051E+00	2.802E+00
1.300E+01	2.454E+00	4.481E+00	2.137E+00	0.000E+00	0.000E+00	7.248E+00	2.871E+00
1.400E+01	2.757E+00	4.542E+00	2.774E+00	0.000E+00	0.000E+00	7.422E+00	2.929E+00
1.500E+01	3.020E+00	4.579E+00	3.423E+00	0.000E+00	0.000E+00	7.610E+00	2.935E+00
1.600E+01	3.189E+00	4.656E+00	4.040E+00	0.000E+00	0.000E+00	7.652E+00	2.910E+00
1.700E+01	3.246E+00	4.765E+00	4.642E+00	0.000E+00	0.000E+00	7.558E+00	2.814E+00
1.800E+01	3.328E+00	4.898E+00	5.169E+00	0.000E+00	0.000E+00	7.477E+00	2.677E+00
1.900E+01	3.452E+00	5.027E+00	5.690E+00	0.000E+00	0.000E+00	7.439E+00	2.538E+00
2.000E+01	3.647E+00	5.248E+00	6.275E+00	0.000E+00	0.000E+00	7.396E+00	2.333E+00

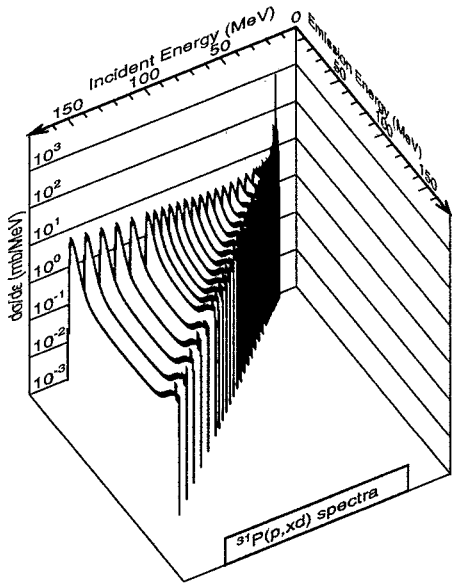
2.200E+01	3.980E+00	5.651E+00	7.336E+00	0.000E+00	0.000E+00	7.473E+00	2.208E+00
2.400E+01	4.391E+00	5.948E+00	8.344E+00	0.000E+00	0.000E+00	7.591E+00	2.175E+00
2.600E+01	4.683E+00	6.336E+00	9.370E+00	0.000E+00	0.000E+00	7.868E+00	2.196E+00
2.800E+01	4.946E+00	6.764E+00	1.040E+01	0.000E+00	0.000E+00	8.165E+00	2.209E+00
3.000E+01	5.211E+00	7.194E+00	1.130E+01	0.000E+00	0.000E+00	8.451E+00	2.212E+00
3.500E+01	5.982E+00	8.366E+00	1.401E+01	0.000E+00	0.000E+00	8.806E+00	2.178E+00
4.000E+01	6.691E+00	9.703E+00	1.692E+01	0.000E+00	0.000E+00	9.029E+00	2.148E+00
4.500E+01	7.432E+00	1.097E+01	1.967E+01	0.000E+00	0.000E+00	9.214E+00	2.162E+00
5.000E+01	8.176E+00	1.201E+01	2.227E+01	0.000E+00	0.000E+00	9.349E+00	2.164E+00
5.500E+01	8.853E+00	1.300E+01	2.468E+01	0.000E+00	0.000E+00	9.485E+00	2.179E+00
6.000E+01	9.495E+00	1.401E+01	2.707E+01	0.000E+00	0.000E+00	9.556E+00	2.178E+00
6.500E+01	1.009E+01	1.487E+01	2.891E+01	0.000E+00	0.000E+00	9.640E+00	2.158E+00
7.000E+01	1.069E+01	1.581E+01	3.129E+01	0.000E+00	0.000E+00	9.670E+00	2.101E+00
7.500E+01	1.108E+01	1.645E+01	3.219E+01	0.000E+00	0.000E+00	9.715E+00	2.090E+00
8.000E+01	1.159E+01	1.711E+01	3.405E+01	0.000E+00	0.000E+00	9.777E+00	2.080E+00
8.500E+01	1.209E+01	1.784E+01	3.570E+01	0.000E+00	0.000E+00	9.838E+00	2.064E+00
9.000E+01	1.265E+01	1.852E+01	3.723E+01	0.000E+00	0.000E+00	9.867E+00	2.057E+00
9.500E+01	1.322E+01	1.922E+01	3.823E+01	0.000E+00	0.000E+00	9.946E+00	2.069E+00
1.000E+02	1.364E+01	1.989E+01	3.932E+01	0.000E+00	0.000E+00	9.968E+00	2.058E+00
1.100E+02	1.463E+01	2.115E+01	4.125E+01	0.000E+00	0.000E+00	1.010E+01	2.054E+00
1.200E+02	1.567E+01	2.236E+01	4.320E+01	0.000E+00	0.000E+00	1.025E+01	2.056E+00
1.300E+02	1.666E+01	2.364E+01	4.414E+01	0.000E+00	0.000E+00	1.039E+01	2.086E+00
1.400E+02	1.758E+01	2.482E+01	4.485E+01	0.000E+00	0.000E+00	1.055E+01	2.096E+00
1.500E+02	1.853E+01	2.601E+01	4.602E+01	0.000E+00	0.000E+00	1.071E+01	2.108E+00

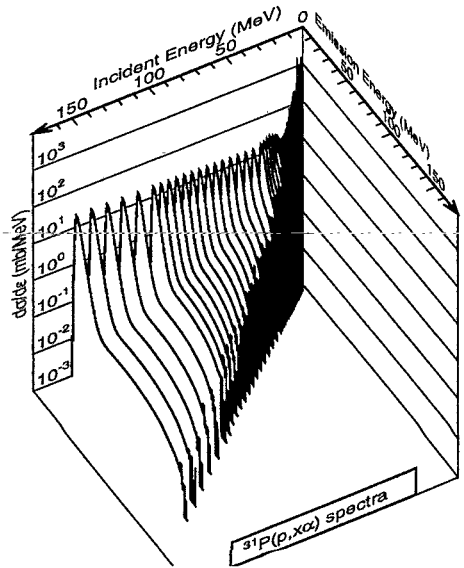

p + 31P nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
p
n
γ
α
d
Nonelastic Cross Section (mb)
10^2
10^1
0
50
100
150
Incident Energy (MeV)

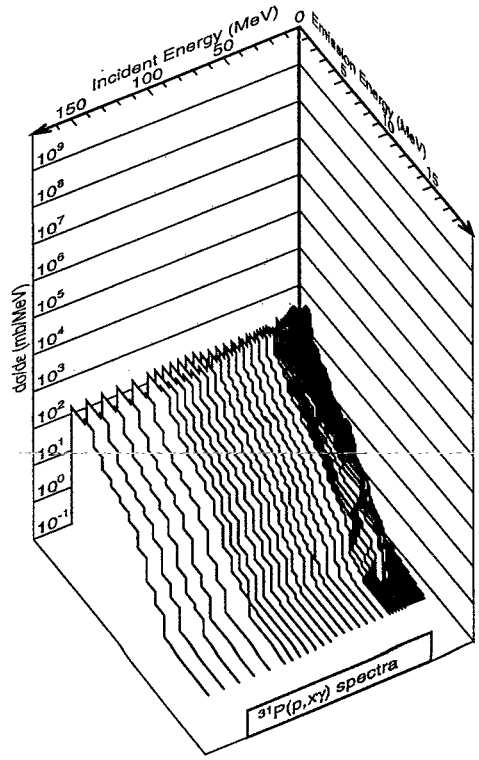
p + ^{31}P angle-integrated emission spectra



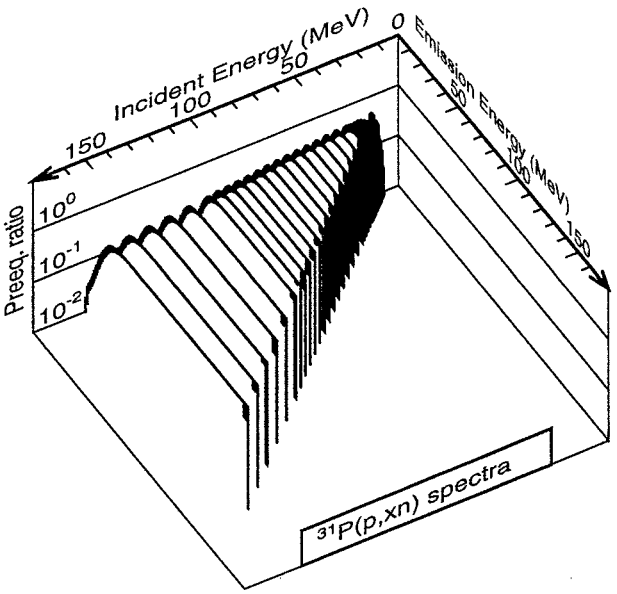


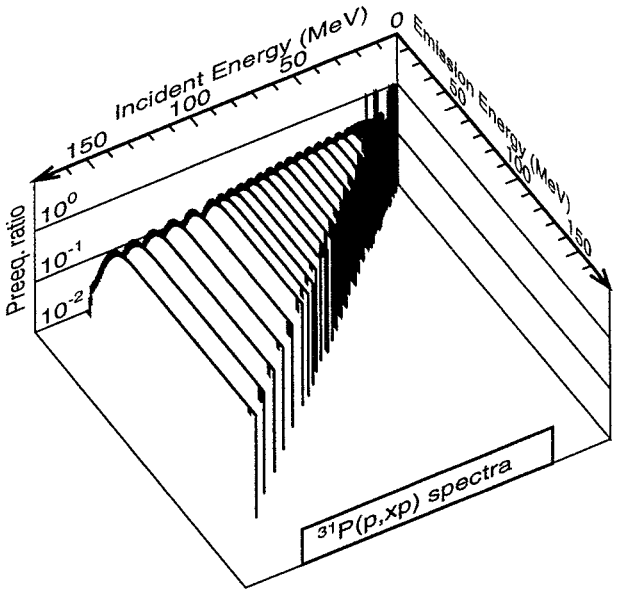


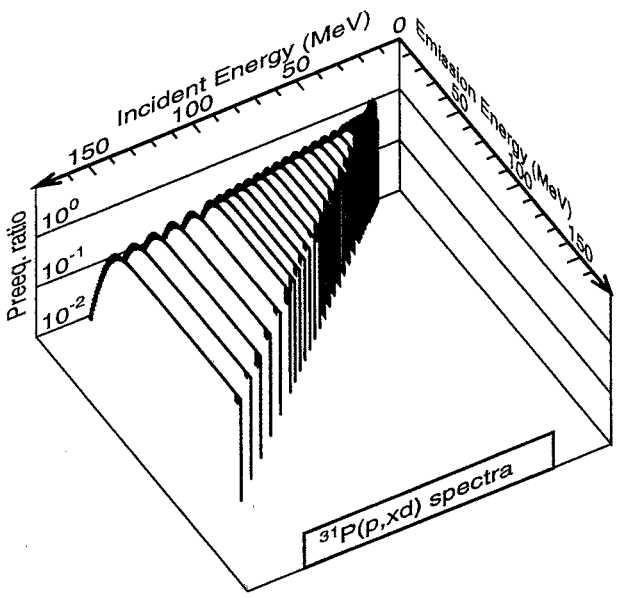


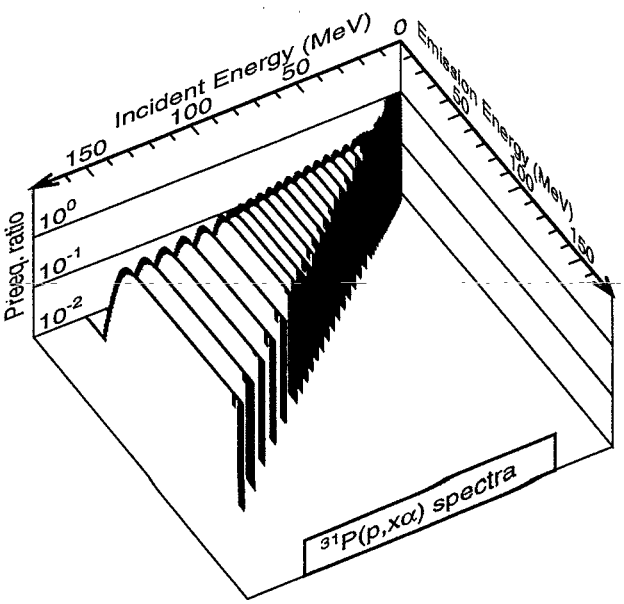


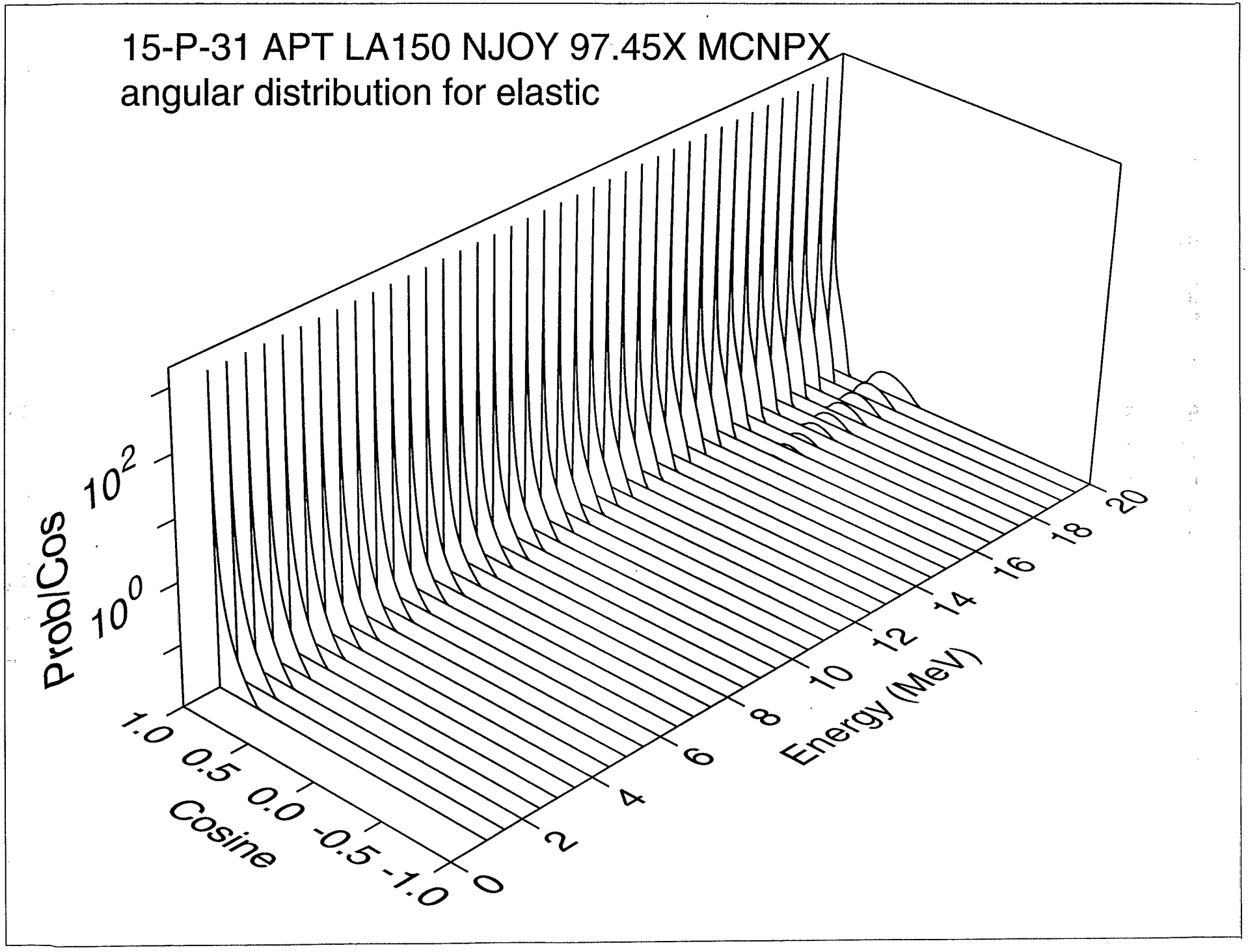
p + ^{31}P Kalbach preequilibrium ratios

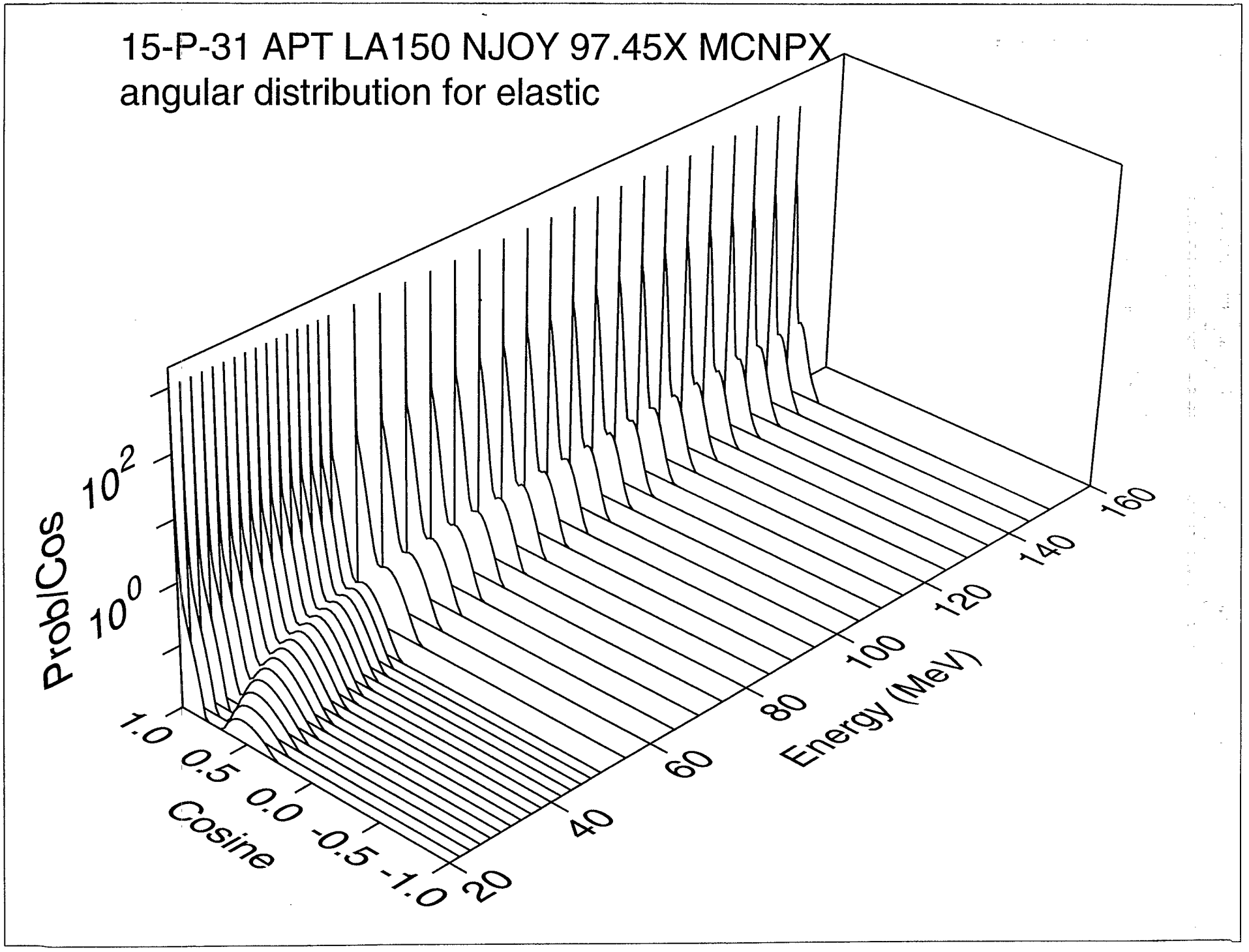


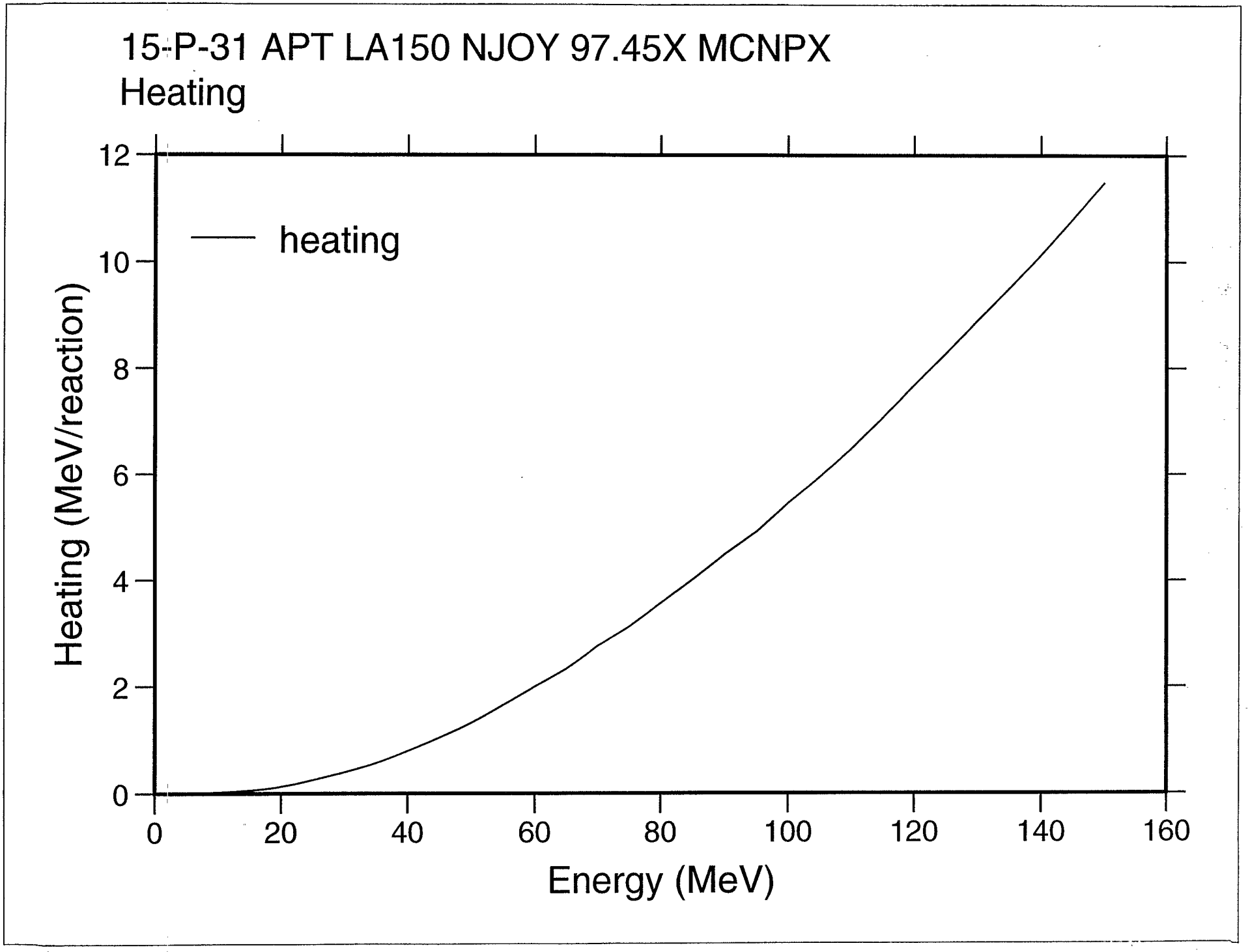







15-P-31 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
1.0
0.5
0.0
-0.5
-1.0
Cosine
0
2
4
6
8
10
12
14
16
18
20
Energy (MeV)


15-P-31 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


15-P-31 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
2
4
6
8
10
12
0
20
40
60
80
100
120
140
160

EVALUATION OF p + 40Ca CROSS SECTIONS FOR THE ENERGY RANGE 1.0 to 150 MeV

M. B. Chadwick and P. G. Young
29 March 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident proton energy range from 1 to 150 MeV. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains.

To summarize, the ENDF sections with non-zero data are:

MF=3	MT= 2	Integral of nuclear plus interference components of the elastic scattering cross section
	MT= 5	Sum of binary (n,n') and (n,x) reactions
MF=6	MT= 2	Elastic angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
	MT= 5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data. We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations,. as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96a). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting..

The starting point for this evaluation was the previous Livermore (1995) evaluation by Chadwick and Young for neutrons up to 100 MeV [Ch95], and protons up to 250 MeV [Ch96b]. The main additions in the current work were: (1) Extension of the neutron calculations to higher energies; (2) Inclusion of direct inelastic scattering to low-lying collective states using ECIS; (3) inclusion of a renormalization of the calculated results to circumvent a numerical inaccuracy at higher incident energies (>150 MeV) which ensure the individual reactions sum to the evaluated nonelastic cross section; (4) inclusion of A>4 nuclide

production and nuclide energy spectra; (5) inclusion of triton emission; and (6) utilization of ENDF-6 format.

The neutron total cross section was evaluated from available experimental data. The evaluation was based primarily on Finlay's 1993 high-accuracy measurements [Fi93].

The optical potential of Islam [Is88] specially developed for n+Ca elastic scattering, was used for neutrons from 20 to 60 MeV, and above this energy the Madland global potential was used [Ma88]. The Wilmore-Hodgson potential was used for neutrons below 20 MeV [Wi64]. For incident protons, the Islam neutron potential was modified to account for proton scattering from 20 to 60 MeV, and again the Madland global potential was used at higher energies. The Becchetti-Greenlees potential was used for protons below 20 MeV [Be69]. For deuterons, tritons and alphas the method of Watanabe, which uses a modified Perey potential [Pe63], was applied at all energies [Ma88].

Direct inelastic scattering to the low-lying collective states was calculated with the ECIS code. Deformation lengths were taken from the works of Alarcon and Rapaport [8] and Honore et al. [Ho86], giving: 3- (Ex= 3.736 MeV, delta=1.340), 2+ (Ex=3.904, delta=0.360), and 5- (Ex=4.492, delta=0.930).

While the above optical potentials did describe the experimental neutron and proton nonelastic cross section data fairly well, we modified these theoretical predictions slightly to better agree with the measurements, and renormalized the transmission coefficients accordingly. The calculated neutron elastic scattering distributions agree well with experimental data.

Nuclear level densities were taken from the Ignatyuk model [Ig75], which includes a washing out of shell effects with increasing excitation energy, and gamma-ray strength functions were obtained from the model of Kopecky and Uhl [Ko90].

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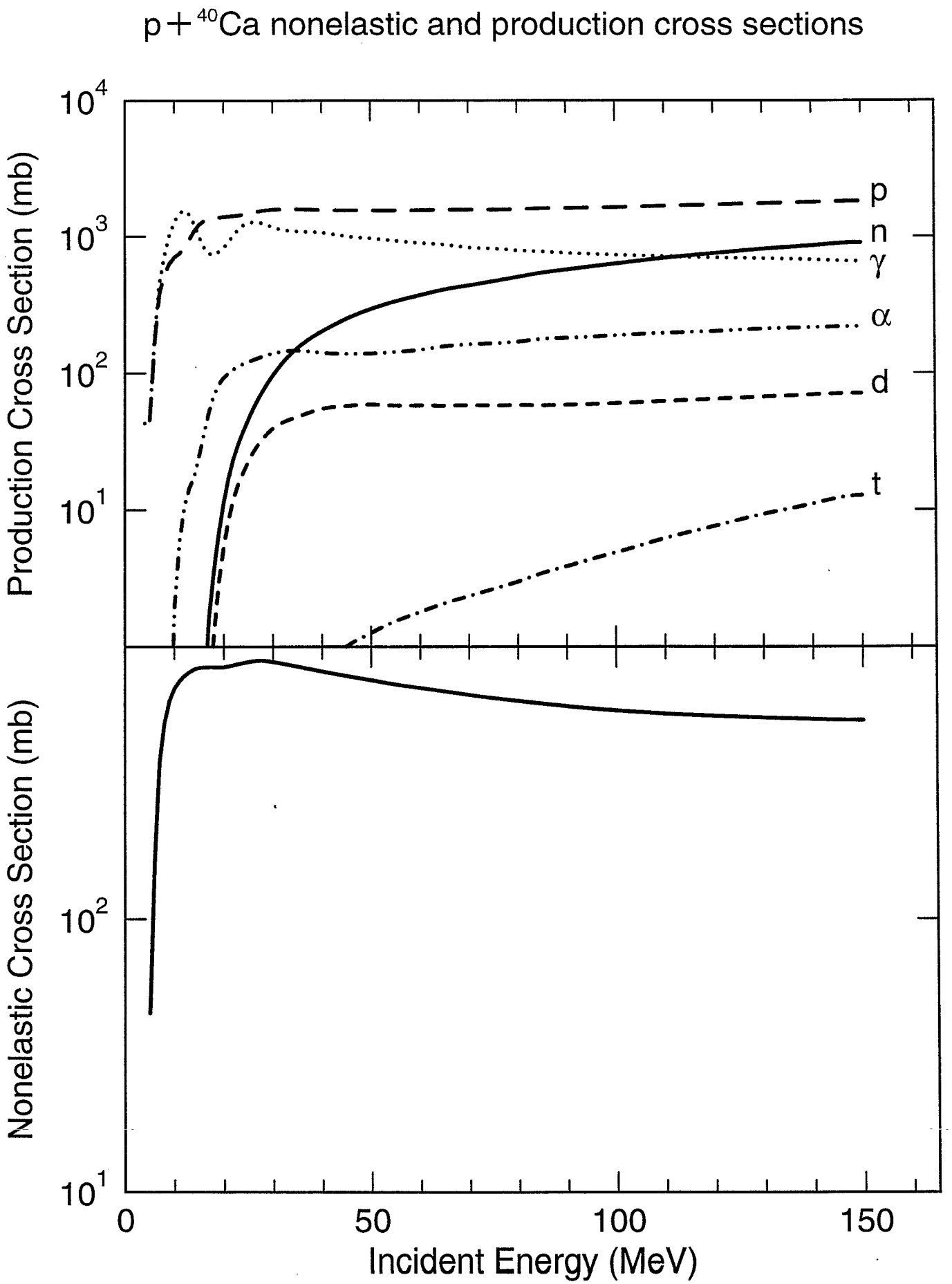
20040 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
5.000E+00	4.526E-02	0.000E+00	0.000E+00	4.526E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.534E-02
6.000E+00	1.652E-01	0.000E+00	0.000E+00	1.652E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.801E-01
7.000E+00	3.817E-01	0.000E+00	0.000E+00	3.816E-01	0.000E+00	0.000E+00	0.000E+00	5.804E-10	4.549E-01
8.000E+00	5.280E-01	0.000E+00	0.000E+00	5.280E-01	0.000E+00	0.000E+00	0.000E+00	1.662E-06	7.208E-01
9.000E+00	6.318E-01	0.000E+00	0.000E+00	6.317E-01	0.000E+00	0.000E+00	0.000E+00	8.038E-05	1.016E+00
1.000E+01	7.031E-01	0.000E+00	0.000E+00	7.012E-01	0.000E+00	0.000E+00	0.000E+00	1.893E-03	1.274E+00
1.100E+01	7.494E-01	0.000E+00	0.000E+00	7.479E-01	0.000E+00	0.000E+00	0.000E+00	5.635E-03	1.467E+00
1.200E+01	7.827E-01	0.000E+00	0.000E+00	8.135E-01	0.000E+00	0.000E+00	0.000E+00	1.043E-02	1.551E+00
1.300E+01	8.079E-01	0.000E+00	0.000E+00	9.365E-01	0.000E+00	0.000E+00	0.000E+00	1.429E-02	1.450E+00
1.400E+01	8.279E-01	0.000E+00	0.000E+00	1.085E+00	0.000E+00	0.000E+00	0.000E+00	1.722E-02	1.243E+00
1.500E+01	8.384E-01	0.000E+00	0.000E+00	1.217E+00	4.674E-07	0.000E+00	0.000E+00	2.438E-02	1.003E+00
1.600E+01	8.410E-01	0.000E+00	5.548E-04	1.293E+00	2.431E-05	0.000E+00	0.000E+00	3.553E-02	8.379E-01
1.700E+01	8.423E-01	0.000E+00	1.626E-03	1.338E+00	2.992E-04	0.000E+00	0.000E+00	5.113E-02	7.494E-01
1.800E+01	8.425E-01	0.000E+00	3.566E-03	1.363E+00	1.219E-03	0.000E+00	0.000E+00	6.837E-02	7.326E-01
1.900E+01	8.412E-01	0.000E+00	6.692E-03	1.375E+00	2.941E-03	0.000E+00	0.000E+00	8.224E-02	7.725E-01
2.000E+01	8.429E-01	0.000E+00	1.117E-02	1.386E+00	5.302E-03	0.000E+00	0.000E+00	9.228E-02	8.234E-01
2.200E+01	8.579E-01	0.000E+00	2.352E-02	1.408E+00	1.200E-02	1.316E-10	0.000E+00	1.065E-01	1.015E+00
2.400E+01	8.733E-01	0.000E+00	3.707E-02	1.441E+00	1.869E-02	7.048E-07	0.000E+00	1.168E-01	1.204E+00
2.600E+01	8.870E-01	0.000E+00	5.431E-02	1.494E+00	2.611E-02	1.038E-05	0.000E+00	1.245E-01	1.273E+00
2.800E+01	8.902E-01	0.000E+00	7.415E-02	1.545E+00	3.298E-02	4.761E-05	0.000E+00	1.324E-01	1.247E+00
3.000E+01	8.800E-01	0.000E+00	9.578E-02	1.571E+00	3.894E-02	1.211E-04	0.000E+00	1.390E-01	1.171E+00
3.500E+01	8.459E-01	0.000E+00	1.525E-01	1.582E+00	4.765E-02	3.917E-04	0.000E+00	1.463E-01	1.089E+00
4.000E+01	8.120E-01	0.000E+00	2.018E-01	1.562E+00	5.456E-02	7.017E-04	0.000E+00	1.407E-01	1.065E+00
4.500E+01	7.820E-01	0.000E+00	2.496E-01	1.551E+00	5.727E-02	1.007E-03	0.000E+00	1.384E-01	1.001E+00
5.000E+01	7.550E-01	0.000E+00	2.935E-01	1.549E+00	5.860E-02	1.264E-03	0.000E+00	1.390E-01	9.657E-01
5.500E+01	7.280E-01	0.000E+00	3.339E-01	1.549E+00	5.754E-02	1.540E-03	0.000E+00	1.426E-01	9.282E-01
6.000E+01	7.060E-01	0.000E+00	3.704E-01	1.555E+00	5.771E-02	1.801E-03	0.000E+00	1.478E-01	8.951E-01
6.500E+01	6.847E-01	0.000E+00	4.080E-01	1.567E+00	5.739E-02	2.085E-03	0.000E+00	1.570E-01	8.711E-01
7.000E+01	6.640E-01	0.000E+00	4.373E-01	1.569E+00	5.783E-02	2.357E-03	0.000E+00	1.622E-01	8.296E-01
7.500E+01	6.461E-01	0.000E+00	4.692E-01	1.571E+00	5.750E-02	2.661E-03	0.000E+00	1.651E-01	8.154E-01
8.000E+01	6.310E-01	0.000E+00	5.042E-01	1.582E+00	5.793E-02	2.999E-03	0.000E+00	1.693E-01	7.897E-01
8.500E+01	6.170E-01	0.000E+00	5.424E-01	1.603E+00	5.768E-02	3.459E-03	0.000E+00	1.772E-01	7.742E-01
9.000E+01	6.041E-01	0.000E+00	5.726E-01	1.611E+00	5.826E-02	3.886E-03	0.000E+00	1.803E-01	7.570E-01
9.500E+01	5.926E-01	0.000E+00	6.026E-01	1.622E+00	5.897E-02	4.364E-03	0.000E+00	1.839E-01	7.442E-01
1.000E+02	5.830E-01	0.000E+00	6.321E-01	1.636E+00	5.979E-02	4.871E-03	0.000E+00	1.880E-01	7.322E-01
1.100E+02	5.679E-01	0.000E+00	6.946E-01	1.675E+00	6.201E-02	6.192E-03	0.000E+00	1.960E-01	7.140E-01
1.200E+02	5.570E-01	0.000E+00	7.507E-01	1.708E+00	6.414E-02	7.594E-03	0.000E+00	2.018E-01	6.986E-01
1.300E+02	5.486E-01	0.000E+00	8.088E-01	1.748E+00	6.654E-02	9.309E-03	0.000E+00	2.103E-01	6.876E-01
1.400E+02	5.420E-01	0.000E+00	8.584E-01	1.785E+00	6.907E-02	1.104E-02	0.000E+00	2.154E-01	6.751E-01
1.500E+02	5.372E-01	0.000E+00	9.029E-01	1.820E+00	7.092E-02	1.275E-02	0.000E+00	2.195E-01	6.594E-01

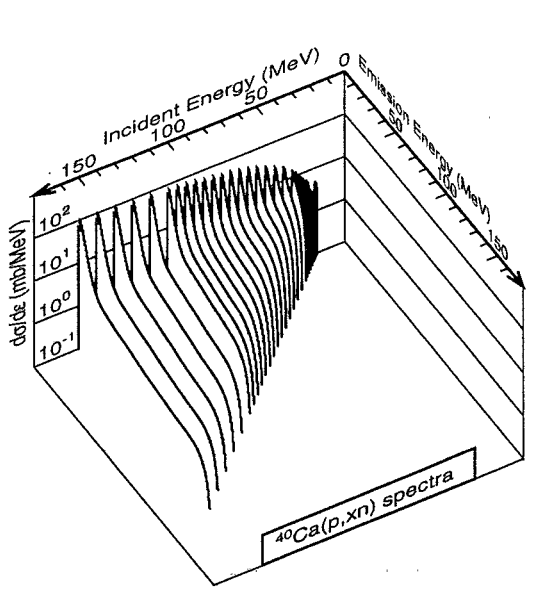
20040 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

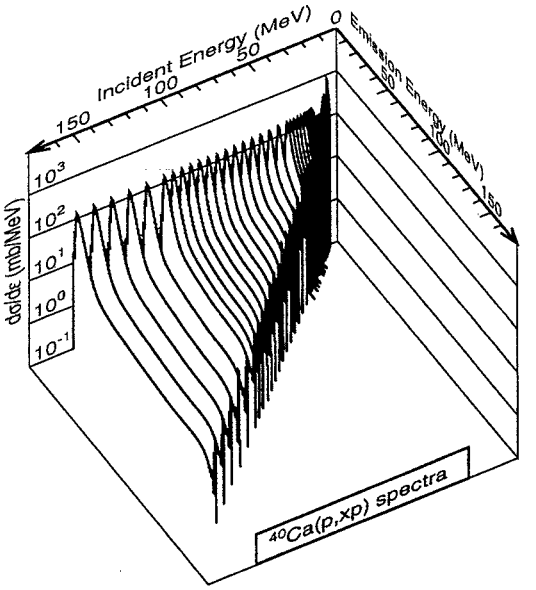
Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
5.000E+00	0.000E+00	1.464E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.267E+00
6.000E+00	0.000E+00	2.242E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.196E+00
7.000E+00	0.000E+00	3.061E+00	0.000E+00	0.000E+00	0.000E+00	1.492E+00	3.068E+00
8.000E+00	0.000E+00	3.719E+00	0.000E+00	0.000E+00	0.000E+00	2.277E+00	2.916E+00
9.000E+00	0.000E+00	4.087E+00	0.000E+00	0.000E+00	0.000E+00	3.164E+00	2.823E+00
1.000E+01	0.000E+00	4.433E+00	0.000E+00	0.000E+00	0.000E+00	4.055E+00	2.822E+00
1.100E+01	0.000E+00	4.726E+00	0.000E+00	0.000E+00	0.000E+00	4.895E+00	2.901E+00
1.200E+01	0.000E+00	4.822E+00	0.000E+00	0.000E+00	0.000E+00	5.495E+00	2.978E+00
1.300E+01	0.000E+00	4.669E+00	0.000E+00	0.000E+00	0.000E+00	6.121E+00	3.002E+00
1.400E+01	0.000E+00	4.568E+00	0.000E+00	0.000E+00	0.000E+00	6.306E+00	2.982E+00
1.500E+01	0.000E+00	4.558E+00	1.131E+00	0.000E+00	0.000E+00	5.855E+00	2.941E+00
1.600E+01	3.907E-01	4.772E+00	2.070E+00	0.000E+00	0.000E+00	5.576E+00	2.872E+00
1.700E+01	9.662E-01	5.032E+00	3.057E+00	0.000E+00	0.000E+00	5.592E+00	2.825E+00
1.800E+01	1.384E+00	5.278E+00	3.844E+00	0.000E+00	0.000E+00	5.782E+00	2.734E+00
1.900E+01	1.713E+00	5.508E+00	4.282E+00	0.000E+00	0.000E+00	6.043E+00	2.625E+00
2.000E+01	1.932E+00	5.687E+00	4.710E+00	0.000E+00	0.000E+00	6.329E+00	2.587E+00
2.200E+01	2.647E+00	6.193E+00	5.781E+00	9.743E-01	0.000E+00	6.757E+00	2.529E+00
2.400E+01	3.328E+00	6.626E+00	6.859E+00	2.745E+00	0.000E+00	7.139E+00	2.528E+00
2.600E+01	3.851E+00	6.979E+00	8.096E+00	3.864E+00	0.000E+00	7.423E+00	2.547E+00
2.800E+01	4.366E+00	7.307E+00	9.288E+00	4.783E+00	0.000E+00	7.567E+00	2.566E+00
3.000E+01	4.826E+00	7.644E+00	1.045E+01	5.805E+00	0.000E+00	7.541E+00	2.545E+00
3.500E+01	5.959E+00	8.599E+00	1.319E+01	8.268E+00	0.000E+00	7.878E+00	2.369E+00
4.000E+01	7.217E+00	9.621E+00	1.612E+01	1.046E+01	0.000E+00	8.414E+00	2.312E+00
4.500E+01	8.269E+00	1.056E+01	1.896E+01	1.231E+01	0.000E+00	8.775E+00	2.330E+00
5.000E+01	9.185E+00	1.135E+01	2.183E+01	1.387E+01	0.000E+00	9.059E+00	2.327E+00
5.500E+01	1.006E+01	1.203E+01	2.421E+01	1.520E+01	0.000E+00	9.302E+00	2.322E+00

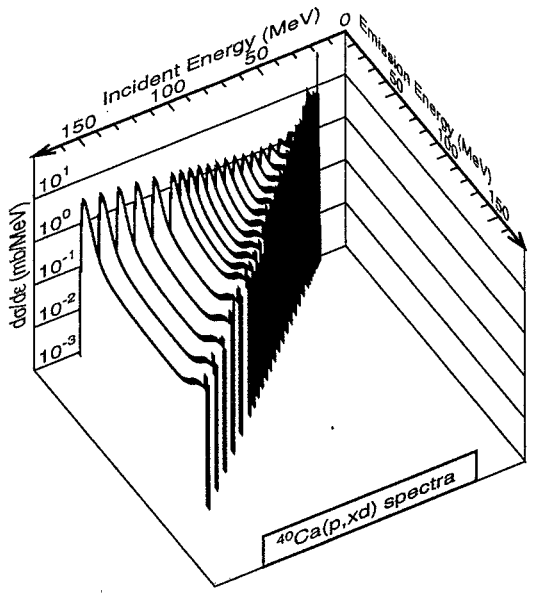
6.000E+01	1.085E+01	1.267E+01	2.667E+01	1.626E+01	0.000E+00	9.521E+00	2.326E+00
6.500E+01	1.136E+01	1.318E+01	2.858E+01	1.681E+01	0.000E+00	9.712E+00	2.331E+00
7.000E+01	1.205E+01	1.379E+01	3.077E+01	1.729E+01	0.000E+00	9.861E+00	2.389E+00
7.500E+01	1.264E+01	1.442E+01	3.245E+01	1.756E+01	0.000E+00	1.012E+01	2.404E+00
8.000E+01	1.308E+01	1.499E+01	3.426E+01	1.762E+01	0.000E+00	1.029E+01	2.390E+00
8.500E+01	1.337E+01	1.542E+01	3.486E+01	1.722E+01	0.000E+00	1.045E+01	2.381E+00
9.000E+01	1.380E+01	1.597E+01	3.622E+01	1.699E+01	0.000E+00	1.062E+01	2.391E+00
9.500E+01	1.421E+01	1.651E+01	3.739E+01	1.666E+01	0.000E+00	1.077E+01	2.387E+00
1.000E+02	1.462E+01	1.703E+01	3.838E+01	1.629E+01	0.000E+00	1.088E+01	2.364E+00
1.100E+02	1.534E+01	1.798E+01	3.921E+01	1.536E+01	0.000E+00	1.119E+01	2.334E+00
1.200E+02	1.619E+01	1.906E+01	3.985E+01	1.470E+01	0.000E+00	1.151E+01	2.341E+00
1.300E+02	1.696E+01	2.001E+01	3.920E+01	1.406E+01	0.000E+00	1.176E+01	2.342E+00
1.400E+02	1.782E+01	2.099E+01	3.885E+01	1.359E+01	0.000E+00	1.200E+01	2.338E+00
1.500E+02	1.880E+01	2.204E+01	3.796E+01	1.327E+01	0.000E+00	1.225E+01	2.319E+00

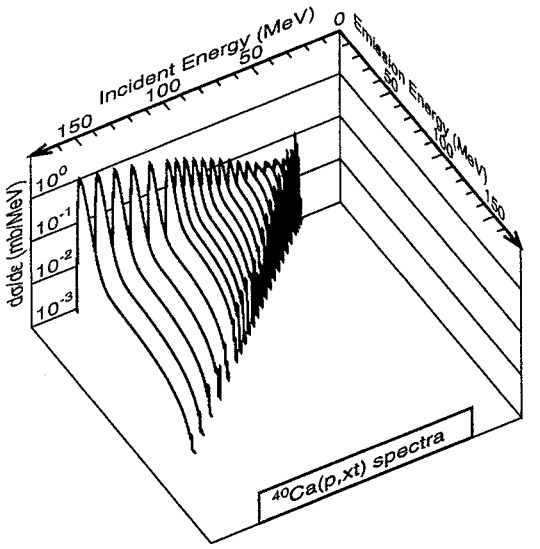

p + 40Ca nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
p
n
γ
α
d
t
Nonelastic Cross Section (mb)
10^2
10^1
0
50
100
150
Incident Energy (MeV)

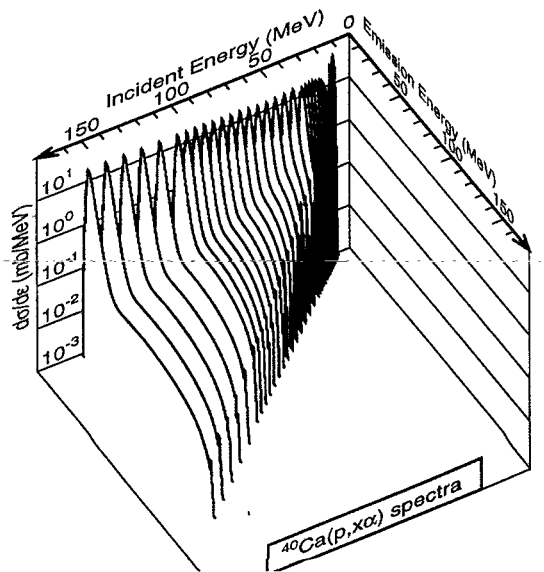
p + ^{40}Ca angle-integrated emission spectra

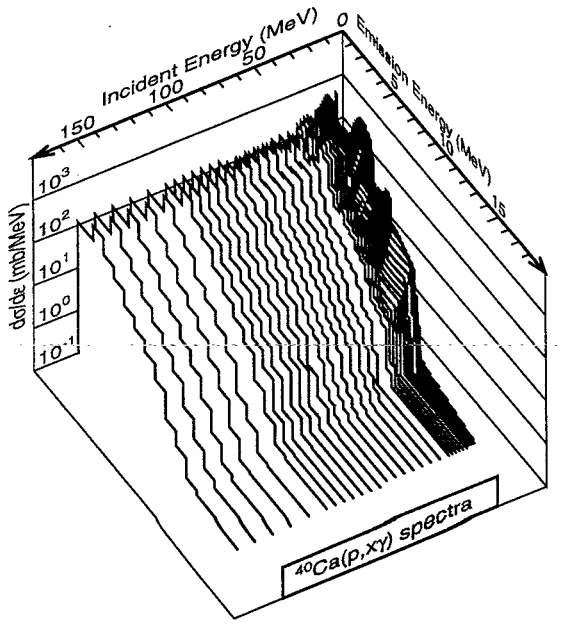




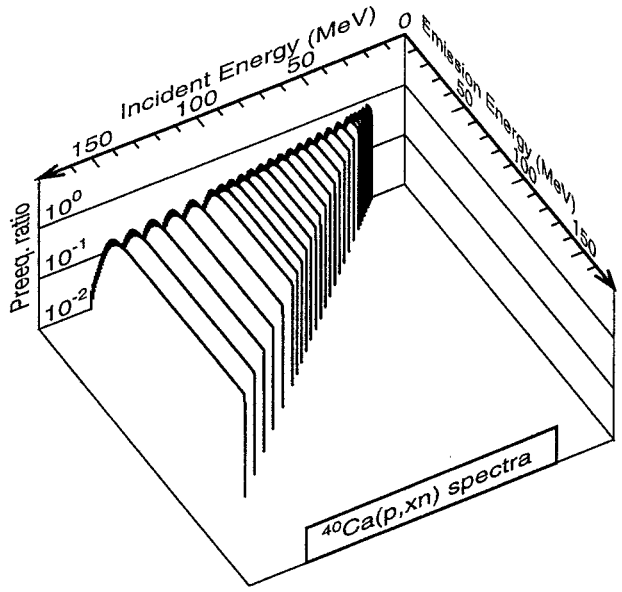


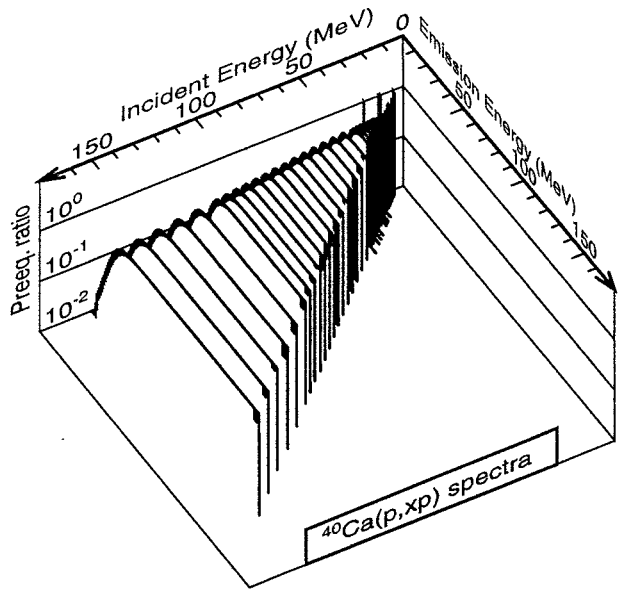


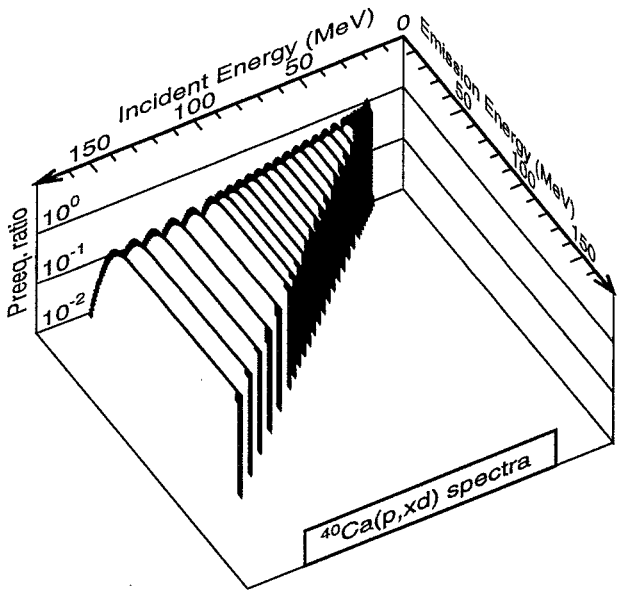


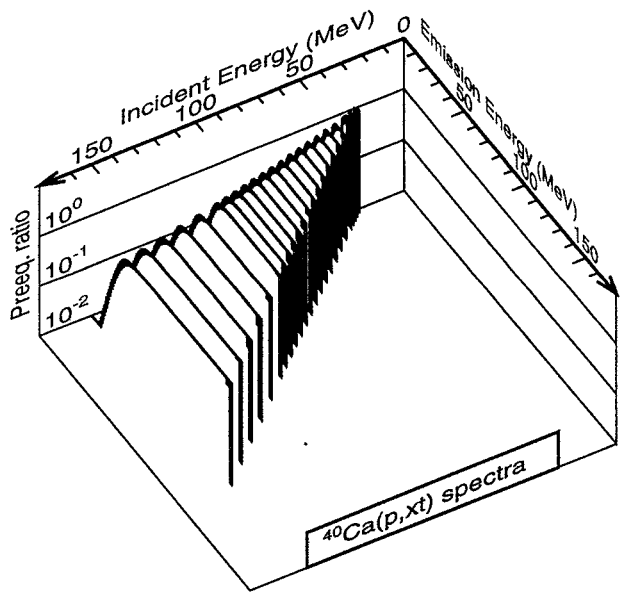


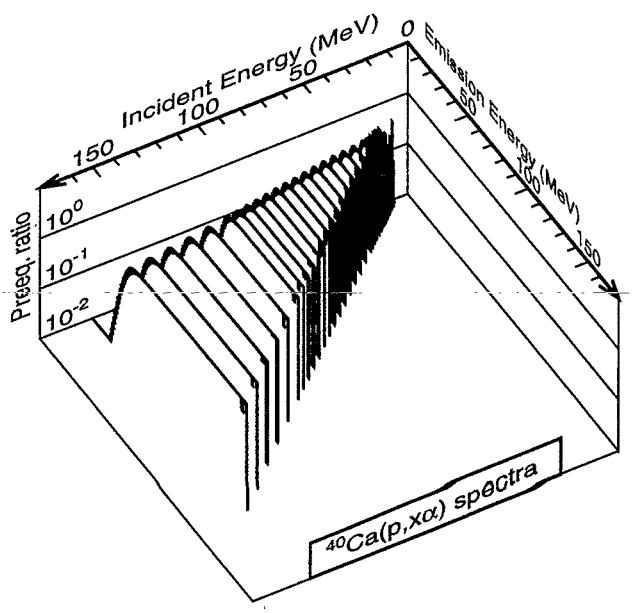
p + ^{40}Ca Kalbach preequilibrium ratios

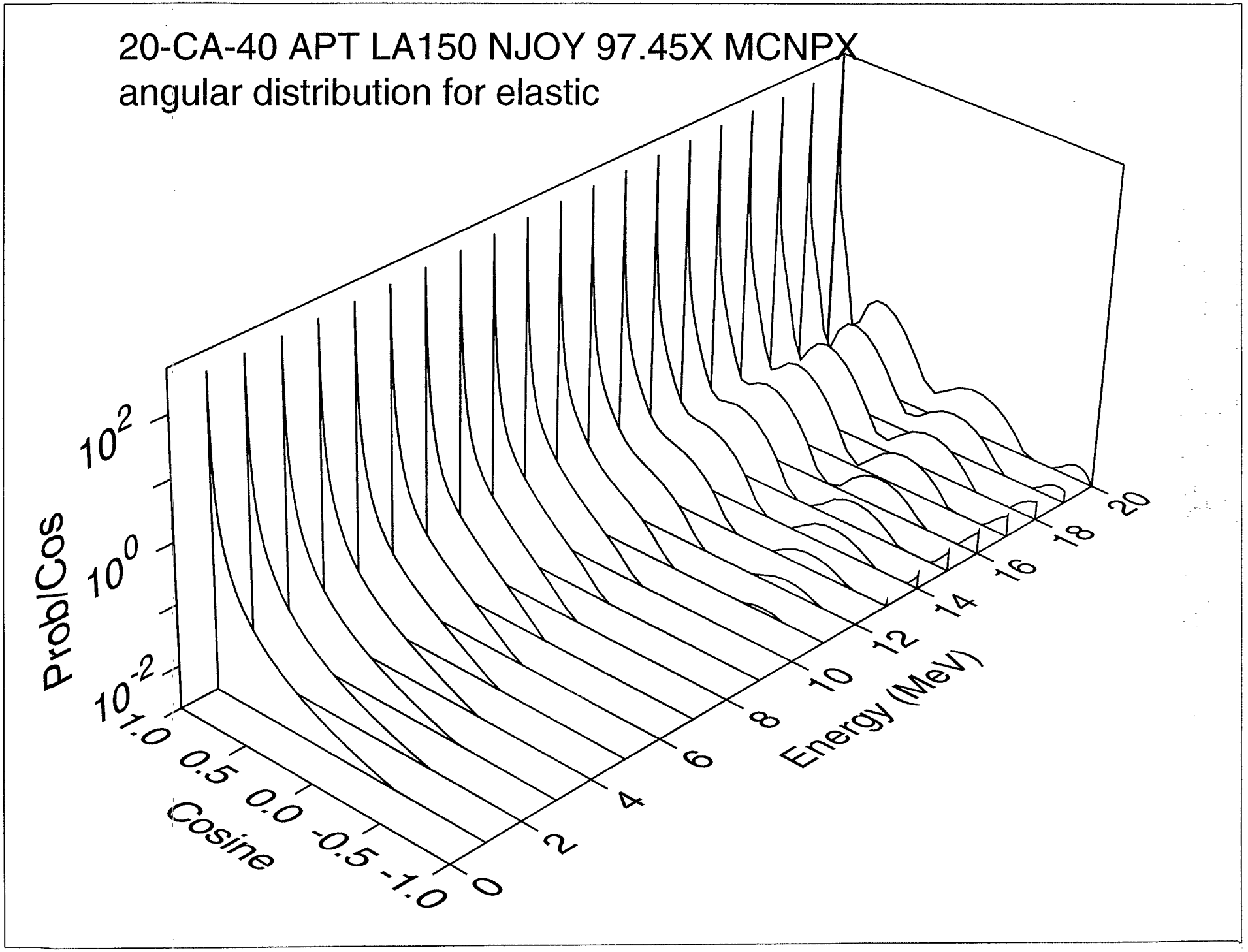


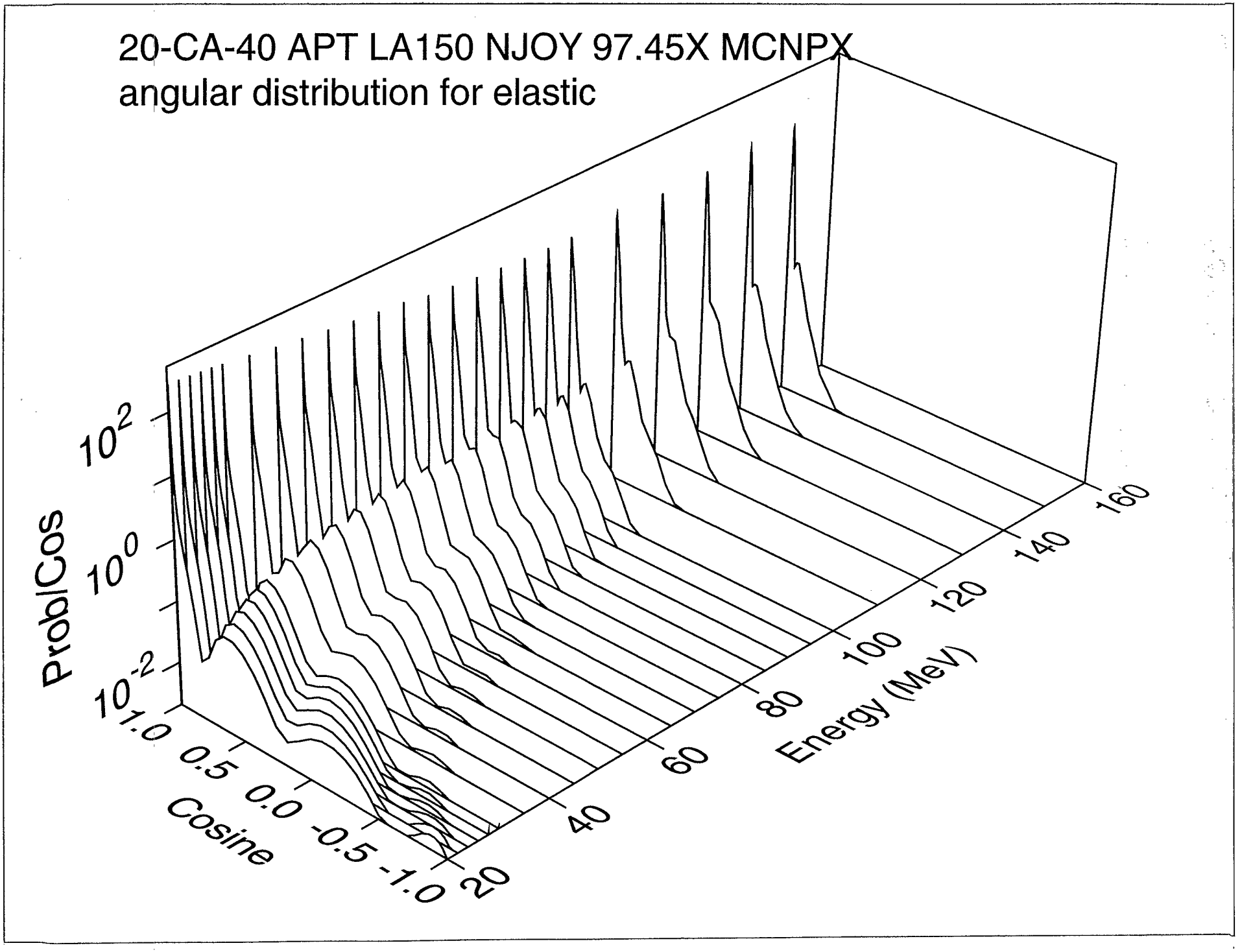


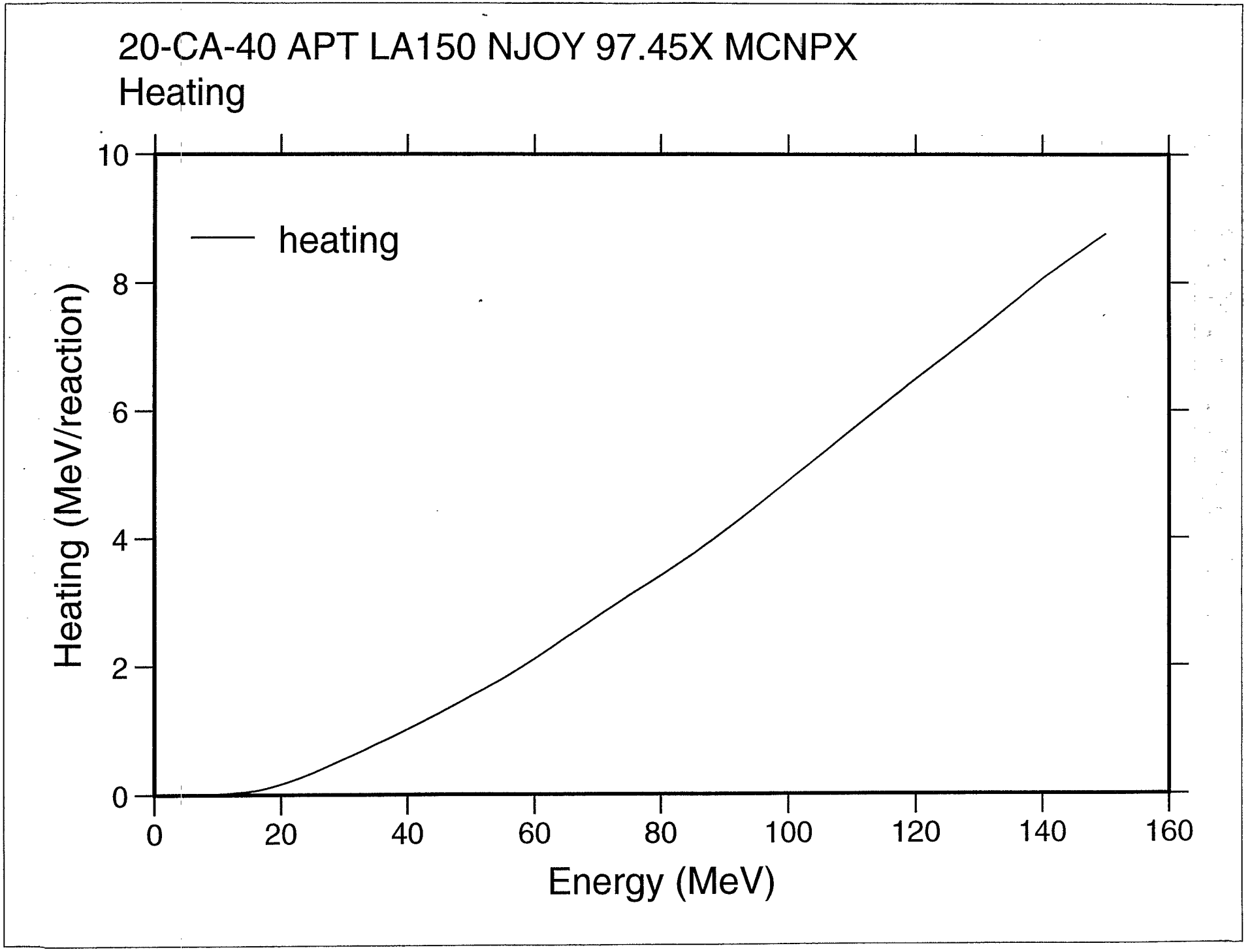







20-CA-40 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
0
2
4
6
8
10
12
14
16
18
20


20-CA-40 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
20
40
60
80
100
120
140
160


20-CA-40 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
2
4
6
8
10
0
20
40
60
80
100
120
140
160

EVALUATION OF p + 50Cr CROSS SECTIONS FOR THE ENERGY RANGE 1 to 150 MeV

S. Chiba, M. B. Chadwick, and P. G. Young
22 October 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident proton energy range from 1 to 150 MeV. The evaluation utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above are:

MF=3	MT= 2	Integral of nuclear plus interference components of the elastic scattering cross section
	MT= 5	Sum of binary (p,n') and (p,x) reactions
MF=6	MT= 2	Elastic (p,p) angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
	MT= 5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Ni58 and p + Ni58 reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic proton angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk et al. (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged- particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray

transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

SOME Cr-SPECIFIC INFORMATION CONCERNING THE EVAL.

The transmission coefficients calculated for p+ Cr-52 evaluation were employed for all the p + Cr-50 channels, by multiplying by a factor of 0.974192, i.e., a ratio of A**(2/3) between Cr-50 and Cr-52.

The Cr-52 transmission coefficients were calculated by using the following potentials:

Neutrons: a newly-searched potential for Cr-52 as described in the File 1 description of the n + Cr-52 evaluation.

Protons: a combination of 2 potentials was used :

below 40 MeV : Becchetti-Greenlees (Be69)
above 40 MeV : Madland medium energy potential (Ma88)

The proton reaction cross section and transmission coefficients below 40 MeV were multiplied by a factor of 0.845 to make the agreement with the measured proton reaction cross section (Ca96) better, and also to make the connection to higher energy values smoothly.

For deuterons, the Lohr-Haeberli (Lo74) global potential was used; for alpha particles the McFadden-Satchler (Mc66) potential was used; and for tritons the Becchetti-Greenlees (Be71) potential was used. The He-3 channel was ignored.

The direct collective inelastic scattering to the following levels in Cr-52 was considered by the DWBA-mode calculation of ECIS95 (Ra96):

Jpi	Ex(MeV)	Deformation length
2+	0.786	1.063
2+	2.922	0.479
2+	3.156	0.591
4+	3.317	0.4
4+	3.621	0.565
4+	3.692	0.447
4+	3.898	0.214
3-	4.045	0.692
2+	4.188	0.648
5-	4.363	0.565
3-	4.543	0.223
2+	4.676	0.316
2+	4.772	0.316
4+	4.924	0.4
4+	5.233	0.469
3-	6.45	0.264
3-	6.65	0.360
3-	6.79	0.244
3-	7.86	0.2

These data were retrieved from the literature (Bu95).

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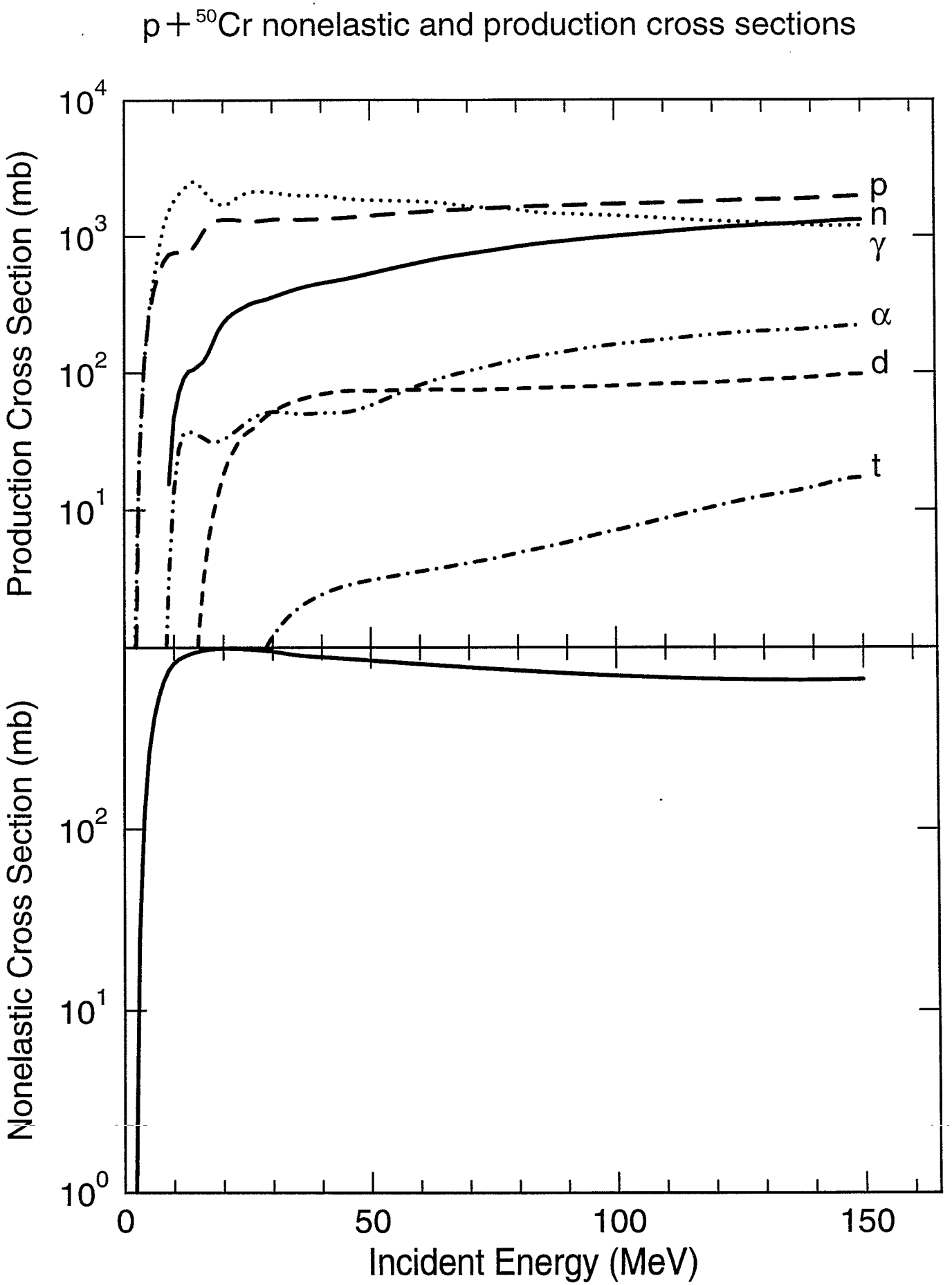
24050 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
1.000E+00	1.999E-05	0.000E+00	0.000E+00	1.441E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.225E-05
2.000E+00	5.925E-04	0.000E+00	0.000E+00	4.272E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	6.594E-04
3.000E+00	2.415E-02	0.000E+00	0.000E+00	2.400E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.423E-02
4.000E+00	1.189E-01	0.000E+00	0.000E+00	1.188E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.215E-01
5.000E+00	2.638E-01	0.000E+00	0.000E+00	2.635E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.846E-01
6.000E+00	4.073E-01	0.000E+00	0.000E+00	4.069E-01	0.000E+00	0.000E+00	0.000E+00	4.783E-09	4.929E-01
7.000E+00	5.375E-01	0.000E+00	0.000E+00	5.370E-01	0.000E+00	0.000E+00	0.000E+00	5.869E-06	7.936E-01
8.000E+00	6.597E-01	0.000E+00	0.000E+00	6.588E-01	0.000E+00	0.000E+00	0.000E+00	3.198E-04	1.186E+00
9.000E+00	7.553E-01	0.000E+00	1.552E-02	7.359E-01	0.000E+00	0.000E+00	0.000E+00	3.314E-03	1.525E+00
1.000E+01	8.197E-01	0.000E+00	4.677E-02	7.588E-01	0.000E+00	0.000E+00	0.000E+00	1.352E-02	1.790E+00
1.100E+01	8.629E-01	0.000E+00	7.129E-02	7.634E-01	0.000E+00	0.000E+00	0.000E+00	2.774E-02	2.016E+00
1.200E+01	8.916E-01	0.000E+00	9.140E-02	7.636E-01	4.318E-09	0.000E+00	0.000E+00	3.603E-02	2.198E+00
1.300E+01	9.156E-01	0.000E+00	1.031E-01	7.774E-01	1.383E-05	0.000E+00	0.000E+00	3.736E-02	2.399E+00
1.400E+01	9.356E-01	0.000E+00	1.059E-01	8.264E-01	2.861E-04	0.000E+00	0.000E+00	3.654E-02	2.515E+00
1.500E+01	9.520E-01	0.000E+00	1.136E-01	9.314E-01	1.227E-03	0.000E+00	0.000E+00	3.493E-02	2.429E+00
1.600E+01	9.652E-01	0.000E+00	1.220E-01	1.075E+00	3.061E-03	0.000E+00	0.000E+00	3.337E-02	2.189E+00
1.700E+01	9.750E-01	0.000E+00	1.401E-01	1.198E+00	6.042E-03	2.688E-08	0.000E+00	3.167E-02	1.960E+00
1.800E+01	9.814E-01	0.000E+00	1.689E-01	1.273E+00	9.411E-03	2.087E-06	0.000E+00	3.123E-02	1.804E+00
1.900E+01	9.849E-01	0.000E+00	2.041E-01	1.307E+00	1.298E-02	1.728E-05	0.000E+00	3.147E-02	1.733E+00
2.000E+01	9.864E-01	0.000E+00	2.322E-01	1.320E+00	1.780E-02	4.866E-05	0.000E+00	3.233E-02	1.677E+00
2.200E+01	9.851E-01	0.000E+00	2.724E-01	1.319E+00	2.630E-02	1.410E-04	0.000E+00	3.617E-02	1.816E+00
2.400E+01	9.805E-01	0.000E+00	3.012E-01	1.296E+00	3.433E-02	3.399E-04	0.000E+00	4.129E-02	2.009E+00
2.600E+01	9.733E-01	0.000E+00	3.269E-01	1.281E+00	3.896E-02	6.073E-04	0.000E+00	4.674E-02	2.112E+00
2.800E+01	9.631E-01	0.000E+00	3.409E-01	1.298E+00	4.568E-02	9.003E-04	0.000E+00	5.025E-02	2.113E+00
3.000E+01	9.503E-01	0.000E+00	3.593E-01	1.324E+00	5.196E-02	1.205E-03	0.000E+00	5.196E-02	2.081E+00
3.500E+01	9.078E-01	0.000E+00	4.135E-01	1.320E+00	6.289E-02	1.911E-03	0.000E+00	5.023E-02	1.979E+00
4.000E+01	8.865E-01	0.000E+00	4.562E-01	1.334E+00	6.978E-02	2.434E-03	0.000E+00	5.090E-02	1.972E+00
4.500E+01	8.680E-01	0.000E+00	4.909E-01	1.365E+00	7.370E-02	2.825E-03	0.000E+00	5.167E-02	1.878E+00
5.000E+01	8.488E-01	0.000E+00	5.366E-01	1.411E+00	7.382E-02	3.098E-03	0.000E+00	5.789E-02	1.832E+00
5.500E+01	8.301E-01	0.000E+00	5.893E-01	1.459E+00	7.453E-02	3.335E-03	0.000E+00	6.875E-02	1.815E+00
6.000E+01	8.123E-01	0.000E+00	6.438E-01	1.501E+00	7.502E-02	3.587E-03	0.000E+00	8.101E-02	1.788E+00
6.500E+01	7.953E-01	0.000E+00	6.984E-01	1.539E+00	7.527E-02	3.838E-03	0.000E+00	9.260E-02	1.743E+00
7.000E+01	7.791E-01	0.000E+00	7.433E-01	1.571E+00	7.464E-02	4.129E-03	0.000E+00	1.028E-01	1.650E+00
7.500E+01	7.637E-01	0.000E+00	7.889E-01	1.601E+00	7.537E-02	4.448E-03	0.000E+00	1.135E-01	1.606E+00
8.000E+01	7.493E-01	0.000E+00	8.385E-01	1.632E+00	7.631E-02	4.882E-03	0.000E+00	1.249E-01	1.564E+00
8.500E+01	7.358E-01	0.000E+00	8.837E-01	1.654E+00	7.717E-02	5.323E-03	0.000E+00	1.341E-01	1.477E+00
9.000E+01	7.233E-01	0.000E+00	9.229E-01	1.673E+00	7.815E-02	5.827E-03	0.000E+00	1.432E-01	1.451E+00
9.500E+01	7.119E-01	0.000E+00	9.637E-01	1.695E+00	7.882E-02	6.493E-03	0.000E+00	1.531E-01	1.429E+00
1.000E+02	7.015E-01	0.000E+00	1.000E+00	1.713E+00	7.999E-02	7.147E-03	0.000E+00	1.613E-01	1.407E+00
1.100E+02	6.845E-01	0.000E+00	1.071E+00	1.748E+00	8.270E-02	8.661E-03	0.000E+00	1.752E-01	1.345E+00
1.200E+02	6.723E-01	0.000E+00	1.145E+00	1.796E+00	8.457E-02	1.057E-02	0.000E+00	1.903E-01	1.287E+00
1.300E+02	6.654E-01	0.000E+00	1.202E+00	1.840E+00	8.862E-02	1.260E-02	0.000E+00	2.018E-01	1.242E+00
1.400E+02	6.638E-01	0.000E+00	1.254E+00	1.883E+00	9.245E-02	1.458E-02	0.000E+00	2.104E-01	1.192E+00
1.500E+02	6.691E-01	0.000E+00	1.311E+00	1.946E+00	9.723E-02	1.716E-02	0.000E+00	2.212E-01	1.187E+00

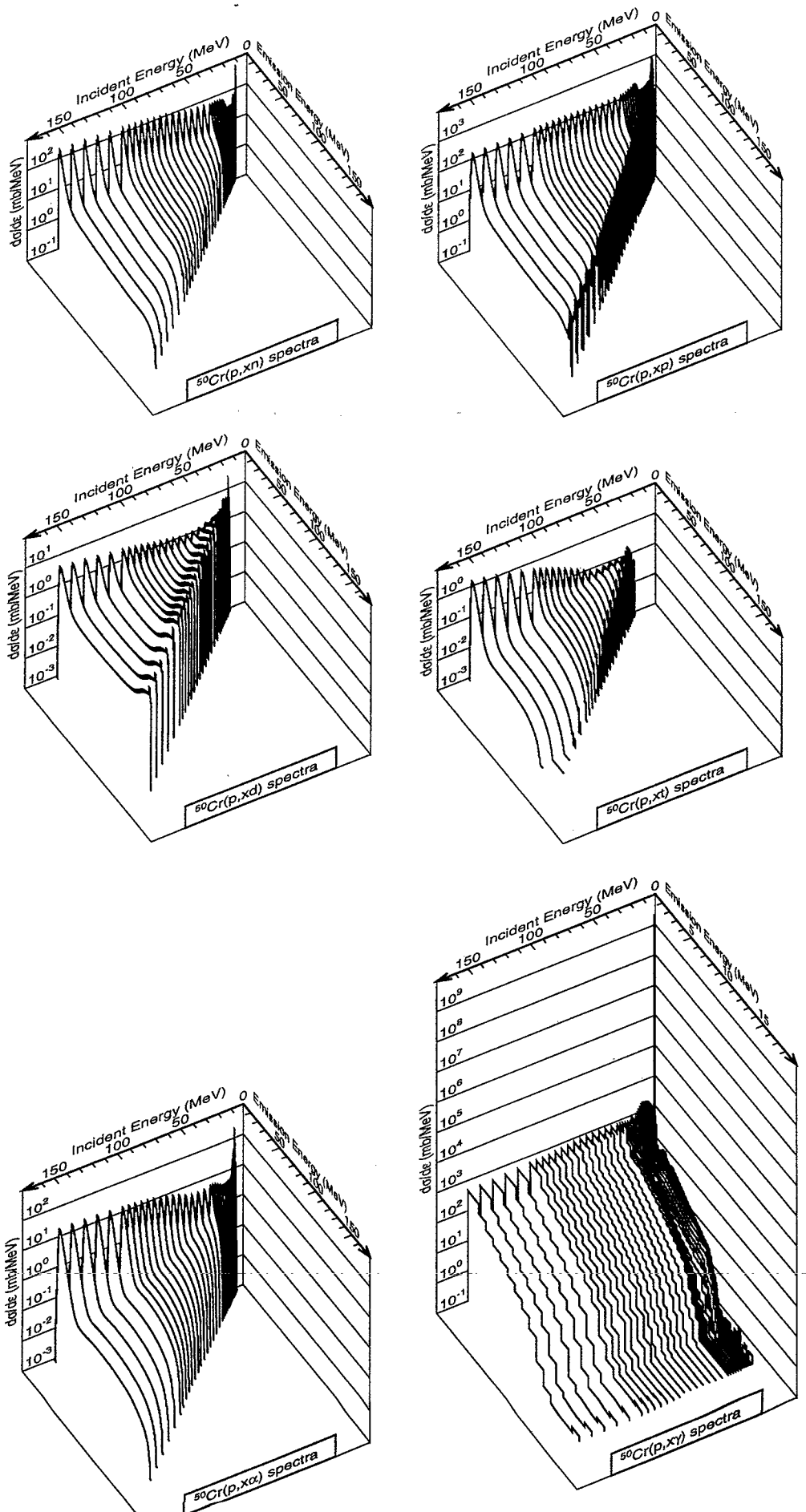
24050 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
1.000E+00	0.000E+00	3.914E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	5.000E-12
2.000E+00	0.000E+00	1.226E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.832E+00
3.000E+00	0.000E+00	2.206E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	7.796E-01
4.000E+00	0.000E+00	3.162E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	7.629E-01
5.000E+00	0.000E+00	3.845E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	7.749E-01
6.000E+00	0.000E+00	4.644E+00	0.000E+00	0.000E+00	0.000E+00	2.202E+00	8.447E-01
7.000E+00	0.000E+00	5.017E+00	0.000E+00	0.000E+00	0.000E+00	3.113E+00	1.110E+00
8.000E+00	0.000E+00	4.991E+00	0.000E+00	0.000E+00	0.000E+00	3.976E+00	1.481E+00
9.000E+00	2.811E-01	5.028E+00	0.000E+00	0.000E+00	0.000E+00	4.868E+00	1.750E+00
1.000E+01	9.064E-01	5.212E+00	0.000E+00	0.000E+00	0.000E+00	5.734E+00	1.894E+00
1.100E+01	1.377E+00	5.454E+00	0.000E+00	0.000E+00	0.000E+00	6.534E+00	1.998E+00
1.200E+01	1.699E+00	5.673E+00	9.034E-01	0.000E+00	0.000E+00	7.145E+00	2.132E+00
1.300E+01	2.029E+00	5.917E+00	1.818E+00	0.000E+00	0.000E+00	7.637E+00	2.226E+00
1.400E+01	2.252E+00	6.009E+00	2.710E+00	0.000E+00	0.000E+00	7.969E+00	2.304E+00
1.500E+01	2.502E+00	5.784E+00	3.454E+00	0.000E+00	0.000E+00	8.186E+00	2.282E+00
1.600E+01	2.707E+00	5.580E+00	4.039E+00	0.000E+00	0.000E+00	8.334E+00	2.166E+00
1.700E+01	2.772E+00	5.553E+00	4.547E+00	1.438E+00	0.000E+00	8.401E+00	2.001E+00
1.800E+01	2.759E+00	5.704E+00	5.231E+00	2.287E+00	0.000E+00	8.504E+00	1.802E+00
1.900E+01	2.768E+00	5.965E+00	5.814E+00	3.004E+00	0.000E+00	8.598E+00	1.643E+00
2.000E+01	2.995E+00	6.287E+00	6.346E+00	3.693E+00	0.000E+00	8.688E+00	1.622E+00
2.200E+01	3.375E+00	6.939E+00	7.621E+00	4.571E+00	0.000E+00	8.876E+00	1.573E+00
2.400E+01	3.846E+00	7.579E+00	8.906E+00	5.499E+00	0.000E+00	9.103E+00	1.678E+00

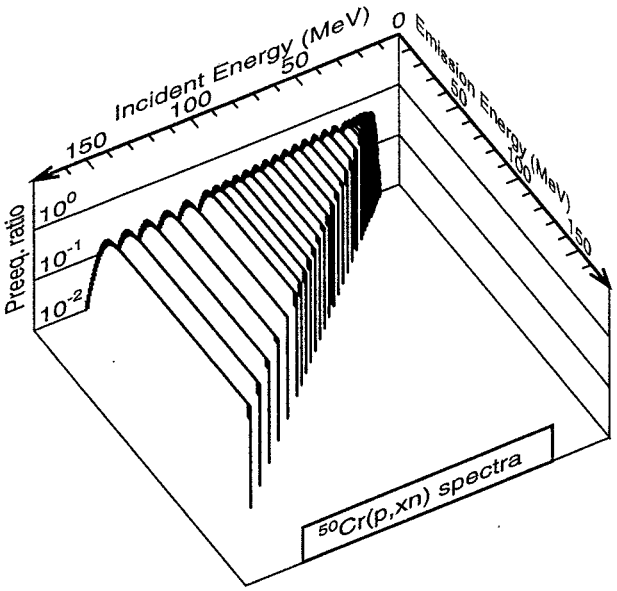
2.600E+01	4.292E+00	8.129E+00	9.970E+00	6.509E+00	0.000E+00	9.358E+00	1.824E+00
2.800E+01	4.812E+00	8.549E+00	1.112E+01	7.488E+00	0.000E+00	9.671E+00	1.878E+00
3.000E+01	5.276E+00	8.892E+00	1.228E+01	8.429E+00	0.000E+00	1.003E+01	1.853E+00
3.500E+01	6.268E+00	1.019E+01	1.531E+01	1.066E+01	0.000E+00	1.095E+01	1.717E+00
4.000E+01	7.465E+00	1.147E+01	1.844E+01	1.267E+01	0.000E+00	1.165E+01	1.706E+00
4.500E+01	8.656E+00	1.263E+01	2.163E+01	1.479E+01	0.000E+00	1.226E+01	1.706E+00
5.000E+01	9.391E+00	1.349E+01	2.449E+01	1.667E+01	0.000E+00	1.240E+01	1.697E+00
5.500E+01	9.912E+00	1.405E+01	2.733E+01	1.818E+01	0.000E+00	1.225E+01	1.709E+00
6.000E+01	1.029E+01	1.458E+01	2.990E+01	1.924E+01	0.000E+00	1.211E+01	1.723E+00
6.500E+01	1.068E+01	1.512E+01	3.229E+01	2.001E+01	0.000E+00	1.205E+01	1.729E+00
7.000E+01	1.115E+01	1.572E+01	3.430E+01	2.055E+01	0.000E+00	1.205E+01	1.775E+00
7.500E+01	1.156E+01	1.628E+01	3.658E+01	2.077E+01	0.000E+00	1.205E+01	1.808E+00
8.000E+01	1.185E+01	1.676E+01	3.849E+01	2.045E+01	0.000E+00	1.205E+01	1.818E+00
8.500E+01	1.221E+01	1.732E+01	4.046E+01	2.015E+01	0.000E+00	1.209E+01	1.842E+00
9.000E+01	1.260E+01	1.789E+01	4.232E+01	1.967E+01	0.000E+00	1.214E+01	1.838E+00
9.500E+01	1.294E+01	1.841E+01	4.346E+01	1.890E+01	0.000E+00	1.218E+01	1.846E+00
1.000E+02	1.332E+01	1.897E+01	4.498E+01	1.821E+01	0.000E+00	1.224E+01	1.839E+00
1.100E+02	1.409E+01	2.010E+01	4.768E+01	1.689E+01	0.000E+00	1.241E+01	1.850E+00
1.200E+02	1.485E+01	2.111E+01	4.854E+01	1.548E+01	0.000E+00	1.256E+01	1.873E+00
1.300E+02	1.580E+01	2.221E+01	5.049E+01	1.419E+01	0.000E+00	1.276E+01	1.904E+00
1.400E+02	1.688E+01	2.340E+01	5.262E+01	1.314E+01	0.000E+00	1.299E+01	1.897E+00
1.500E+02	1.798E+01	2.456E+01	5.348E+01	1.219E+01	0.000E+00	1.322E+01	1.875E+00

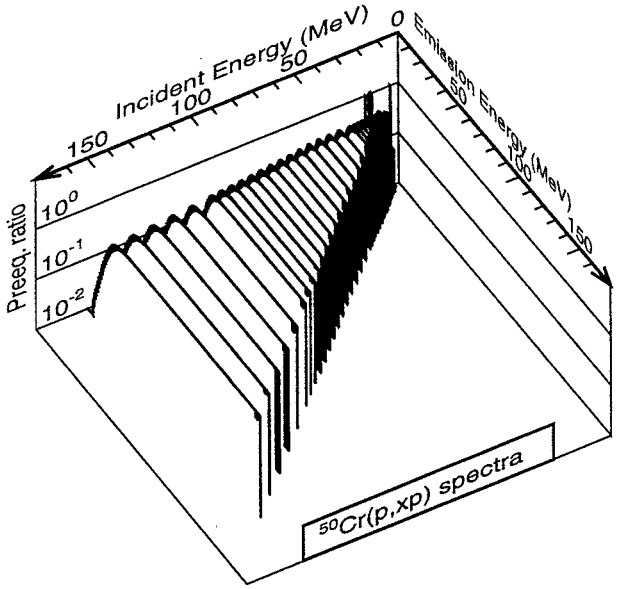

p + 50Cr nonelastic and production cross sections
Production Cross Section (mb)
Nonelastic Cross Section (mb)
Incident Energy (MeV)
p
n
γ
α
d
t
10^4
10^3
10^2
10^1
10^0
0
50
100
150

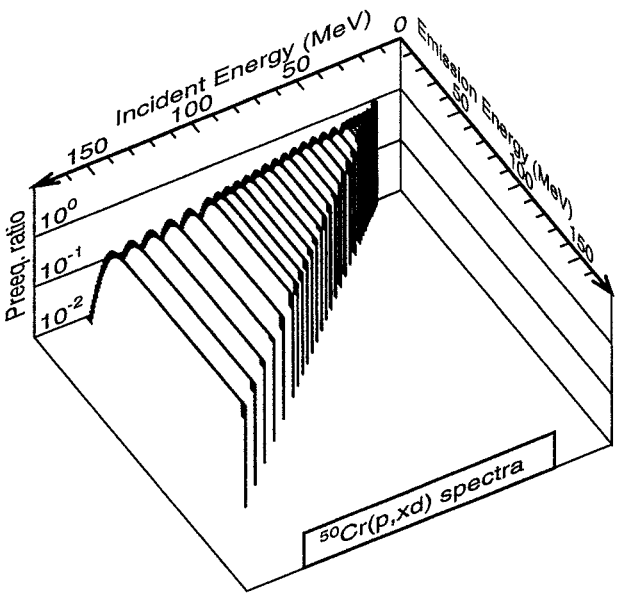
p + ^{50}Cr angle-integrated emission spectra

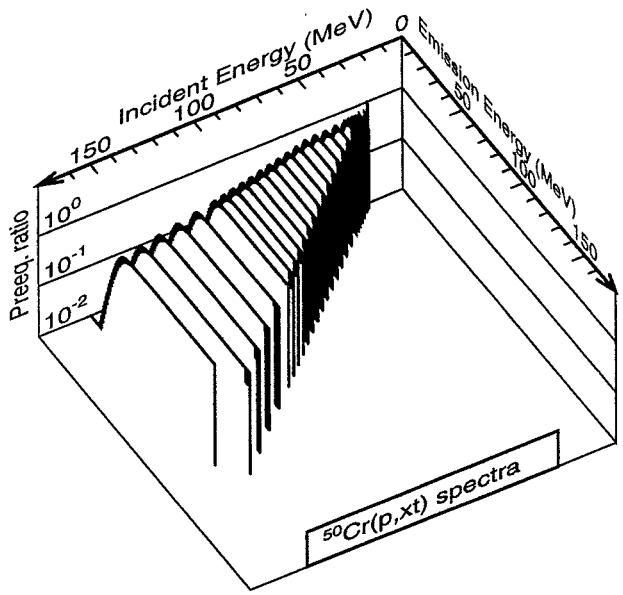


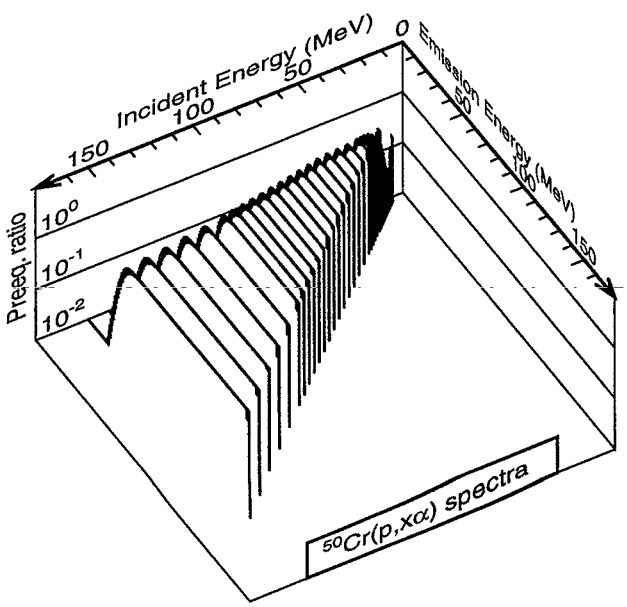
p + ^{50}Cr Kalbach preequilibrium ratios

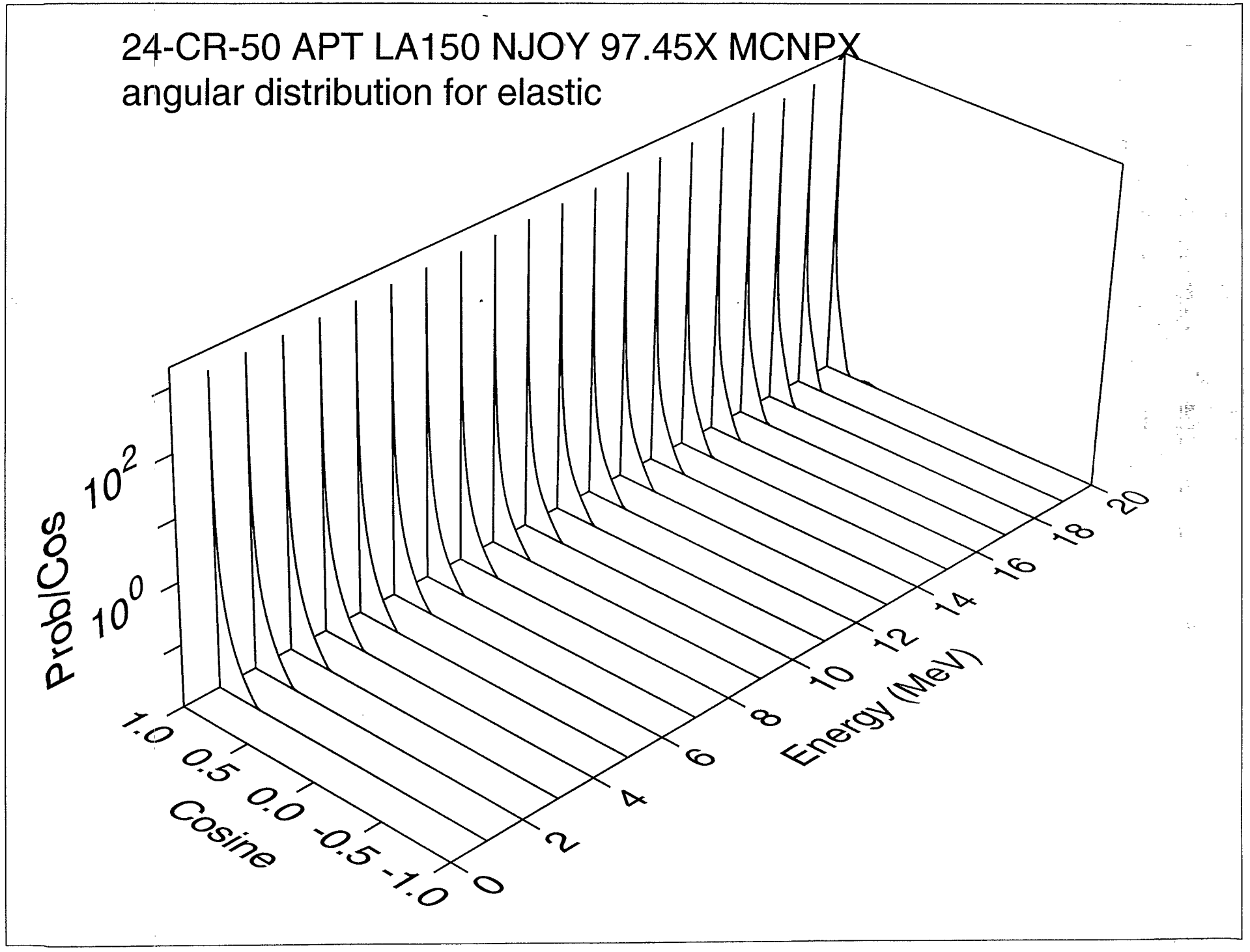


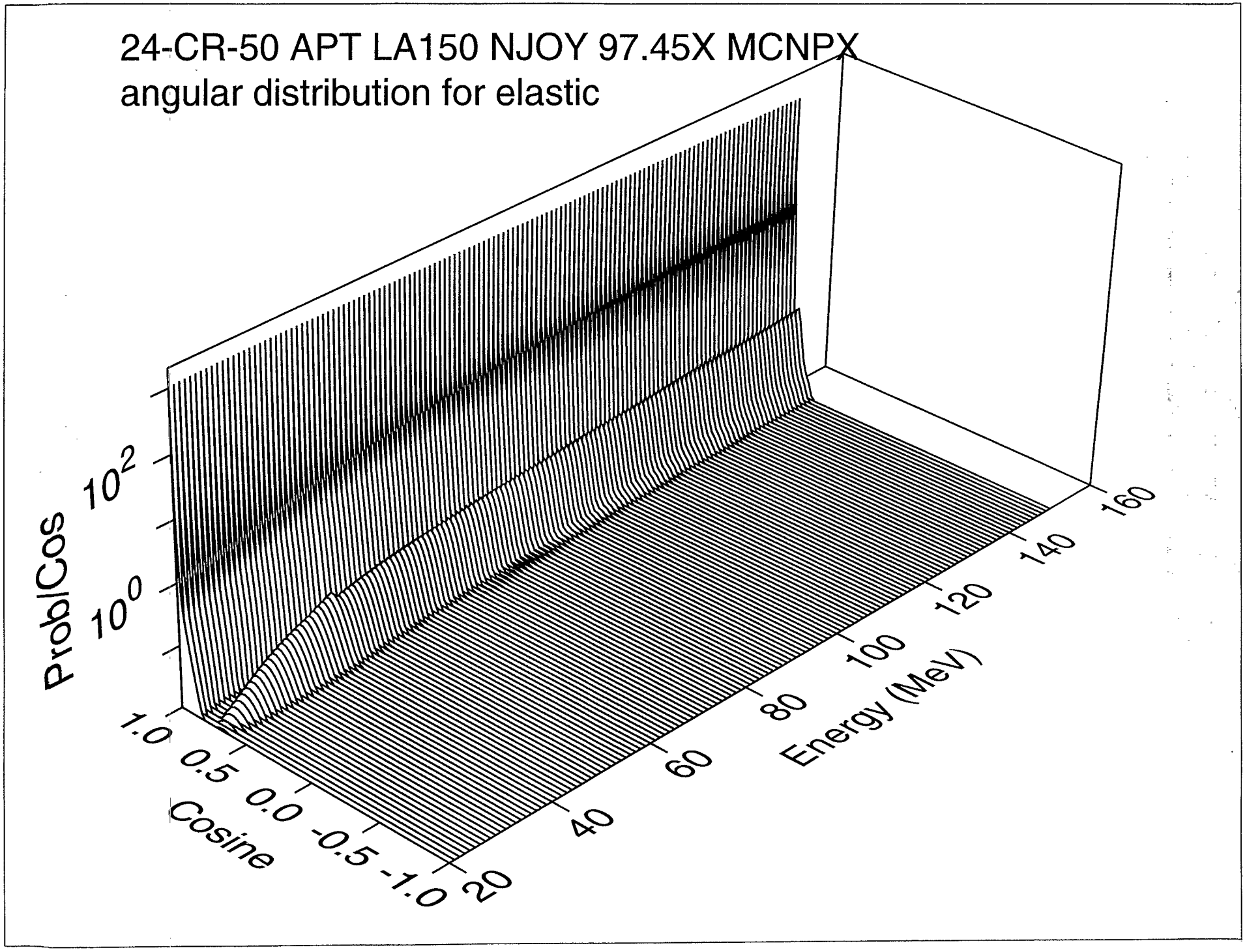


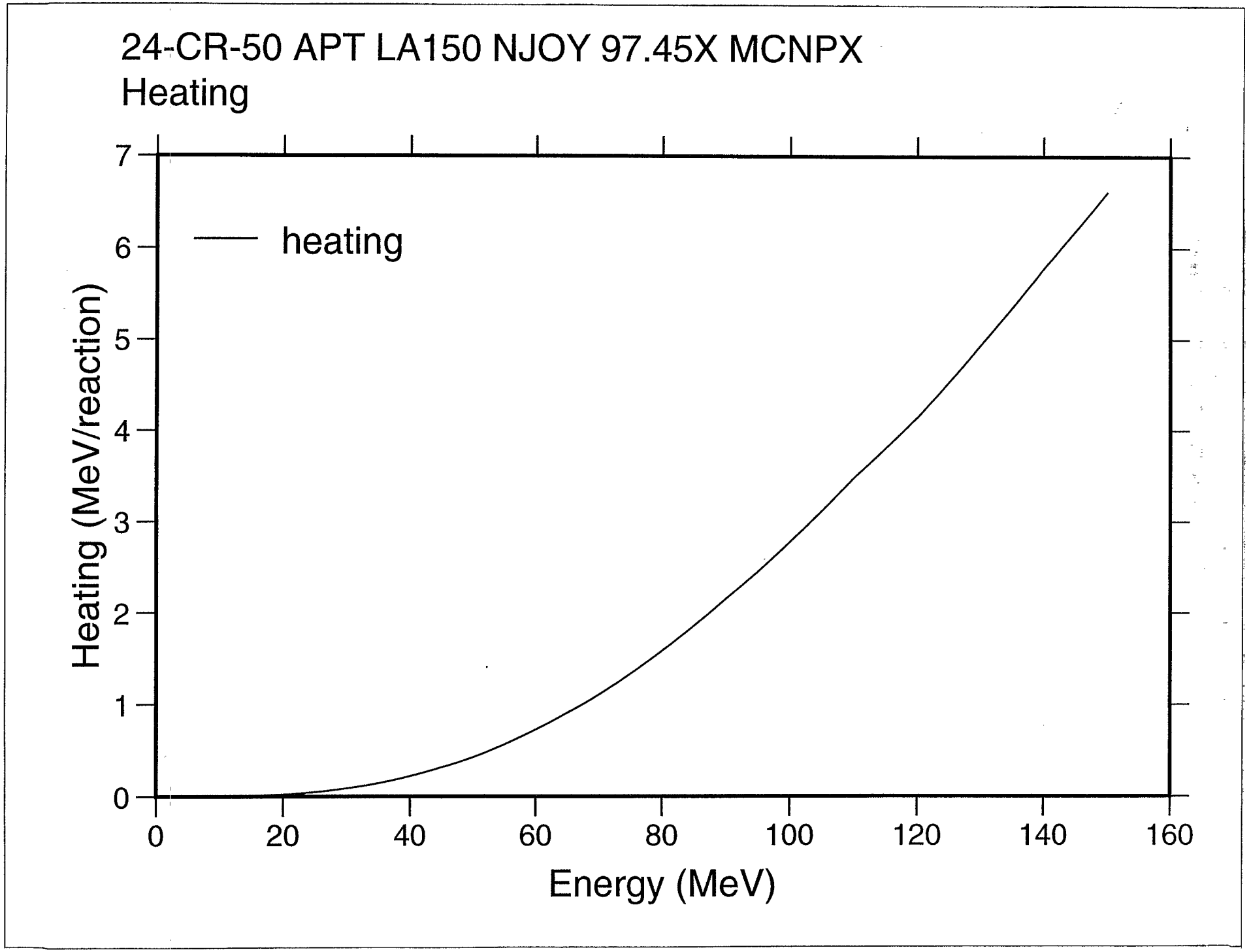







24-CR-50 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
1.0
0.5
0.0
-0.5
-1.0
Cosine
0
2
4
6
8
10
12
14
16
18
20
Energy (MeV)


24-CR-50 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


24-CR-50 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
1
2
3
4
5
6
7
0
20
40
60
80
100
120
140
160

EVALUATION OF p + 52Cr CROSS SECTIONS FOR THE ENERGY RANGE 1 to 150 MeV

S. Chiba, M. B. Chadwick, and P. G. Young
22 October 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident proton energy range from 1 to 150 MeV. The evaluation utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above are:

MF=3	MT= 2	Integral of nuclear plus interference components of the elastic scattering cross section
	MT= 5	Sum of binary (p,n') and (p,x) reactions
MF=6	MT= 2	Elastic (p,p) angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
	MT= 5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Ni58 and p + Ni58 reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic proton angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk et al. (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged- particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray

transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

SOME Cr-SPECIFIC INFORMATION CONCERNING THE EVAL.

The Cr-52 transmission coefficients were calculated by using the following OMP potentials and DWBA cross sections:

Neutrons: a newly-searched potential for Cr-52 as described in the File 1 description of the n + Cr-52 evaluation.

Protons: a combination of 2 potentials was used :

below 40 MeV : Becchetti-Greenlees (Be69)
above 40 MeV : Madland medium energy potential (Ma88)

The proton reaction cross section and transmission coefficients below 40 MeV were multiplied by a factor of 0.845 to make the agreement with the measured proton reaction cross section (Ca96) better, and also to make the connection to higher energy values smoothly.

For deuterons, the Lohr-Haeberli (Lo74) global potential was used; for alpha particles the McFadden-Satchler (Mc66) potential was used; and for tritons the Becchetti-Greenlees (Be71) potential was used. The He-3 channel was ignored.

The direct collective inelastic scattering to the following levels in Cr-52 was considered by the DWBA-mode calculation of ECIS95 (Ra96):

Jpi	Ex(MeV)	Deformation length
2+	1.434	0.87
4+	2.369	0.33
0+	2.647	0.095
4+	2.768	0.30
2+	2.965	0.08
6+	3.114	0.35
2+	3.162	0.27
4+	3.415	0.13
2+	3.772	0.28
4+	4.040	0.16
3-	4.563	0.61
4+	4.630	0.36
0+	4.738	0.145
4+	4.951	0.20
4+	5.095	0.15
4+	5.425	0.32
4+	5.541	0.074
2+	5.661	0.095
3-	5.873	0.082
3-	5.996	0.087
2+	6.055	0.13
2+	6.143	0.07
2+	6.175	0.21
2+	6.493	0.21
3-	6.580	0.34
3-	6.786	0.26
2+	6.810	0.22
5-	6.871	0.16

3-	6.993	0.18
3-	7.080	0.34
4+	7.140	0.14
2+	7.217	0.10
4+	7.278	0.13
2+	7.344	0.074
5-	7.376	0.11
3-	7.409	0.091
3-	7.482	0.13
3-	7.585	0.074
3-	7.738	0.26
3-	7.823	0.12
4+	7.848	0.11
4+	7.893	0.12
3-	7.967	0.095
2+	8.022	0.10
3-	8.089	0.091
3-	8.281	0.15
3-	8.457	0.13
3-	8.505	0.10
3-	8.679	0.10
3-	8.782	0.10
3-	8.778	0.13
3-	9.440	0.095

These data were retrieved from the literature (Ju94).

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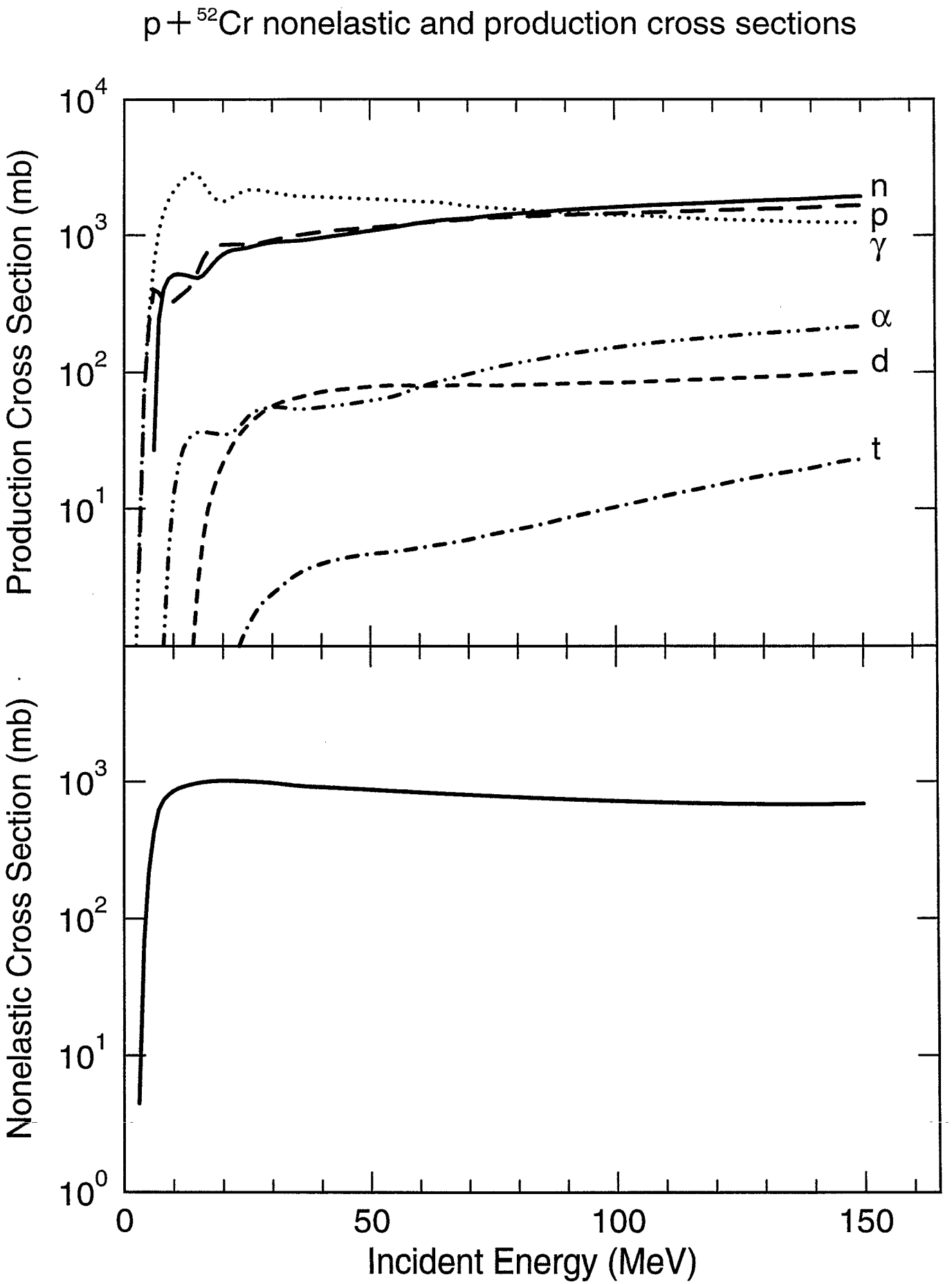
24052 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+00	4.008E-04	0.000E+00	0.000E+00	3.239E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	6.081E-04
3.000E+00	4.435E-03	0.000E+00	0.000E+00	3.584E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.796E-03
4.000E+00	6.783E-02	0.000E+00	0.000E+00	6.702E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	6.936E-02
5.000E+00	2.230E-01	0.000E+00	0.000E+00	2.222E-01	0.000E+00	0.000E+00	0.000E+00	1.040E-08	2.580E-01
6.000E+00	4.270E-01	0.000E+00	2.714E-02	3.990E-01	0.000E+00	0.000E+00	0.000E+00	2.896E-06	6.130E-01
7.000E+00	6.227E-01	0.000E+00	2.414E-01	3.806E-01	0.000E+00	0.000E+00	0.000E+00	1.167E-04	1.068E+00
8.000E+00	7.342E-01	0.000E+00	4.043E-01	3.284E-01	0.000E+00	0.000E+00	0.000E+00	1.048E-03	1.474E+00
9.000E+00	8.038E-01	0.000E+00	4.813E-01	3.172E-01	0.000E+00	0.000E+00	0.000E+00	4.882E-03	1.817E+00
1.000E+01	8.540E-01	0.000E+00	5.110E-01	3.300E-01	0.000E+00	0.000E+00	0.000E+00	1.258E-02	2.107E+00
1.100E+01	8.914E-01	0.000E+00	5.179E-01	3.521E-01	2.616E-09	0.000E+00	0.000E+00	2.096E-02	2.356E+00
1.200E+01	9.178E-01	0.000E+00	5.125E-01	3.769E-01	8.272E-06	0.000E+00	0.000E+00	2.802E-02	2.570E+00
1.300E+01	9.411E-01	0.000E+00	5.034E-01	4.043E-01	1.918E-04	0.000E+00	0.000E+00	3.282E-02	2.772E+00
1.400E+01	9.610E-01	0.000E+00	4.903E-01	4.508E-01	1.047E-03	1.065E-11	0.000E+00	3.562E-02	2.874E+00
1.500E+01	9.775E-01	0.000E+00	4.856E-01	5.503E-01	3.013E-03	3.258E-07	0.000E+00	3.667E-02	2.761E+00
1.600E+01	9.909E-01	0.000E+00	5.080E-01	6.711E-01	6.105E-03	1.048E-05	0.000E+00	3.679E-02	2.448E+00
1.700E+01	1.001E+00	0.000E+00	5.558E-01	7.641E-01	1.002E-02	5.356E-05	0.000E+00	3.645E-02	2.123E+00
1.800E+01	1.007E+00	0.000E+00	6.167E-01	8.170E-01	1.350E-02	1.193E-04	0.000E+00	3.596E-02	1.904E+00
1.900E+01	1.011E+00	0.000E+00	6.764E-01	8.401E-01	1.770E-02	2.003E-04	0.000E+00	3.554E-02	1.805E+00
2.000E+01	1.012E+00	0.000E+00	7.231E-01	8.485E-01	2.159E-02	3.184E-04	0.000E+00	3.526E-02	1.761E+00
2.200E+01	1.011E+00	0.000E+00	7.778E-01	8.533E-01	2.972E-02	7.086E-04	0.000E+00	3.666E-02	1.908E+00
2.400E+01	1.007E+00	0.000E+00	7.956E-01	8.540E-01	3.744E-02	1.157E-03	0.000E+00	4.274E-02	2.089E+00
2.600E+01	9.991E-01	0.000E+00	8.252E-01	8.561E-01	4.445E-02	1.616E-03	0.000E+00	5.071E-02	2.165E+00
2.800E+01	9.887E-01	0.000E+00	8.597E-01	8.840E-01	5.097E-02	2.063E-03	0.000E+00	5.410E-02	2.126E+00
3.000E+01	9.755E-01	0.000E+00	8.849E-01	9.195E-01	5.683E-02	2.402E-03	0.000E+00	5.587E-02	2.067E+00
3.500E+01	9.319E-01	0.000E+00	9.110E-01	9.973E-01	6.554E-02	3.331E-03	0.000E+00	5.398E-02	1.937E+00
4.000E+01	9.100E-01	0.000E+00	9.592E-01	1.058E+00	7.224E-02	3.981E-03	0.000E+00	5.589E-02	1.905E+00
4.500E+01	8.910E-01	0.000E+00	1.018E+00	1.101E+00	7.590E-02	4.398E-03	0.000E+00	5.862E-02	1.878E+00
5.000E+01	8.712E-01	0.000E+00	1.080E+00	1.138E+00	7.892E-02	4.684E-03	0.000E+00	6.254E-02	1.845E+00
5.500E+01	8.521E-01	0.000E+00	1.149E+00	1.178E+00	8.062E-02	4.882E-03	0.000E+00	6.751E-02	1.809E+00
6.000E+01	8.338E-01	0.000E+00	1.230E+00	1.230E+00	8.007E-02	5.197E-03	0.000E+00	7.815E-02	1.767E+00
6.500E+01	8.163E-01	0.000E+00	1.296E+00	1.270E+00	8.012E-02	5.545E-03	0.000E+00	8.810E-02	1.733E+00
7.000E+01	7.997E-01	0.000E+00	1.334E+00	1.310E+00	8.130E-02	5.958E-03	0.000E+00	9.736E-02	1.640E+00
7.500E+01	7.840E-01	0.000E+00	1.396E+00	1.348E+00	8.032E-02	6.525E-03	0.000E+00	1.078E-01	1.591E+00
8.000E+01	7.691E-01	0.000E+00	1.445E+00	1.369E+00	8.109E-02	7.088E-03	0.000E+00	1.173E-01	1.547E+00
8.500E+01	7.553E-01	0.000E+00	1.488E+00	1.392E+00	8.192E-02	7.734E-03	0.000E+00	1.262E-01	1.505E+00
9.000E+01	7.424E-01	0.000E+00	1.536E+00	1.415E+00	8.312E-02	8.571E-03	0.000E+00	1.362E-01	1.473E+00
9.500E+01	7.307E-01	0.000E+00	1.575E+00	1.432E+00	8.418E-02	9.388E-03	0.000E+00	1.444E-01	1.430E+00
1.000E+02	7.201E-01	0.000E+00	1.614E+00	1.450E+00	8.433E-02	1.030E-02	0.000E+00	1.522E-01	1.410E+00
1.100E+02	7.026E-01	0.000E+00	1.682E+00	1.486E+00	8.711E-02	1.246E-02	0.000E+00	1.675E-01	1.369E+00
1.200E+02	6.901E-01	0.000E+00	1.739E+00	1.525E+00	8.972E-02	1.477E-02	0.000E+00	1.810E-01	1.315E+00
1.300E+02	6.830E-01	0.000E+00	1.804E+00	1.565E+00	9.288E-02	1.752E-02	0.000E+00	1.941E-01	1.284E+00
1.400E+02	6.814E-01	0.000E+00	1.864E+00	1.607E+00	9.660E-02	2.007E-02	0.000E+00	2.047E-01	1.253E+00
1.500E+02	6.868E-01	0.000E+00	1.934E+00	1.664E+00	1.006E-01	2.308E-02	0.000E+00	2.161E-01	1.243E+00

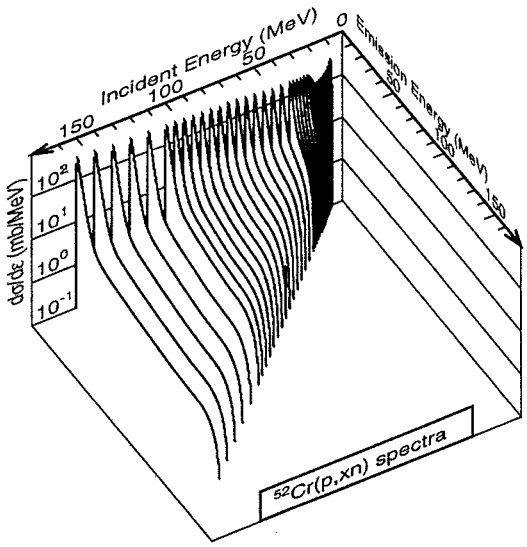
24052 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

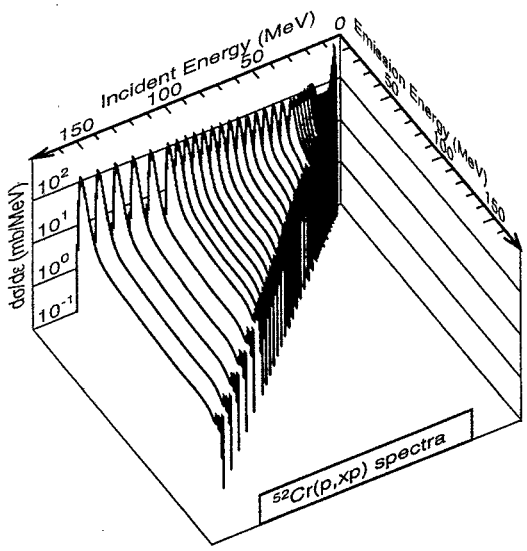
Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+00	0.000E+00	7.249E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.012E+00
3.000E+00	0.000E+00	1.473E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.282E+00
4.000E+00	0.000E+00	2.435E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.549E+00
5.000E+00	0.000E+00	3.244E+00	0.000E+00	0.000E+00	0.000E+00	2.057E+00	1.484E+00
6.000E+00	1.942E-01	3.767E+00	0.000E+00	0.000E+00	0.000E+00	2.974E+00	1.430E+00
7.000E+00	6.409E-01	4.195E+00	0.000E+00	0.000E+00	0.000E+00	3.832E+00	1.147E+00
8.000E+00	1.151E+00	4.539E+00	0.000E+00	0.000E+00	0.000E+00	4.712E+00	1.085E+00
9.000E+00	1.609E+00	4.820E+00	0.000E+00	0.000E+00	0.000E+00	5.548E+00	1.170E+00
1.000E+01	1.972E+00	5.101E+00	0.000E+00	0.000E+00	0.000E+00	6.236E+00	1.324E+00
1.100E+01	2.264E+00	5.353E+00	8.989E-01	0.000E+00	0.000E+00	6.801E+00	1.493E+00
1.200E+01	2.502E+00	5.618E+00	1.842E+00	0.000E+00	0.000E+00	7.240E+00	1.677E+00
1.300E+01	2.703E+00	5.882E+00	2.672E+00	0.000E+00	0.000E+00	7.603E+00	1.865E+00
1.400E+01	2.840E+00	5.966E+00	3.369E+00	8.595E-01	0.000E+00	7.887E+00	2.041E+00
1.500E+01	2.966E+00	5.642E+00	3.971E+00	1.794E+00	0.000E+00	8.121E+00	2.179E+00
1.600E+01	2.957E+00	5.435E+00	4.609E+00	2.594E+00	0.000E+00	8.319E+00	2.251E+00
1.700E+01	2.878E+00	5.508E+00	5.227E+00	3.181E+00	0.000E+00	8.492E+00	2.244E+00
1.800E+01	2.775E+00	5.697E+00	5.852E+00	3.842E+00	0.000E+00	8.655E+00	2.188E+00
1.900E+01	2.771E+00	6.006E+00	6.486E+00	4.423E+00	0.000E+00	8.814E+00	2.123E+00
2.000E+01	2.876E+00	6.383E+00	7.067E+00	4.748E+00	0.000E+00	8.967E+00	2.040E+00
2.200E+01	3.123E+00	7.053E+00	8.316E+00	5.585E+00	0.000E+00	9.163E+00	2.088E+00
2.400E+01	3.442E+00	7.708E+00	9.543E+00	6.583E+00	0.000E+00	9.161E+00	2.147E+00
2.600E+01	3.685E+00	8.292E+00	1.071E+01	7.540E+00	0.000E+00	9.231E+00	2.207E+00
2.800E+01	3.909E+00	8.757E+00	1.188E+01	8.450E+00	0.000E+00	9.540E+00	2.185E+00

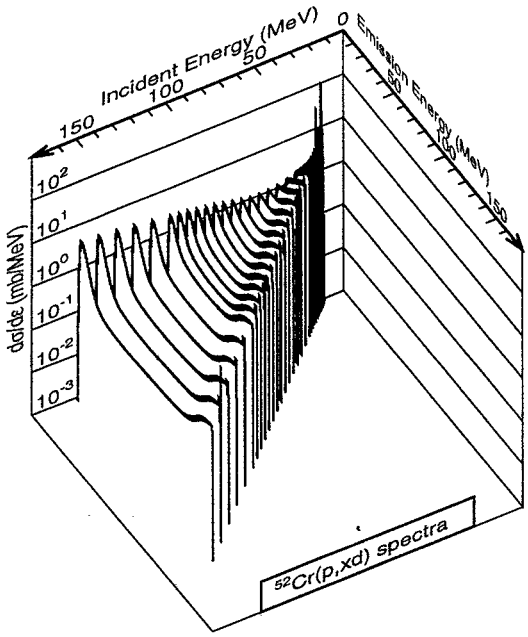
3.000E+01	4.170E+00	9.183E+00	1.305E+01	9.187E+00	0.000E+00	9.867E+00	2.114E+00
3.500E+01	4.942E+00	1.032E+01	1.595E+01	1.125E+01	0.000E+00	1.068E+01	1.999E+00
4.000E+01	5.655E+00	1.157E+01	1.908E+01	1.320E+01	0.000E+00	1.116E+01	1.972E+00
4.500E+01	6.288E+00	1.291E+01	2.218E+01	1.512E+01	0.000E+00	1.151E+01	1.960E+00
5.000E+01	6.823E+00	1.415E+01	2.533E+01	1.695E+01	0.000E+00	1.175E+01	1.935E+00
5.500E+01	7.310E+00	1.508E+01	2.829E+01	1.847E+01	0.000E+00	1.189E+01	1.947E+00
6.000E+01	7.614E+00	1.565E+01	3.064E+01	1.934E+01	0.000E+00	1.180E+01	1.953E+00
6.500E+01	7.946E+00	1.628E+01	3.298E+01	1.986E+01	0.000E+00	1.176E+01	1.943E+00
7.000E+01	8.389E+00	1.686E+01	3.548E+01	2.007E+01	0.000E+00	1.176E+01	1.912E+00
7.500E+01	8.687E+00	1.741E+01	3.703E+01	1.979E+01	0.000E+00	1.175E+01	1.940E+00
8.000E+01	9.018E+00	1.811E+01	3.911E+01	1.949E+01	0.000E+00	1.175E+01	1.953E+00
8.500E+01	9.357E+00	1.877E+01	4.106E+01	1.904E+01	0.000E+00	1.177E+01	1.935E+00
9.000E+01	9.632E+00	1.936E+01	4.271E+01	1.832E+01	0.000E+00	1.178E+01	1.904E+00
9.500E+01	9.977E+00	2.001E+01	4.438E+01	1.769E+01	0.000E+00	1.182E+01	1.916E+00
1.000E+02	1.032E+01	2.068E+01	4.543E+01	1.708E+01	0.000E+00	1.188E+01	1.916E+00
1.100E+02	1.101E+01	2.190E+01	4.795E+01	1.578E+01	0.000E+00	1.200E+01	1.929E+00
1.200E+02	1.178E+01	2.316E+01	4.999E+01	1.461E+01	0.000E+00	1.212E+01	1.958E+00
1.300E+02	1.252E+01	2.446E+01	5.119E+01	1.342E+01	0.000E+00	1.228E+01	2.004E+00
1.400E+02	1.334E+01	2.586E+01	5.330E+01	1.250E+01	0.000E+00	1.245E+01	2.009E+00
1.500E+02	1.420E+01	2.725E+01	5.440E+01	1.173E+01	0.000E+00	1.264E+01	1.967E+00

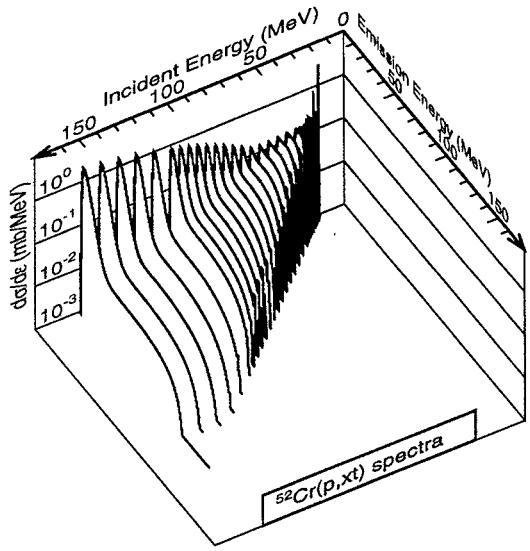

p + 52Cr nonelastic and production cross sections
Production Cross Section (mb)
Nonelastic Cross Section (mb)
Incident Energy (MeV)
n
p
γ
α
d
t
10^4
10^3
10^2
10^1
10^0
0
50
100
150

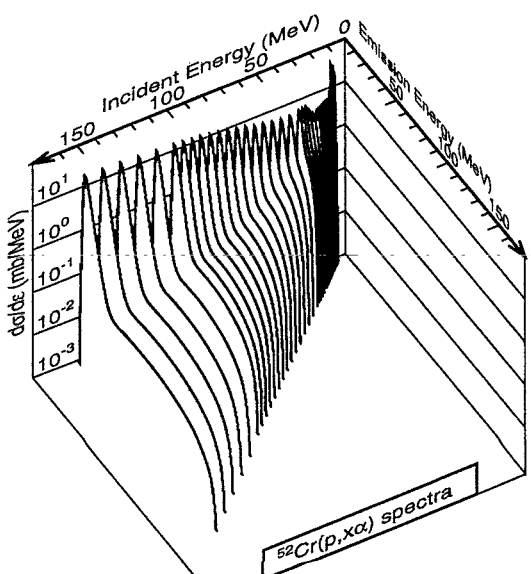
p + ^{52}Cr angle-integrated emission spectra

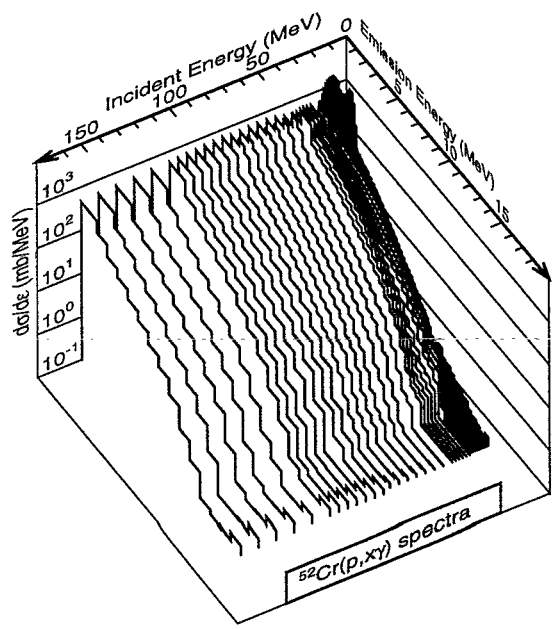




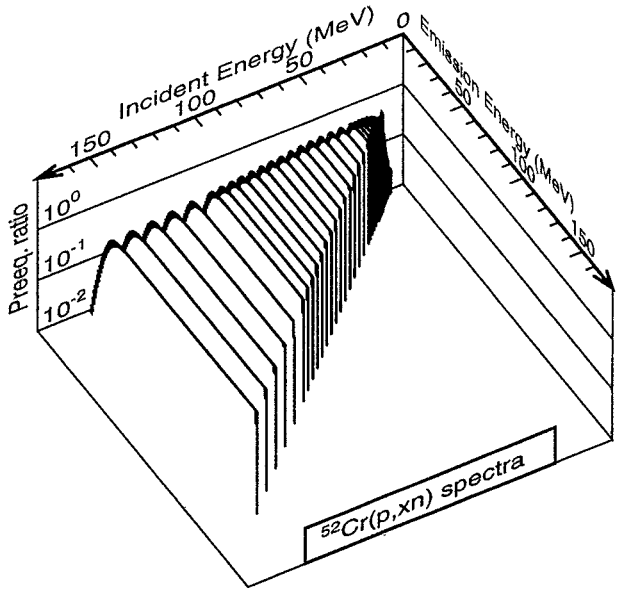


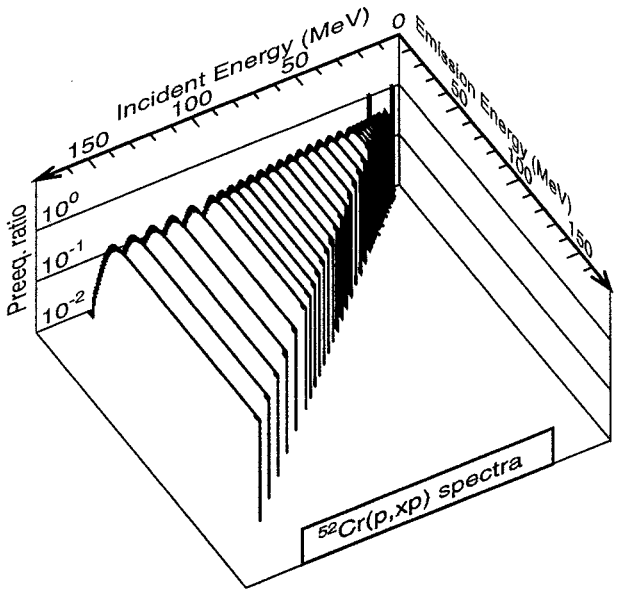


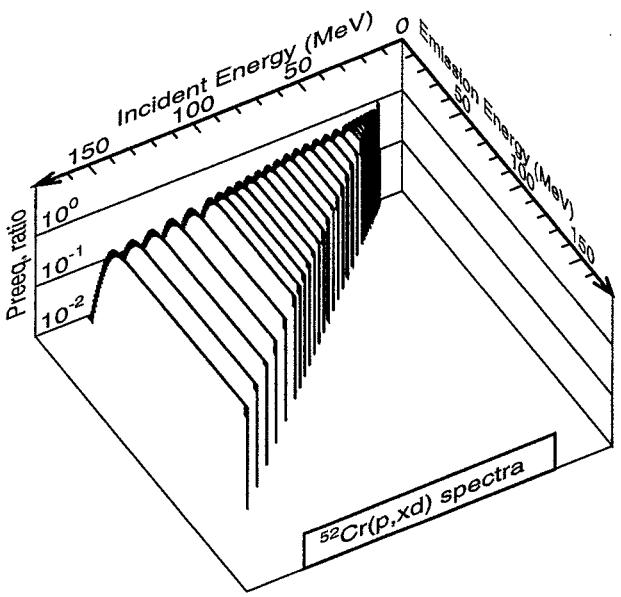


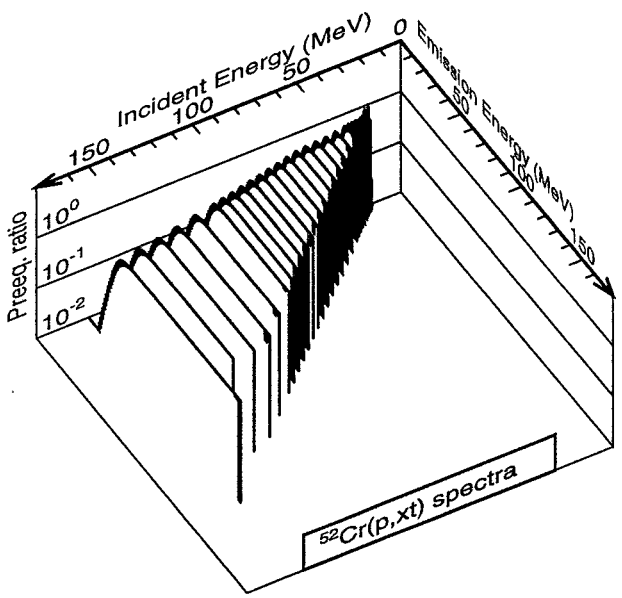


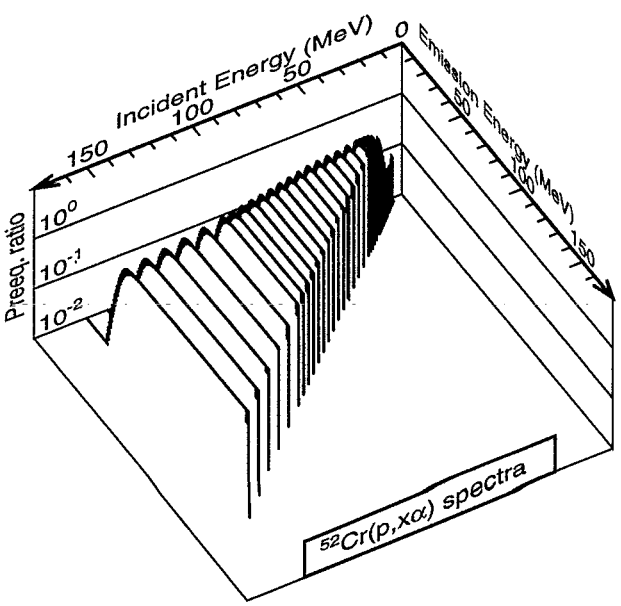
p + ^{52}Cr Kalbach preequilibrium ratios

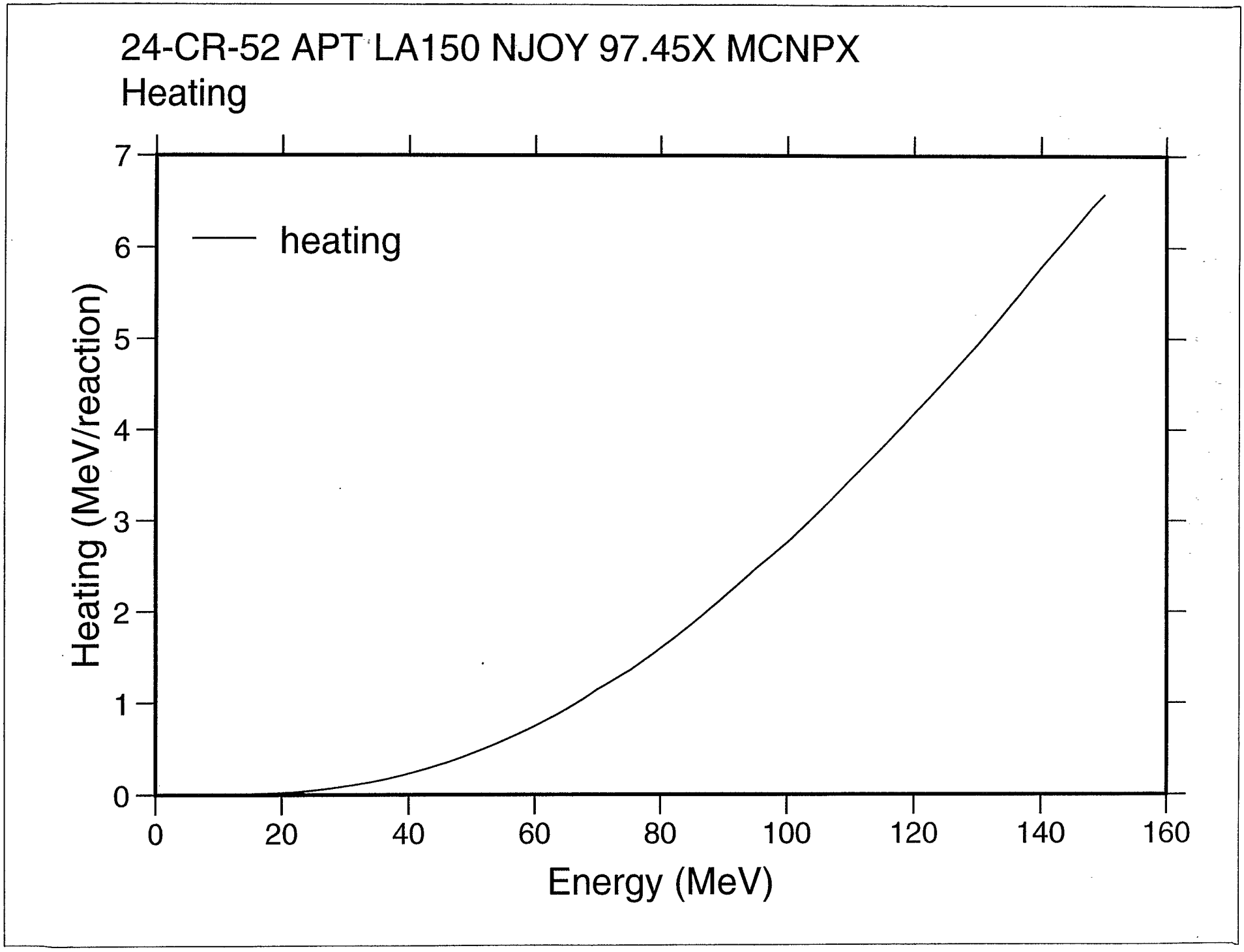


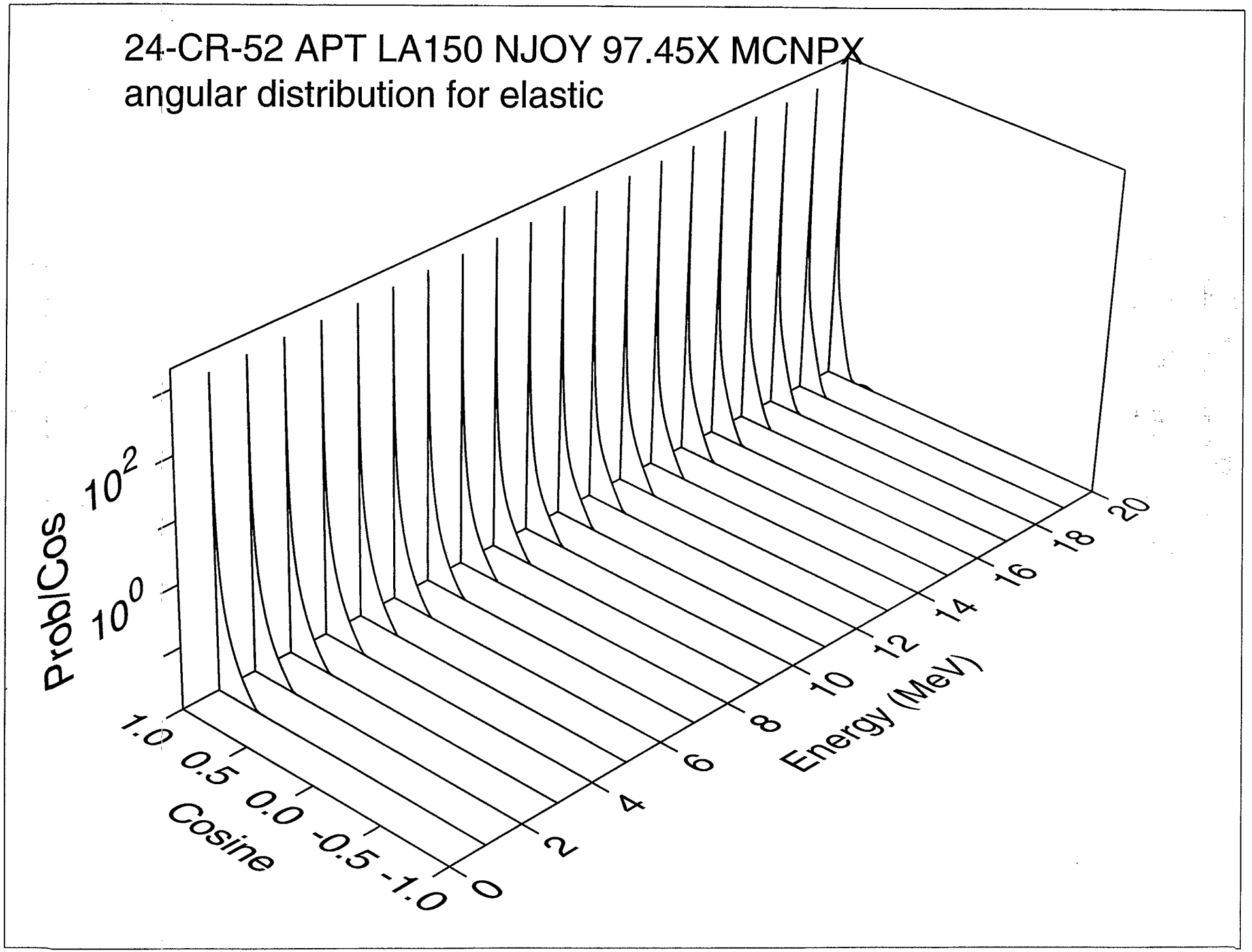


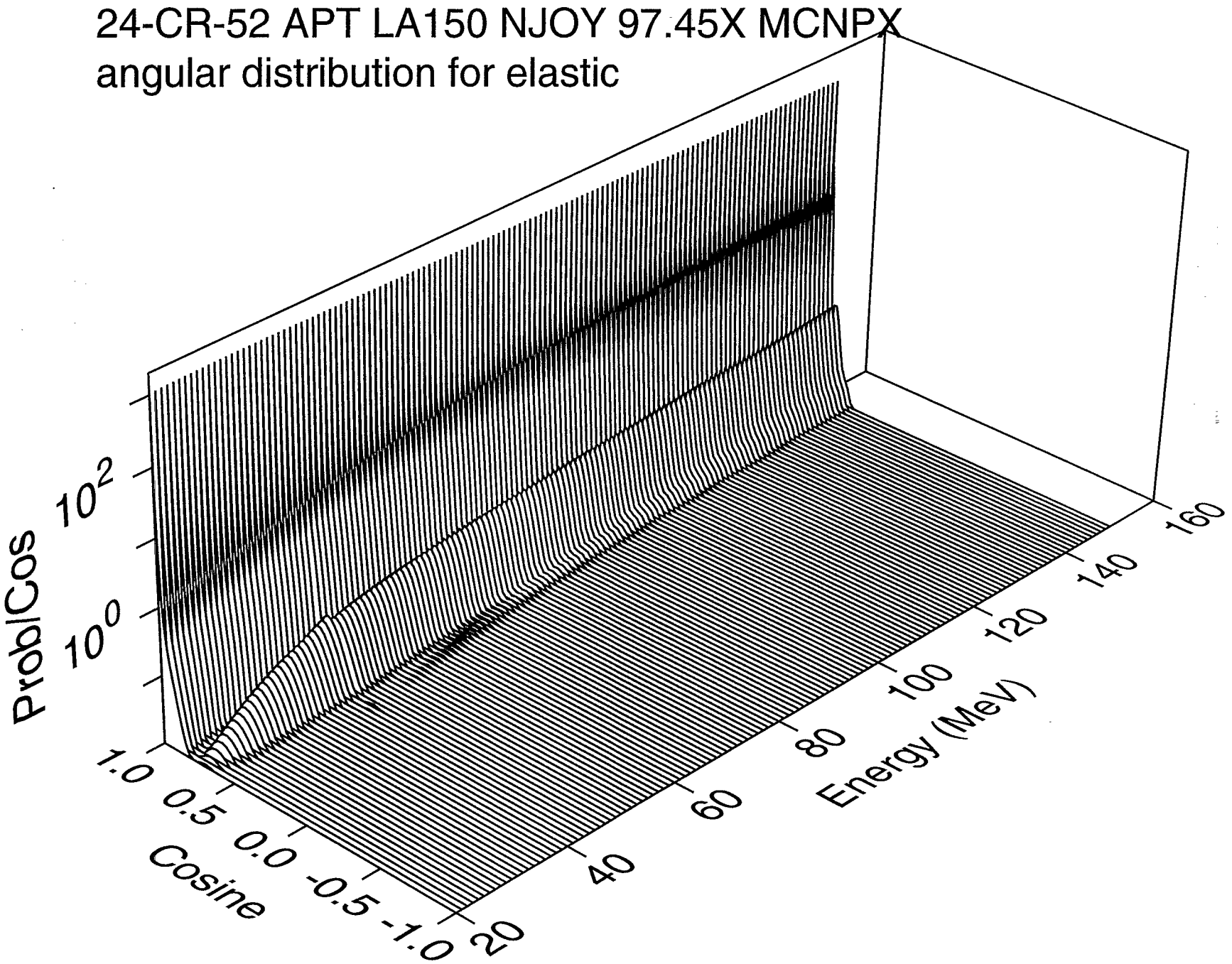







24-CR-52 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
1
2
3
4
5
6
7
0
20
40
60
80
100
120
140
160


24-CR-52 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
1.0
0.5
0.0
-0.5
-1.0
Cosine
0
2
4
6
8
10
12
14
16
18
20
Energy (MeV)


24-CR-52 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF p + 53Cr CROSS SECTIONS FOR THE ENERGY RANGE 1 to 150 MeV

S. Chiba, M. B. Chadwick, and P. G. Young
22 October 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident proton energy range from 1 to 150 MeV. The evaluation utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above are:

MF=3	MT= 2	Integral of nuclear plus interference components of the elastic scattering cross section
	MT= 5	Sum of binary (p,n') and (p,x) reactions
MF=6	MT= 2	Elastic (p,p) angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
	MT= 5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Ni58 and p + Ni58 reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic proton angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk et al. (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged- particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray

transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

SOME Cr-SPECIFIC INFORMATION CONCERNING THE EVAL.

The transmission coefficients calculated for the p + Cr-52 evaluation were employed for all the channels in the p + Cr-53 evaluation by multiplying by a factor of 1.01278, i.e., a ratio of A**(2/3) between Cr-53 and Cr-52.

The Cr-52 transmission coefficients were calculated by using the following optical model potentials:

Neutrons: a newly-searched potential for Cr-52 as described in the File 1 description of the n + Cr-52 evaluation.

Protons: a combination of 2 potentials was used :

below 40 MeV : Becchetti-Greenlees (Be69)
above 40 MeV : Madland medium energy potential (Ma88)

The proton reaction cross section and transmission coefficients below 40 MeV were multiplied by a factor of 0.845 to make the agreement with the measured proton reaction cross section (Ca96) better, and also to make the connection to higher energy values smoothly.

For deuterons, the Lohr-Haeberli (Lo74) global potential was used; for alpha particles the McFadden-Satchler (Mc66) potential was used; and for tritons the Becchetti-Greenlees (Be71) potential was used. The He-3 channel was ignored.

No direct collective inelastic scattering was considered.

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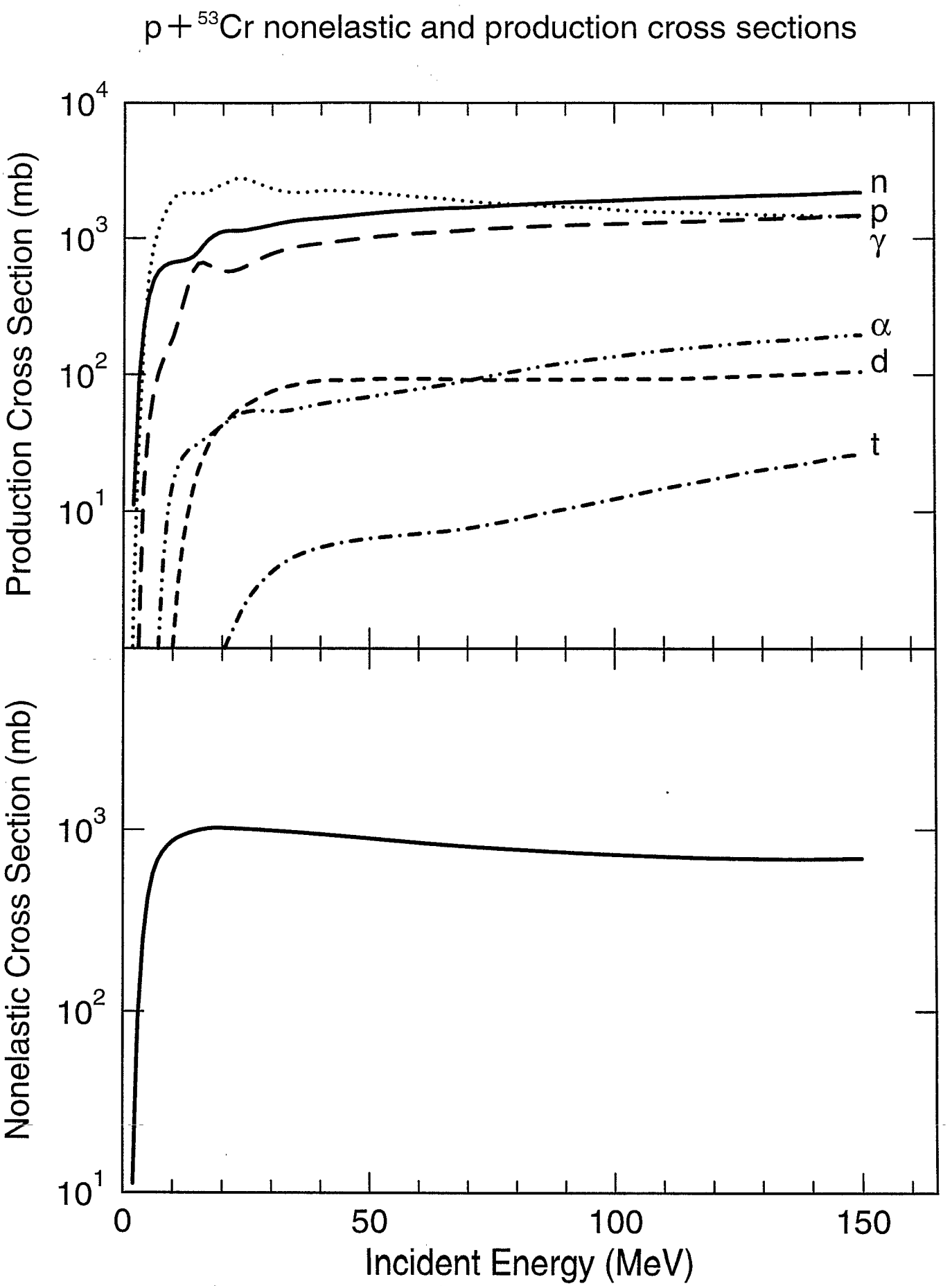
24053 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
1.000E+00	3.750E-05	0.000E+00	0.000E+00	1.020E-08	0.000E+00	0.000E+00	0.000E+00	0.000E+00	6.642E-06
2.000E+00	1.123E-02	0.000E+00	1.119E-02	3.053E-06	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.988E-03
3.000E+00	9.162E-02	0.000E+00	9.075E-02	7.581E-04	0.000E+00	0.000E+00	0.000E+00	1.652E-14	3.514E-02
4.000E+00	2.452E-01	0.000E+00	2.303E-01	1.463E-02	0.000E+00	0.000E+00	0.000E+00	7.070E-09	1.922E-01
5.000E+00	4.208E-01	0.000E+00	3.765E-01	4.408E-02	0.000E+00	0.000E+00	0.000E+00	2.270E-06	5.419E-01
6.000E+00	5.714E-01	0.000E+00	4.960E-01	7.500E-02	0.000E+00	0.000E+00	0.000E+00	8.653E-05	8.923E-01
7.000E+00	6.794E-01	0.000E+00	5.740E-01	1.042E-01	7.534E-09	0.000E+00	0.000E+00	9.615E-04	1.187E+00
8.000E+00	7.576E-01	0.000E+00	6.212E-01	1.317E-01	8.363E-06	0.000E+00	0.000E+00	4.313E-03	1.471E+00
9.000E+00	8.182E-01	0.000E+00	6.489E-01	1.582E-01	2.005E-04	0.000E+00	0.000E+00	1.055E-02	1.745E+00
1.000E+01	8.660E-01	0.000E+00	6.647E-01	1.913E-01	1.040E-03	0.000E+00	0.000E+00	1.677E-02	1.981E+00
1.100E+01	9.028E-01	0.000E+00	6.735E-01	2.511E-01	2.924E-03	0.000E+00	0.000E+00	2.167E-02	2.117E+00
1.200E+01	9.292E-01	0.000E+00	6.825E-01	3.403E-01	5.952E-03	0.000E+00	0.000E+00	2.526E-02	2.147E+00
1.300E+01	9.527E-01	0.000E+00	7.011E-01	4.572E-01	9.665E-03	3.831E-09	0.000E+00	2.796E-02	2.139E+00
1.400E+01	9.730E-01	0.000E+00	7.314E-01	5.786E-01	1.448E-02	2.376E-06	0.000E+00	2.932E-02	2.142E+00
1.500E+01	9.896E-01	0.000E+00	7.906E-01	6.501E-01	1.976E-02	2.633E-05	0.000E+00	3.136E-02	2.133E+00
1.600E+01	1.003E+00	0.000E+00	8.814E-01	6.587E-01	2.474E-02	8.773E-05	0.000E+00	3.334E-02	2.135E+00
1.700E+01	1.013E+00	0.000E+00	9.727E-01	6.334E-01	3.006E-02	1.978E-04	0.000E+00	3.530E-02	2.195E+00
1.800E+01	1.020E+00	0.000E+00	1.035E+00	6.147E-01	3.517E-02	3.592E-04	0.000E+00	3.757E-02	2.293E+00
1.900E+01	1.024E+00	0.000E+00	1.085E+00	5.931E-01	3.998E-02	5.647E-04	0.000E+00	4.016E-02	2.410E+00
2.000E+01	1.021E+00	0.000E+00	1.117E+00	5.739E-01	4.310E-02	8.479E-04	0.000E+00	4.282E-02	2.478E+00
2.200E+01	1.016E+00	0.000E+00	1.132E+00	5.720E-01	5.099E-02	1.327E-03	0.000E+00	4.844E-02	2.701E+00
2.400E+01	1.010E+00	0.000E+00	1.136E+00	6.052E-01	5.806E-02	1.912E-03	0.000E+00	5.268E-02	2.753E+00
2.600E+01	1.004E+00	0.000E+00	1.168E+00	6.571E-01	6.379E-02	2.497E-03	0.000E+00	5.452E-02	2.623E+00
2.800E+01	9.965E-01	0.000E+00	1.205E+00	7.160E-01	6.994E-02	3.050E-03	0.000E+00	5.472E-02	2.461E+00
3.000E+01	9.888E-01	0.000E+00	1.251E+00	7.670E-01	7.567E-02	3.582E-03	0.000E+00	5.397E-02	2.317E+00
3.500E+01	9.678E-01	0.000E+00	1.351E+00	8.622E-01	8.479E-02	4.707E-03	0.000E+00	5.632E-02	2.166E+00
4.000E+01	9.447E-01	0.000E+00	1.405E+00	9.159E-01	9.062E-02	5.431E-03	0.000E+00	6.148E-02	2.233E+00
4.500E+01	9.204E-01	0.000E+00	1.462E+00	9.679E-01	9.110E-02	5.940E-03	0.000E+00	6.531E-02	2.218E+00
5.000E+01	8.957E-01	0.000E+00	1.523E+00	1.017E+00	9.289E-02	6.311E-03	0.000E+00	6.919E-02	2.155E+00
5.500E+01	8.715E-01	0.000E+00	1.581E+00	1.061E+00	9.323E-02	6.591E-03	0.000E+00	7.406E-02	2.092E+00
6.000E+01	8.485E-01	0.000E+00	1.626E+00	1.091E+00	9.353E-02	6.854E-03	0.000E+00	7.900E-02	2.012E+00
6.500E+01	8.277E-01	0.000E+00	1.667E+00	1.117E+00	9.302E-02	7.130E-03	0.000E+00	8.432E-02	1.958E+00
7.000E+01	8.099E-01	0.000E+00	1.688E+00	1.151E+00	9.189E-02	7.519E-03	0.000E+00	9.069E-02	1.877E+00
7.500E+01	7.939E-01	0.000E+00	1.729E+00	1.184E+00	9.185E-02	8.087E-03	0.000E+00	9.874E-02	1.816E+00
8.000E+01	7.789E-01	0.000E+00	1.769E+00	1.205E+00	9.196E-02	8.748E-03	0.000E+00	1.063E-01	1.775E+00
8.500E+01	7.649E-01	0.000E+00	1.807E+00	1.229E+00	9.237E-02	9.621E-03	0.000E+00	1.149E-01	1.741E+00
9.000E+01	7.519E-01	0.000E+00	1.842E+00	1.249E+00	9.202E-02	1.048E-02	0.000E+00	1.220E-01	1.705E+00
9.500E+01	7.400E-01	0.000E+00	1.870E+00	1.266E+00	9.255E-02	1.140E-02	0.000E+00	1.292E-01	1.683E+00
1.000E+02	7.293E-01	0.000E+00	1.898E+00	1.279E+00	9.320E-02	1.240E-02	0.000E+00	1.360E-01	1.625E+00
1.100E+02	7.116E-01	0.000E+00	1.966E+00	1.312E+00	9.316E-02	1.484E-02	0.000E+00	1.507E-01	1.565E+00
1.200E+02	6.989E-01	0.000E+00	2.010E+00	1.349E+00	9.556E-02	1.735E-02	0.000E+00	1.629E-01	1.535E+00
1.300E+02	6.917E-01	0.000E+00	2.064E+00	1.392E+00	9.866E-02	2.031E-02	0.000E+00	1.757E-01	1.490E+00
1.400E+02	6.900E-01	0.000E+00	2.116E+00	1.429E+00	1.017E-01	2.302E-02	0.000E+00	1.851E-01	1.473E+00
1.500E+02	6.956E-01	0.000E+00	2.186E+00	1.478E+00	1.052E-01	2.620E-02	0.000E+00	1.959E-01	1.452E+00

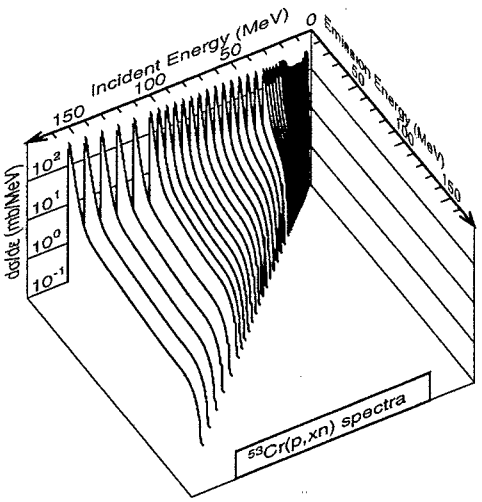
24053 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

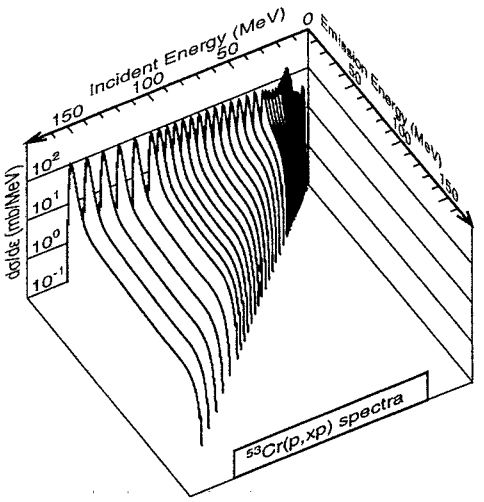
Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
1.000E+00	0.000E+00	3.491E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	5.000E-12
2.000E+00	4.384E-01	1.436E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	5.989E-01
3.000E+00	1.308E+00	1.996E+00	0.000E+00	0.000E+00	0.000E+00	4.190E-03	6.943E-01
4.000E+00	1.822E+00	2.700E+00	0.000E+00	0.000E+00	0.000E+00	2.502E+00	9.799E-01
5.000E+00	1.864E+00	3.337E+00	0.000E+00	0.000E+00	0.000E+00	3.318E+00	1.289E+00
6.000E+00	1.975E+00	3.922E+00	0.000E+00	0.000E+00	0.000E+00	4.137E+00	1.580E+00
7.000E+00	2.149E+00	4.344E+00	1.212E+00	0.000E+00	0.000E+00	5.007E+00	1.805E+00
8.000E+00	2.326E+00	4.690E+00	2.161E+00	0.000E+00	0.000E+00	5.814E+00	2.008E+00
9.000E+00	2.476E+00	4.978E+00	2.838E+00	0.000E+00	0.000E+00	6.534E+00	2.181E+00
1.000E+01	2.603E+00	5.064E+00	3.537E+00	0.000E+00	0.000E+00	7.067E+00	2.330E+00
1.100E+01	2.712E+00	4.835E+00	4.139E+00	0.000E+00	0.000E+00	7.469E+00	2.447E+00
1.200E+01	2.788E+00	4.566E+00	4.699E+00	0.000E+00	0.000E+00	7.782E+00	2.490E+00
1.300E+01	2.835E+00	4.360E+00	5.144E+00	1.202E+00	0.000E+00	8.019E+00	2.411E+00
1.400E+01	2.847E+00	4.269E+00	5.689E+00	2.127E+00	0.000E+00	8.160E+00	2.208E+00
1.500E+01	2.798E+00	4.464E+00	6.268E+00	2.965E+00	0.000E+00	8.331E+00	2.010E+00
1.600E+01	2.714E+00	4.829E+00	6.786E+00	3.552E+00	0.000E+00	8.497E+00	1.854E+00
1.700E+01	2.706E+00	5.248E+00	7.414E+00	4.023E+00	0.000E+00	8.650E+00	1.737E+00
1.800E+01	2.786E+00	5.662E+00	8.039E+00	4.487E+00	0.000E+00	8.784E+00	1.705E+00
1.900E+01	2.905E+00	6.118E+00	8.657E+00	4.939E+00	0.000E+00	8.901E+00	1.702E+00
2.000E+01	3.062E+00	6.592E+00	9.215E+00	5.474E+00	0.000E+00	9.009E+00	1.718E+00
2.200E+01	3.384E+00	7.287E+00	1.039E+01	6.272E+00	0.000E+00	9.278E+00	1.843E+00
2.400E+01	3.653E+00	7.735E+00	1.153E+01	7.156E+00	0.000E+00	9.597E+00	1.943E+00

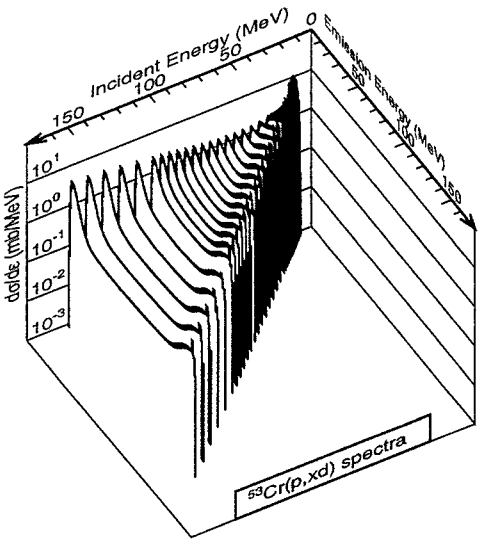
2.600E+01	3.877E+00	8.036E+00	1.260E+01	8.000E+00	0.000E+00	9.953E+00	2.006E+00
2.800E+01	4.048E+00	8.340E+00	1.375E+01	8.790E+00	0.000E+00	1.031E+01	2.058E+00
3.000E+01	4.224E+00	8.704E+00	1.493E+01	9.592E+00	0.000E+00	1.064E+01	2.090E+00
3.500E+01	4.729E+00	9.868E+00	1.791E+01	1.153E+01	0.000E+00	1.114E+01	1.995E+00
4.000E+01	5.314E+00	1.117E+01	2.109E+01	1.332E+01	0.000E+00	1.139E+01	1.948E+00
4.500E+01	5.873E+00	1.237E+01	2.393E+01	1.491E+01	0.000E+00	1.167E+01	1.934E+00
5.000E+01	6.347E+00	1.339E+01	2.693E+01	1.631E+01	0.000E+00	1.187E+01	1.921E+00
5.500E+01	6.764E+00	1.435E+01	2.965E+01	1.753E+01	0.000E+00	1.198E+01	1.925E+00
6.000E+01	7.184E+00	1.533E+01	3.239E+01	1.853E+01	0.000E+00	1.206E+01	1.912E+00
6.500E+01	7.592E+00	1.630E+01	3.490E+01	1.929E+01	0.000E+00	1.212E+01	1.899E+00
7.000E+01	8.090E+00	1.710E+01	3.697E+01	1.966E+01	0.000E+00	1.215E+01	1.800E+00
7.500E+01	8.444E+00	1.782E+01	3.922E+01	1.950E+01	0.000E+00	1.213E+01	1.793E+00
8.000E+01	8.773E+00	1.861E+01	4.138E+01	1.916E+01	0.000E+00	1.214E+01	1.795E+00
8.500E+01	9.087E+00	1.930E+01	4.321E+01	1.851E+01	0.000E+00	1.214E+01	1.803E+00
9.000E+01	9.425E+00	2.008E+01	4.482E+01	1.796E+01	0.000E+00	1.216E+01	1.796E+00
9.500E+01	9.767E+00	2.086E+01	4.661E+01	1.741E+01	0.000E+00	1.219E+01	1.814E+00
1.000E+02	1.011E+01	2.167E+01	4.830E+01	1.684E+01	0.000E+00	1.222E+01	1.820E+00
1.100E+02	1.075E+01	2.317E+01	4.996E+01	1.560E+01	0.000E+00	1.228E+01	1.830E+00
1.200E+02	1.150E+01	2.462E+01	5.253E+01	1.449E+01	0.000E+00	1.237E+01	1.857E+00
1.300E+02	1.222E+01	2.600E+01	5.431E+01	1.335E+01	0.000E+00	1.249E+01	1.866E+00
1.400E+02	1.303E+01	2.767E+01	5.668E+01	1.247E+01	0.000E+00	1.264E+01	1.895E+00
1.500E+02	1.382E+01	2.936E+01	5.818E+01	1.173E+01	0.000E+00	1.280E+01	1.899E+00

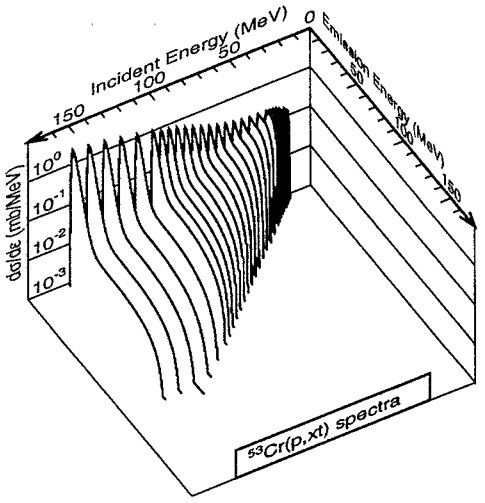

p + 53Cr nonelastic and production cross sections
Production Cross Section (mb)
Nonelastic Cross Section (mb)
Incident Energy (MeV)
n
p
γ
α
d
t
10^4
10^3
10^2
10^1
0
50
100
150

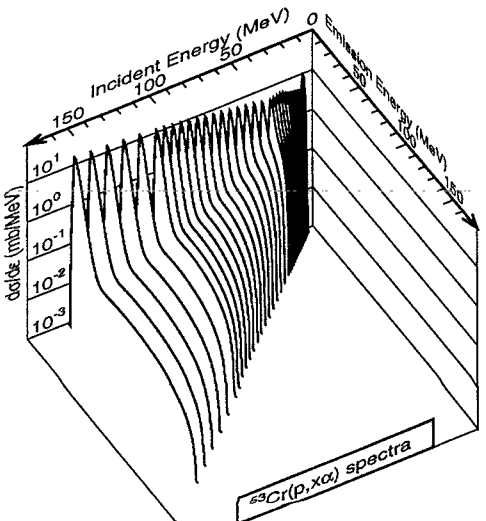
p + ^{53}Cr angle-integrated emission spectra

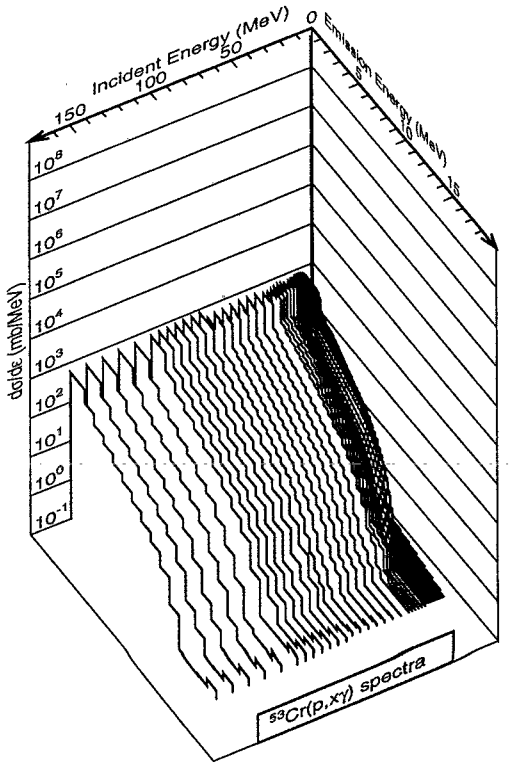




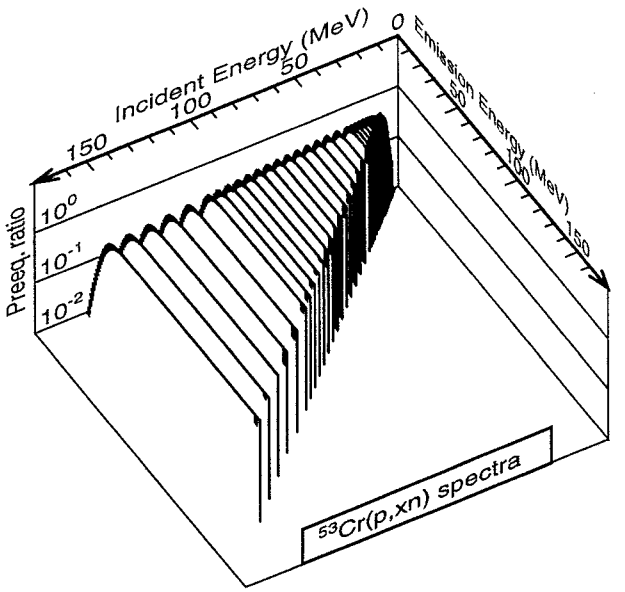


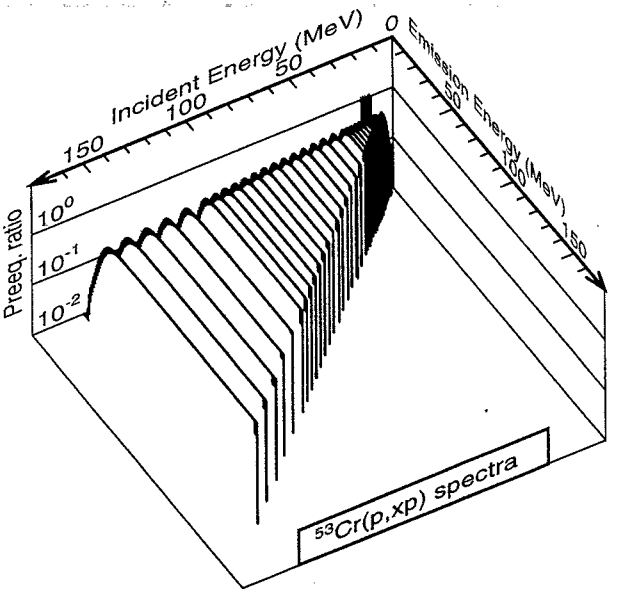


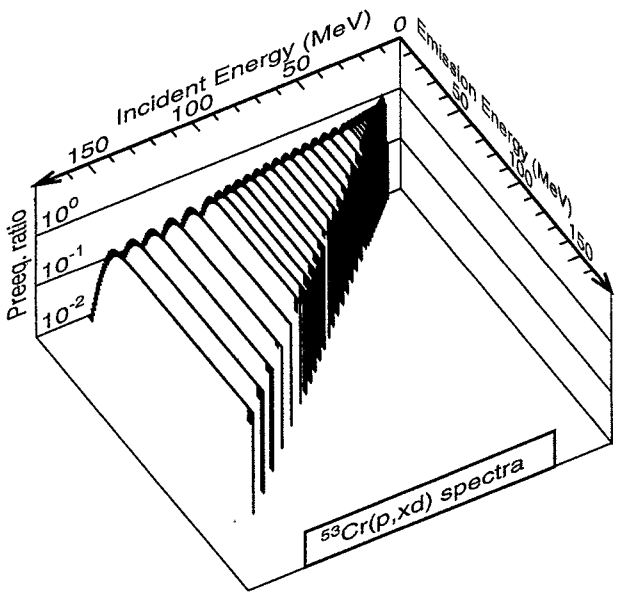


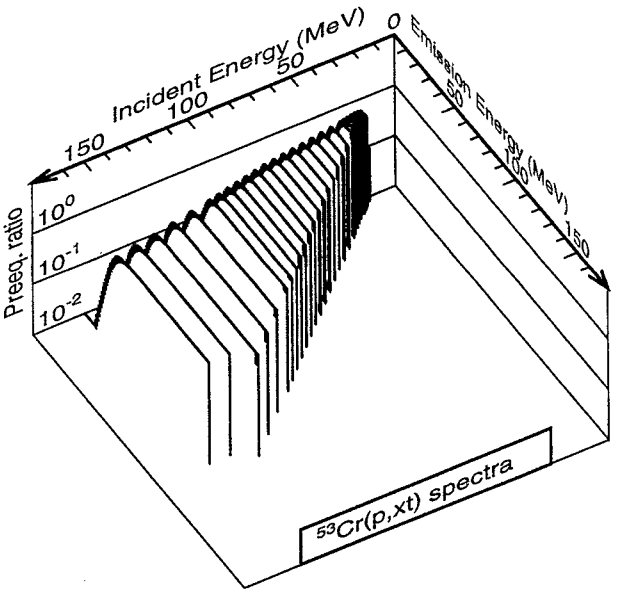


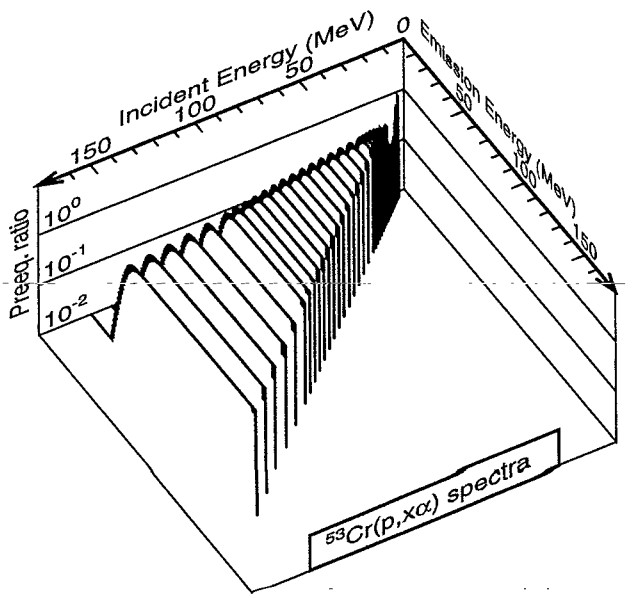
p + ^{53}Cr Kalbach preequilibrium ratios

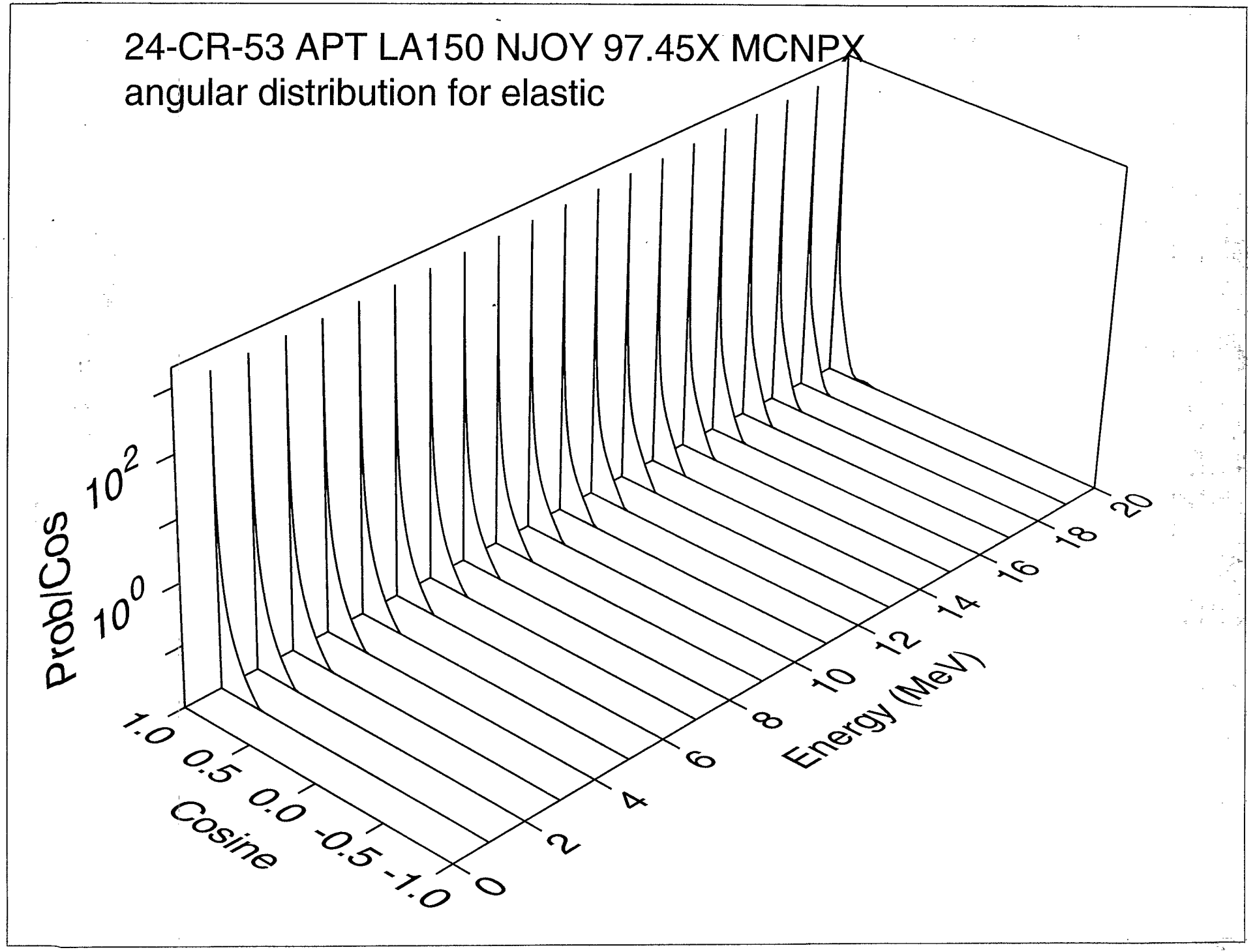


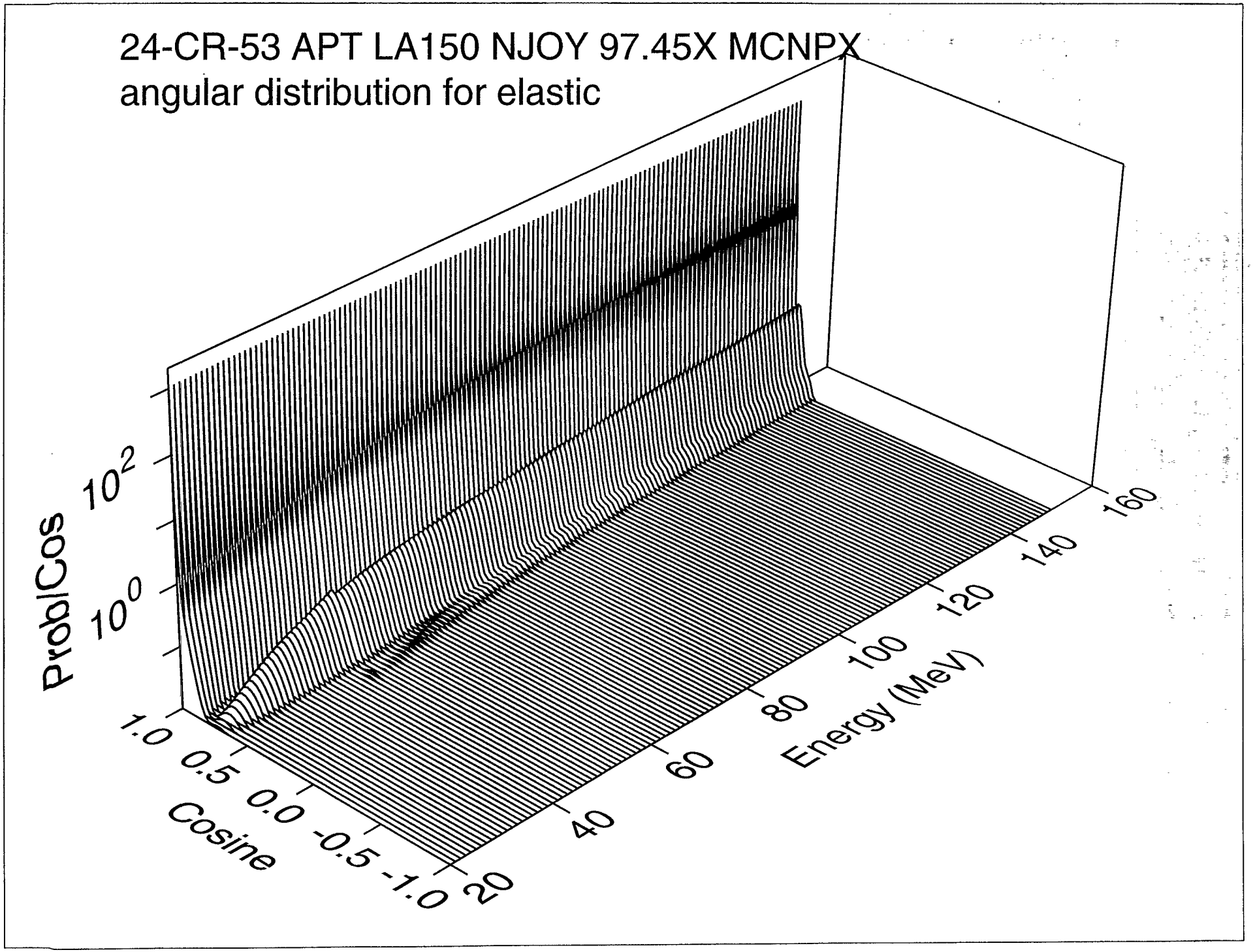


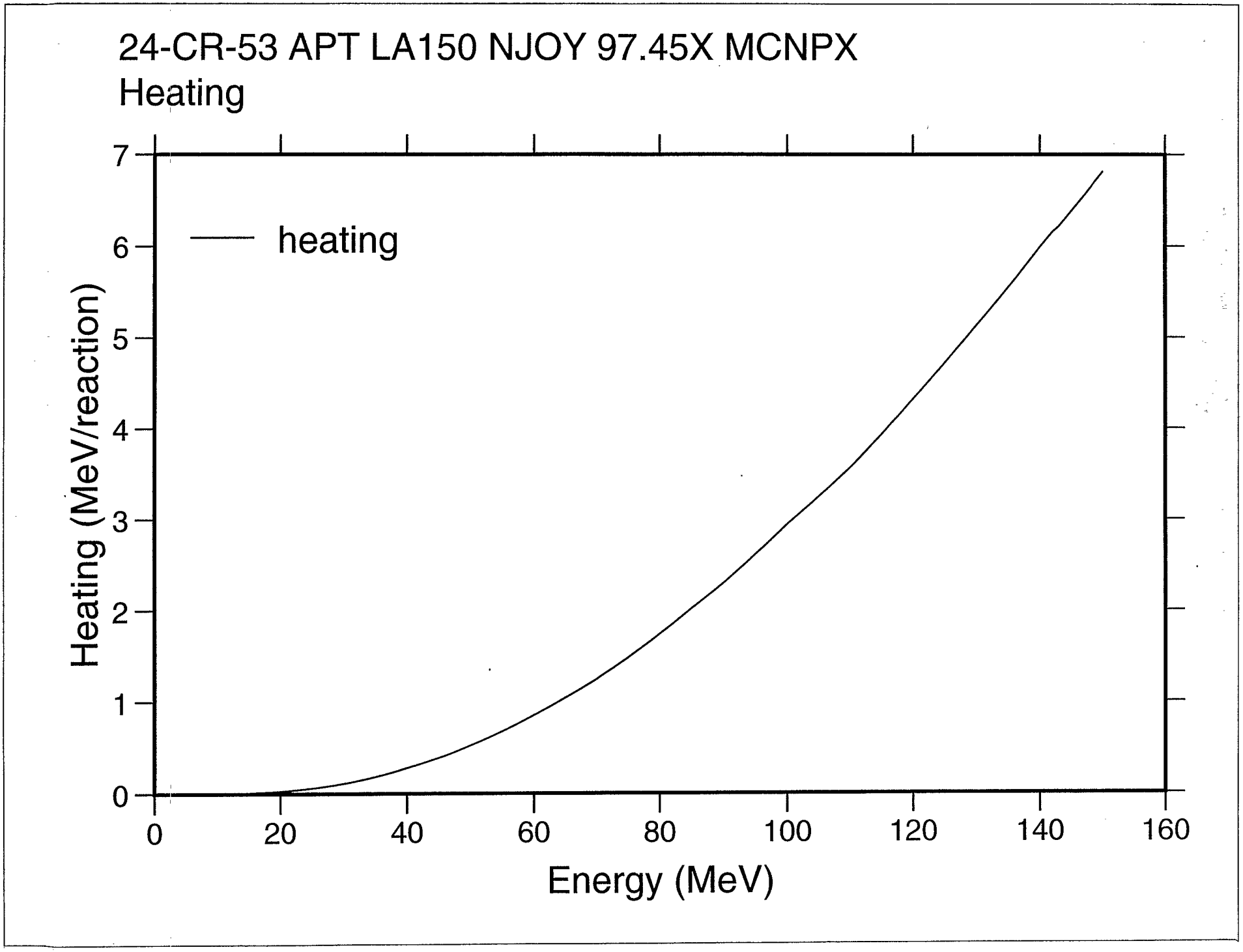







24-CR-53 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
ProblCos
10^2
10^0
1.0
0.5
0.0
-0.5
-1.0
Cosine
0
2
4
6
8
10
12
14
16
18
20
Energy (MeV)


24-CR-53 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
ProbCos
10^2
10^0
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


24-CR-53 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
1
2
3
4
5
6
7
0
20
40
60
80
100
120
140
160

EVALUATION OF p + 54Cr CROSS SECTIONS FOR THE ENERGY RANGE 1 to 150 MeV

S. Chiba, M. B. Chadwick, and P. G. Young
22 October 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident proton energy range from 1 to 150 MeV. The evaluation utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above are:

MF=3	MT= 2	Integral of nuclear plus interference components of the elastic scattering cross section
	MT= 5	Sum of binary (p,n') and (p,x) reactions
MF=6	MT= 2	Elastic (p,p) angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
	MT= 5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Ni58 and p + Ni58 reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic proton angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk et al. (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged- particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray

transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

SOME Cr-SPECIFIC INFORMATION CONCERNING THE EVAL.

The transmission coefficients calculated for the p + Cr-52 evaluation were employed for all the channels in the p + Cr-54 evaluation by multiplying by a factor of 1.025479,, i.e., a ratio of A**(2/3) between Cr-54 and Cr-52.

The Cr-52 transmission coefficients were calculated by using the following optical model potentials:

Neutrons: a newly-searched potential for Cr-52 as described in the File 1 description of the n + Cr-52 evaluation.

Protons: a combination of 2 potentials was used :

below 40 MeV : Becchetti-Greenlees (Be69)
above 40 MeV : Madland medium energy potential (Ma88)

The proton reaction cross section and transmission coefficients below 40 MeV were multiplied by a factor of 0.845 to make the agreement with the measured proton reaction cross section (Ca96) better, and also to make the connection to higher energy values smoothly.

For deuterons, the Lohr-Haeberli (Lo74) global potential was used; for alpha particles the McFadden-Satchler (Mc66) potential was used; and for tritons the Becchetti-Greenlees (Be71) potential was used. The He-3 channel was ignored.

The direct collective inelastic scattering to the following levels in Cr-54 was considered by the DWBA-mode calculation of ECIS95 (Ra96):

Jpi	Ex(MeV)	Deformation Parameter
2+	0.835	0.250

The data was retrieved from the literature (Ra87).

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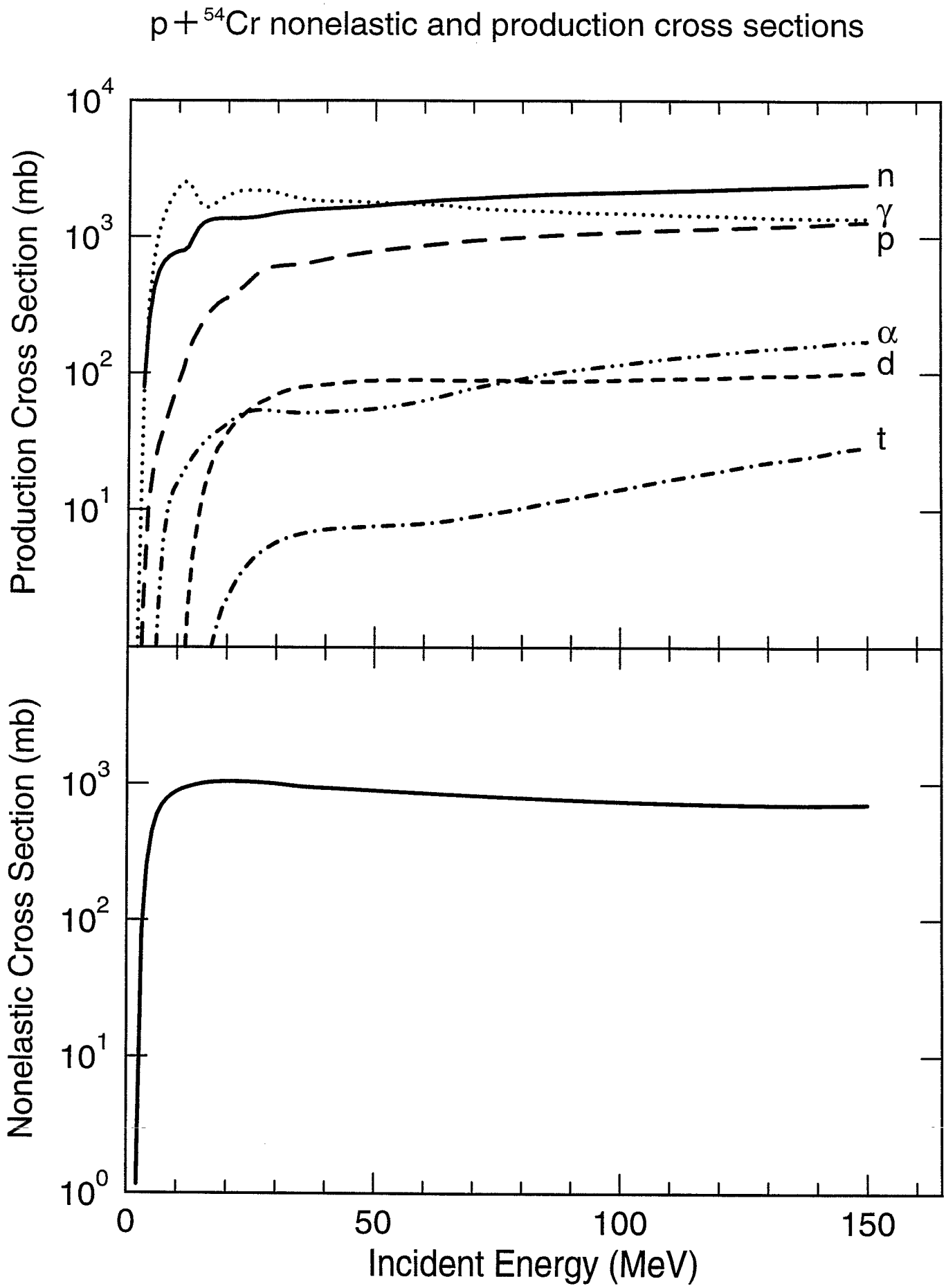
24054 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
1.000E+00	3.530E-05	0.000E+00	0.000E+00	6.670E-06	0.000E+00	0.000E+00	0.000E+00	5.396E-10	4.283E-05
2.000E+00	1.164E-03	0.000E+00	0.000E+00	2.199E-04	0.000E+00	0.000E+00	0.000E+00	1.779E-08	1.412E-03
3.000E+00	8.113E-02	0.000E+00	7.909E-02	1.915E-03	0.000E+00	0.000E+00	0.000E+00	1.242E-07	6.669E-02
4.000E+00	2.539E-01	0.000E+00	2.431E-01	1.066E-02	0.000E+00	0.000E+00	0.000E+00	1.158E-05	3.226E-01
5.000E+00	4.413E-01	0.000E+00	4.208E-01	2.015E-02	0.000E+00	0.000E+00	0.000E+00	2.308E-04	6.968E-01
6.000E+00	5.923E-01	0.000E+00	5.609E-01	2.952E-02	0.000E+00	0.000E+00	0.000E+00	1.746E-03	1.080E+00
7.000E+00	6.980E-01	0.000E+00	6.532E-01	3.873E-02	0.000E+00	0.000E+00	0.000E+00	5.907E-03	1.432E+00
8.000E+00	7.738E-01	0.000E+00	7.122E-01	5.076E-02	0.000E+00	0.000E+00	0.000E+00	1.062E-02	1.751E+00
9.000E+00	8.328E-01	0.000E+00	7.526E-01	6.632E-02	1.651E-07	0.000E+00	0.000E+00	1.370E-02	2.042E+00
1.000E+01	8.796E-01	0.000E+00	7.781E-01	8.514E-02	3.967E-05	0.000E+00	0.000E+00	1.612E-02	2.305E+00
1.100E+01	9.160E-01	0.000E+00	7.903E-01	1.072E-01	4.703E-04	1.803E-07	0.000E+00	1.874E-02	2.533E+00
1.200E+01	9.422E-01	0.000E+00	8.438E-01	1.456E-01	1.907E-03	1.230E-05	0.000E+00	2.154E-02	2.516E+00
1.300E+01	9.656E-01	0.000E+00	1.001E+00	1.772E-01	4.729E-03	6.517E-05	0.000E+00	2.453E-02	2.181E+00
1.400E+01	9.858E-01	0.000E+00	1.160E+00	2.070E-01	8.256E-03	1.763E-04	0.000E+00	2.749E-02	1.824E+00
1.500E+01	1.003E+00	0.000E+00	1.261E+00	2.396E-01	1.295E-02	3.781E-04	0.000E+00	3.038E-02	1.649E+00
1.600E+01	1.016E+00	0.000E+00	1.313E+00	2.720E-01	1.799E-02	6.811E-04	0.000E+00	3.299E-02	1.647E+00
1.700E+01	1.026E+00	0.000E+00	1.344E+00	2.986E-01	2.310E-02	1.062E-03	0.000E+00	3.532E-02	1.721E+00
1.800E+01	1.033E+00	0.000E+00	1.355E+00	3.252E-01	2.812E-02	1.472E-03	0.000E+00	3.754E-02	1.821E+00
1.900E+01	1.037E+00	0.000E+00	1.365E+00	3.435E-01	3.143E-02	1.917E-03	0.000E+00	4.008E-02	1.922E+00
2.000E+01	1.038E+00	0.000E+00	1.365E+00	3.572E-01	3.661E-02	2.273E-03	0.000E+00	4.274E-02	2.004E+00
2.200E+01	1.037E+00	0.000E+00	1.363E+00	3.973E-01	4.488E-02	3.128E-03	0.000E+00	4.809E-02	2.152E+00
2.400E+01	1.032E+00	0.000E+00	1.378E+00	4.581E-01	5.235E-02	3.922E-03	0.000E+00	5.173E-02	2.195E+00
2.600E+01	1.025E+00	0.000E+00	1.400E+00	5.367E-01	5.934E-02	4.651E-03	0.000E+00	5.342E-02	2.188E+00
2.800E+01	1.014E+00	0.000E+00	1.441E+00	5.863E-01	6.452E-02	5.270E-03	0.000E+00	5.320E-02	2.174E+00
3.000E+01	1.000E+00	0.000E+00	1.489E+00	6.077E-01	7.013E-02	5.797E-03	0.000E+00	5.240E-02	2.098E+00
3.500E+01	9.556E-01	0.000E+00	1.566E+00	6.313E-01	7.912E-02	6.691E-03	0.000E+00	5.110E-02	1.906E+00
4.000E+01	9.332E-01	0.000E+00	1.613E+00	6.858E-01	8.244E-02	7.208E-03	0.000E+00	5.193E-02	1.833E+00
4.500E+01	9.137E-01	0.000E+00	1.649E+00	7.408E-01	8.633E-02	7.437E-03	0.000E+00	5.308E-02	1.825E+00
5.000E+01	8.934E-01	0.000E+00	1.702E+00	7.885E-01	8.835E-02	7.616E-03	0.000E+00	5.492E-02	1.790E+00
5.500E+01	8.738E-01	0.000E+00	1.766E+00	8.292E-01	8.900E-02	7.763E-03	0.000E+00	5.824E-02	1.763E+00
6.000E+01	8.551E-01	0.000E+00	1.826E+00	8.680E-01	8.959E-02	7.974E-03	0.000E+00	6.326E-02	1.741E+00
6.500E+01	8.371E-01	0.000E+00	1.887E+00	9.076E-01	8.857E-02	8.367E-03	0.000E+00	7.010E-02	1.705E+00
7.000E+01	8.201E-01	0.000E+00	1.929E+00	9.439E-01	8.888E-02	8.997E-03	0.000E+00	7.792E-02	1.634E+00
7.500E+01	8.039E-01	0.000E+00	1.977E+00	9.724E-01	8.884E-02	9.589E-03	0.000E+00	8.456E-02	1.593E+00
8.000E+01	7.887E-01	0.000E+00	2.019E+00	9.977E-01	8.731E-02	1.030E-02	0.000E+00	9.109E-02	1.568E+00
8.500E+01	7.745E-01	0.000E+00	2.058E+00	1.027E+00	8.707E-02	1.125E-02	0.000E+00	9.872E-02	1.553E+00
9.000E+01	7.614E-01	0.000E+00	2.086E+00	1.050E+00	8.768E-02	1.214E-02	0.000E+00	1.047E-01	1.523E+00
9.500E+01	7.493E-01	0.000E+00	2.112E+00	1.070E+00	8.848E-02	1.313E-02	0.000E+00	1.107E-01	1.504E+00
1.000E+02	7.385E-01	0.000E+00	2.130E+00	1.091E+00	8.926E-02	1.417E-02	0.000E+00	1.162E-01	1.498E+00
1.100E+02	7.205E-01	0.000E+00	2.183E+00	1.130E+00	9.141E-02	1.667E-02	0.000E+00	1.288E-01	1.457E+00
1.200E+02	7.077E-01	0.000E+00	2.237E+00	1.162E+00	9.285E-02	1.929E-02	0.000E+00	1.398E-01	1.434E+00
1.300E+02	7.004E-01	0.000E+00	2.300E+00	1.197E+00	9.594E-02	2.237E-02	0.000E+00	1.519E-01	1.394E+00
1.400E+02	6.987E-01	0.000E+00	2.362E+00	1.240E+00	9.750E-02	2.519E-02	0.000E+00	1.619E-01	1.378E+00
1.500E+02	7.043E-01	0.000E+00	2.439E+00	1.292E+00	1.015E-01	2.851E-02	0.000E+00	1.728E-01	1.374E+00

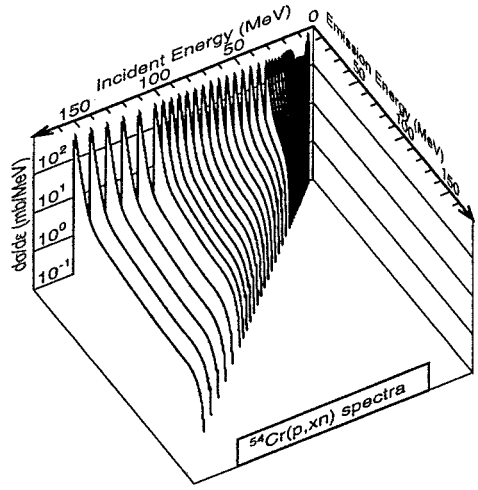
24054 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

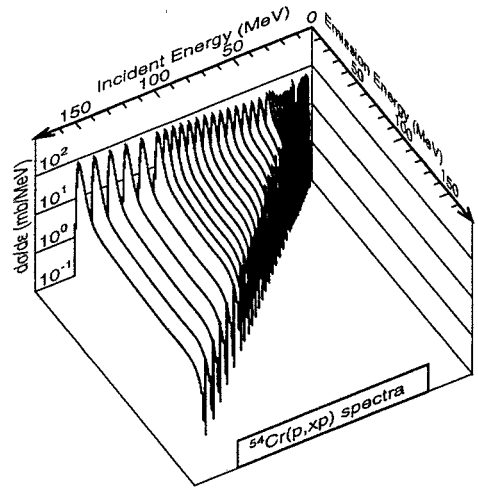
Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
1.000E+00	0.000E+00	3.366E-04	0.000E+00	0.000E+00	0.000E+00	1.346E-03	5.000E-12
2.000E+00	0.000E+00	1.228E+00	0.000E+00	0.000E+00	0.000E+00	1.861E+00	4.595E+00
3.000E+00	6.720E-01	1.964E+00	0.000E+00	0.000E+00	0.000E+00	2.709E+00	2.161E-01
4.000E+00	1.110E+00	2.932E+00	0.000E+00	0.000E+00	0.000E+00	3.604E+00	5.371E-01
5.000E+00	1.508E+00	3.789E+00	0.000E+00	0.000E+00	0.000E+00	4.483E+00	7.742E-01
6.000E+00	1.864E+00	4.533E+00	0.000E+00	0.000E+00	0.000E+00	5.356E+00	1.005E+00
7.000E+00	2.136E+00	5.164E+00	0.000E+00	0.000E+00	0.000E+00	6.188E+00	1.222E+00
8.000E+00	2.336E+00	5.602E+00	0.000E+00	0.000E+00	0.000E+00	6.918E+00	1.436E+00
9.000E+00	2.487E+00	5.949E+00	1.199E+00	0.000E+00	0.000E+00	7.415E+00	1.628E+00
1.000E+01	2.610E+00	6.280E+00	2.081E+00	0.000E+00	0.000E+00	7.692E+00	1.833E+00
1.100E+01	2.719E+00	6.577E+00	2.910E+00	1.442E+00	0.000E+00	7.838E+00	2.027E+00
1.200E+01	2.666E+00	6.276E+00	3.592E+00	2.374E+00	0.000E+00	8.011E+00	2.126E+00
1.300E+01	2.450E+00	6.354E+00	4.227E+00	3.196E+00	0.000E+00	8.192E+00	2.112E+00
1.400E+01	2.385E+00	6.640E+00	4.810E+00	3.706E+00	0.000E+00	8.387E+00	2.002E+00
1.500E+01	2.462E+00	6.827E+00	5.483E+00	4.041E+00	0.000E+00	8.594E+00	1.877E+00
1.600E+01	2.551E+00	7.073E+00	6.149E+00	4.491E+00	0.000E+00	8.806E+00	1.786E+00
1.700E+01	2.692E+00	7.397E+00	6.803E+00	4.946E+00	0.000E+00	9.017E+00	1.753E+00
1.800E+01	2.855E+00	7.685E+00	7.425E+00	5.371E+00	0.000E+00	9.207E+00	1.785E+00
1.900E+01	2.986E+00	8.000E+00	7.965E+00	5.862E+00	0.000E+00	9.359E+00	1.848E+00
2.000E+01	3.153E+00	8.433E+00	8.612E+00	6.350E+00	0.000E+00	9.492E+00	1.945E+00
2.200E+01	3.429E+00	8.925E+00	9.806E+00	7.287E+00	0.000E+00	9.740E+00	2.079E+00
2.400E+01	3.640E+00	9.024E+00	1.096E+01	8.162E+00	0.000E+00	1.003E+01	2.122E+00

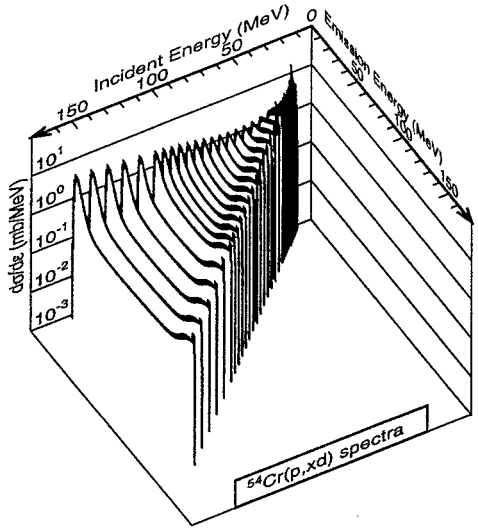
2.600E+01	3.795E+00	8.985E+00	1.209E+01	8.996E+00	0.000E+00	1.036E+01	2.076E+00
2.800E+01	3.951E+00	9.378E+00	1.313E+01	9.811E+00	0.000E+00	1.066E+01	2.025E+00
3.000E+01	4.082E+00	1.009E+01	1.433E+01	1.060E+01	0.000E+00	1.099E+01	1.980E+00
3.500E+01	4.532E+00	1.210E+01	1.745E+01	1.254E+01	0.000E+00	1.163E+01	1.942E+00
4.000E+01	5.079E+00	1.376E+01	2.035E+01	1.438E+01	0.000E+00	1.207E+01	2.013E+00
4.500E+01	5.609E+00	1.523E+01	2.357E+01	1.599E+01	0.000E+00	1.239E+01	2.023E+00
5.000E+01	6.048E+00	1.656E+01	2.663E+01	1.759E+01	0.000E+00	1.262E+01	2.017E+00
5.500E+01	6.430E+00	1.769E+01	2.936E+01	1.892E+01	0.000E+00	1.270E+01	1.994E+00
6.000E+01	6.784E+00	1.863E+01	3.213E+01	1.984E+01	0.000E+00	1.268E+01	1.957E+00
6.500E+01	7.102E+00	1.942E+01	3.445E+01	2.015E+01	0.000E+00	1.258E+01	1.963E+00
7.000E+01	7.444E+00	2.011E+01	3.674E+01	1.991E+01	0.000E+00	1.246E+01	1.897E+00
7.500E+01	7.743E+00	2.095E+01	3.900E+01	1.971E+01	0.000E+00	1.242E+01	1.836E+00
8.000E+01	8.066E+00	2.183E+01	4.060E+01	1.934E+01	0.000E+00	1.241E+01	1.841E+00
8.500E+01	8.365E+00	2.249E+01	4.211E+01	1.859E+01	0.000E+00	1.238E+01	1.847E+00
9.000E+01	8.688E+00	2.328E+01	4.406E+01	1.807E+01	0.000E+00	1.239E+01	1.871E+00
9.500E+01	9.011E+00	2.403E+01	4.589E+01	1.750E+01	0.000E+00	1.241E+01	1.872E+00
1.000E+02	9.365E+00	2.477E+01	4.762E+01	1.693E+01	0.000E+00	1.245E+01	1.889E+00
1.100E+02	1.000E+01	2.627E+01	5.060E+01	1.566E+01	0.000E+00	1.249E+01	1.887E+00
1.200E+02	1.067E+01	2.798E+01	5.275E+01	1.451E+01	0.000E+00	1.258E+01	1.910E+00
1.300E+02	1.130E+01	2.960E+01	5.478E+01	1.333E+01	0.000E+00	1.264E+01	1.867E+00
1.400E+02	1.205E+01	3.134E+01	5.611E+01	1.245E+01	0.000E+00	1.275E+01	1.903E+00
1.500E+02	1.277E+01	3.300E+01	5.807E+01	1.171E+01	0.000E+00	1.288E+01	1.941E+00

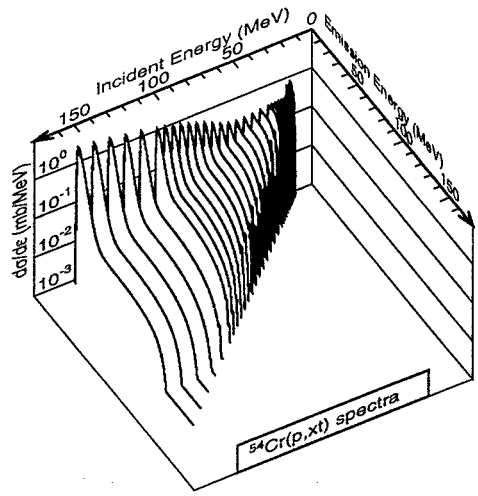

p + 54Cr nonelastic and production cross sections
Production Cross Section (mb)
Nonelastic Cross Section (mb)
Incident Energy (MeV)
n
γ
p
α
d
t
10^4
10^3
10^2
10^1
10^0
0
50
100
150

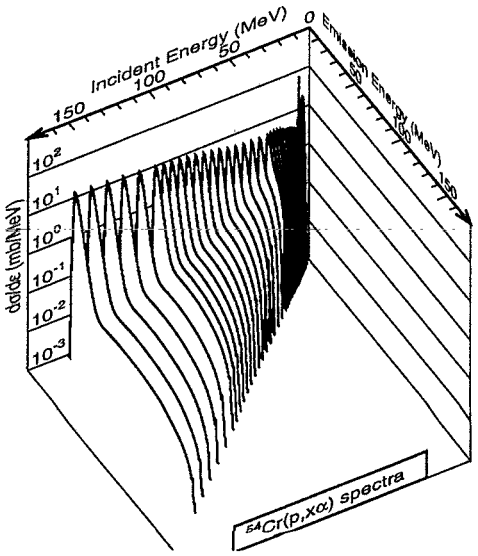
p + ^{54}Cr angle-integrated emission spectra

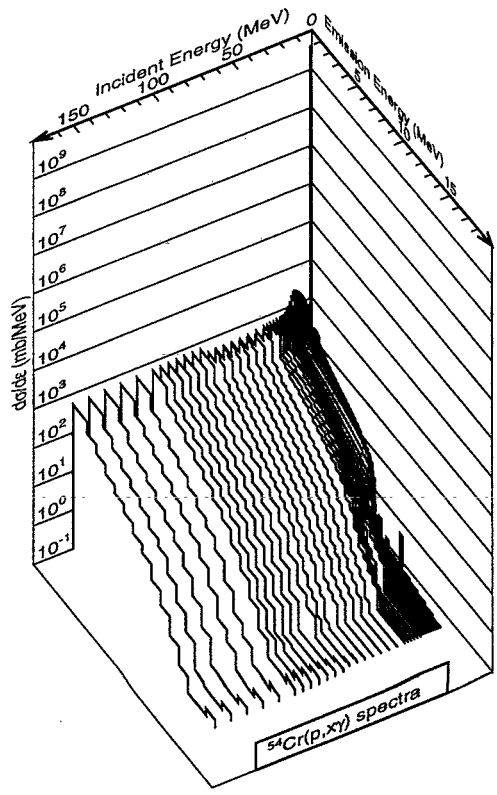




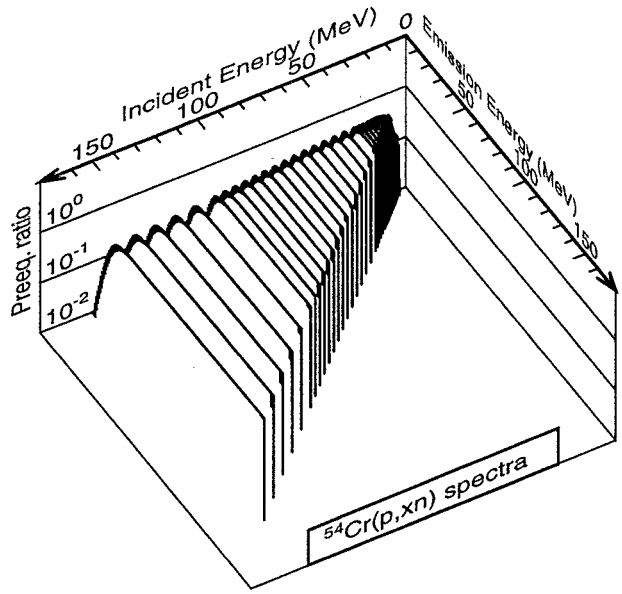


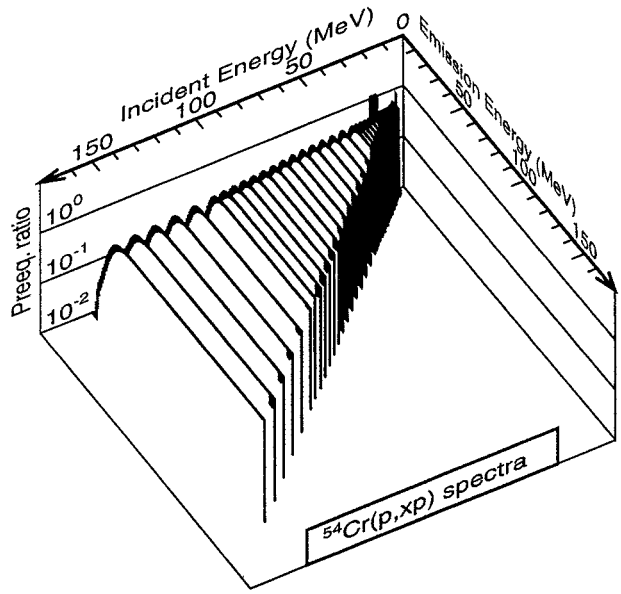


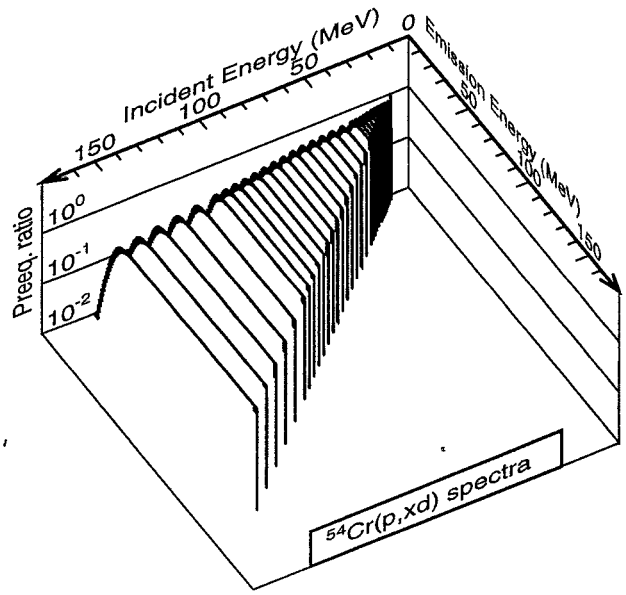


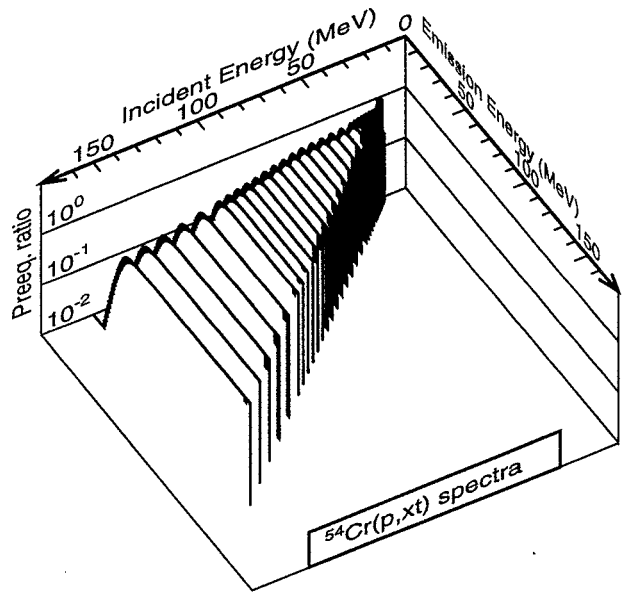


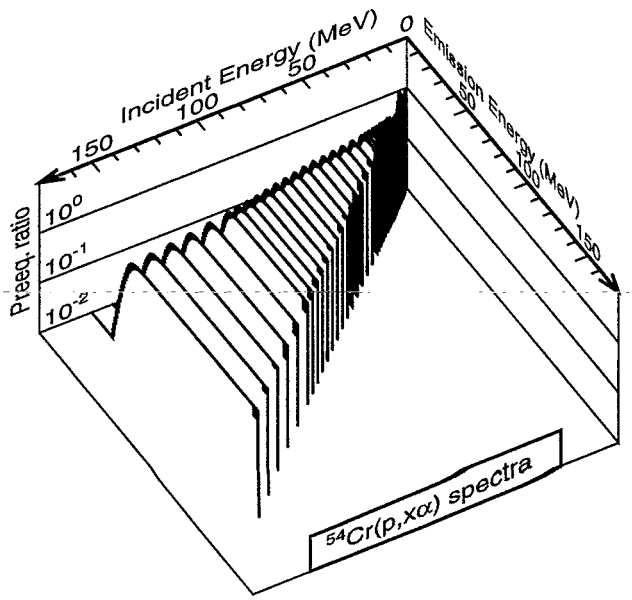
p + ^{54}Cr Kalbach preequilibrium ratios

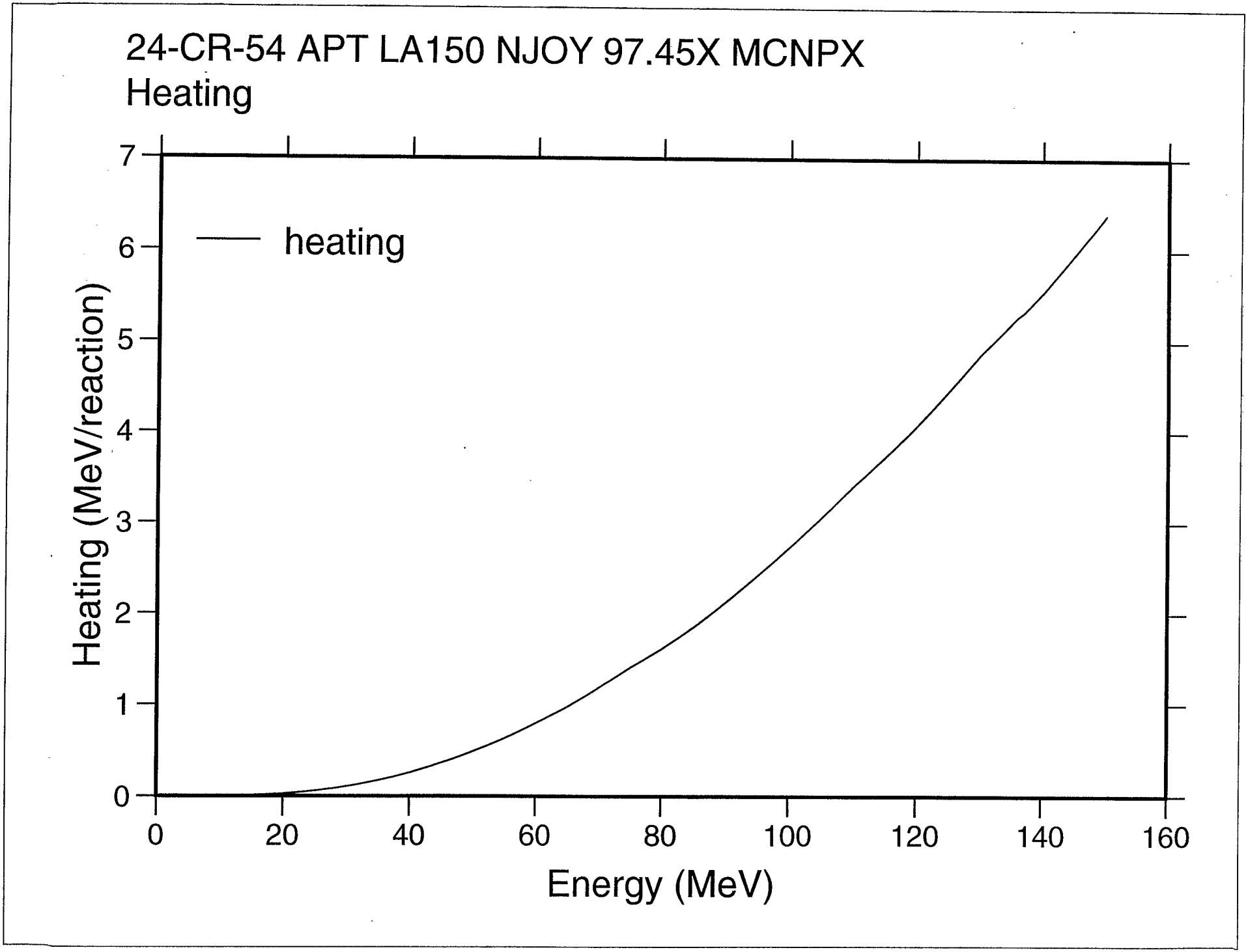


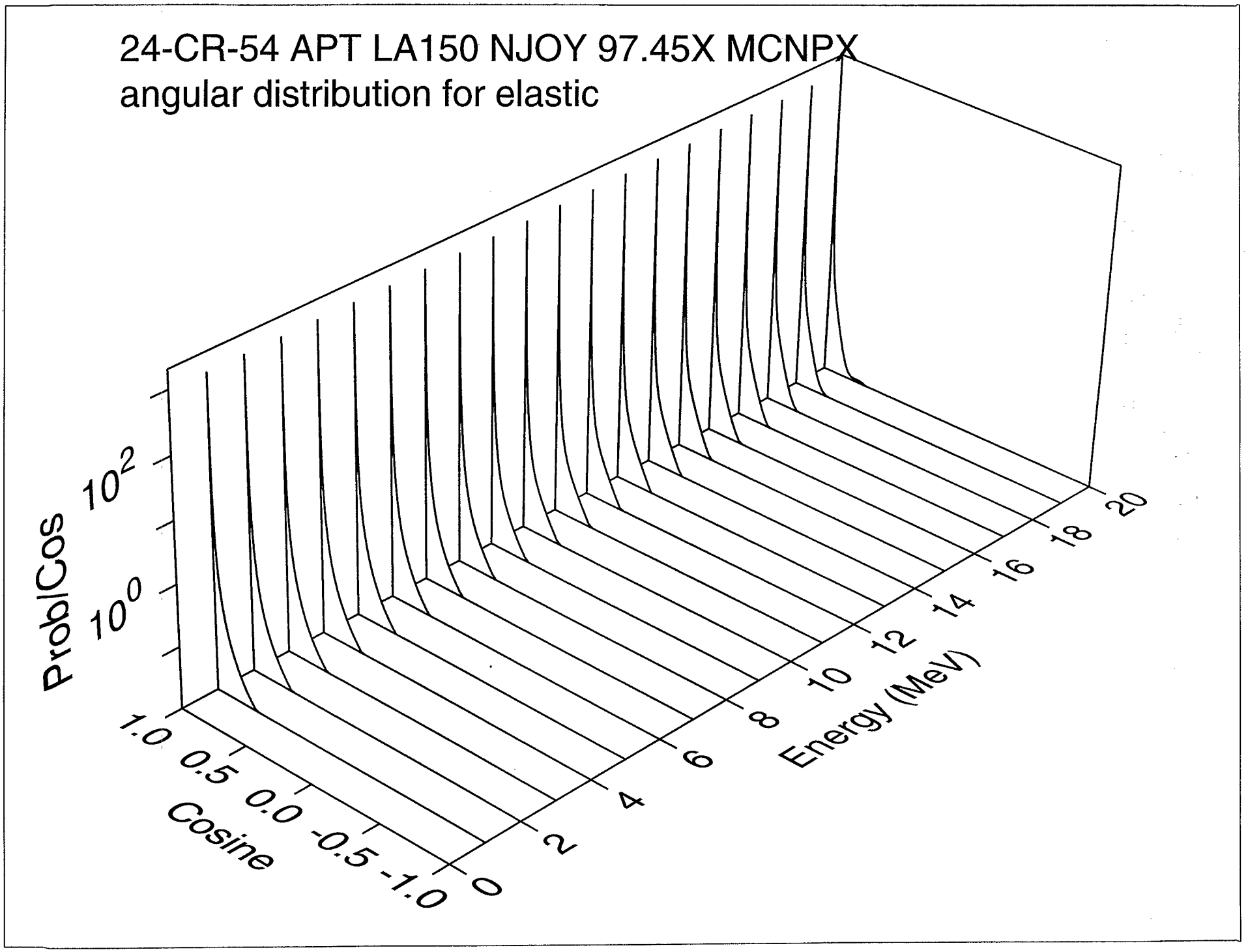


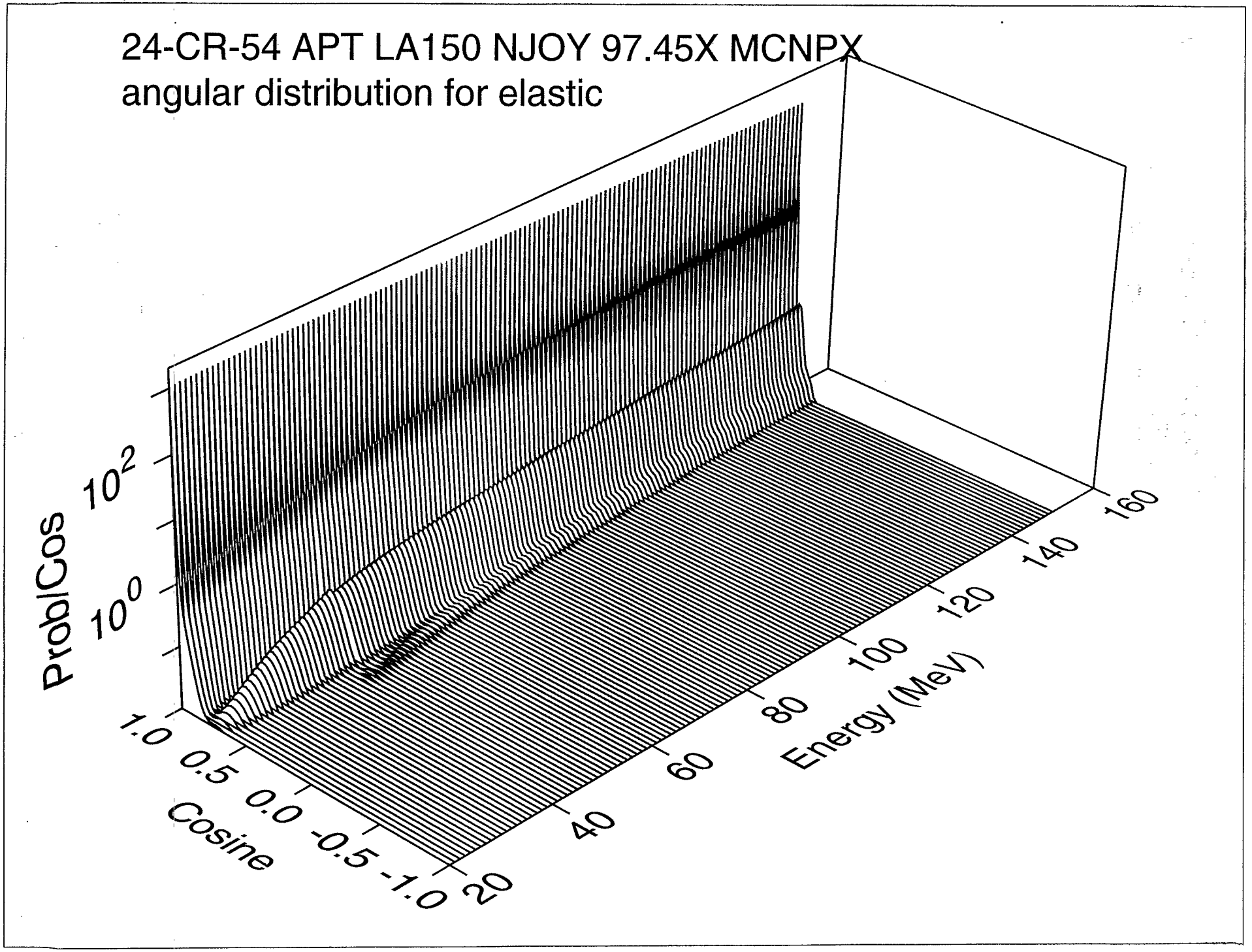







24-CR-54 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
1
2
3
4
5
6
7
0
20
40
60
80
100
120
140
160


24-CR-54 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
1.0
0.5
0.0
-0.5
-1.0
Cosine
0
2
4
6
8
10
12
14
16
18
20
Energy (MeV)


24-CR-54 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
ProbCos
10^2
10^0
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)

EVALUATION OF p + 54Fe CROSS SECTIONS FOR THE ENERGY RANGE 1 to 150 MeV

M. B. Chadwick, P. G. Young, and A. J. Koning

22 October 1996

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1 to 150 MeV. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains.

To summarize, the ENDF sections with non-zero data are:

MF=3	MT= 2	Integral of nuclear plus interference components of the elastic scattering cross section
	MT= 5	Sum of binary (n,n') and (n,x) reactions
MF=6	MT= 2	Elastic angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
	MT= 5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Fe56 and p + Fe56 reactions (Ch96a). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96b). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. Note that all other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation requires a modification of the original ENDF-6 format, i.e., we use LCT=3 with LAW 1 to indicate that data for the heavy recoils are in the lab system but all other reactions are in the cm system.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-

particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

Direct reaction cross sections to discrete states were calculated with the ECIS95 code [Re95] using deformation parameters compiled in Nuclear Data Sheets.

The optical model potential of Arthur et al. (Ar80) was used to calculate transmission coefficients with the SCAT2 code (Be92) for neutrons up to an energy of 26 MeV. Between 26 and 52 MeV, the imaginary volume component of Arthur's potential was modified to better account for nonelastic cross section measurements, and above 52 MeV the Semmering potential of Madland (Ma88) was used. For protons, the Beccetti-Greenlees potential (Be69) was utilized for both transmission coefficients and scattering and reaction cross sections below 28 MeV, and the Madland potential (Ma88) was used at higher energies. The global spherical potential of Perey (Pe63) was utilized for deuteron transmission coefficients, and the potential of Beccetti-Greenlees (Be) was adopted for tritons. Finally, the alpha potential of Lemos (Le72), as adapted by Arthur et al. (Ar80), was used for alpha particles.

MT=2 elastic scattering data in MF=3 and MF=6 are based on optical model calculations with the SCAT2 code (Be92). We have made use of the "nuclear-plus-interference" option in MF=6, which corresponds to LAW=5, LTP=12, and the appropriate integrated cross section is stored in MF=3. Note that because of the interference effect, the tabulations in both MF=6 and MF=3 can be negative at some energies and angles.

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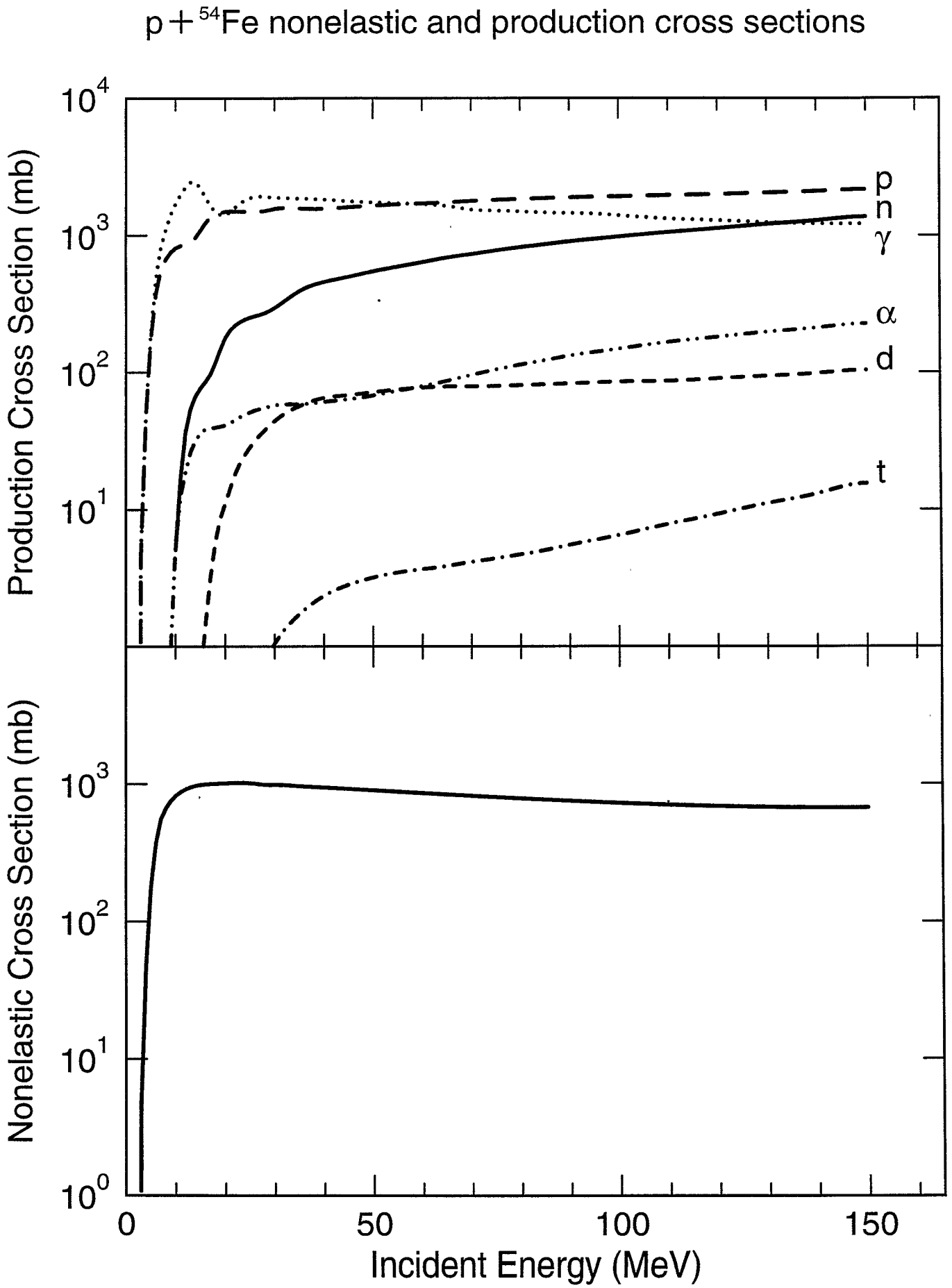
26054 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+00	1.000E-20	0.000E+00	0.000E+00	1.000E-20	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.000E-20
3.000E+00	4.538E-03	0.000E+00	0.000E+00	4.538E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.667E-03
4.000E+00	4.766E-02	0.000E+00	0.000E+00	4.766E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.880E-02
5.000E+00	1.773E-01	0.000E+00	0.000E+00	1.773E-01	0.000E+00	0.000E+00	0.000E+00	2.298E-10	1.930E-01
6.000E+00	3.724E-01	0.000E+00	0.000E+00	3.724E-01	0.000E+00	0.000E+00	0.000E+00	1.591E-08	4.670E-01
7.000E+00	5.575E-01	0.000E+00	0.000E+00	5.575E-01	0.000E+00	0.000E+00	0.000E+00	4.349E-06	8.016E-01
8.000E+00	6.666E-01	0.000E+00	0.000E+00	6.665E-01	0.000E+00	0.000E+00	0.000E+00	1.138E-04	1.096E+00
9.000E+00	7.531E-01	0.000E+00	0.000E+00	7.522E-01	0.000E+00	0.000E+00	0.000E+00	9.183E-04	1.416E+00
1.000E+01	8.212E-01	0.000E+00	5.087E-03	8.106E-01	0.000E+00	0.000E+00	0.000E+00	5.573E-03	1.705E+00
1.100E+01	8.736E-01	0.000E+00	1.706E-02	8.440E-01	0.000E+00	0.000E+00	0.000E+00	1.260E-02	1.976E+00
1.200E+01	9.160E-01	0.000E+00	3.662E-02	8.621E-01	8.528E-11	0.000E+00	0.000E+00	1.879E-02	2.240E+00
1.300E+01	9.478E-01	0.000E+00	5.388E-02	8.862E-01	2.799E-06	0.000E+00	0.000E+00	2.612E-02	2.429E+00
1.400E+01	9.703E-01	0.000E+00	6.683E-02	9.594E-01	4.932E-05	0.000E+00	0.000E+00	3.181E-02	2.427E+00
1.500E+01	9.846E-01	0.000E+00	7.648E-02	1.085E+00	4.283E-04	0.000E+00	0.000E+00	3.592E-02	2.211E+00
1.600E+01	9.946E-01	0.000E+00	8.473E-02	1.230E+00	1.402E-03	0.000E+00	0.000E+00	3.825E-02	1.901E+00
1.700E+01	9.996E-01	0.000E+00	9.633E-02	1.343E+00	3.133E-03	2.624E-08	0.000E+00	3.911E-02	1.642E+00
1.800E+01	1.004E+00	0.000E+00	1.162E-01	1.416E+00	5.711E-03	1.846E-07	0.000E+00	3.948E-02	1.481E+00
1.900E+01	1.008E+00	0.000E+00	1.459E-01	1.455E+00	8.537E-03	4.179E-06	0.000E+00	4.013E-02	1.413E+00
2.000E+01	1.012E+00	0.000E+00	1.775E-01	1.482E+00	1.101E-02	2.106E-05	0.000E+00	4.085E-02	1.399E+00
2.200E+01	1.018E+00	0.000E+00	2.202E-01	1.492E+00	1.802E-02	9.150E-05	0.000E+00	4.478E-02	1.589E+00
2.400E+01	1.017E+00	0.000E+00	2.437E-01	1.485E+00	2.491E-02	2.468E-04	0.000E+00	4.875E-02	1.804E+00
2.600E+01	1.004E+00	0.000E+00	2.578E-01	1.484E+00	3.142E-02	4.850E-04	0.000E+00	5.239E-02	1.911E+00
2.800E+01	9.856E-01	0.000E+00	2.712E-01	1.502E+00	3.754E-02	7.582E-04	0.000E+00	5.484E-02	1.913E+00
3.000E+01	9.855E-01	0.000E+00	2.965E-01	1.559E+00	4.392E-02	1.048E-03	0.000E+00	5.725E-02	1.888E+00
3.500E+01	9.638E-01	0.000E+00	3.940E-01	1.569E+00	5.654E-02	1.723E-03	0.000E+00	5.833E-02	1.858E+00
4.000E+01	9.418E-01	0.000E+00	4.590E-01	1.563E+00	6.497E-02	2.350E-03	0.000E+00	6.077E-02	1.825E+00
4.500E+01	9.200E-01	0.000E+00	5.025E-01	1.603E+00	6.816E-02	2.830E-03	0.000E+00	6.346E-02	1.770E+00
5.000E+01	8.983E-01	0.000E+00	5.508E-01	1.646E+00	7.164E-02	3.196E-03	0.000E+00	6.769E-02	1.738E+00
5.500E+01	8.772E-01	0.000E+00	5.956E-01	1.684E+00	7.476E-02	3.482E-03	0.000E+00	7.333E-02	1.715E+00
6.000E+01	8.569E-01	0.000E+00	6.410E-01	1.710E+00	7.725E-02	3.688E-03	0.000E+00	7.893E-02	1.688E+00
6.500E+01	8.372E-01	0.000E+00	6.925E-01	1.742E+00	7.868E-02	3.891E-03	0.000E+00	8.628E-02	1.636E+00
7.000E+01	8.184E-01	0.000E+00	7.344E-01	1.780E+00	7.881E-02	4.163E-03	0.000E+00	9.559E-02	1.536E+00
7.500E+01	8.004E-01	0.000E+00	7.807E-01	1.813E+00	7.920E-02	4.410E-03	0.000E+00	1.046E-01	1.508E+00
8.000E+01	7.834E-01	0.000E+00	8.235E-01	1.840E+00	8.019E-02	4.709E-03	0.000E+00	1.134E-01	1.488E+00
8.500E+01	7.672E-01	0.000E+00	8.631E-01	1.866E+00	8.120E-02	5.054E-03	0.000E+00	1.218E-01	1.461E+00
9.000E+01	7.523E-01	0.000E+00	9.051E-01	1.889E+00	8.247E-02	5.523E-03	0.000E+00	1.317E-01	1.447E+00
9.500E+01	7.384E-01	0.000E+00	9.416E-01	1.907E+00	8.373E-02	5.990E-03	0.000E+00	1.399E-01	1.433E+00
1.000E+02	7.258E-01	0.000E+00	9.790E-01	1.922E+00	8.503E-02	6.510E-03	0.000E+00	1.477E-01	1.394E+00
1.100E+02	7.043E-01	0.000E+00	1.055E+00	1.960E+00	8.613E-02	7.833E-03	0.000E+00	1.657E-01	1.320E+00
1.200E+02	6.879E-01	0.000E+00	1.127E+00	1.993E+00	8.979E-02	9.287E-03	0.000E+00	1.806E-01	1.283E+00
1.300E+02	6.774E-01	0.000E+00	1.208E+00	2.040E+00	9.383E-02	1.112E-02	0.000E+00	1.969E-01	1.239E+00
1.400E+02	6.722E-01	0.000E+00	1.282E+00	2.094E+00	9.830E-02	1.309E-02	0.000E+00	2.116E-01	1.220E+00
1.500E+02	6.721E-01	0.000E+00	1.365E+00	2.158E+00	1.036E-01	1.546E-02	0.000E+00	2.267E-01	1.216E+00

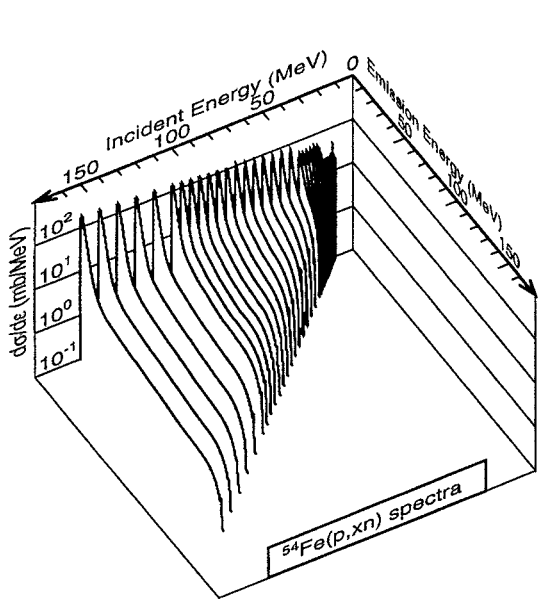
26054 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

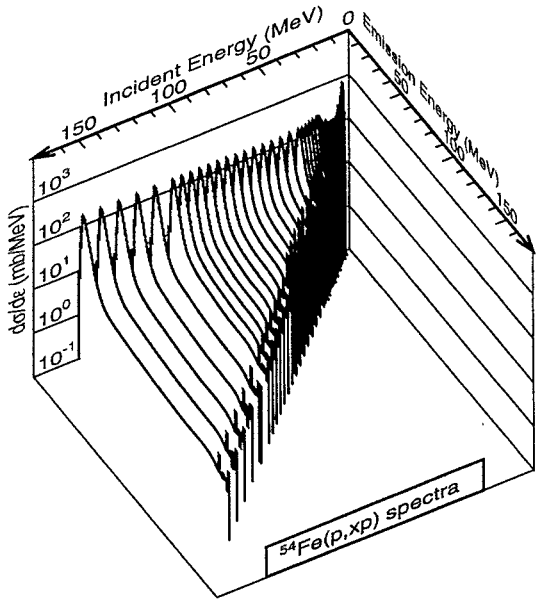
Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+00	0.000E+00	4.915E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.428E+00
3.000E+00	0.000E+00	1.474E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.565E+00
4.000E+00	0.000E+00	2.433E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.504E+00
5.000E+00	0.000E+00	3.295E+00	0.000E+00	0.000E+00	0.000E+00	1.651E+00	1.517E+00
6.000E+00	0.000E+00	3.931E+00	0.000E+00	0.000E+00	0.000E+00	2.481E+00	1.597E+00
7.000E+00	0.000E+00	4.522E+00	0.000E+00	0.000E+00	0.000E+00	3.413E+00	1.671E+00
8.000E+00	0.000E+00	4.998E+00	0.000E+00	0.000E+00	0.000E+00	4.334E+00	1.771E+00
9.000E+00	0.000E+00	5.282E+00	0.000E+00	0.000E+00	0.000E+00	5.231E+00	1.919E+00
1.000E+01	7.162E-01	5.535E+00	0.000E+00	0.000E+00	0.000E+00	6.132E+00	2.053E+00
1.100E+01	7.901E-01	5.790E+00	0.000E+00	0.000E+00	0.000E+00	6.876E+00	2.170E+00
1.200E+01	1.166E+00	5.974E+00	7.306E-01	0.000E+00	0.000E+00	7.331E+00	2.246E+00
1.300E+01	1.550E+00	6.101E+00	1.450E+00	0.000E+00	0.000E+00	7.607E+00	2.330E+00
1.400E+01	1.920E+00	5.973E+00	2.358E+00	0.000E+00	0.000E+00	7.831E+00	2.366E+00
1.500E+01	2.246E+00	5.663E+00	3.201E+00	0.000E+00	0.000E+00	8.092E+00	2.339E+00
1.600E+01	2.534E+00	5.461E+00	3.870E+00	0.000E+00	0.000E+00	8.337E+00	2.259E+00
1.700E+01	2.719E+00	5.472E+00	4.482E+00	1.037E+00	0.000E+00	8.553E+00	2.148E+00
1.800E+01	2.686E+00	5.625E+00	5.087E+00	1.809E+00	0.000E+00	8.733E+00	2.019E+00
1.900E+01	2.688E+00	5.820E+00	5.644E+00	2.744E+00	0.000E+00	8.870E+00	1.888E+00
2.000E+01	2.864E+00	6.093E+00	6.170E+00	3.342E+00	0.000E+00	8.929E+00	1.727E+00
2.200E+01	3.190E+00	6.539E+00	7.441E+00	4.479E+00	0.000E+00	9.160E+00	1.730E+00
2.400E+01	3.726E+00	7.069E+00	8.712E+00	5.269E+00	0.000E+00	9.458E+00	1.889E+00
2.600E+01	4.207E+00	7.466E+00	9.942E+00	6.349E+00	0.000E+00	9.738E+00	2.035E+00
2.800E+01	4.739E+00	7.784E+00	1.113E+01	7.398E+00	0.000E+00	1.005E+01	2.085E+00

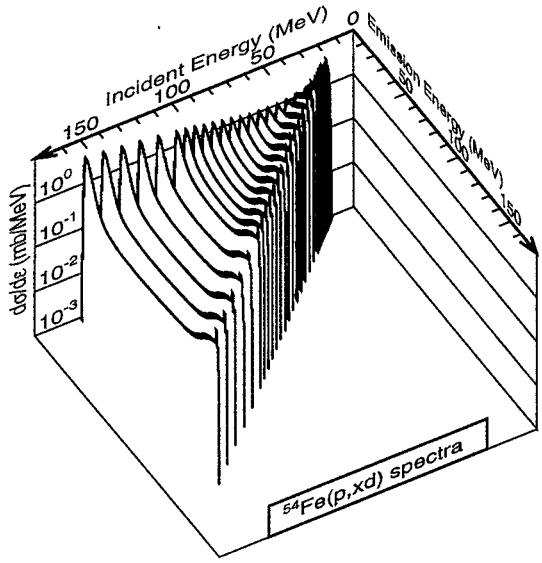
3.000E+01	5.162E+00	8.055E+00	1.230E+01	8.385E+00	0.000E+00	1.037E+01	2.034E+00
3.500E+01	5.831E+00	9.211E+00	1.531E+01	1.053E+01	0.000E+00	1.125E+01	1.861E+00
4.000E+01	6.830E+00	1.040E+01	1.850E+01	1.263E+01	0.000E+00	1.192E+01	1.880E+00
4.500E+01	7.886E+00	1.135E+01	2.136E+01	1.464E+01	0.000E+00	1.249E+01	1.899E+00
5.000E+01	8.684E+00	1.215E+01	2.430E+01	1.653E+01	0.000E+00	1.283E+01	1.892E+00
5.500E+01	9.389E+00	1.289E+01	2.727E+01	1.829E+01	0.000E+00	1.305E+01	1.912E+00
6.000E+01	1.002E+01	1.360E+01	3.012E+01	1.985E+01	0.000E+00	1.323E+01	1.874E+00
6.500E+01	1.049E+01	1.421E+01	3.278E+01	2.116E+01	0.000E+00	1.330E+01	1.871E+00
7.000E+01	1.094E+01	1.463E+01	3.491E+01	2.191E+01	0.000E+00	1.327E+01	1.872E+00
7.500E+01	1.138E+01	1.509E+01	3.701E+01	2.229E+01	0.000E+00	1.325E+01	1.856E+00
8.000E+01	1.181E+01	1.555E+01	3.920E+01	2.248E+01	0.000E+00	1.325E+01	1.845E+00
8.500E+01	1.224E+01	1.599E+01	4.128E+01	2.241E+01	0.000E+00	1.326E+01	1.824E+00
9.000E+01	1.256E+01	1.641E+01	4.300E+01	2.188E+01	0.000E+00	1.323E+01	1.828E+00
9.500E+01	1.296E+01	1.688E+01	4.484E+01	2.142E+01	0.000E+00	1.326E+01	1.843E+00
1.000E+02	1.331E+01	1.735E+01	4.658E+01	2.084E+01	0.000E+00	1.329E+01	1.825E+00
1.100E+02	1.397E+01	1.826E+01	4.838E+01	1.936E+01	0.000E+00	1.333E+01	1.887E+00
1.200E+02	1.459E+01	1.922E+01	5.126E+01	1.807E+01	0.000E+00	1.342E+01	1.910E+00
1.300E+02	1.514E+01	2.008E+01	5.323E+01	1.678E+01	0.000E+00	1.350E+01	1.910E+00
1.400E+02	1.581E+01	2.099E+01	5.524E+01	1.579E+01	0.000E+00	1.361E+01	1.901E+00
1.500E+02	1.642E+01	2.190E+01	5.669E+01	1.491E+01	0.000E+00	1.373E+01	1.924E+00

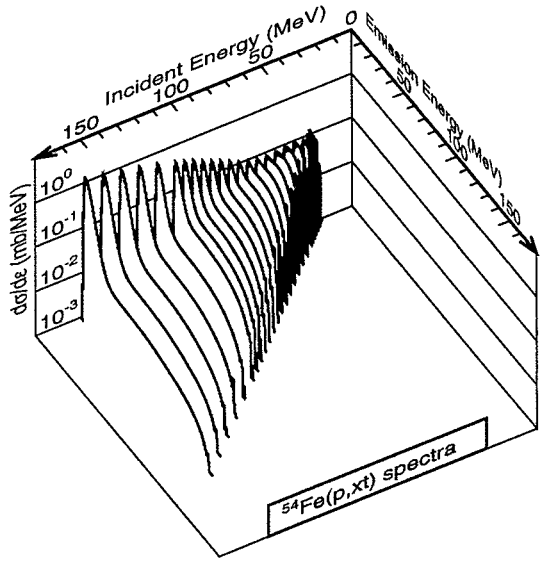

p + 54Fe nonelastic and production cross sections
Production Cross Section (mb)
Nonelastic Cross Section (mb)
Incident Energy (MeV)
p
n
γ
α
d
t
10^4
10^3
10^2
10^1
10^0
0
50
100
150

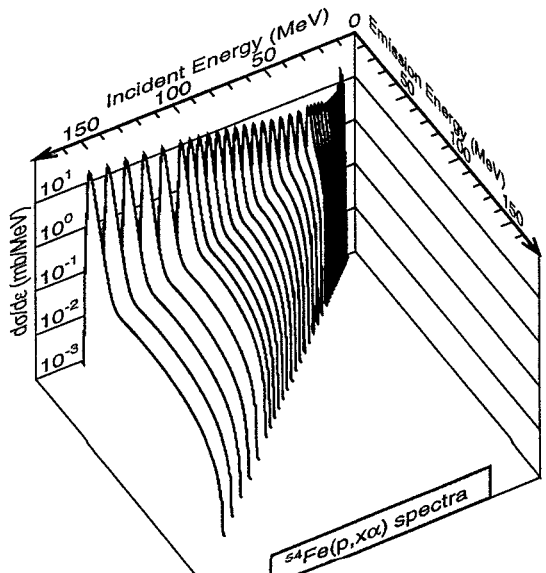
p + ^{54}Fe angle-integrated emission spectra

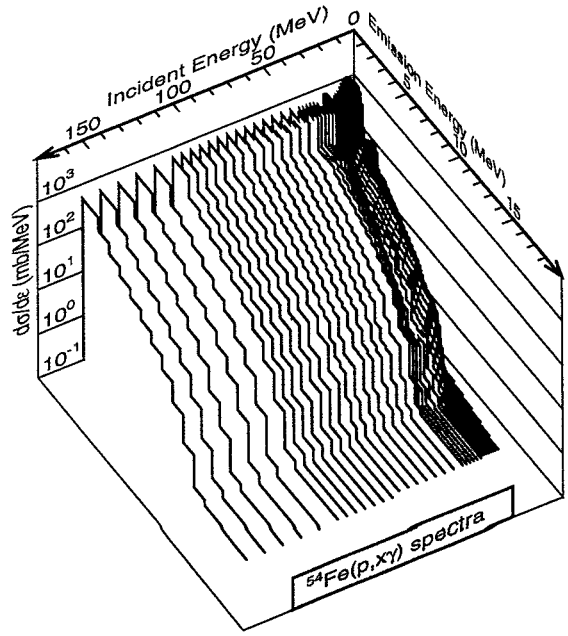




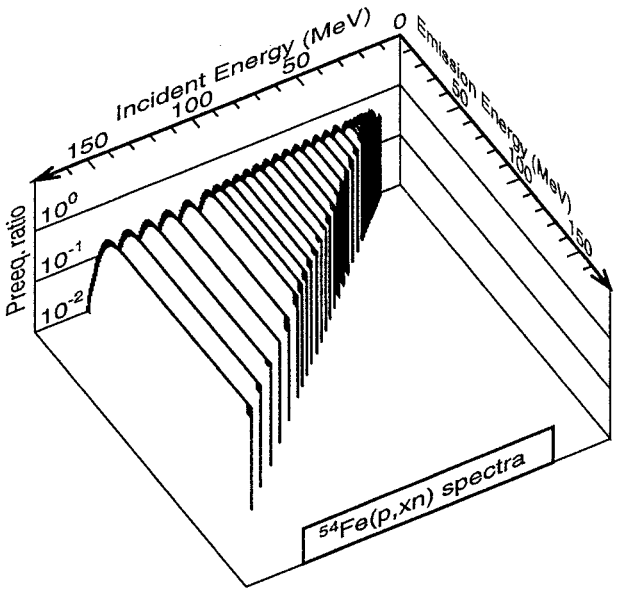


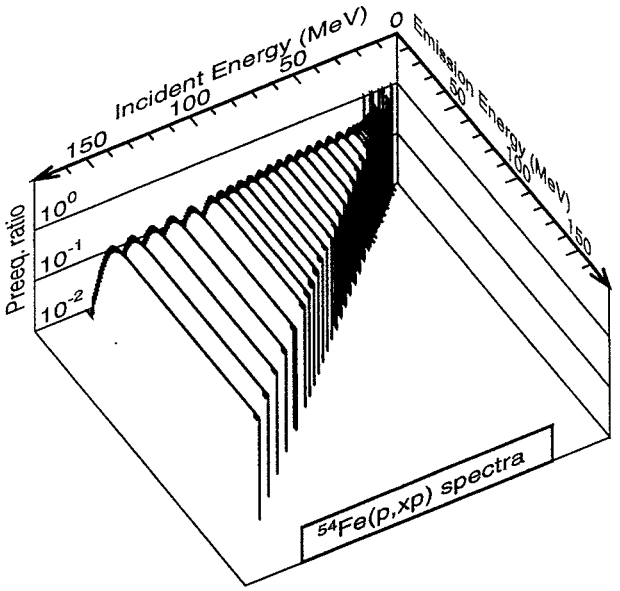


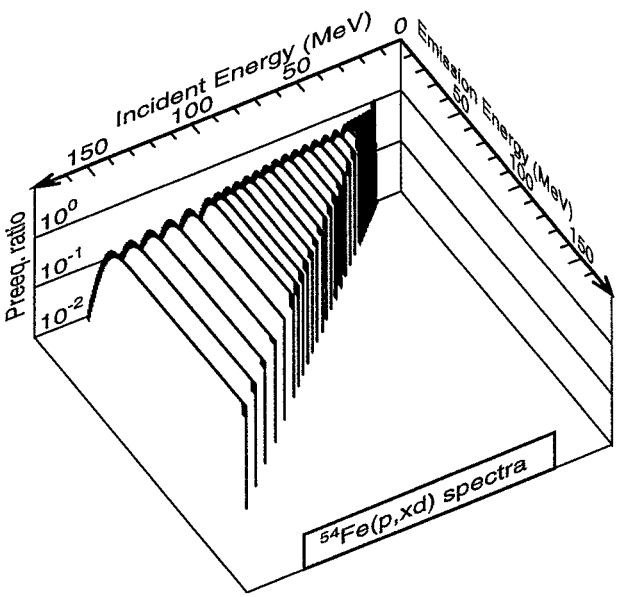


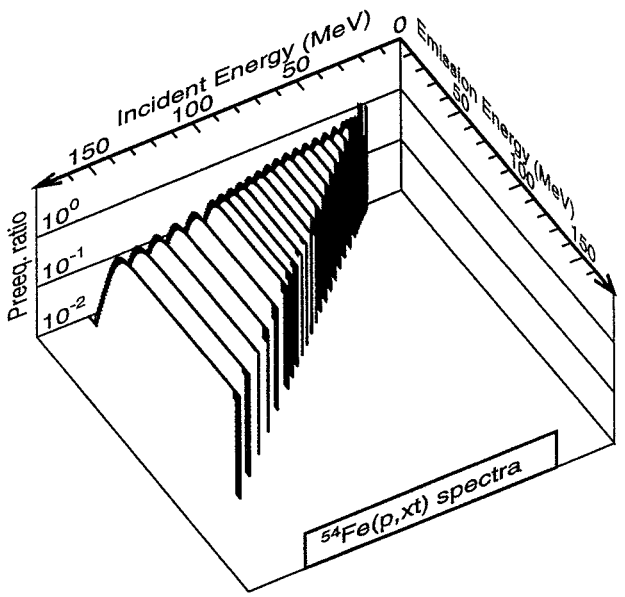


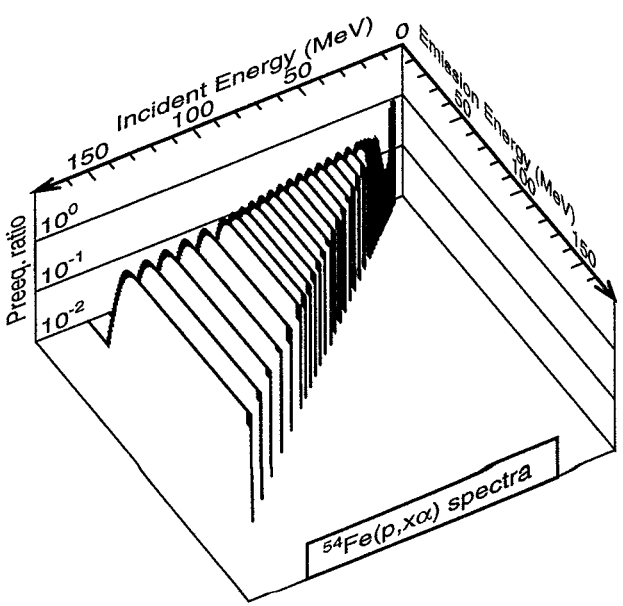
p + ^{54}Fe Kalbach preequilibrium ratios

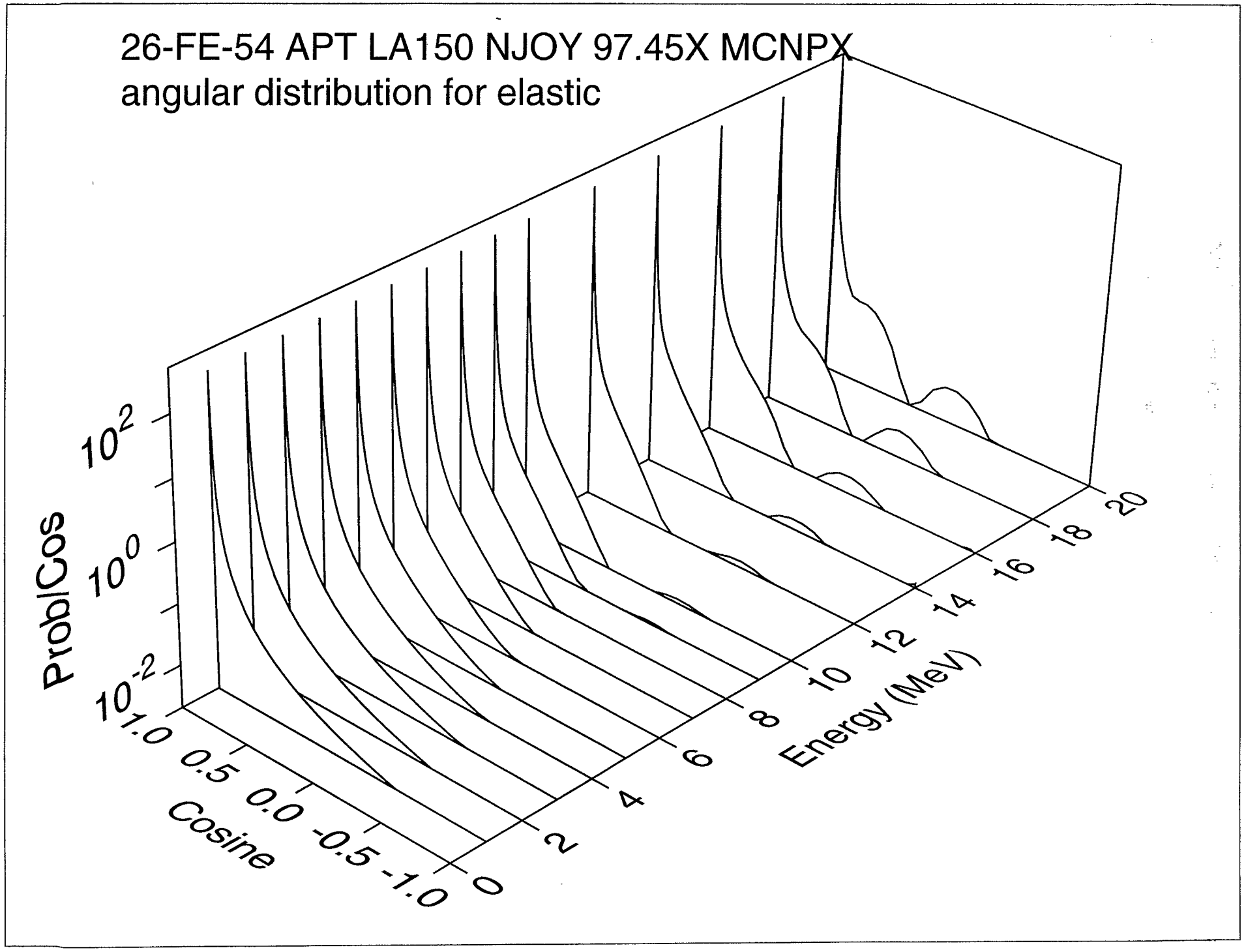


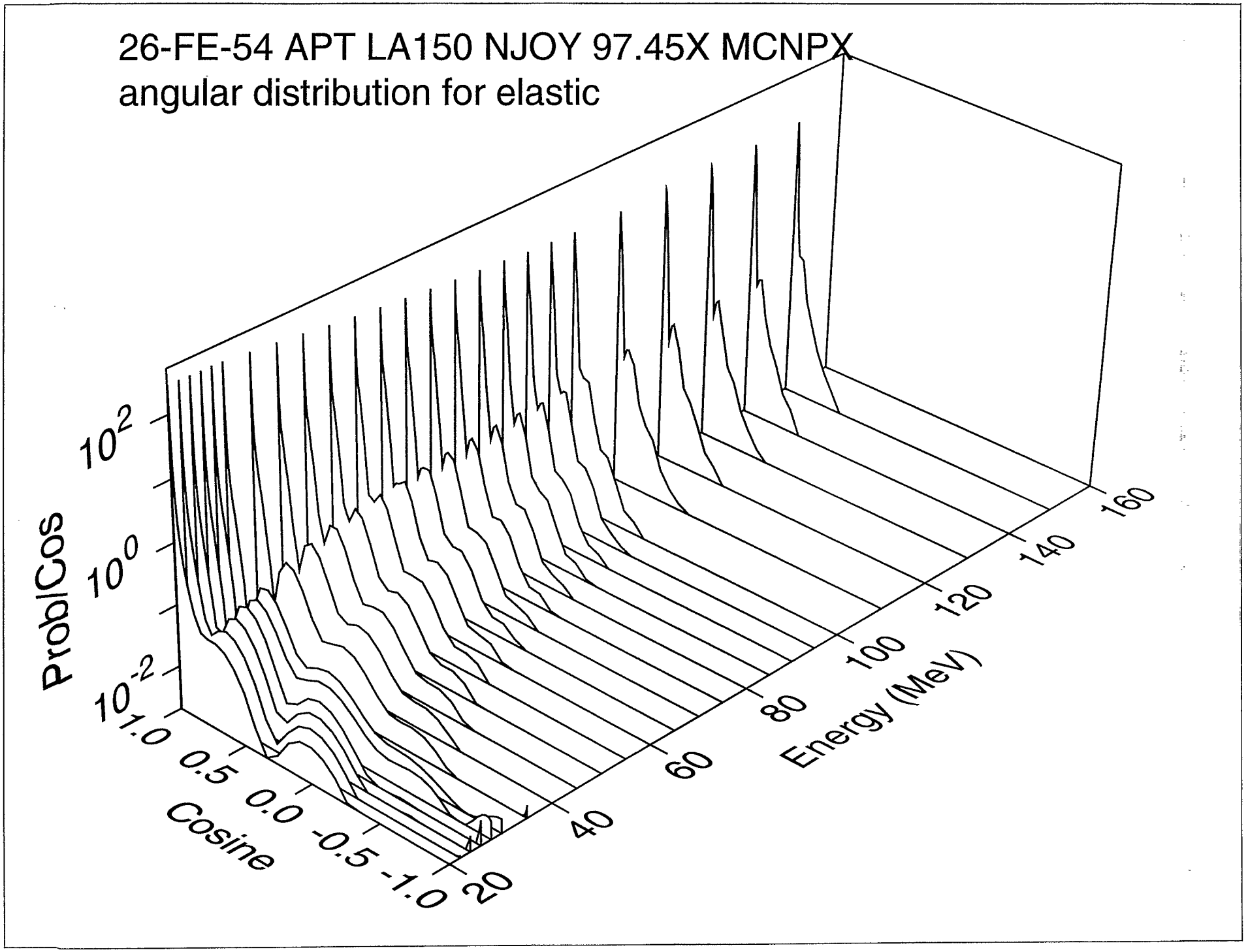


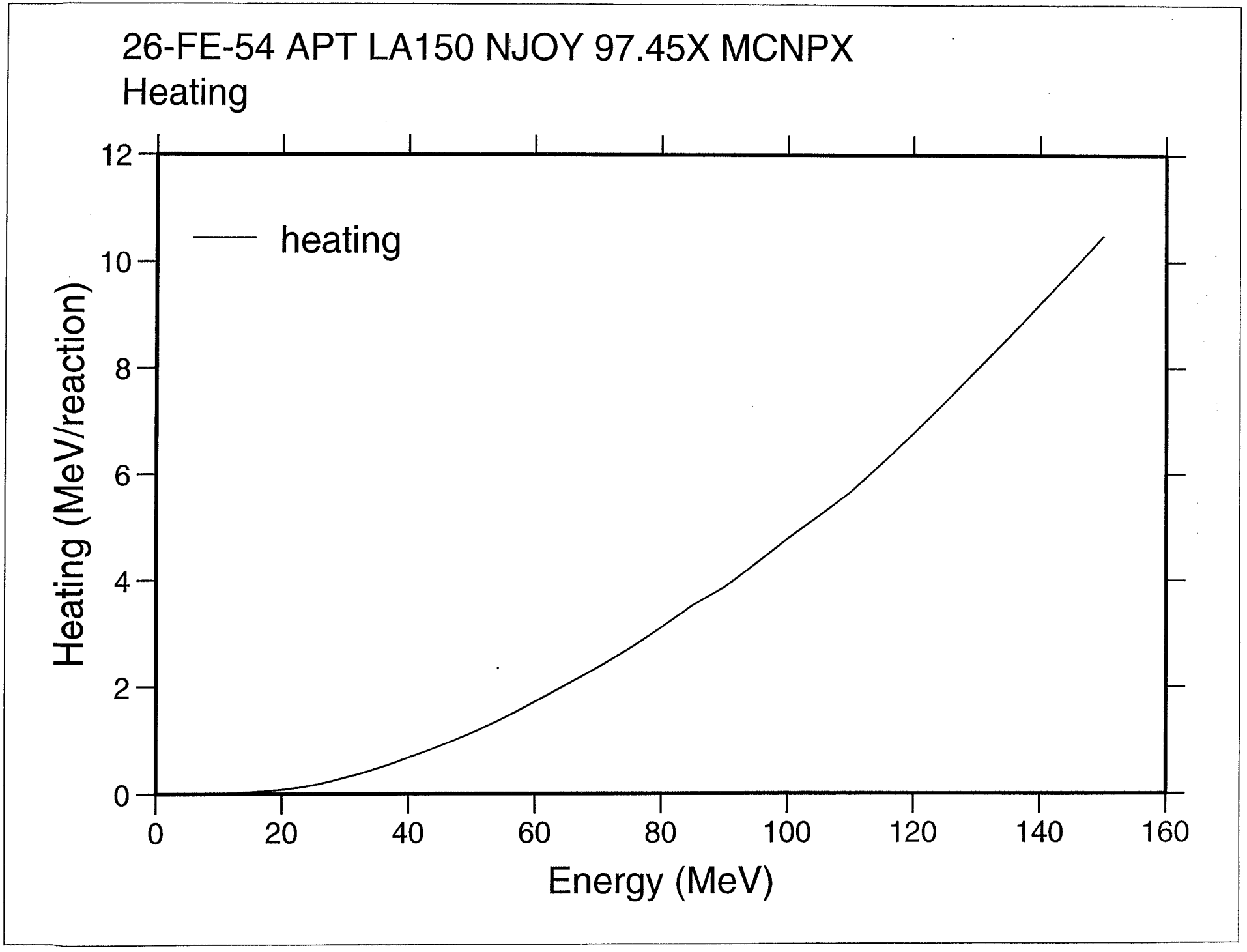







26-FE-54 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
0
2
4
6
8
10
12
14
16
18
20


26-FE-54 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
20
40
60
80
100
120
140
160


26-FE-54 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
2
4
6
8
10
12
0
20
40
60
80
100
120
140
160

EVALUATION OF p + 56Fe CROSS SECTIONS FOR THE ENERGY RANGE 1 to 150 MeV

M. B. Chadwick, P. G. Young, and A. J. Koning
22 October 1996

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1 to 150 MeV. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains.

To summarize, the ENDF sections with non-zero data are:

MF=3 MT=	2	Integral of nuclear plus interference components of the elastic scattering cross section
MT=	5	Sum of binary (n,n') and (n,x) reactions
MF=6 MT=	2	Elastic angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
MT=	5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Fe56 and p + Fe56 reactions (Ch96a). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96b). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. Note that all other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation requires a modification of the original ENDF-6 format, i.e., we use LCT=3 with LAW 1 to indicate that data for the heavy recoils are in the lab system but all other reactions are in the cm system.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-

particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

Direct reaction cross sections to discrete states were calculated with the ECIS95 code [Re95] using deformation parameters compiled in Nuclear Data Sheets.

The optical model potential of Arthur et al. (Ar80) was used to calculate transmission coefficients with the SCAT2 code (Be92) for neutrons up to an energy of 26 MeV. Between 26 and 52 MeV, the imaginary volume component of Arthur's potential was modified to better account for nonelastic cross section measurements, and above 52 MeV the Semmering potential of Madland (Ma88) was used. For protons, the Beccetti-Greenlees potential (Be69) was utilized for both transmission coefficients and scattering and reaction cross sections below 28 MeV, and the Madland potential (Ma88) was used at higher energies. The global spherical potential of Perey (Pe63) was utilized for deuteron transmission coefficients, and the potential of Beccetti-Greenlees (Be) was adopted for tritons. Finally, the alpha potential of Lemos (Le72), as adapted by Arthur et al. (Ar80), was used for alpha particles.

MT=2 elastic scattering data in MF=3 and MF=6 are based on optical model calculations with the SCAT2 code (Be92). We have made use of the "nuclear-plus-interference" option in MF=6, which corresponds to LAW=5, LTP=12, and the appropriate integrated cross section is stored in MF=3. Note that because of the interference effect, the tabulations in both MF=6 and MF=3 can be negative at some energies and angles.

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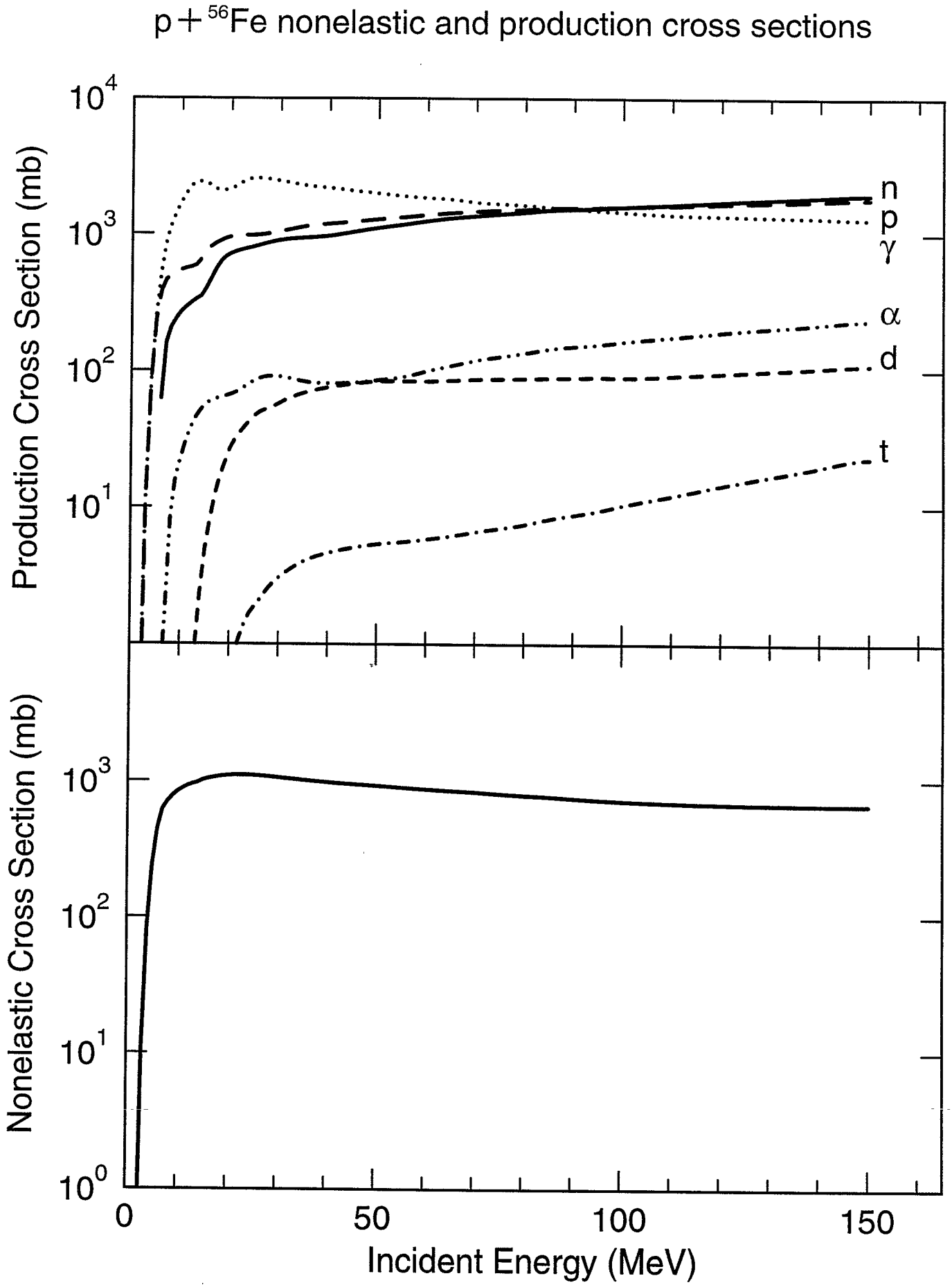
26056 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+00	3.407E-04	0.000E+00	0.000E+00	3.407E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	5.371E-04
3.000E+00	1.104E-02	0.000E+00	0.000E+00	1.104E-02	0.000E+00	0.000E+00	0.000E+00	1.212E-12	1.130E-02
4.000E+00	8.287E-02	0.000E+00	0.000E+00	8.287E-02	0.000E+00	0.000E+00	0.000E+00	3.346E-08	8.427E-02
5.000E+00	2.361E-01	0.000E+00	0.000E+00	2.361E-01	0.000E+00	0.000E+00	0.000E+00	1.002E-05	2.576E-01
6.000E+00	4.436E-01	0.000E+00	6.221E-02	3.810E-01	0.000E+00	0.000E+00	0.000E+00	3.424E-04	5.437E-01
7.000E+00	6.204E-01	0.000E+00	1.593E-01	4.595E-01	0.000E+00	0.000E+00	0.000E+00	1.613E-03	8.995E-01
8.000E+00	7.063E-01	0.000E+00	2.080E-01	4.899E-01	0.000E+00	0.000E+00	0.000E+00	8.384E-03	1.190E+00
9.000E+00	7.743E-01	0.000E+00	2.394E-01	5.183E-01	0.000E+00	0.000E+00	0.000E+00	1.657E-02	1.464E+00
1.000E+01	8.318E-01	0.000E+00	2.680E-01	5.410E-01	2.034E-08	0.000E+00	0.000E+00	2.273E-02	1.741E+00
1.100E+01	8.790E-01	0.000E+00	2.903E-01	5.582E-01	6.560E-06	0.000E+00	0.000E+00	3.050E-02	2.006E+00
1.200E+01	9.188E-01	0.000E+00	3.115E-01	5.690E-01	1.232E-04	0.000E+00	0.000E+00	3.823E-02	2.253E+00
1.300E+01	9.492E-01	0.000E+00	3.306E-01	5.897E-01	8.188E-04	7.007E-11	0.000E+00	4.554E-02	2.415E+00
1.400E+01	9.711E-01	0.000E+00	3.487E-01	6.494E-01	2.301E-03	2.899E-07	0.000E+00	5.144E-02	2.420E+00
1.500E+01	1.012E+00	0.000E+00	3.971E-01	7.349E-01	4.858E-03	7.468E-06	0.000E+00	5.648E-02	2.389E+00
1.600E+01	1.036E+00	0.000E+00	4.657E-01	8.063E-01	7.989E-03	3.583E-05	0.000E+00	5.970E-02	2.253E+00
1.700E+01	1.055E+00	0.000E+00	5.499E-01	8.535E-01	1.222E-02	8.939E-05	0.000E+00	6.179E-02	2.133E+00
1.800E+01	1.072E+00	0.000E+00	6.266E-01	8.916E-01	1.679E-02	1.912E-04	0.000E+00	6.347E-02	2.074E+00
1.900E+01	1.085E+00	0.000E+00	6.805E-01	9.266E-01	2.139E-02	3.558E-04	0.000E+00	6.494E-02	2.099E+00
2.000E+01	1.094E+00	0.000E+00	7.143E-01	9.496E-01	2.689E-02	5.737E-04	0.000E+00	6.672E-02	2.137E+00
2.200E+01	1.103E+00	0.000E+00	7.589E-01	9.750E-01	3.532E-02	1.105E-03	0.000E+00	7.214E-02	2.362E+00
2.400E+01	1.102E+00	0.000E+00	7.920E-01	9.749E-01	4.291E-02	1.654E-03	0.000E+00	8.065E-02	2.540E+00
2.600E+01	1.092E+00	0.000E+00	8.286E-01	9.835E-01	4.983E-02	2.061E-03	0.000E+00	8.795E-02	2.571E+00
2.800E+01	1.077E+00	0.000E+00	8.667E-01	1.009E+00	5.312E-02	2.580E-03	0.000E+00	9.096E-02	2.518E+00
3.000E+01	1.060E+00	0.000E+00	8.987E-01	1.040E+00	5.774E-02	3.025E-03	0.000E+00	9.029E-02	2.457E+00
3.500E+01	1.017E+00	0.000E+00	9.375E-01	1.133E+00	6.863E-02	3.982E-03	0.000E+00	8.309E-02	2.277E+00
4.000E+01	9.800E-01	0.000E+00	9.724E-01	1.191E+00	7.559E-02	4.610E-03	0.000E+00	8.073E-02	2.187E+00
4.500E+01	9.510E-01	0.000E+00	1.040E+00	1.236E+00	8.051E-02	5.032E-03	0.000E+00	8.173E-02	2.083E+00
5.000E+01	9.250E-01	0.000E+00	1.114E+00	1.291E+00	8.360E-02	5.345E-03	0.000E+00	8.539E-02	2.000E+00
5.500E+01	8.980E-01	0.000E+00	1.179E+00	1.337E+00	8.397E-02	5.542E-03	0.000E+00	8.984E-02	1.917E+00
6.000E+01	8.730E-01	0.000E+00	1.253E+00	1.390E+00	8.380E-02	5.812E-03	0.000E+00	9.949E-02	1.856E+00
6.500E+01	8.520E-01	0.000E+00	1.321E+00	1.438E+00	8.504E-02	6.147E-03	0.000E+00	1.093E-01	1.807E+00
7.000E+01	8.340E-01	0.000E+00	1.371E+00	1.479E+00	8.673E-02	6.604E-03	0.000E+00	1.197E-01	1.721E+00
7.500E+01	8.100E-01	0.000E+00	1.416E+00	1.505E+00	8.722E-02	7.009E-03	0.000E+00	1.275E-01	1.677E+00
8.000E+01	7.900E-01	0.000E+00	1.462E+00	1.529E+00	8.800E-02	7.500E-03	0.000E+00	1.352E-01	1.640E+00
8.500E+01	7.740E-01	0.000E+00	1.517E+00	1.562E+00	8.865E-02	8.214E-03	0.000E+00	1.450E-01	1.583E+00
9.000E+01	7.530E-01	0.000E+00	1.540E+00	1.575E+00	8.932E-02	8.812E-03	0.000E+00	1.510E-01	1.541E+00
9.500E+01	7.340E-01	0.000E+00	1.563E+00	1.582E+00	8.992E-02	9.478E-03	0.000E+00	1.563E-01	1.504E+00
1.000E+02	7.190E-01	0.000E+00	1.599E+00	1.604E+00	8.947E-02	1.042E-02	0.000E+00	1.642E-01	1.469E+00
1.100E+02	6.980E-01	0.000E+00	1.661E+00	1.636E+00	9.261E-02	1.224E-02	0.000E+00	1.777E-01	1.403E+00
1.200E+02	6.850E-01	0.000E+00	1.741E+00	1.681E+00	9.643E-02	1.458E-02	0.000E+00	1.929E-01	1.377E+00
1.300E+02	6.770E-01	0.000E+00	1.817E+00	1.726E+00	1.010E-01	1.708E-02	0.000E+00	2.067E-01	1.352E+00
1.400E+02	6.720E-01	0.000E+00	1.896E+00	1.775E+00	1.060E-01	2.003E-02	0.000E+00	2.212E-01	1.330E+00
1.500E+02	6.690E-01	0.000E+00	1.965E+00	1.825E+00	1.104E-01	2.307E-02	0.000E+00	2.347E-01	1.299E+00

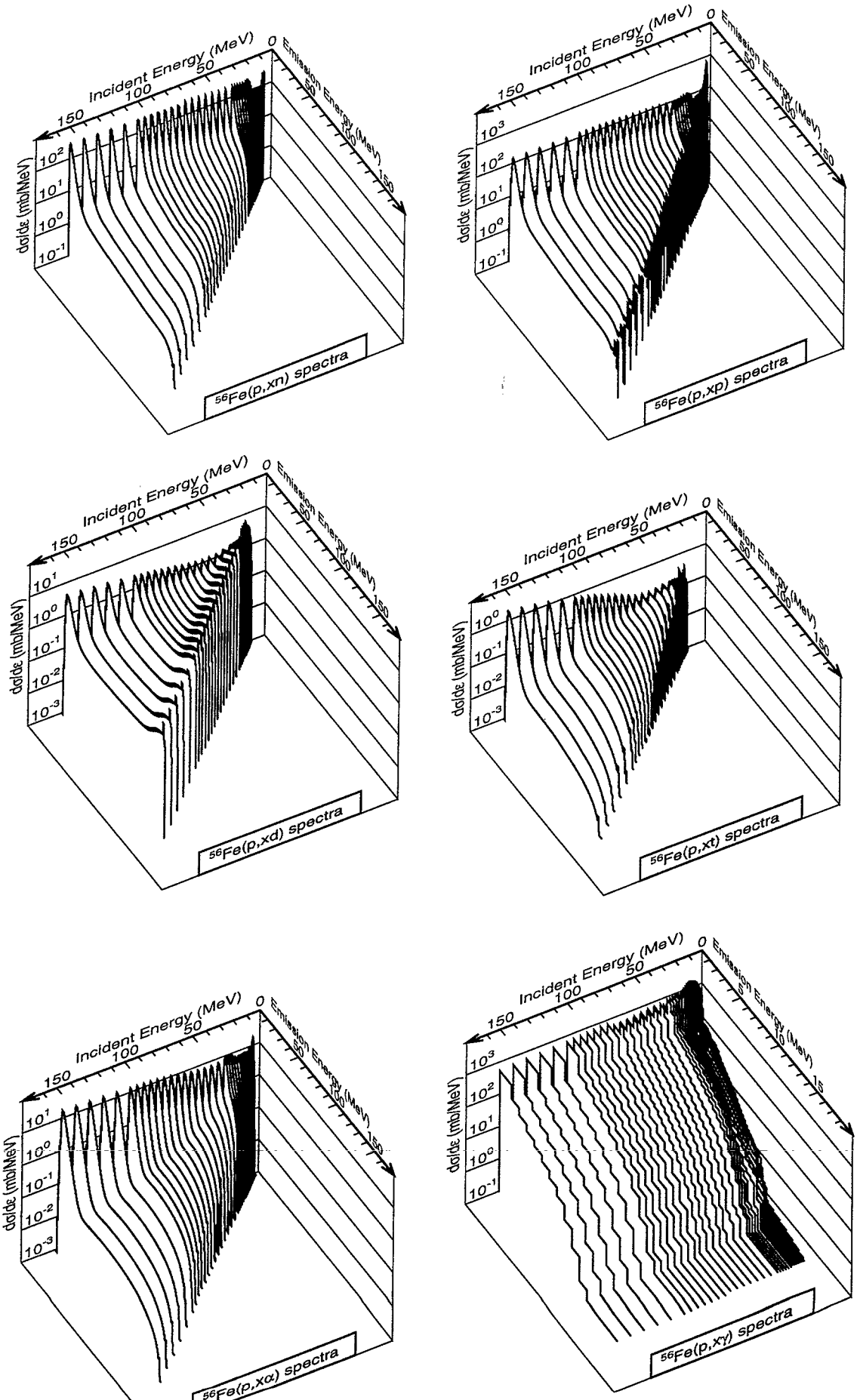
26056 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+00	0.000E+00	9.831E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.893E+00
3.000E+00	0.000E+00	1.966E+00	0.000E+00	0.000E+00	0.000E+00	1.702E+00	8.345E-01
4.000E+00	0.000E+00	2.929E+00	0.000E+00	0.000E+00	0.000E+00	2.640E+00	7.740E-01
5.000E+00	0.000E+00	3.776E+00	0.000E+00	0.000E+00	0.000E+00	3.416E+00	8.443E-01
6.000E+00	4.930E-01	4.272E+00	0.000E+00	0.000E+00	0.000E+00	4.366E+00	1.011E+00
7.000E+00	9.226E-01	4.636E+00	0.000E+00	0.000E+00	0.000E+00	5.255E+00	1.148E+00
8.000E+00	1.420E+00	5.070E+00	0.000E+00	0.000E+00	0.000E+00	6.142E+00	1.256E+00
9.000E+00	1.788E+00	5.414E+00	0.000E+00	0.000E+00	0.000E+00	6.898E+00	1.427E+00
1.000E+01	2.039E+00	5.708E+00	7.584E-01	0.000E+00	0.000E+00	7.427E+00	1.602E+00
1.100E+01	2.242E+00	6.027E+00	1.646E+00	0.000E+00	0.000E+00	7.653E+00	1.767E+00
1.200E+01	2.411E+00	6.334E+00	2.579E+00	0.000E+00	0.000E+00	7.840E+00	1.929E+00
1.300E+01	2.562E+00	6.478E+00	3.384E+00	7.736E-01	0.000E+00	8.062E+00	2.084E+00
1.400E+01	2.630E+00	6.316E+00	3.954E+00	1.674E+00	0.000E+00	8.287E+00	2.212E+00
1.500E+01	2.636E+00	6.167E+00	4.565E+00	2.596E+00	0.000E+00	8.482E+00	2.253E+00
1.600E+01	2.566E+00	6.107E+00	5.089E+00	3.416E+00	0.000E+00	8.654E+00	2.198E+00
1.700E+01	2.499E+00	6.254E+00	5.724E+00	3.842E+00	0.000E+00	8.806E+00	2.078E+00
1.800E+01	2.531E+00	6.475E+00	6.370E+00	4.272E+00	0.000E+00	8.952E+00	1.940E+00
1.900E+01	2.647E+00	6.729E+00	7.001E+00	4.615E+00	0.000E+00	9.092E+00	1.825E+00
2.000E+01	2.797E+00	7.033E+00	7.711E+00	4.969E+00	0.000E+00	9.211E+00	1.821E+00
2.200E+01	3.132E+00	7.660E+00	8.890E+00	5.979E+00	0.000E+00	9.387E+00	1.842E+00
2.400E+01	3.435E+00	8.316E+00	1.011E+01	6.970E+00	0.000E+00	9.505E+00	1.929E+00
2.600E+01	3.693E+00	8.903E+00	1.128E+01	7.901E+00	0.000E+00	9.703E+00	1.952E+00
2.800E+01	3.916E+00	9.423E+00	1.222E+01	8.798E+00	0.000E+00	9.974E+00	1.912E+00

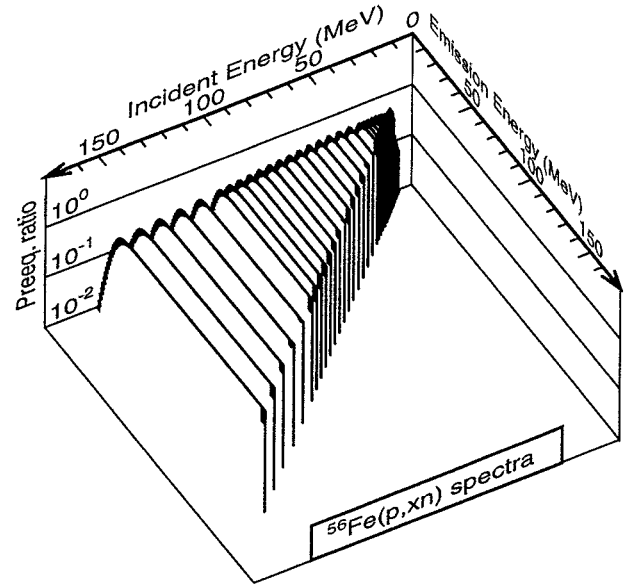
3.000E+01	4.154E+00	9.866E+00	1.324E+01	9.680E+00	0.000E+00	1.027E+01	1.851E+00
3.500E+01	4.874E+00	1.094E+01	1.630E+01	1.179E+01	0.000E+00	1.101E+01	1.774E+00
4.000E+01	5.587E+00	1.210E+01	1.946E+01	1.378E+01	0.000E+00	1.151E+01	1.777E+00
4.500E+01	6.143E+00	1.323E+01	2.265E+01	1.567E+01	0.000E+00	1.187E+01	1.826E+00
5.000E+01	6.617E+00	1.409E+01	2.561E+01	1.739E+01	0.000E+00	1.210E+01	1.844E+00
5.500E+01	7.055E+00	1.484E+01	2.814E+01	1.886E+01	0.000E+00	1.227E+01	1.864E+00
6.000E+01	7.350E+00	1.532E+01	3.045E+01	1.984E+01	0.000E+00	1.224E+01	1.872E+00
6.500E+01	7.644E+00	1.576E+01	3.291E+01	2.047E+01	0.000E+00	1.225E+01	1.867E+00
7.000E+01	8.025E+00	1.623E+01	3.514E+01	2.053E+01	0.000E+00	1.225E+01	1.793E+00
7.500E+01	8.366E+00	1.669E+01	3.735E+01	2.059E+01	0.000E+00	1.229E+01	1.774E+00
8.000E+01	8.697E+00	1.718E+01	3.946E+01	2.042E+01	0.000E+00	1.233E+01	1.770E+00
8.500E+01	8.967E+00	1.759E+01	4.094E+01	1.985E+01	0.000E+00	1.235E+01	1.775E+00
9.000E+01	9.323E+00	1.807E+01	4.288E+01	1.941E+01	0.000E+00	1.241E+01	1.785E+00
9.500E+01	9.664E+00	1.859E+01	4.463E+01	1.890E+01	0.000E+00	1.248E+01	1.782E+00
1.000E+02	9.956E+00	1.902E+01	4.519E+01	1.817E+01	0.000E+00	1.253E+01	1.804E+00
1.100E+02	1.060E+01	2.007E+01	4.824E+01	1.707E+01	0.000E+00	1.264E+01	1.817E+00
1.200E+02	1.117E+01	2.106E+01	5.036E+01	1.594E+01	0.000E+00	1.273E+01	1.810E+00
1.300E+02	1.178E+01	2.210E+01	5.276E+01	1.505E+01	0.000E+00	1.285E+01	1.806E+00
1.400E+02	1.236E+01	2.309E+01	5.456E+01	1.425E+01	0.000E+00	1.295E+01	1.811E+00
1.500E+02	1.301E+01	2.413E+01	5.592E+01	1.365E+01	0.000E+00	1.304E+01	1.842E+00

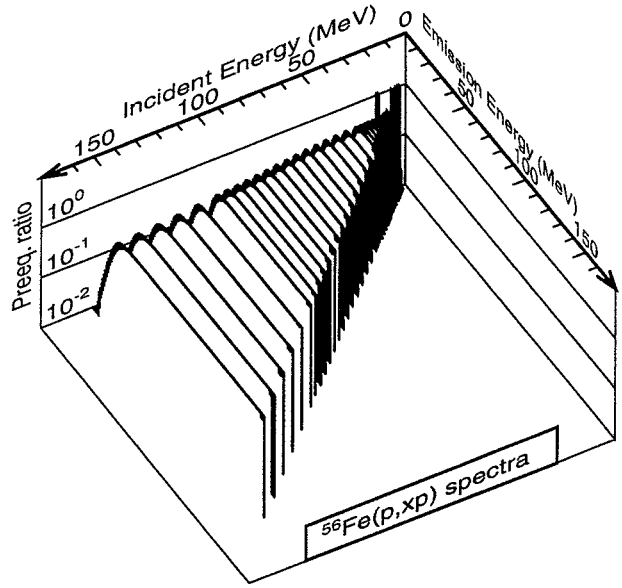

p + 56Fe nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
n
p
γ
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
10^1
10^0
0
50
100
150
Incident Energy (MeV)

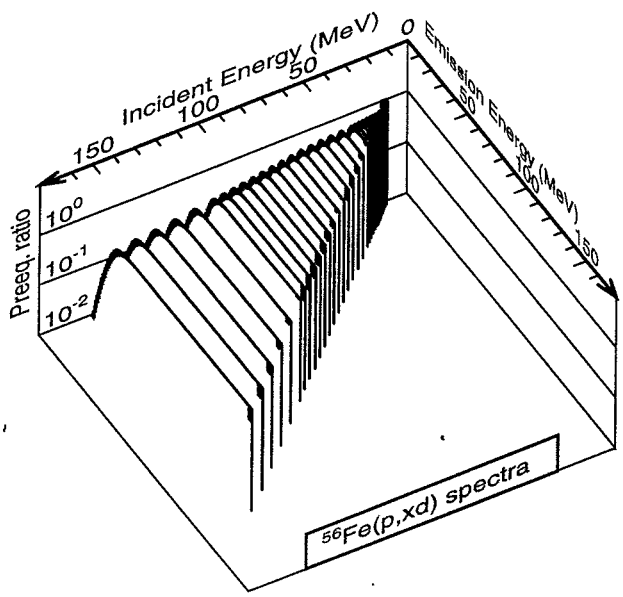
p + ^{56}Fe angle-integrated emission spectra

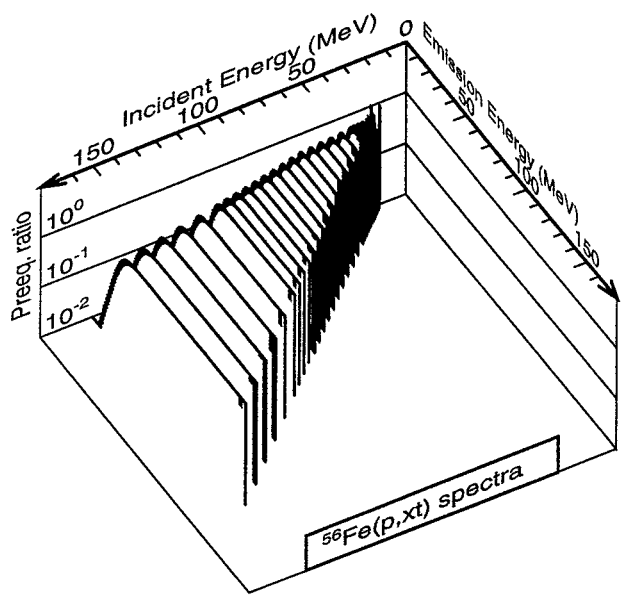


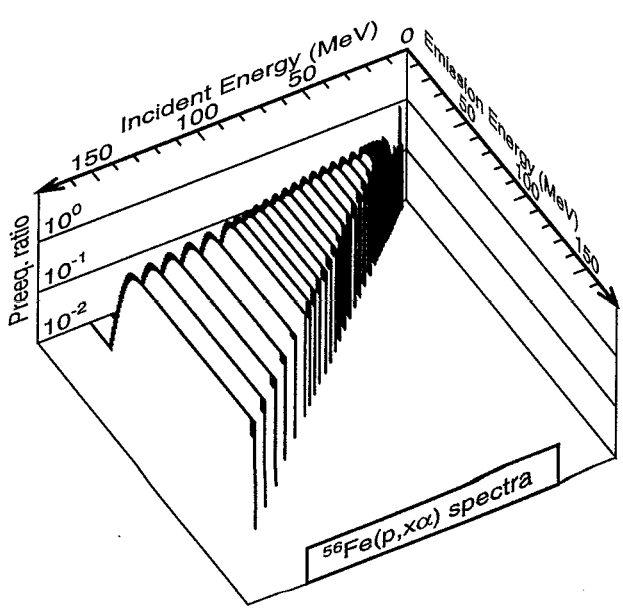
p + ^{56}Fe Kalbach preequilibrium ratios

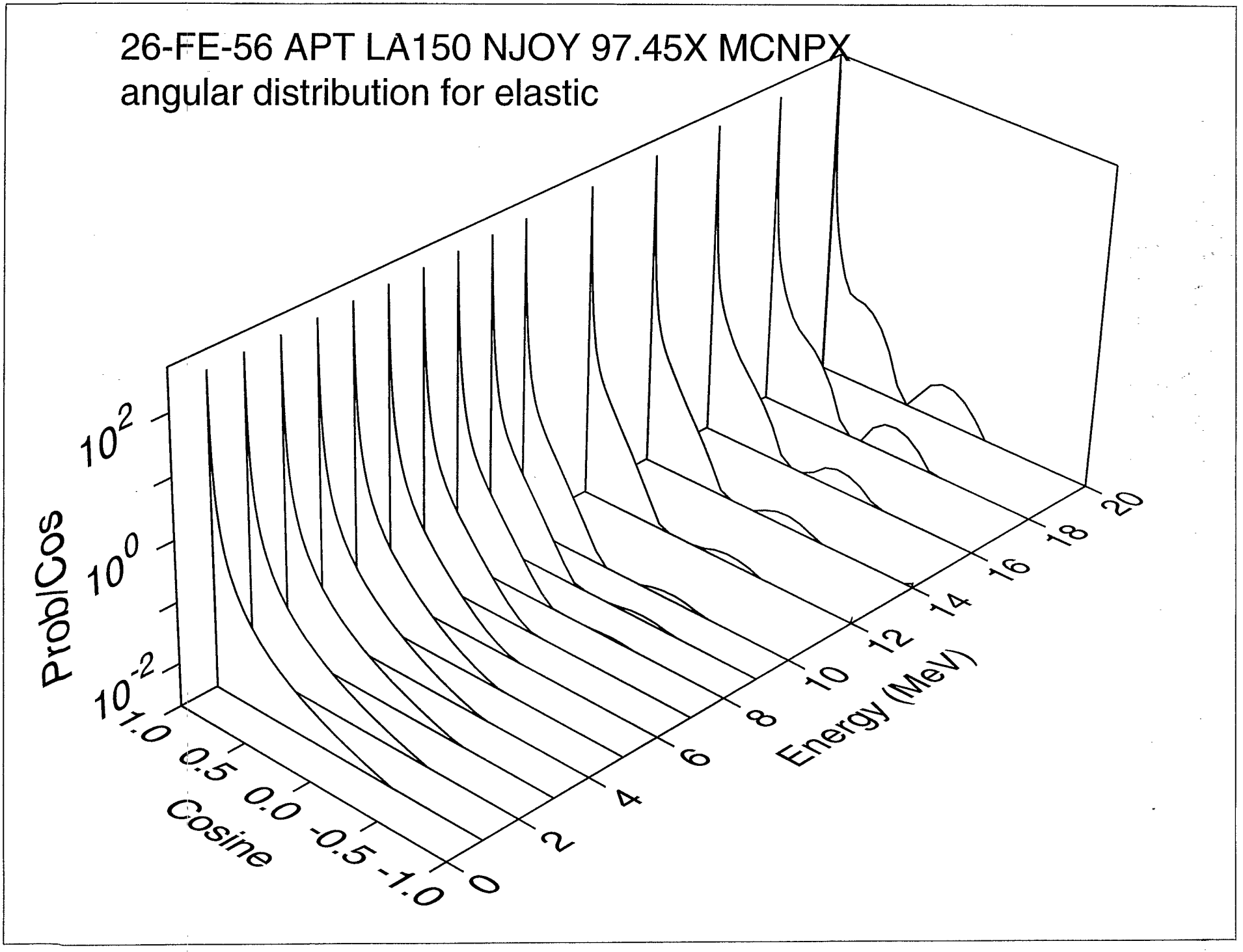


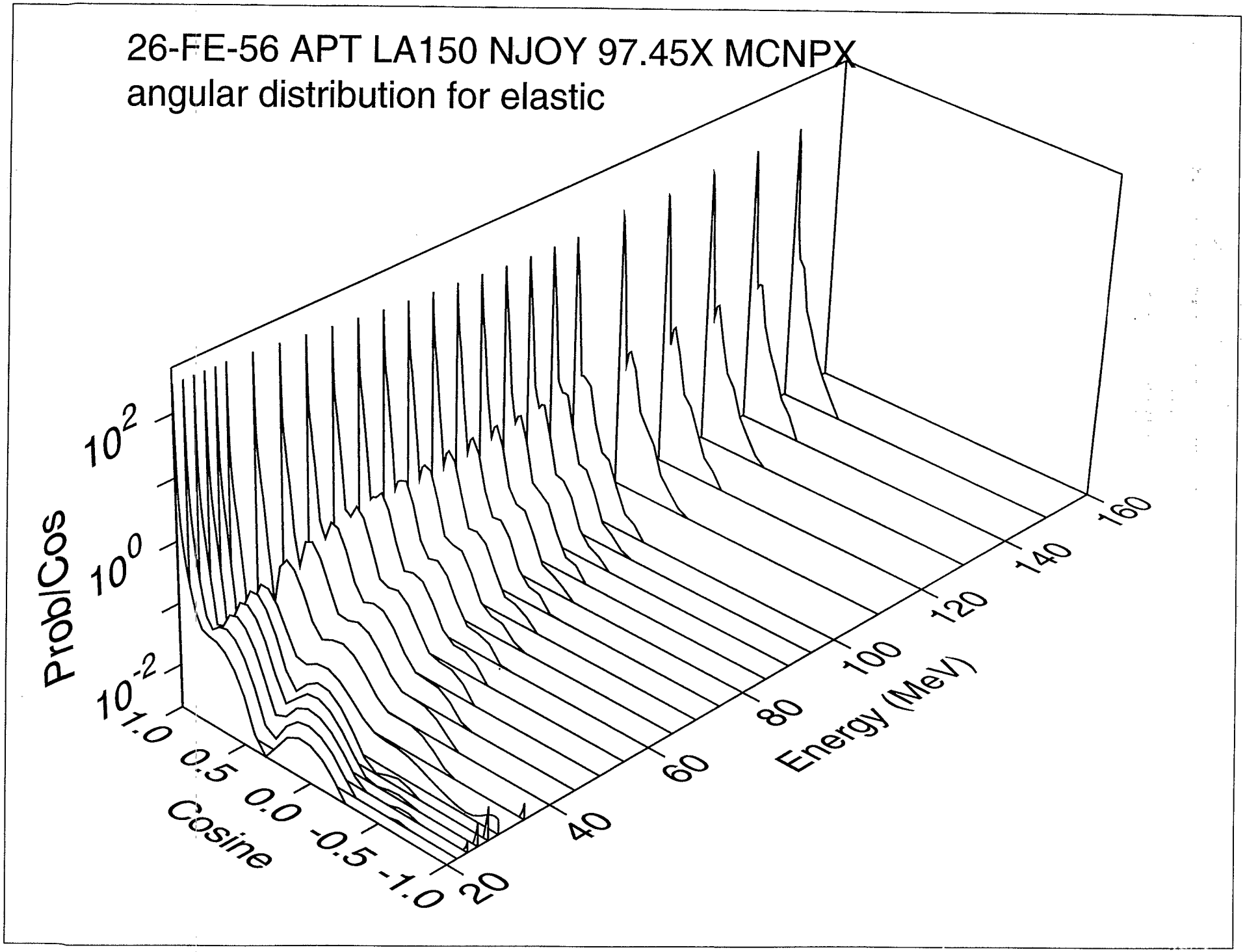









26-FE-56 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
0
2
4
6
8
10
12
14
16
18
20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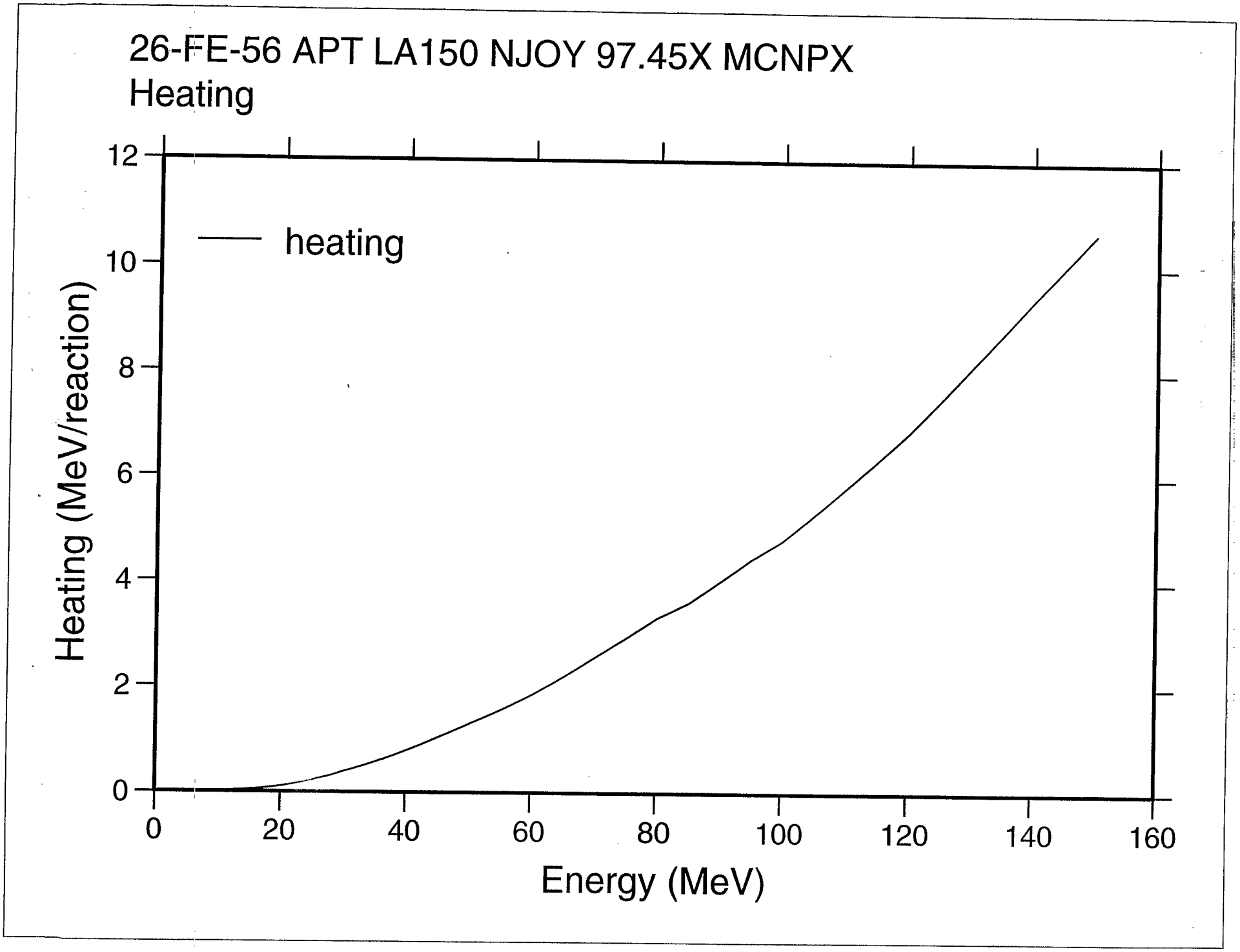
angular distribution for elastic
ProblCos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
20
40
60
80
100
120
140
160


26-FE-56 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
2
4
6
8
10
12
0
20
40
60
80
100
120
140
160

EVALUATION OF p + 57Fe CROSS SECTIONS FOR THE ENERGY RANGE 1 to 150 MeV

M. B. Chadwick, P. G. Young, and A. J. Koning
22 October 1996

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1 to 150 MeV. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains.

To summarize, the ENDF sections with non-zero data are:

MF=3	MT= 2	Integral of nuclear plus interference components of the elastic scattering cross section
	MT= 5	Sum of binary (n,n') and (n,x) reactions
MF=6	MT= 2	Elastic angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
	MT= 5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Fe56 and p + Fe56 reactions (Ch96a). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96b). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. Note that all other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation requires a modification of the original ENDF-6 format, i.e., we use LCT=3 with LAW 1 to indicate that data for the heavy recoils are in the lab system but all other reactions are in the cm system.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-

particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

Direct reaction cross sections to discrete states were calculated with the ECIS95 code [Re95] using deformation parameters compiled in Nuclear Data Sheets.

The optical model potential of Arthur et al. (Ar80) was used to calculate transmission coefficients with the SCAT2 code (Be92) for neutrons up to an energy of 26 MeV. Between 26 and 52 MeV, the imaginary volume component of Arthur's potential was modified to better account for nonelastic cross section measurements, and above 52 MeV the Semmering potential of Madland (Ma88) was used. For protons, the Beccetti-Greenlees potential (Be69) was utilized for both transmission coefficients and scattering and reaction cross sections below 28 MeV, and the Madland potential (Ma88) was used at higher energies. The global spherical potential of Perey (Pe63) was utilized for deuteron transmission coefficients, and the potential of Beccetti-Greenlees (Be) was adopted for tritons. Finally, the alpha potential of Lemos (Le72), as adapted by Arthur et al. (Ar80), was used for alpha particles.

MT=2 elastic scattering data in MF=3 and MF=6 are based on optical model calculations with the SCAT2 code (Be92). We have made use of the "nuclear-plus-interference" option in MF=6, which corresponds to LAW=5, LTP=12, and the appropriate integrated cross section is stored in MF=3. Note that because of the interference effect, the tabulations in both MF=6 and MF=3 can be negative at some energies and angles.

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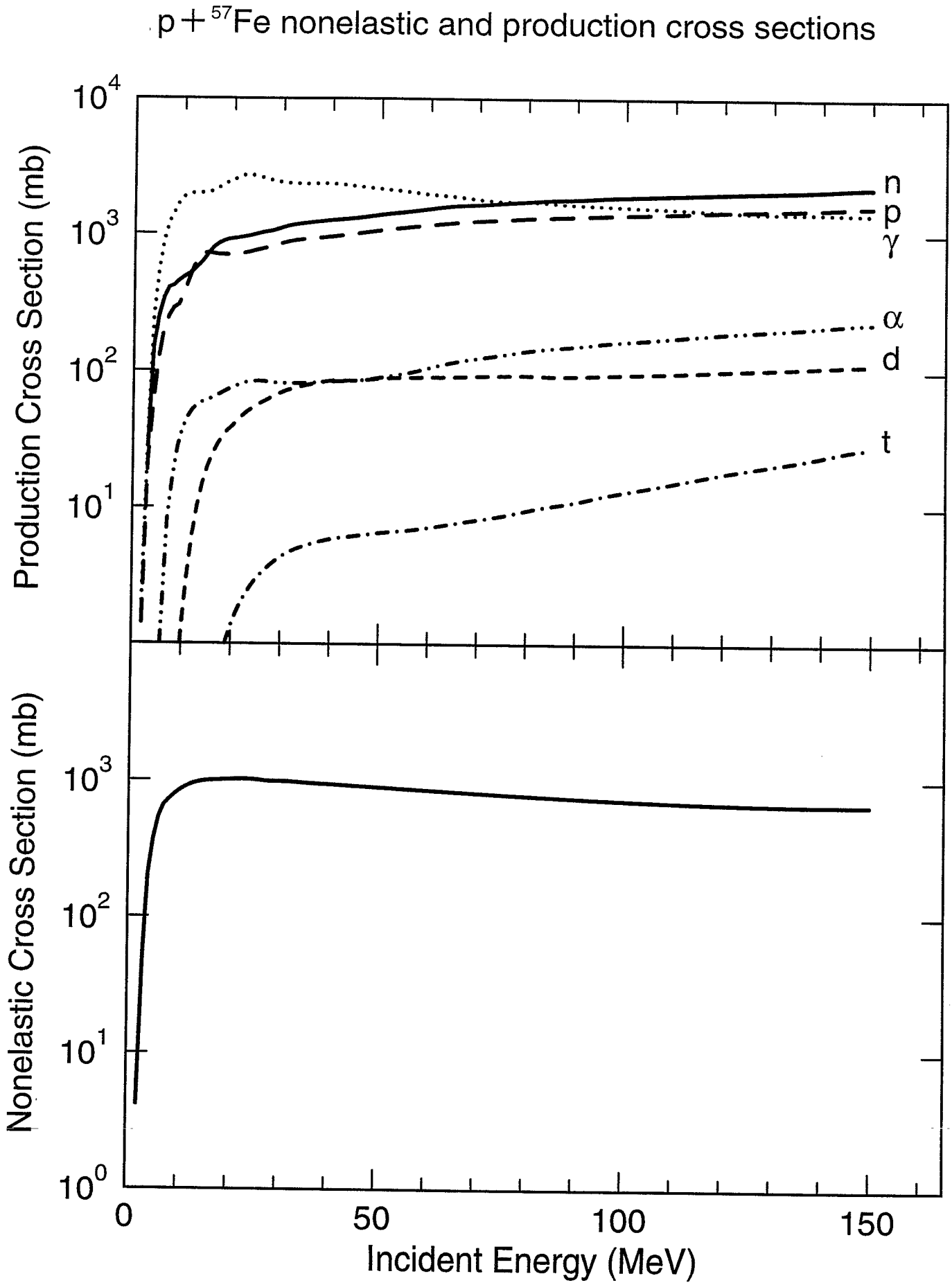
26057 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+00	4.183E-03	0.000E+00	2.761E-03	1.422E-03	0.000E+00	0.000E+00	0.000E+00	5.035E-10	2.050E-03
3.000E+00	4.940E-02	0.000E+00	2.786E-02	2.153E-02	0.000E+00	0.000E+00	0.000E+00	2.117E-07	3.253E-02
4.000E+00	2.054E-01	0.000E+00	1.486E-01	5.689E-02	0.000E+00	0.000E+00	0.000E+00	6.095E-06	2.545E-01
5.000E+00	3.721E-01	0.000E+00	2.491E-01	1.228E-01	0.000E+00	0.000E+00	0.000E+00	2.190E-04	5.525E-01
6.000E+00	5.387E-01	0.000E+00	3.397E-01	1.974E-01	0.000E+00	0.000E+00	0.000E+00	1.521E-03	9.050E-01
7.000E+00	6.592E-01	0.000E+00	4.024E-01	2.486E-01	1.614E-06	0.000E+00	0.000E+00	8.181E-03	1.223E+00
8.000E+00	7.212E-01	0.000E+00	4.179E-01	2.867E-01	2.705E-05	0.000E+00	0.000E+00	1.668E-02	1.447E+00
9.000E+00	7.810E-01	0.000E+00	4.525E-01	3.032E-01	3.157E-04	0.000E+00	0.000E+00	2.801E-02	1.705E+00
1.000E+01	8.351E-01	0.000E+00	4.809E-01	3.616E-01	1.302E-03	0.000E+00	0.000E+00	3.832E-02	1.872E+00
1.100E+01	8.807E-01	0.000E+00	5.049E-01	4.623E-01	3.111E-03	0.000E+00	0.000E+00	4.619E-02	1.949E+00
1.200E+01	9.197E-01	0.000E+00	5.390E-01	5.702E-01	6.121E-03	2.144E-07	0.000E+00	5.236E-02	1.977E+00
1.300E+01	9.497E-01	0.000E+00	5.841E-01	6.585E-01	1.011E-02	5.159E-06	0.000E+00	5.655E-02	1.982E+00
1.400E+01	9.713E-01	0.000E+00	6.418E-01	7.137E-01	1.473E-02	4.843E-05	0.000E+00	5.944E-02	1.985E+00
1.500E+01	9.851E-01	0.000E+00	7.192E-01	7.207E-01	1.961E-02	1.437E-04	0.000E+00	6.141E-02	2.007E+00
1.600E+01	9.948E-01	0.000E+00	7.922E-01	7.111E-01	2.405E-02	2.935E-04	0.000E+00	6.335E-02	2.073E+00
1.700E+01	9.997E-01	0.000E+00	8.432E-01	7.025E-01	2.867E-02	4.963E-04	0.000E+00	6.622E-02	2.173E+00
1.800E+01	1.004E+00	0.000E+00	8.797E-01	6.991E-01	3.261E-02	7.482E-04	0.000E+00	6.925E-02	2.293E+00
1.900E+01	1.008E+00	0.000E+00	9.057E-01	6.981E-01	3.636E-02	1.038E-03	0.000E+00	7.238E-02	2.417E+00
2.000E+01	1.012E+00	0.000E+00	9.168E-01	7.029E-01	3.935E-02	1.357E-03	0.000E+00	7.493E-02	2.489E+00
2.200E+01	1.018E+00	0.000E+00	9.432E-01	7.143E-01	4.678E-02	2.020E-03	0.000E+00	8.059E-02	2.678E+00
2.400E+01	1.017E+00	0.000E+00	9.774E-01	7.446E-01	5.310E-02	2.661E-03	0.000E+00	8.329E-02	2.679E+00
2.600E+01	1.004E+00	0.000E+00	1.021E+00	7.746E-01	5.887E-02	3.266E-03	0.000E+00	8.372E-02	2.573E+00
2.800E+01	9.856E-01	0.000E+00	1.054E+00	8.059E-01	6.408E-02	3.825E-03	0.000E+00	8.170E-02	2.462E+00
3.000E+01	9.855E-01	0.000E+00	1.112E+00	8.506E-01	6.954E-02	4.340E-03	0.000E+00	8.104E-02	2.390E+00
3.500E+01	9.638E-01	0.000E+00	1.203E+00	9.162E-01	7.832E-02	5.255E-03	0.000E+00	8.117E-02	2.335E+00
4.000E+01	9.418E-01	0.000E+00	1.264E+00	9.560E-01	8.475E-02	5.879E-03	0.000E+00	8.354E-02	2.342E+00
4.500E+01	9.200E-01	0.000E+00	1.315E+00	1.008E+00	8.515E-02	6.212E-03	0.000E+00	8.502E-02	2.245E+00
5.000E+01	8.983E-01	0.000E+00	1.391E+00	1.067E+00	8.826E-02	6.545E-03	0.000E+00	8.976E-02	2.147E+00
5.500E+01	8.772E-01	0.000E+00	1.458E+00	1.119E+00	8.962E-02	6.798E-03	0.000E+00	9.601E-02	2.064E+00
6.000E+01	8.569E-01	0.000E+00	1.540E+00	1.169E+00	9.047E-02	7.170E-03	0.000E+00	1.060E-01	1.967E+00
6.500E+01	8.372E-01	0.000E+00	1.621E+00	1.218E+00	9.101E-02	7.696E-03	0.000E+00	1.170E-01	1.905E+00
7.000E+01	8.184E-01	0.000E+00	1.656E+00	1.258E+00	9.253E-02	8.220E-03	0.000E+00	1.254E-01	1.816E+00
7.500E+01	8.004E-01	0.000E+00	1.707E+00	1.285E+00	9.324E-02	8.804E-03	0.000E+00	1.332E-01	1.757E+00
8.000E+01	7.834E-01	0.000E+00	1.756E+00	1.318E+00	9.361E-02	9.618E-03	0.000E+00	1.420E-01	1.748E+00
8.500E+01	7.672E-01	0.000E+00	1.801E+00	1.340E+00	9.235E-02	1.040E-02	0.000E+00	1.490E-01	1.709E+00
9.000E+01	7.523E-01	0.000E+00	1.826E+00	1.360E+00	9.285E-02	1.116E-02	0.000E+00	1.543E-01	1.659E+00
9.500E+01	7.384E-01	0.000E+00	1.873E+00	1.383E+00	9.404E-02	1.227E-02	0.000E+00	1.621E-01	1.632E+00
1.000E+02	7.258E-01	0.000E+00	1.905E+00	1.401E+00	9.554E-02	1.328E-02	0.000E+00	1.678E-01	1.605E+00
1.100E+02	7.043E-01	0.000E+00	1.962E+00	1.443E+00	9.813E-02	1.550E-02	0.000E+00	1.796E-01	1.554E+00
1.200E+02	6.879E-01	0.000E+00	2.020E+00	1.487E+00	1.020E-01	1.822E-02	0.000E+00	1.925E-01	1.496E+00
1.300E+02	6.774E-01	0.000E+00	2.069E+00	1.520E+00	1.056E-01	2.099E-02	0.000E+00	2.034E-01	1.451E+00
1.400E+02	6.722E-01	0.000E+00	2.139E+00	1.563E+00	1.100E-01	2.438E-02	0.000E+00	2.169E-01	1.453E+00
1.500E+02	6.721E-01	0.000E+00	2.220E+00	1.614E+00	1.131E-01	2.789E-02	0.000E+00	2.298E-01	1.427E+00

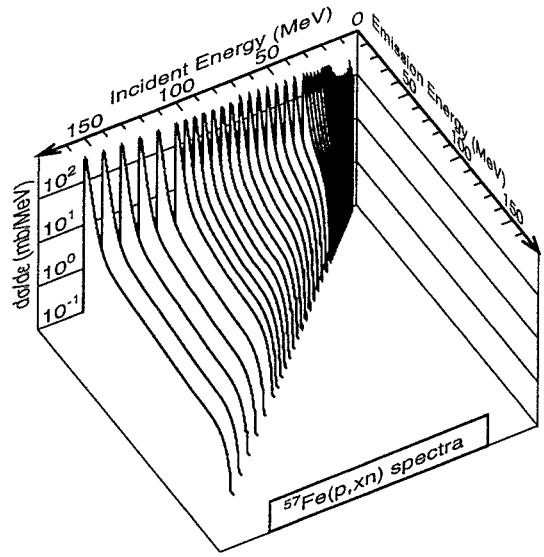
26057 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

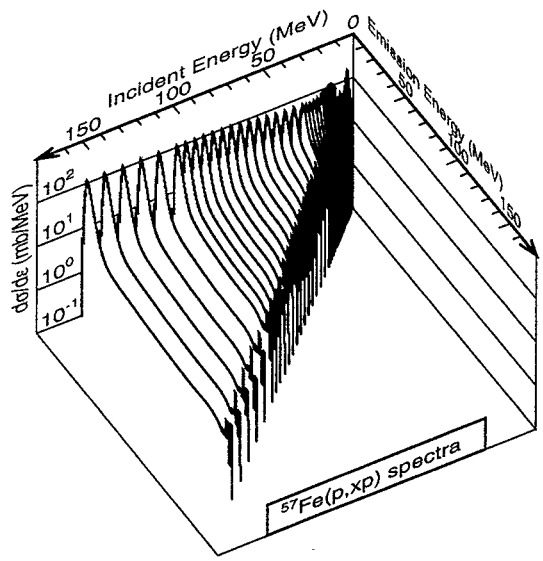
Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+00	1.848E-01	1.781E+00	0.000E+00	0.000E+00	0.000E+00	2.093E+00	2.983E-01
3.000E+00	1.224E+00	2.699E+00	0.000E+00	0.000E+00	0.000E+00	2.996E+00	2.450E-01
4.000E+00	1.000E+00	3.475E+00	0.000E+00	0.000E+00	0.000E+00	3.752E+00	9.224E-01
5.000E+00	1.378E+00	4.179E+00	0.000E+00	0.000E+00	0.000E+00	4.624E+00	1.064E+00
6.000E+00	1.695E+00	4.864E+00	0.000E+00	0.000E+00	0.000E+00	5.473E+00	1.216E+00
7.000E+00	1.983E+00	5.395E+00	1.455E+00	0.000E+00	0.000E+00	6.287E+00	1.392E+00
8.000E+00	2.216E+00	6.070E+00	2.256E+00	0.000E+00	0.000E+00	6.869E+00	1.528E+00
9.000E+00	2.418E+00	6.268E+00	3.097E+00	0.000E+00	0.000E+00	7.348E+00	1.734E+00
1.000E+01	2.584E+00	5.872E+00	3.763E+00	0.000E+00	0.000E+00	7.742E+00	1.858E+00
1.100E+01	2.701E+00	5.395E+00	4.385E+00	0.000E+00	0.000E+00	8.051E+00	1.856E+00
1.200E+01	2.713E+00	5.196E+00	4.897E+00	1.430E+00	0.000E+00	8.294E+00	1.785E+00
1.300E+01	2.721E+00	5.260E+00	5.427E+00	2.318E+00	0.000E+00	8.501E+00	1.679E+00
1.400E+01	2.676E+00	5.443E+00	5.995E+00	3.132E+00	0.000E+00	8.664E+00	1.572E+00
1.500E+01	2.613E+00	5.771E+00	6.579E+00	3.716E+00	0.000E+00	8.805E+00	1.497E+00
1.600E+01	2.612E+00	6.158E+00	7.178E+00	4.143E+00	0.000E+00	8.916E+00	1.468E+00
1.700E+01	2.679E+00	6.555E+00	7.792E+00	4.597E+00	0.000E+00	8.989E+00	1.484E+00
1.800E+01	2.782E+00	6.945E+00	8.349E+00	5.051E+00	0.000E+00	9.076E+00	1.533E+00
1.900E+01	2.916E+00	7.338E+00	8.908E+00	5.528E+00	0.000E+00	9.186E+00	1.594E+00
2.000E+01	3.065E+00	7.822E+00	9.485E+00	6.001E+00	0.000E+00	9.326E+00	1.723E+00
2.200E+01	3.373E+00	8.470E+00	1.066E+01	6.964E+00	0.000E+00	9.581E+00	1.859E+00
2.400E+01	3.595E+00	9.063E+00	1.179E+01	7.888E+00	0.000E+00	9.863E+00	1.894E+00
2.600E+01	3.766E+00	9.518E+00	1.292E+01	8.774E+00	0.000E+00	1.015E+01	1.852E+00
2.800E+01	3.955E+00	9.995E+00	1.404E+01	9.606E+00	0.000E+00	1.045E+01	1.803E+00

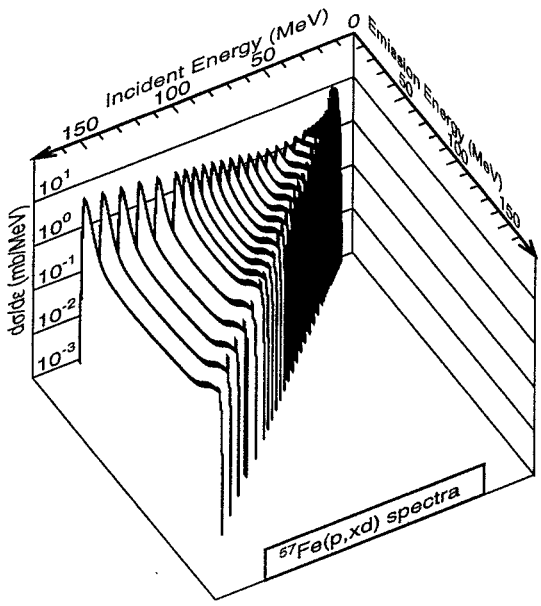
3.000E+01	4.147E+00	1.043E+01	1.519E+01	1.042E+01	0.000E+00	1.070E+01	1.767E+00
3.500E+01	4.682E+00	1.188E+01	1.817E+01	1.233E+01	0.000E+00	1.115E+01	1.712E+00
4.000E+01	5.250E+00	1.334E+01	2.135E+01	1.423E+01	0.000E+00	1.150E+01	1.730E+00
4.500E+01	5.760E+00	1.488E+01	2.414E+01	1.601E+01	0.000E+00	1.179E+01	1.747E+00
5.000E+01	6.212E+00	1.557E+01	2.699E+01	1.761E+01	0.000E+00	1.198E+01	1.789E+00
5.500E+01	6.584E+00	1.632E+01	2.974E+01	1.884E+01	0.000E+00	1.205E+01	1.815E+00
6.000E+01	6.861E+00	1.679E+01	3.226E+01	1.952E+01	0.000E+00	1.204E+01	1.825E+00
6.500E+01	7.102E+00	1.713E+01	3.442E+01	1.962E+01	0.000E+00	1.203E+01	1.834E+00
7.000E+01	7.514E+00	1.761E+01	3.690E+01	1.974E+01	0.000E+00	1.206E+01	1.752E+00
7.500E+01	7.833E+00	1.819E+01	3.908E+01	1.963E+01	0.000E+00	1.210E+01	1.732E+00
8.000E+01	8.127E+00	1.862E+01	4.075E+01	1.906E+01	0.000E+00	1.214E+01	1.754E+00
8.500E+01	8.428E+00	1.924E+01	4.195E+01	1.869E+01	0.000E+00	1.221E+01	1.763E+00
9.000E+01	8.735E+00	2.000E+01	4.381E+01	1.825E+01	0.000E+00	1.228E+01	1.757E+00
9.500E+01	8.987E+00	2.042E+01	4.513E+01	1.757E+01	0.000E+00	1.233E+01	1.750E+00
1.000E+02	9.292E+00	2.092E+01	4.682E+01	1.708E+01	0.000E+00	1.241E+01	1.739E+00
1.100E+02	9.916E+00	2.187E+01	4.968E+01	1.610E+01	0.000E+00	1.253E+01	1.744E+00
1.200E+02	1.051E+01	2.276E+01	5.223E+01	1.514E+01	0.000E+00	1.265E+01	1.741E+00
1.300E+02	1.114E+01	2.406E+01	5.460E+01	1.441E+01	0.000E+00	1.276E+01	1.755E+00
1.400E+02	1.172E+01	2.519E+01	5.613E+01	1.373E+01	0.000E+00	1.286E+01	1.783E+00
1.500E+02	1.230E+01	2.650E+01	5.662E+01	1.323E+01	0.000E+00	1.295E+01	1.801E+00

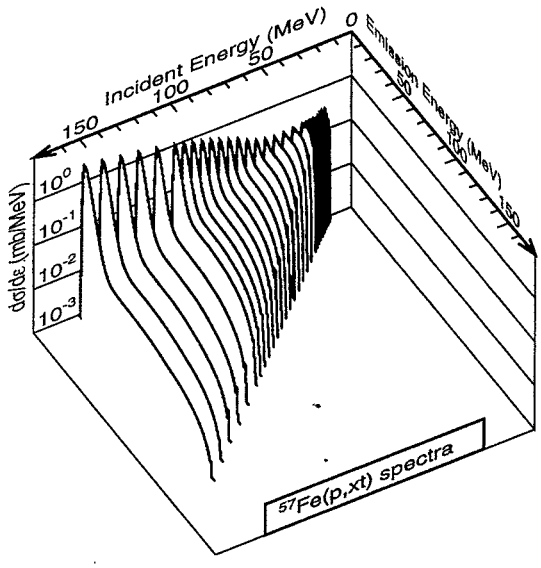

p + 57Fe nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
n
p
γ
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
10^1
10^0
0
50
100
150
Incident Energy (MeV)

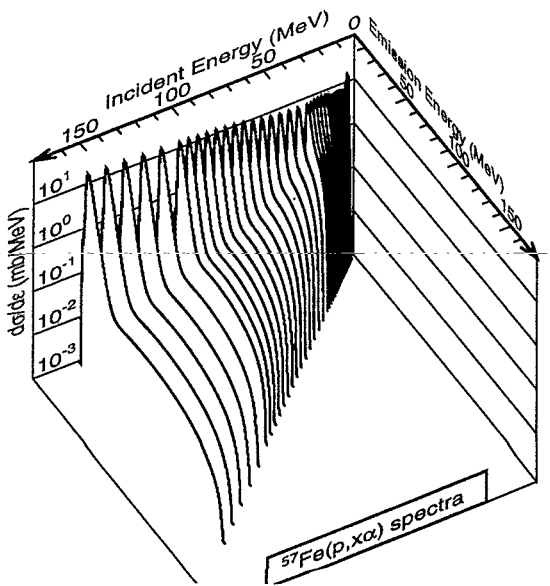
p + ^{57}Fe angle-integrated emission spectra

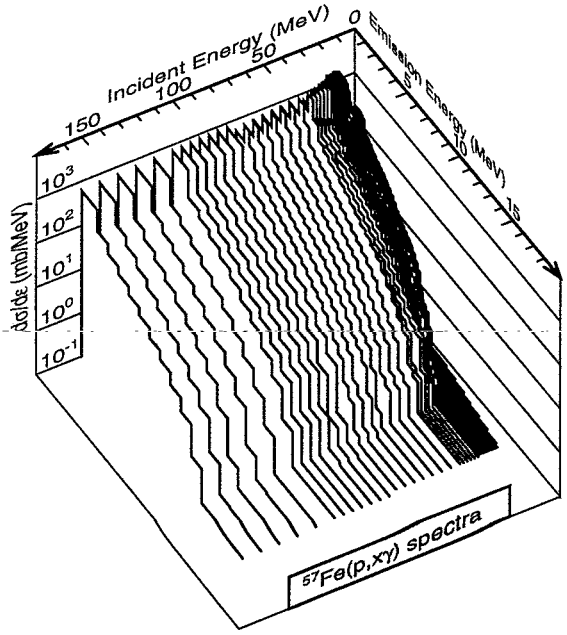




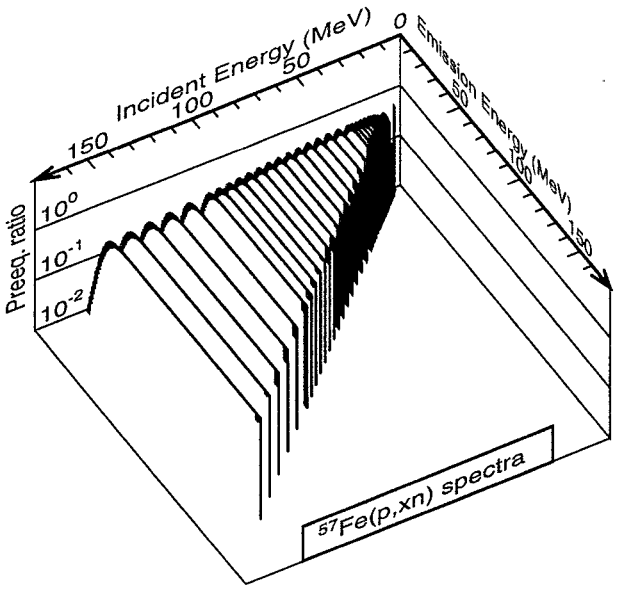


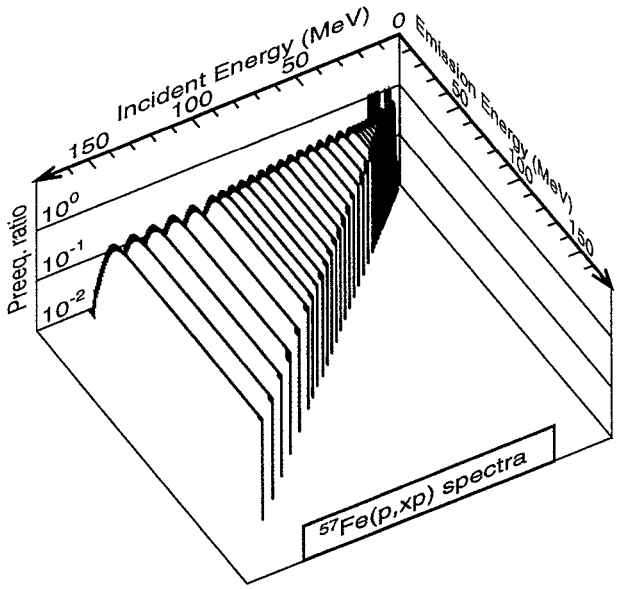


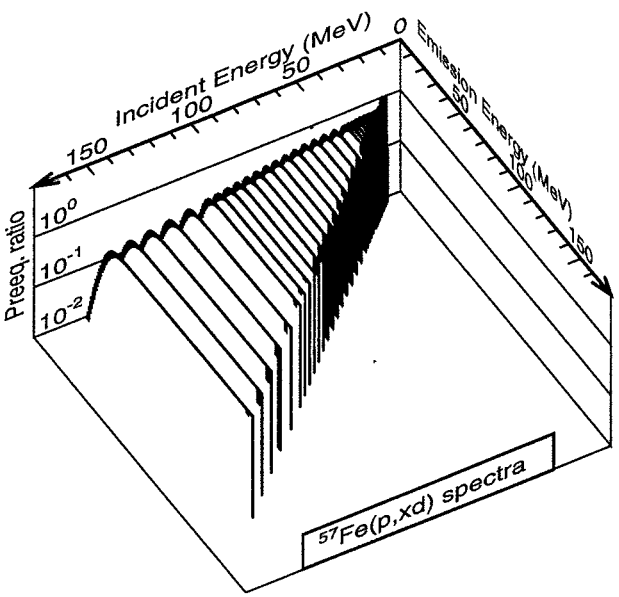


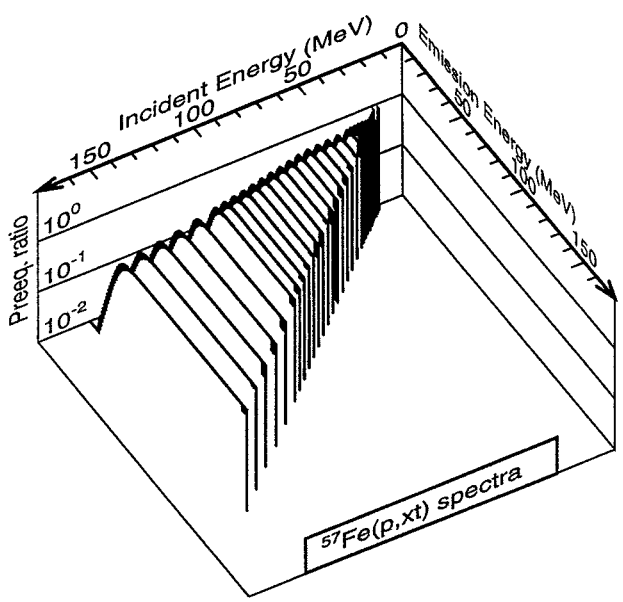


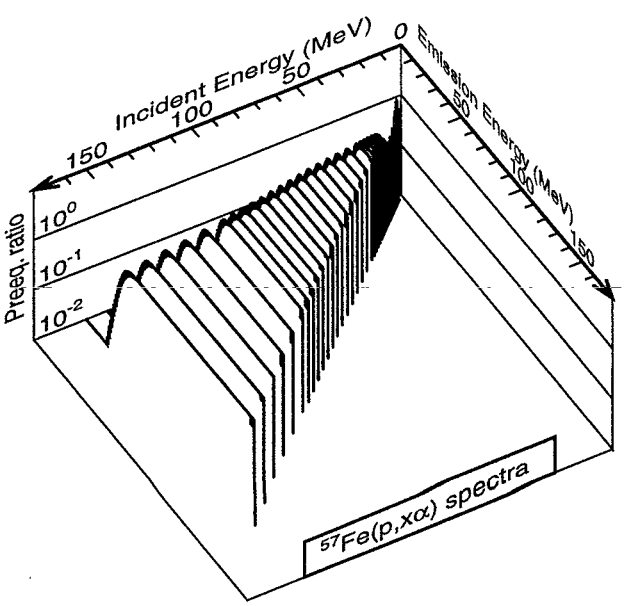
p + ^{57}Fe Kalbach preequilibrium ratios

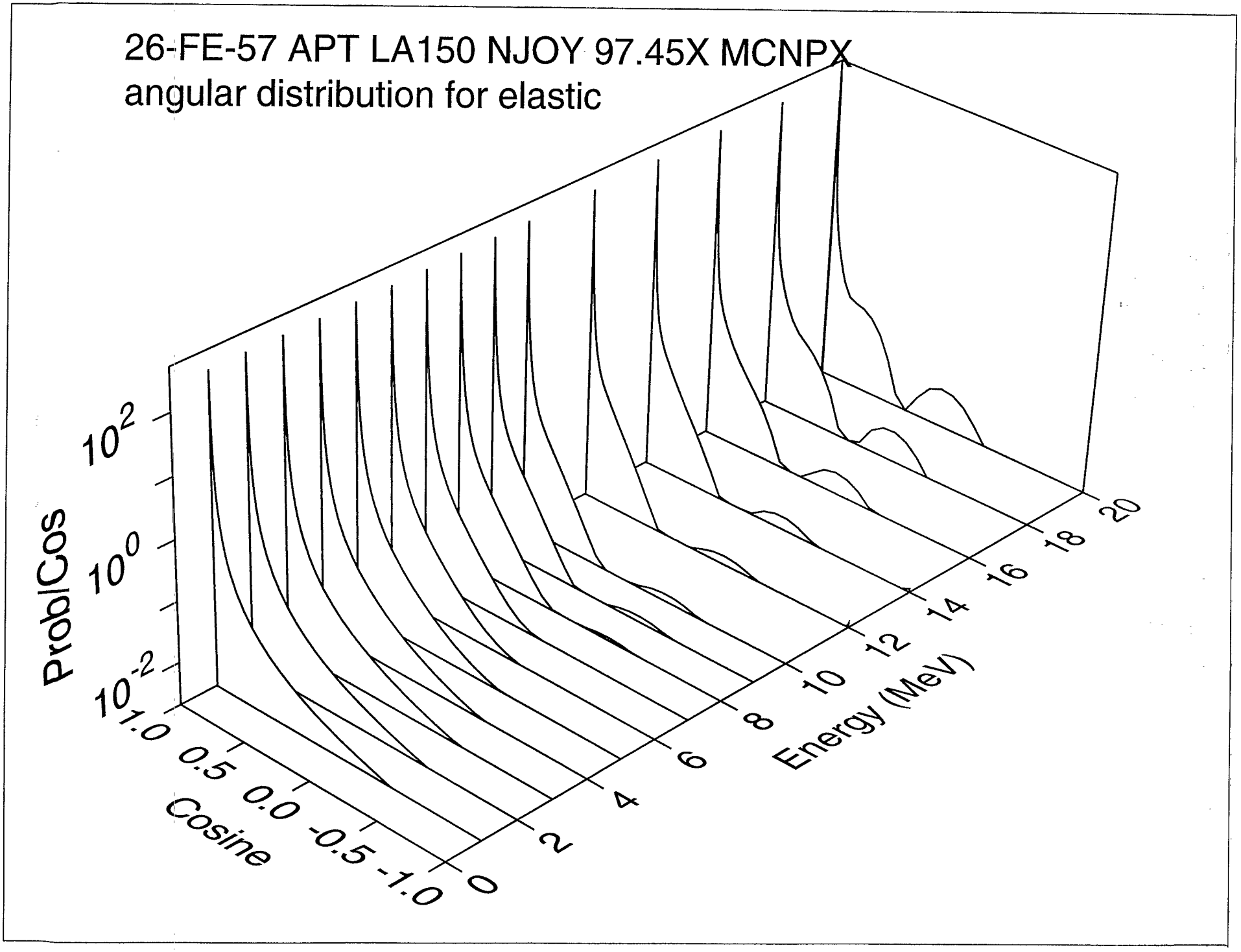


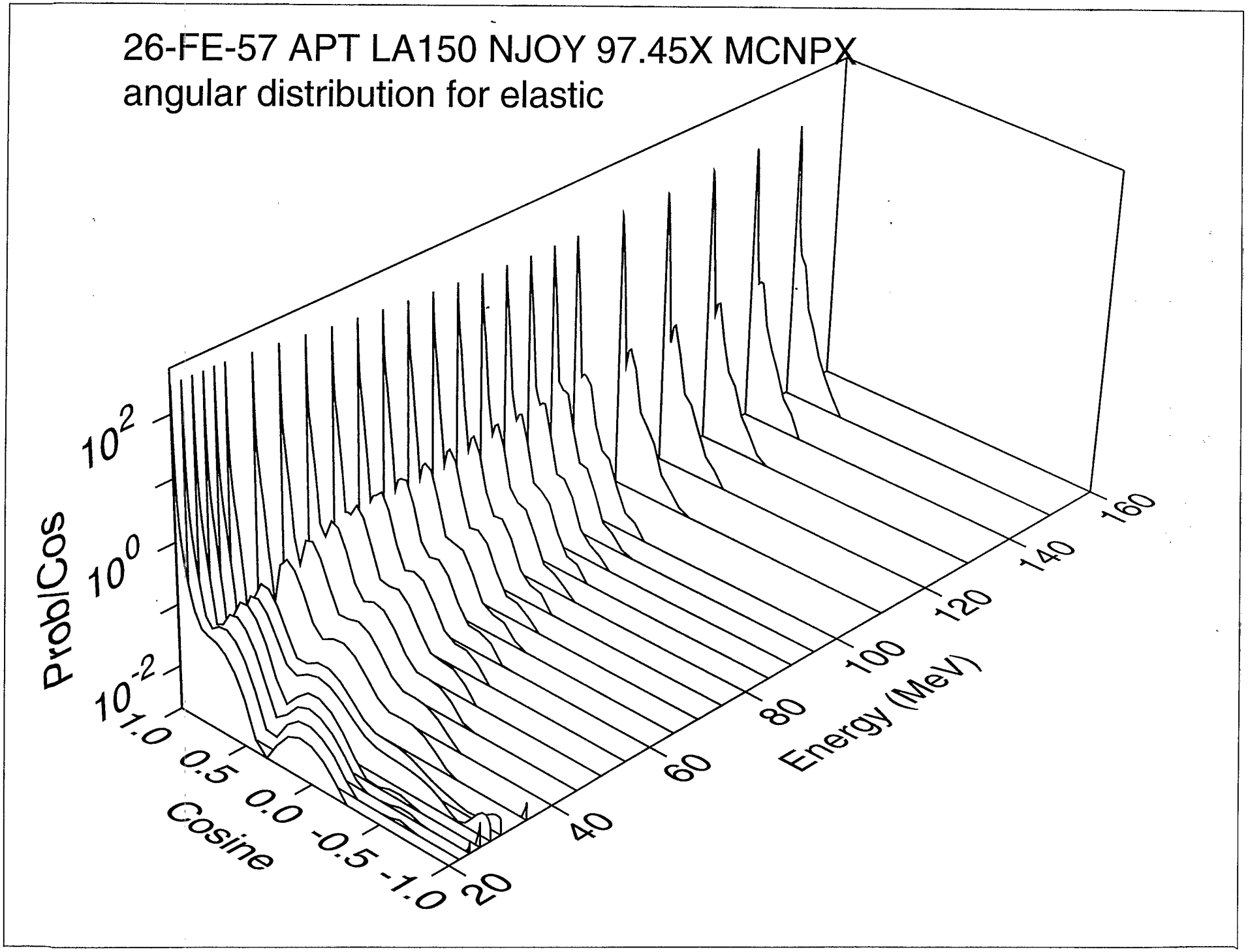


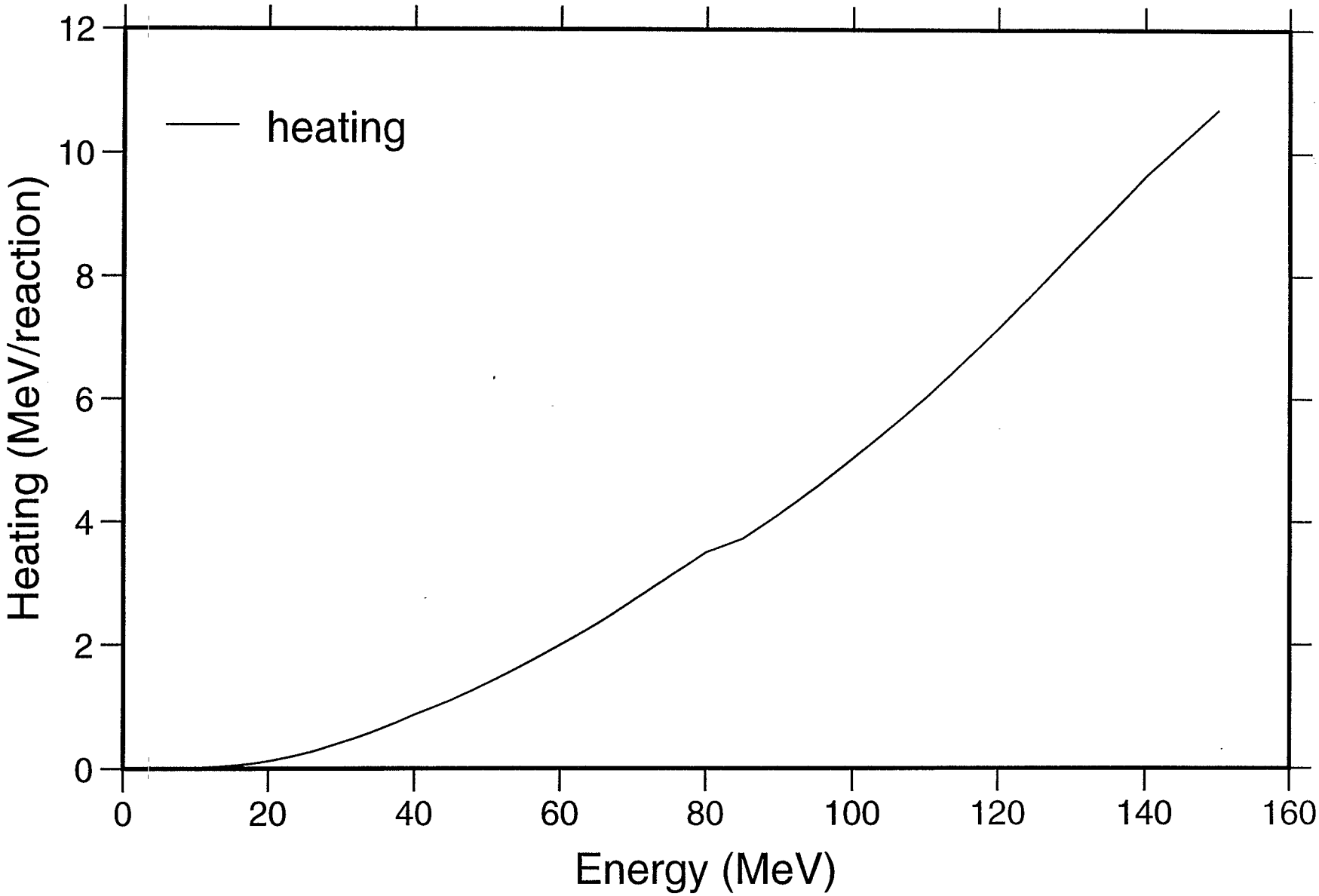







26-FE-57 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
0
2
4
6
8
10
12
14
16
18
20


26-FE-57 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
20
40
60
80
100
120
140
160


26-FE-57 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
2
4
6
8
10
12
0
20
40
60
80
100
120
140
160

EVALUATION OF p + 58Ni CROSS SECTIONS FOR THE ENERGY RANGE 1 to 150 MeV

S. Chiba, M. B. Chadwick, P. G. Young, and A. J. Koning

24 September 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident proton energy range from 1 to 150 MeV. The evaluation utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above are:

MF=3	MT= 2	Integral of nuclear plus interference components of the elastic scattering cross section
	MT= 5	Sum of binary (p,n') and (p,x) reactions
MF=6	MT= 2	Elastic (p,p) angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
	MT= 5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Ni58 and p + Ni58 reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic proton angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Gilbert and Cameron [Gi65] and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged- particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray

transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

DETAILS OF THE p + SI-28 ANALYSIS

The neutron optical model potential was adjusted to reproduce the measured total cross section data (Ci68, Pe73, Sc73, La83, Sm92, Di97), s-wave strength function (Mu81), and elastic scattering angular distribution data (Sm92, Gu85, Tu73, Pe88, Ya79). The total cross section data for natural Ni was used above 20 MeV because there was no data for Ni-58 at this energy region. The data for natural Ni were transformed to the Ni-58 cross section according to A*(2/3) law. The parameter estimation was carried out based on Marquart-Bayesian approach (Sm91), where ECIS95 code was used for the optical model calculation. We have employed the energy dependence of the optical potential similar to Delaroche's work (De89). The initial potential parameters were adopted from Koning and Delaroche (Ko97). Total of 17 parameters concerning the central potential were estimated with associated covariance matrix. Presently obtained potential was used for the calculation of neutron transmission coefficients and DWBA cross sections in the entire energy region.

The proton optical potential was also searched for to obtain a good description of proton-total reaction cross section as predicted by Wellisch-Axen systematic (We96) above 50 MeV. The parameter estimation was carried out by the Marquart-Bayesian approach similar to the neutron OMP, but trying to seek the best parameter to reproduce the reaction cross sections compiled by Carlson (Ca96) and Wellisch values. In this search, the geometrical parameters were fixed to be same as the neutron potential. The present potential gives a good description of the proton total reaction cross section from 10 MeV to 250 MeV. However, after some trial and error to reproduce both the elastic scattering and reaction cross section data, we have employed the following combination of proton potentials:

0 to 5 MeV : Harper proton potential (Ha82)
5 to 50 MeV : Koning and Delaroche (Ko97)
50 to 260 MeV : Present OMP

For deuterons, the Lohr-Haeberli [Lo74] global potential was used; for alpha particles the McFadden-Satchler [Mc66] potential was used; and for tritons the Beccheti-Greenlees [Be71] potential was used. The He-3 channel was ignored.

The direct collective inelastic scattering to the following levels in Ni-58 was considered by the DWBA-mode calculation of ECIS95 (Ra96):

Jpi	Ex(MeV)	Deformation length
2+	1.454	0.900
4+	2.459	0.350
2+	3.038	0.242
2+	3.263	0.306
4+	3.620	0.246
2+	3.898	0.111
2+	4.108	0.063
4+	4.299	0.127
4+	4.405	0.329

3-	4.475	0.708
4+	4.757	0.403
4+	5.438	0.151
4+	5.472	0.080
2+	5.749	0.048
4+	5.766	0.086
2+	5.906	0.115
3-	6.312	0.128
2+	6.417	0.068
4+	6.460	0.098
2+	6.475	0.065
2+	6.569	0.056
2+	6.752	0.141
3-	6.854	0.296
2+	6.983	0.116
4+	7.051	0.090
4+	7.068	0.086
3-	7.111	0.079
4+	7.141	0.112
3-	7.210	0.323
2+	7.272	0.088
3-	7.300	0.063
3-	7.420	0.048
3-	7.514	0.171
2+	7.580	0.051
4+	7.618	0.083
3-	7.858	0.106
4+	7.860	0.097
3-	8.134	0.142
3-	8.797	0.097
3-	8.841	0.112
4+	8.902	0.072
3-	9.012	0.056
3-	9.304	0.065
3-	9.379	0.106
4+	9.436	0.071
3-	9.458	0.082
4+	9.588	0.052
4+	9.632	0.080
3-	9.672	0.121
3-	9.835	0.083
3-	9.870	0.076
3-	9.929	0.061
3-	9.956	0.071

These data were retrieved from the literature (Nuclear Data Sheets) or were evaluated by Koning [Ko97].

The level densities used in our ENDF 150-MeV evaluation for n+58Ni (see the file1 for that evaluation) were used in this work.

Results were extensively benchmarked against experimental data for protons incident on 58Ni, including: the total nonelastic cross section; (p,xp) emission spectra at 65 MeV by Sakai et al.; (p,xp) emission spectra at 100, 120, and 150 MeV by Richter et al.; radionuclide production excitation functions; and (p,xn) spectra at 22 MeV by Biryukov and at 26.5 MeV by Scobel et al. See Ref. [Ch97] for details on benchmark calculations.

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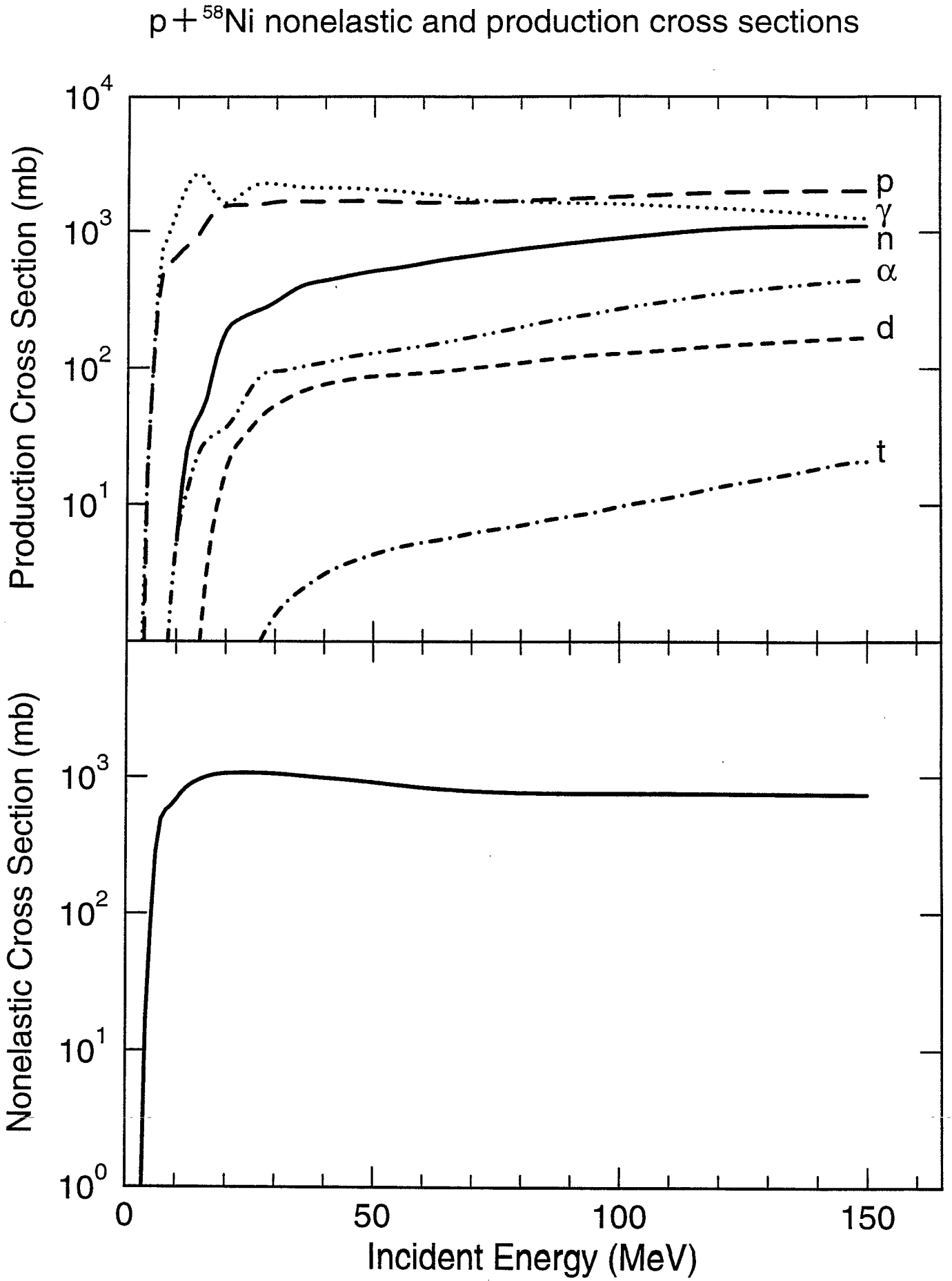
28058 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
3.000E+00	5.901E-04	0.000E+00	0.000E+00	2.464E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	7.920E-04
4.000E+00	1.672E-02	0.000E+00	0.000E+00	1.629E-02	0.000E+00	0.000E+00	0.000E+00	1.866E-08	1.700E-02
5.000E+00	8.264E-02	0.000E+00	0.000E+00	8.229E-02	0.000E+00	0.000E+00	0.000E+00	5.865E-08	8.979E-02
6.000E+00	2.862E-01	0.000E+00	0.000E+00	2.857E-01	0.000E+00	0.000E+00	0.000E+00	4.697E-06	3.758E-01
7.000E+00	4.918E-01	0.000E+00	0.000E+00	4.912E-01	0.000E+00	0.000E+00	0.000E+00	1.661E-04	7.516E-01
8.000E+00	5.699E-01	0.000E+00	0.000E+00	5.688E-01	0.000E+00	0.000E+00	0.000E+00	7.337E-04	9.119E-01
9.000E+00	6.150E-01	0.000E+00	0.000E+00	6.123E-01	0.000E+00	0.000E+00	0.000E+00	2.371E-03	1.144E+00
1.000E+01	6.773E-01	0.000E+00	5.455E-03	6.657E-01	0.000E+00	0.000E+00	0.000E+00	5.923E-03	1.456E+00
1.100E+01	7.552E-01	0.000E+00	1.337E-02	7.325E-01	9.043E-09	0.000E+00	0.000E+00	9.071E-03	1.821E+00
1.200E+01	8.256E-01	0.000E+00	2.498E-02	7.884E-01	4.945E-07	0.000E+00	0.000E+00	1.231E-02	2.205E+00
1.300E+01	8.815E-01	0.000E+00	3.450E-02	8.374E-01	4.366E-05	0.000E+00	0.000E+00	1.710E-02	2.533E+00
1.400E+01	9.253E-01	0.000E+00	4.134E-02	9.122E-01	4.014E-04	0.000E+00	0.000E+00	2.187E-02	2.682E+00
1.500E+01	9.629E-01	0.000E+00	4.844E-02	1.045E+00	1.296E-03	0.000E+00	0.000E+00	2.655E-02	2.585E+00
1.600E+01	9.952E-01	0.000E+00	6.026E-02	1.194E+00	3.089E-03	9.744E-09	0.000E+00	2.957E-02	2.337E+00
1.700E+01	1.021E+00	0.000E+00	8.665E-02	1.340E+00	5.816E-03	1.400E-06	0.000E+00	3.159E-02	2.019E+00
1.800E+01	1.040E+00	0.000E+00	1.213E-01	1.447E+00	9.283E-03	1.153E-05	0.000E+00	3.316E-02	1.771E+00
1.900E+01	1.053E+00	0.000E+00	1.562E-01	1.510E+00	1.327E-02	2.835E-05	0.000E+00	3.488E-02	1.651E+00
2.000E+01	1.061E+00	0.000E+00	1.879E-01	1.541E+00	1.840E-02	5.855E-05	0.000E+00	3.705E-02	1.607E+00
2.200E+01	1.069E+00	0.000E+00	2.215E-01	1.565E+00	2.703E-02	2.012E-04	0.000E+00	4.694E-02	1.774E+00
2.400E+01	1.072E+00	0.000E+00	2.426E-01	1.564E+00	3.291E-02	4.581E-04	0.000E+00	6.327E-02	2.022E+00
2.600E+01	1.071E+00	0.000E+00	2.602E-01	1.568E+00	4.031E-02	8.143E-04	0.000E+00	8.106E-02	2.210E+00
2.800E+01	1.066E+00	0.000E+00	2.784E-01	1.601E+00	4.760E-02	1.192E-03	0.000E+00	9.332E-02	2.255E+00
3.000E+01	1.056E+00	0.000E+00	3.064E-01	1.645E+00	5.344E-02	1.564E-03	0.000E+00	9.509E-02	2.231E+00
3.500E+01	1.021E+00	0.000E+00	3.965E-01	1.662E+00	6.682E-02	2.347E-03	0.000E+00	1.023E-01	2.116E+00
4.000E+01	9.844E-01	0.000E+00	4.394E-01	1.656E+00	7.598E-02	3.105E-03	0.000E+00	1.103E-01	2.094E+00
4.500E+01	9.528E-01	0.000E+00	4.780E-01	1.676E+00	8.243E-02	3.761E-03	0.000E+00	1.208E-01	2.085E+00
5.000E+01	9.132E-01	0.000E+00	5.163E-01	1.674E+00	8.691E-02	4.316E-03	0.000E+00	1.283E-01	2.043E+00
5.500E+01	8.722E-01	0.000E+00	5.462E-01	1.652E+00	8.928E-02	4.838E-03	0.000E+00	1.367E-01	1.989E+00
6.000E+01	8.366E-01	0.000E+00	5.860E-01	1.635E+00	9.205E-02	5.263E-03	0.000E+00	1.450E-01	1.900E+00
6.500E+01	8.093E-01	0.000E+00	6.291E-01	1.636E+00	9.581E-02	5.646E-03	0.000E+00	1.559E-01	1.833E+00
7.000E+01	7.894E-01	0.000E+00	6.674E-01	1.642E+00	1.008E-01	6.168E-03	0.000E+00	1.701E-01	1.717E+00
7.500E+01	7.758E-01	0.000E+00	7.089E-01	1.665E+00	1.053E-01	6.599E-03	0.000E+00	1.845E-01	1.688E+00
8.000E+01	7.672E-01	0.000E+00	7.494E-01	1.697E+00	1.100E-01	7.045E-03	0.000E+00	2.000E-01	1.672E+00
8.500E+01	7.622E-01	0.000E+00	7.882E-01	1.729E+00	1.156E-01	7.702E-03	0.000E+00	2.183E-01	1.648E+00
9.000E+01	7.596E-01	0.000E+00	8.296E-01	1.764E+00	1.205E-01	8.251E-03	0.000E+00	2.360E-01	1.633E+00
9.500E+01	7.584E-01	0.000E+00	8.681E-01	1.799E+00	1.251E-01	8.851E-03	0.000E+00	2.535E-01	1.629E+00
1.000E+02	7.580E-01	0.000E+00	9.044E-01	1.835E+00	1.285E-01	9.749E-03	0.000E+00	2.738E-01	1.618E+00
1.100E+02	7.574E-01	0.000E+00	9.808E-01	1.899E+00	1.364E-01	1.127E-02	0.000E+00	3.106E-01	1.557E+00
1.200E+02	7.559E-01	0.000E+00	1.051E+00	1.960E+00	1.461E-01	1.352E-02	0.000E+00	3.525E-01	1.500E+00
1.300E+02	7.528E-01	0.000E+00	1.090E+00	1.994E+00	1.537E-01	1.565E-02	0.000E+00	3.861E-01	1.435E+00
1.400E+02	7.484E-01	0.000E+00	1.110E+00	2.014E+00	1.617E-01	1.837E-02	0.000E+00	4.196E-01	1.360E+00
1.500E+02	7.428E-01	0.000E+00	1.109E+00	2.013E+00	1.671E-01	2.078E-02	0.000E+00	4.438E-01	1.265E+00

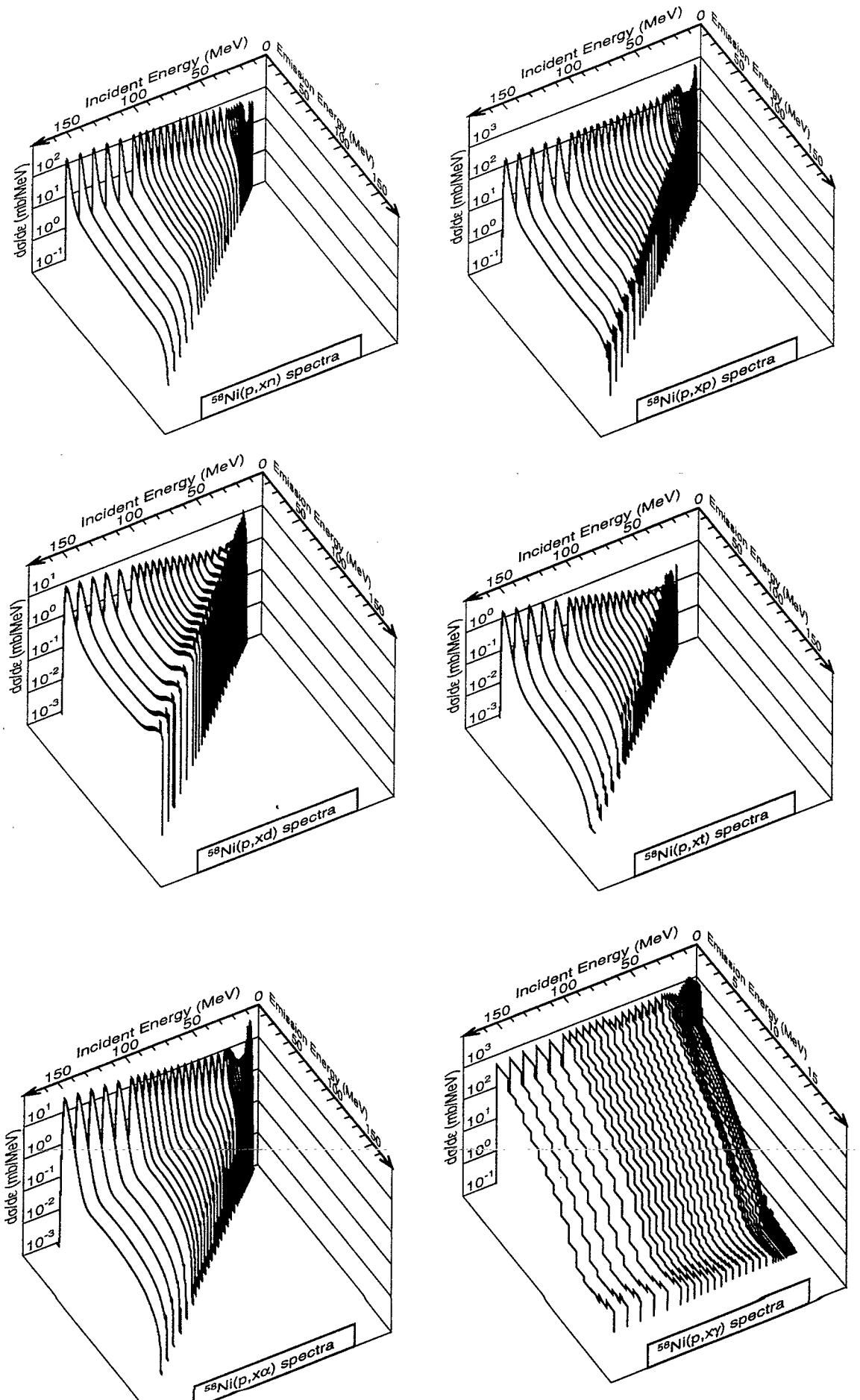
28058 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
3.000E+00	0.000E+00	1.475E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.654E+00
4.000E+00	0.000E+00	2.454E+00	0.000E+00	0.000E+00	0.000E+00	2.343E+00	1.581E+00
5.000E+00	0.000E+00	3.338E+00	0.000E+00	0.000E+00	0.000E+00	3.254E+00	1.497E+00
6.000E+00	0.000E+00	3.929E+00	0.000E+00	0.000E+00	0.000E+00	4.173E+00	1.506E+00
7.000E+00	0.000E+00	4.469E+00	0.000E+00	0.000E+00	0.000E+00	5.098E+00	1.564E+00
8.000E+00	0.000E+00	5.185E+00	0.000E+00	0.000E+00	0.000E+00	6.019E+00	1.659E+00
9.000E+00	0.000E+00	5.521E+00	0.000E+00	0.000E+00	0.000E+00	6.917E+00	1.768E+00
1.000E+01	3.470E-01	5.724E+00	0.000E+00	0.000E+00	0.000E+00	7.742E+00	1.810E+00
1.100E+01	1.065E+00	6.005E+00	7.314E-01	0.000E+00	0.000E+00	8.349E+00	1.883E+00
1.200E+01	1.332E+00	6.227E+00	1.664E+00	0.000E+00	0.000E+00	8.599E+00	1.959E+00
1.300E+01	1.722E+00	6.385E+00	2.580E+00	0.000E+00	0.000E+00	8.698E+00	2.047E+00
1.400E+01	2.078E+00	6.386E+00	3.411E+00	0.000E+00	0.000E+00	8.890E+00	2.116E+00
1.500E+01	2.410E+00	6.095E+00	4.120E+00	0.000E+00	0.000E+00	9.148E+00	2.157E+00
1.600E+01	2.488E+00	5.972E+00	4.728E+00	1.612E+00	0.000E+00	9.401E+00	2.156E+00
1.700E+01	2.300E+00	5.915E+00	5.333E+00	2.558E+00	0.000E+00	9.641E+00	2.097E+00
1.800E+01	2.252E+00	5.985E+00	5.933E+00	3.510E+00	0.000E+00	9.850E+00	1.994E+00
1.900E+01	2.347E+00	6.151E+00	6.556E+00	4.359E+00	0.000E+00	1.000E+01	1.889E+00
2.000E+01	2.456E+00	6.380E+00	7.069E+00	4.649E+00	0.000E+00	1.008E+01	1.795E+00
2.200E+01	2.993E+00	6.838E+00	8.345E+00	5.410E+00	0.000E+00	1.007E+01	1.773E+00
2.400E+01	3.524E+00	7.321E+00	9.558E+00	6.295E+00	0.000E+00	1.005E+01	1.857E+00
2.600E+01	4.039E+00	7.741E+00	1.069E+01	7.227E+00	0.000E+00	1.020E+01	1.951E+00
2.800E+01	4.528E+00	8.038E+00	1.178E+01	8.225E+00	0.000E+00	1.053E+01	1.993E+00
3.000E+01	4.880E+00	8.329E+00	1.273E+01	9.195E+00	0.000E+00	1.089E+01	1.966E+00
3.500E+01	5.545E+00	9.326E+00	1.552E+01	1.126E+01	0.000E+00	1.155E+01	1.811E+00

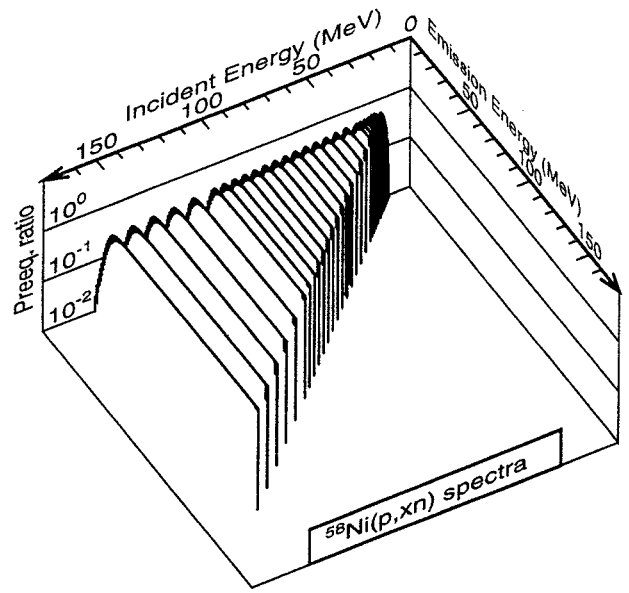
4.000E+01	6.638E+00	1.040E+01	1.833E+01	1.316E+01	0.000E+00	1.200E+01	1.803E+00
4.500E+01	7.592E+00	1.120E+01	2.085E+01	1.477E+01	0.000E+00	1.237E+01	1.818E+00
5.000E+01	8.383E+00	1.193E+01	2.327E+01	1.615E+01	0.000E+00	1.269E+01	1.803E+00
5.500E+01	9.129E+00	1.277E+01	2.508E+01	1.727E+01	0.000E+00	1.294E+01	1.792E+00
6.000E+01	9.678E+00	1.356E+01	2.685E+01	1.827E+01	0.000E+00	1.314E+01	1.824E+00
6.500E+01	1.020E+01	1.424E+01	2.855E+01	1.900E+01	0.000E+00	1.327E+01	1.830E+00
7.000E+01	1.080E+01	1.490E+01	2.976E+01	1.945E+01	0.000E+00	1.337E+01	1.778E+00
7.500E+01	1.139E+01	1.547E+01	3.107E+01	1.986E+01	0.000E+00	1.345E+01	1.789E+00
8.000E+01	1.203E+01	1.601E+01	3.227E+01	2.012E+01	0.000E+00	1.352E+01	1.795E+00
8.500E+01	1.269E+01	1.655E+01	3.314E+01	1.996E+01	0.000E+00	1.358E+01	1.781E+00
9.000E+01	1.330E+01	1.711E+01	3.414E+01	1.991E+01	0.000E+00	1.364E+01	1.801E+00
9.500E+01	1.395E+01	1.768E+01	3.505E+01	1.974E+01	0.000E+00	1.371E+01	1.817E+00
1.000E+02	1.464E+01	1.827E+01	3.509E+01	1.926E+01	0.000E+00	1.379E+01	1.831E+00
1.100E+02	1.581E+01	1.943E+01	3.633E+01	1.850E+01	0.000E+00	1.393E+01	1.852E+00
1.200E+02	1.679E+01	2.049E+01	3.674E+01	1.731E+01	0.000E+00	1.405E+01	1.848E+00
1.300E+02	1.807E+01	2.175E+01	3.787E+01	1.644E+01	0.000E+00	1.422E+01	1.833E+00
1.400E+02	1.944E+01	2.304E+01	3.859E+01	1.546E+01	0.000E+00	1.439E+01	1.842E+00
1.500E+02	2.109E+01	2.454E+01	3.975E+01	1.472E+01	0.000E+00	1.458E+01	1.854E+00

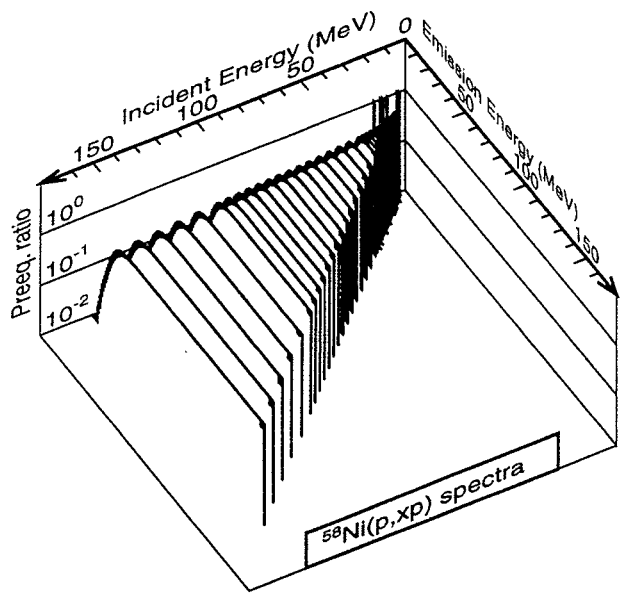

p + 58Ni nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
p
γ
n
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
10^1
10^0
0
50
100
150
Incident Energy (MeV)

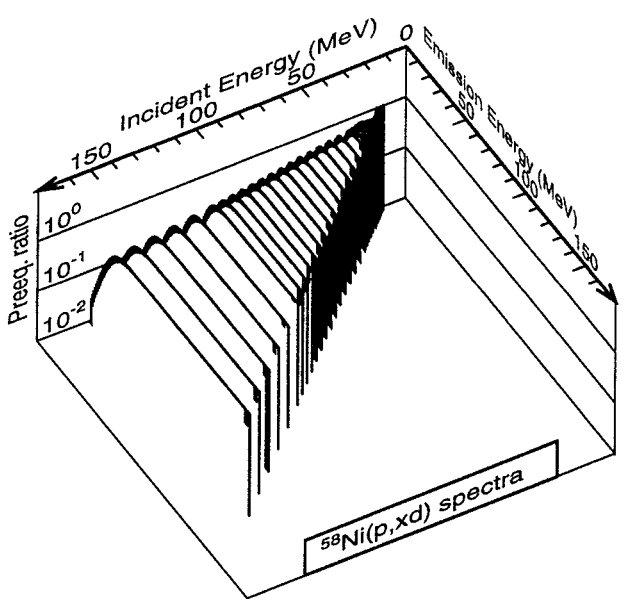
p + ^{58}Ni angle-integrated emission spectra

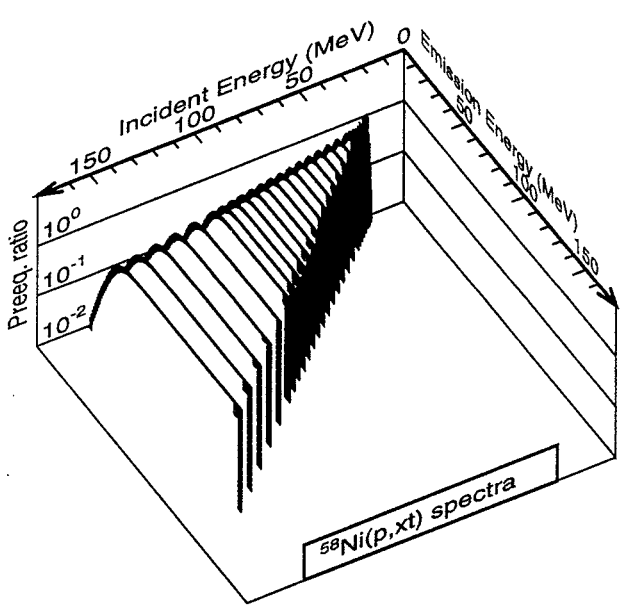


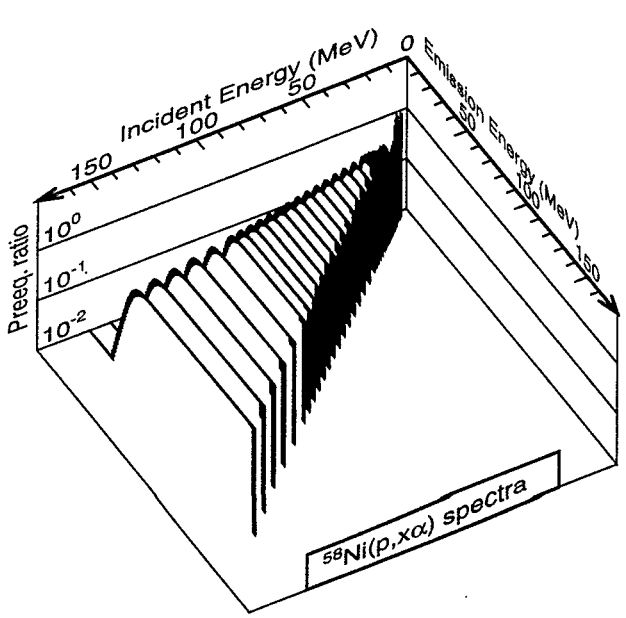
p + ^{58}Ni Kalbach preequilibrium ratios

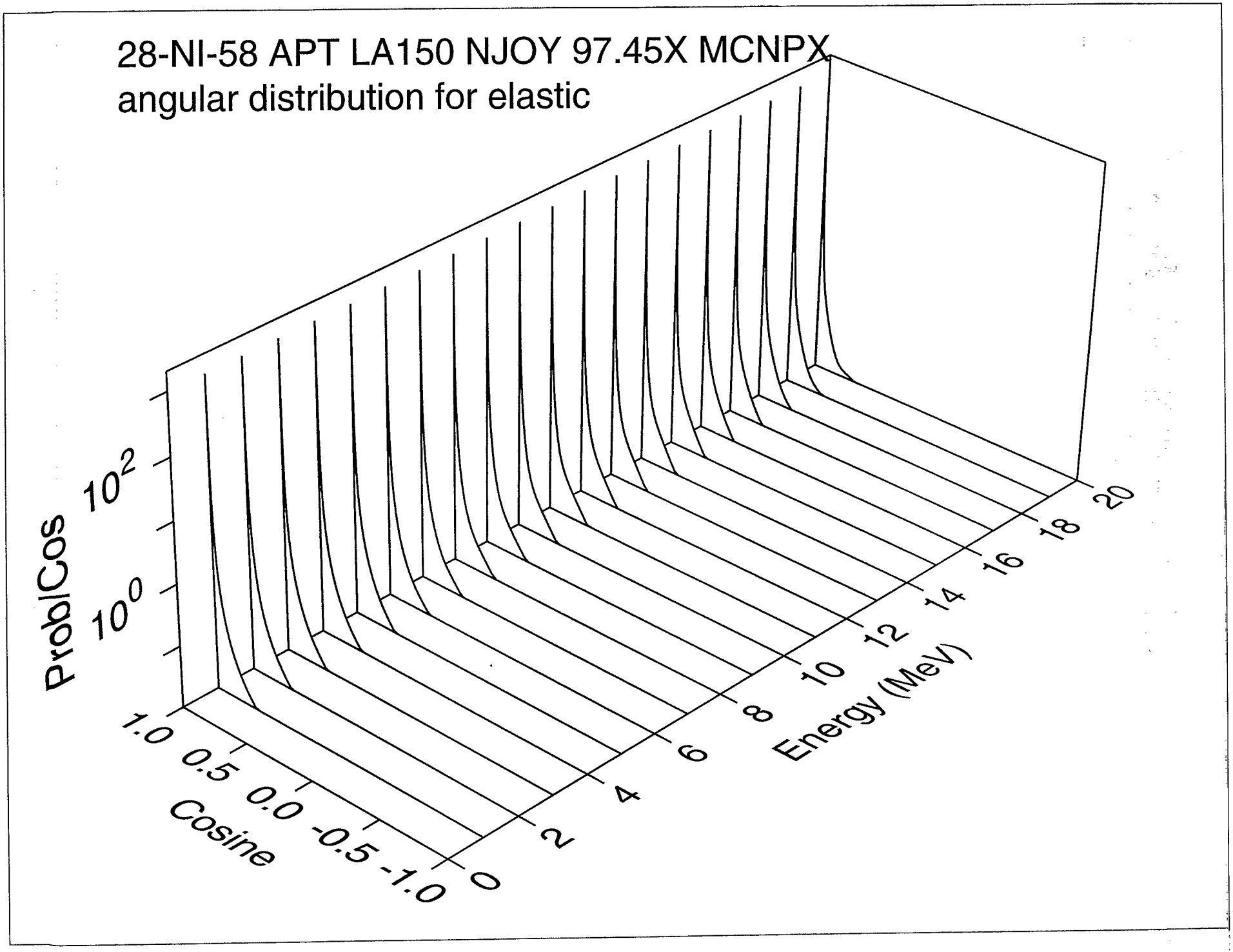


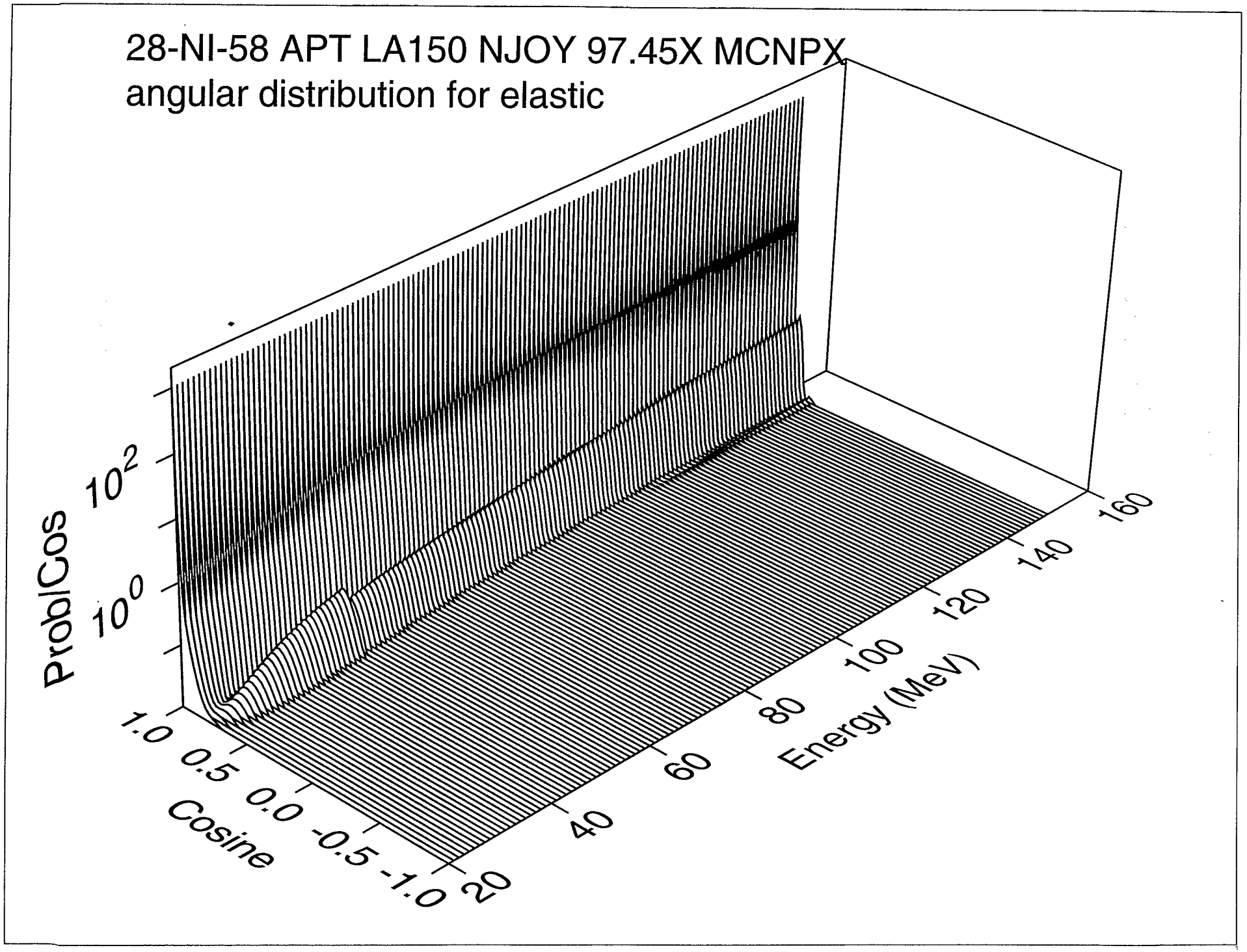


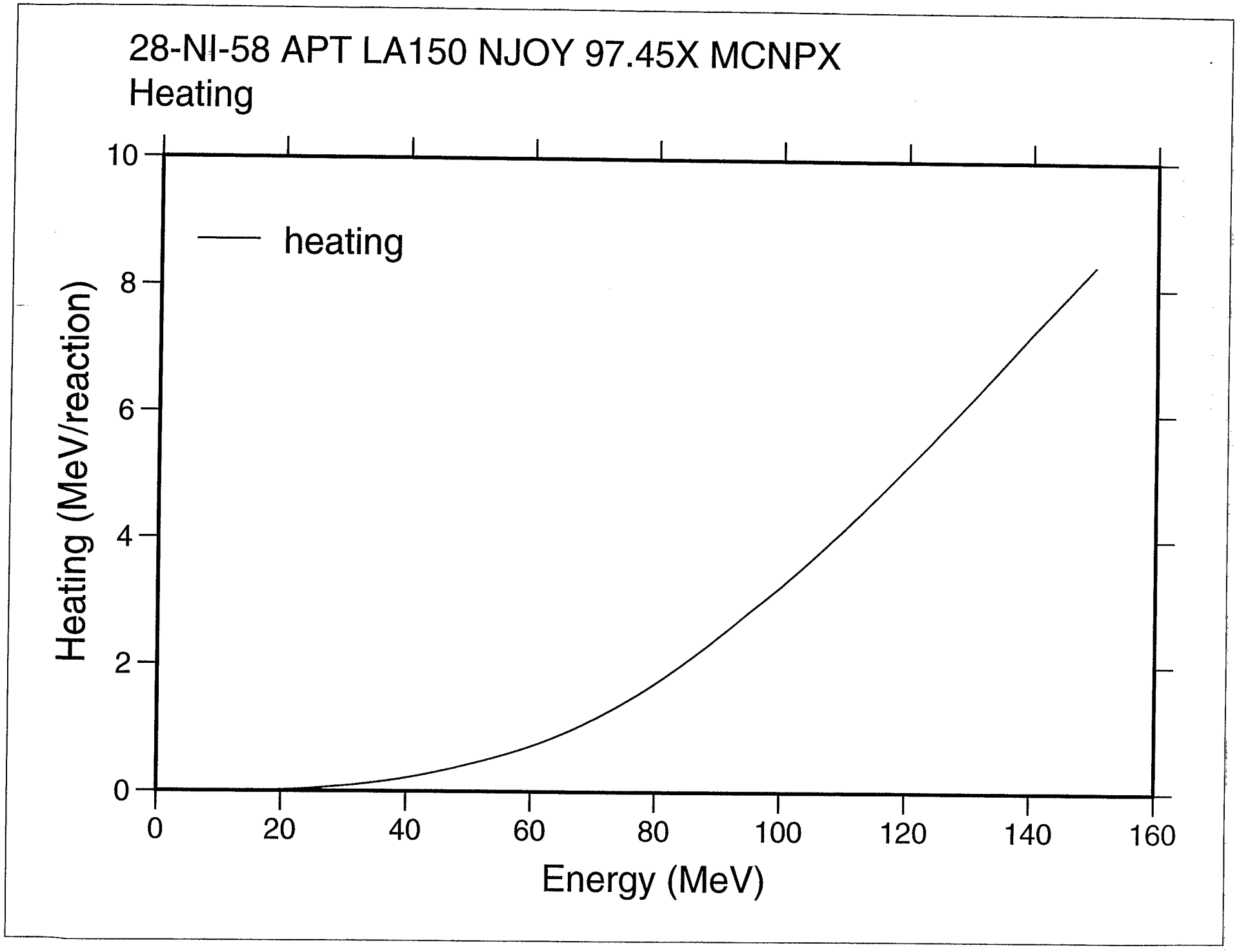







28-NI-58 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
1.0
0.5
0.0
-0.5
-1.0
Cosine
0
2
4
6
8
10
12
14
16
18
20
Energy (MeV)


28-NI-58 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
ProblCos
10^2
10^0
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


28-NI-58 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
2
4
6
8
10
0
20
40
60
80
100
120
140
160

EVALUATION OF p + 60Ni CROSS SECTIONS FOR THE ENERGY RANGE 1 to 150 MeV

S. Chiba, M. B. Chadwick, P. G. Young, and A. J. Koning

24 September 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident proton energy range from 1 to 150 MeV. The evaluation utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above are:

MF=3	MT= 2	Integral of nuclear plus interference components of the elastic scattering cross section
	MT= 5	Sum of binary (p,n') and (p,x) reactions
MF=6	MT= 2	Elastic (p,p) angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
	MT= 5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Ni58 and p + Ni58 reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic proton angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Gilbert and Cameron [Gi65] and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged- particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray

transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

DETAILS OF THE p + 60Ni ANALYSIS

The neutron optical model potential was adjusted to reproduce the total cross section data((Du67, Bo71, St71, Sm79, Fe80, Pe82, Ha82, Di97), s-wave strength function (Mu81) and elastic scattering angular distritution data (Bo71, Gu85, Tu73, Ya79). The data for natural Ni (Di97) was also used because there was not enough data for Ni-60 above 20 MeV. The data for natural Ni were transformed to the Ni-60 cross section according to A*(2/3) law.

The parameter estimation was carried out based on Marquart-Bayesian approach (Sm91), where ECIS95 code was used for the optical model calculation. We have employed the energy dependence of the optical potential similar to Delaroche's work(De89). The initial potential parameters were adopted from Koning and Delaroche (Ko97). Total of 7 parameters concerning the central potential depth were estimated with associated covariance matrix, while the geometircal parameters were fixed to the result of a similar search for n + Ni-58. Presently obtained potential was used for the calculation of neutron transmission coefficients and DWBA cross sections in the energy region above 20 MeV. Below 20 MeV, the Harper neutron potential (Ha82) was used for the calculation of transmission coefficients.

The proton optical potential was also searched for to obtain a good description of proton-total reaction cross section as predicted by Wellisch-Axen systematic (We96) above 50 MeV. The parameter estimation was carried out by the Marquart-Bayesian approach similar to the neutron OMP, but trying to seek the best parameter to reproduce the reaction cross sections compiled by Carlson (Ca96) and Wellisch values. The experimental data in Carlson (Ca96) was scaled for Ni-60 according to A**(2/3) law. In this search, the geometrical parameters were fixed to be same as the neutron potential. The present potential gives a good description of the proton total reaction cross section from 10 MeV to 250 MeV. However, after some trial and error to reproduce both the elastic scattering and reaction cross section data for Ni-58, we have employed the following combination of proton potentials:

0 to 5 MeV	:	Harper potential (Ha82)
6 to 47 MeV	:	Koning and Delaroche (Ko97)
48 to 260 MeV	:	Present OMP

For deuterons, the Lohr-Haeberli [Lo74] global potential was used; for alpha particles the McFadden-Satchler [Mc66] potential was used; and for tritons the Beccheti-Greenlees [Be71] potential was used. The He-3 channel was ignored.

The direct collective inelastic scattering to the following level in Ni-60 was considered by the DWBA-mode calculation of ECIS95:

Jpi	Ex(MeV)	Deformation length
2+	1.331	0.8535

The deformation length was determined to match the ENDF/B-VI value at 20 MeV for the incident neutron channel.

Certain nuclear level densities were modified from their default values due to experimental information available, as documented in the ENDF-file1 of our n+60Ni evaluation.

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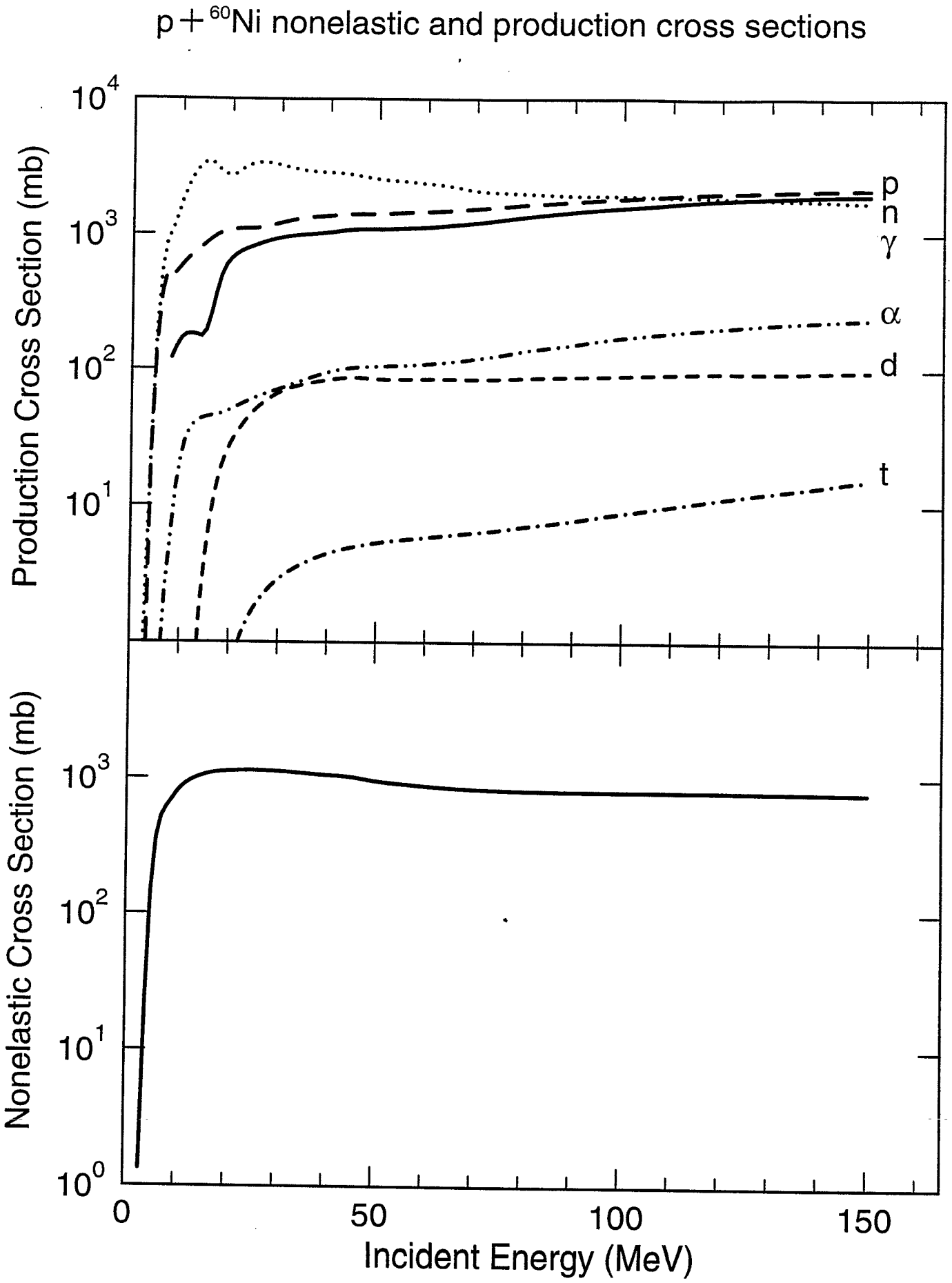
28060 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+00	2.707E-04	0.000E+00	0.000E+00	4.956E-09	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.234E-04
3.000E+00	1.342E-03	0.000E+00	0.000E+00	5.345E-04	0.000E+00	0.000E+00	0.000E+00	2.509E-10	1.728E-03
4.000E+00	2.374E-02	0.000E+00	0.000E+00	2.274E-02	0.000E+00	0.000E+00	0.000E+00	3.210E-07	2.498E-02
5.000E+00	1.450E-01	0.000E+00	0.000E+00	1.440E-01	0.000E+00	0.000E+00	0.000E+00	1.707E-05	1.758E-01
6.000E+00	3.613E-01	0.000E+00	0.000E+00	3.598E-01	0.000E+00	0.000E+00	0.000E+00	4.832E-04	5.436E-01
7.000E+00	5.181E-01	0.000E+00	0.000E+00	5.148E-01	0.000E+00	0.000E+00	0.000E+00	2.466E-03	8.960E-01
8.000E+00	6.064E-01	0.000E+00	1.218E-01	4.782E-01	0.000E+00	0.000E+00	0.000E+00	5.829E-03	1.053E+00
9.000E+00	6.827E-01	0.000E+00	1.461E-01	5.228E-01	0.000E+00	0.000E+00	0.000E+00	1.336E-02	1.346E+00
1.000E+01	7.703E-01	0.000E+00	1.684E-01	5.791E-01	0.000E+00	0.000E+00	0.000E+00	2.244E-02	1.755E+00
1.100E+01	8.491E-01	0.000E+00	1.799E-01	6.374E-01	1.911E-07	0.000E+00	0.000E+00	3.140E-02	2.191E+00
1.200E+01	9.117E-01	0.000E+00	1.819E-01	6.920E-01	3.256E-05	0.000E+00	0.000E+00	3.737E-02	2.603E+00
1.300E+01	9.597E-01	0.000E+00	1.794E-01	7.390E-01	4.065E-04	4.445E-14	0.000E+00	4.075E-02	2.978E+00
1.400E+01	9.991E-01	0.000E+00	1.747E-01	7.936E-01	1.670E-03	6.401E-08	0.000E+00	4.274E-02	3.286E+00
1.500E+01	1.032E+00	0.000E+00	1.934E-01	8.526E-01	4.106E-03	3.730E-06	0.000E+00	4.405E-02	3.467E+00
1.600E+01	1.060E+00	0.000E+00	2.544E-01	9.122E-01	7.809E-03	2.415E-05	0.000E+00	4.484E-02	3.414E+00
1.700E+01	1.081E+00	0.000E+00	3.612E-01	9.679E-01	1.259E-02	6.548E-05	0.000E+00	4.556E-02	3.151E+00
1.800E+01	1.096E+00	0.000E+00	4.832E-01	1.010E+00	1.795E-02	1.487E-04	0.000E+00	4.643E-02	2.855E+00
1.900E+01	1.107E+00	0.000E+00	5.808E-01	1.039E+00	2.289E-02	2.960E-04	0.000E+00	4.782E-02	2.743E+00
2.000E+01	1.115E+00	0.000E+00	6.463E-01	1.059E+00	2.762E-02	5.063E-04	0.000E+00	4.981E-02	2.685E+00
2.200E+01	1.126E+00	0.000E+00	7.357E-01	1.078E+00	3.641E-02	1.018E-03	0.000E+00	5.410E-02	2.970E+00
2.400E+01	1.132E+00	0.000E+00	7.890E-01	1.082E+00	4.526E-02	1.520E-03	0.000E+00	5.847E-02	3.257E+00
2.600E+01	1.133E+00	0.000E+00	8.382E-01	1.097E+00	5.315E-02	1.998E-03	0.000E+00	6.271E-02	3.377E+00
2.800E+01	1.129E+00	0.000E+00	8.850E-01	1.135E+00	6.022E-02	2.447E-03	0.000E+00	6.689E-02	3.319E+00
3.000E+01	1.120E+00	0.000E+00	9.208E-01	1.185E+00	6.645E-02	2.871E-03	0.000E+00	7.063E-02	3.199E+00
3.500E+01	1.087E+00	0.000E+00	9.782E-01	1.293E+00	7.636E-02	3.724E-03	0.000E+00	8.236E-02	2.899E+00
4.000E+01	1.051E+00	0.000E+00	1.017E+00	1.341E+00	8.263E-02	4.422E-03	0.000E+00	9.456E-02	2.801E+00
4.500E+01	1.018E+00	0.000E+00	1.072E+00	1.384E+00	8.611E-02	4.931E-03	0.000E+00	1.019E-01	2.689E+00
5.000E+01	9.494E-01	0.000E+00	1.079E+00	1.389E+00	8.398E-02	5.302E-03	0.000E+00	1.045E-01	2.511E+00
5.500E+01	9.063E-01	0.000E+00	1.091E+00	1.415E+00	8.382E-02	5.587E-03	0.000E+00	1.064E-01	2.415E+00
6.000E+01	8.737E-01	0.000E+00	1.112E+00	1.439E+00	8.431E-02	5.828E-03	0.000E+00	1.092E-01	2.321E+00
6.500E+01	8.481E-01	0.000E+00	1.154E+00	1.475E+00	8.452E-02	6.091E-03	0.000E+00	1.138E-01	2.219E+00
7.000E+01	8.297E-01	0.000E+00	1.200E+00	1.522E+00	8.416E-02	6.362E-03	0.000E+00	1.203E-01	2.056E+00
7.500E+01	8.173E-01	0.000E+00	1.264E+00	1.574E+00	8.499E-02	6.651E-03	0.000E+00	1.282E-01	2.004E+00
8.000E+01	8.094E-01	0.000E+00	1.333E+00	1.634E+00	8.622E-02	7.062E-03	0.000E+00	1.378E-01	1.971E+00
8.500E+01	8.046E-01	0.000E+00	1.395E+00	1.681E+00	8.748E-02	7.426E-03	0.000E+00	1.460E-01	1.939E+00
9.000E+01	8.020E-01	0.000E+00	1.458E+00	1.734E+00	8.868E-02	7.832E-03	0.000E+00	1.544E-01	1.917E+00
9.500E+01	8.005E-01	0.000E+00	1.520E+00	1.790E+00	8.957E-02	8.387E-03	0.000E+00	1.649E-01	1.930E+00
1.000E+02	7.996E-01	0.000E+00	1.574E+00	1.840E+00	9.077E-02	8.871E-03	0.000E+00	1.734E-01	1.928E+00
1.100E+02	7.978E-01	0.000E+00	1.680E+00	1.925E+00	9.301E-02	9.963E-03	0.000E+00	1.892E-01	1.884E+00
1.200E+02	7.951E-01	0.000E+00	1.785E+00	2.003E+00	9.494E-02	1.132E-02	0.000E+00	2.054E-01	1.856E+00
1.300E+02	7.910E-01	0.000E+00	1.864E+00	2.065E+00	9.528E-02	1.263E-02	0.000E+00	2.188E-01	1.817E+00
1.400E+02	7.856E-01	0.000E+00	1.912E+00	2.111E+00	9.676E-02	1.399E-02	0.000E+00	2.298E-01	1.777E+00
1.500E+02	7.792E-01	0.000E+00	1.938E+00	2.137E+00	9.791E-02	1.539E-02	0.000E+00	2.386E-01	1.724E+00

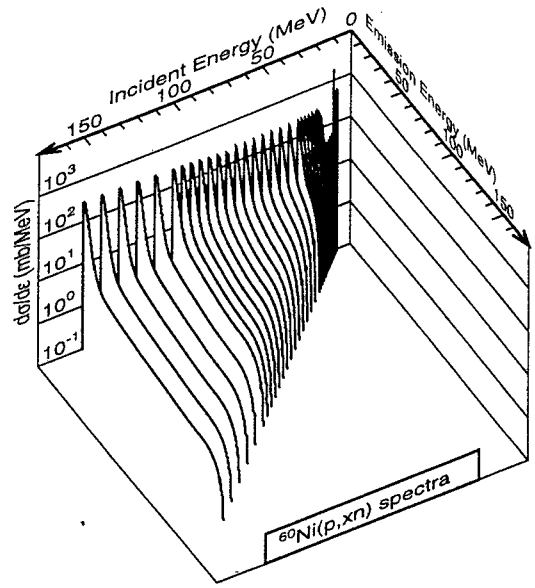
28060 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

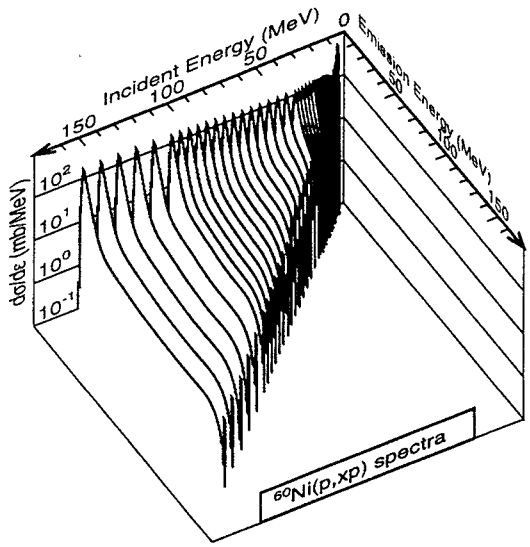
Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+00	0.000E+00	5.473E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.309E+00
3.000E+00	0.000E+00	1.476E+00	0.000E+00	0.000E+00	0.000E+00	2.485E+00	2.972E+00
4.000E+00	0.000E+00	2.428E+00	0.000E+00	0.000E+00	0.000E+00	3.412E+00	1.409E+00
5.000E+00	0.000E+00	3.261E+00	0.000E+00	0.000E+00	0.000E+00	4.338E+00	1.230E+00
6.000E+00	0.000E+00	3.898E+00	0.000E+00	0.000E+00	0.000E+00	5.255E+00	1.214E+00
7.000E+00	0.000E+00	4.467E+00	0.000E+00	0.000E+00	0.000E+00	5.994E+00	1.295E+00
8.000E+00	6.296E-01	4.949E+00	0.000E+00	0.000E+00	0.000E+00	6.757E+00	1.284E+00
9.000E+00	1.375E+00	5.247E+00	0.000E+00	0.000E+00	0.000E+00	7.418E+00	1.401E+00
1.000E+01	1.734E+00	5.445E+00	0.000E+00	0.000E+00	0.000E+00	7.936E+00	1.521E+00
1.100E+01	2.061E+00	5.632E+00	1.566E+00	0.000E+00	0.000E+00	8.385E+00	1.637E+00
1.200E+01	2.365E+00	5.809E+00	2.418E+00	0.000E+00	0.000E+00	8.765E+00	1.760E+00
1.300E+01	2.637E+00	5.992E+00	3.202E+00	1.067E-02	0.000E+00	9.075E+00	1.884E+00
1.400E+01	2.803E+00	6.125E+00	3.941E+00	1.704E+00	0.000E+00	9.329E+00	1.994E+00
1.500E+01	2.787E+00	6.144E+00	4.555E+00	2.617E+00	0.000E+00	9.526E+00	2.066E+00
1.600E+01	2.428E+00	6.232E+00	5.133E+00	3.472E+00	0.000E+00	9.694E+00	2.065E+00
1.700E+01	2.087E+00	6.331E+00	5.719E+00	3.991E+00	0.000E+00	9.844E+00	1.999E+00
1.800E+01	1.974E+00	6.452E+00	6.316E+00	4.381E+00	0.000E+00	1.000E+01	1.871E+00
1.900E+01	2.032E+00	6.635E+00	6.896E+00	4.746E+00	0.000E+00	1.014E+01	1.742E+00
2.000E+01	2.235E+00	6.851E+00	7.466E+00	5.250E+00	0.000E+00	1.027E+01	1.737E+00
2.200E+01	2.519E+00	7.333E+00	8.543E+00	6.208E+00	0.000E+00	1.057E+01	1.701E+00
2.400E+01	2.900E+00	7.867E+00	9.711E+00	7.151E+00	0.000E+00	1.087E+01	1.761E+00
2.600E+01	3.246E+00	8.339E+00	1.084E+01	8.153E+00	0.000E+00	1.116E+01	1.801E+00
2.800E+01	3.555E+00	8.717E+00	1.199E+01	9.122E+00	0.000E+00	1.140E+01	1.805E+00

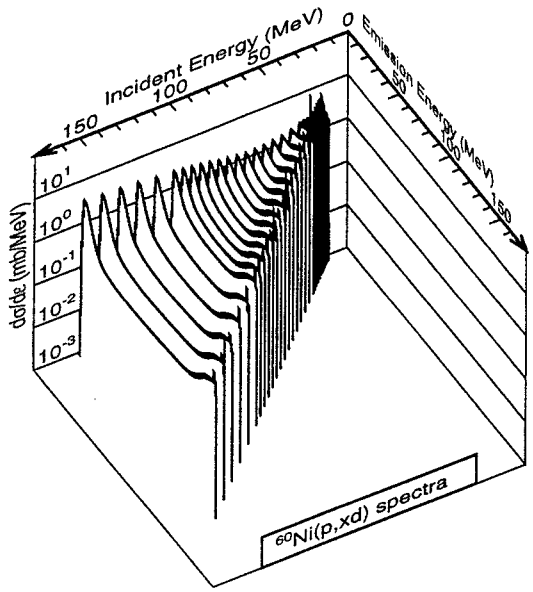
3.000E+01	3.860E+00	9.057E+00	1.315E+01	1.004E+01	0.000E+00	1.161E+01	1.780E+00
3.500E+01	4.648E+00	1.002E+01	1.609E+01	1.207E+01	0.000E+00	1.189E+01	1.689E+00
4.000E+01	5.397E+00	1.117E+01	1.922E+01	1.402E+01	0.000E+00	1.215E+01	1.687E+00
4.500E+01	6.032E+00	1.223E+01	2.231E+01	1.583E+01	0.000E+00	1.246E+01	1.709E+00
5.000E+01	6.632E+00	1.313E+01	2.500E+01	1.746E+01	0.000E+00	1.275E+01	1.699E+00
5.500E+01	7.232E+00	1.394E+01	2.773E+01	1.891E+01	0.000E+00	1.302E+01	1.686E+00
6.000E+01	7.813E+00	1.472E+01	3.047E+01	2.016E+01	0.000E+00	1.323E+01	1.680E+00
6.500E+01	8.289E+00	1.536E+01	3.285E+01	2.098E+01	0.000E+00	1.338E+01	1.686E+00
7.000E+01	8.737E+00	1.587E+01	3.489E+01	2.160E+01	0.000E+00	1.348E+01	1.689E+00
7.500E+01	9.106E+00	1.635E+01	3.706E+01	2.196E+01	0.000E+00	1.354E+01	1.701E+00
8.000E+01	9.452E+00	1.678E+01	3.892E+01	2.190E+01	0.000E+00	1.357E+01	1.721E+00
8.500E+01	9.857E+00	1.735E+01	4.090E+01	2.190E+01	0.000E+00	1.364E+01	1.734E+00
9.000E+01	1.026E+01	1.788E+01	4.275E+01	2.176E+01	0.000E+00	1.371E+01	1.752E+00
9.500E+01	1.065E+01	1.840E+01	4.402E+01	2.130E+01	0.000E+00	1.374E+01	1.744E+00
1.000E+02	1.109E+01	1.896E+01	4.571E+01	2.097E+01	0.000E+00	1.381E+01	1.724E+00
1.100E+02	1.190E+01	2.016E+01	4.889E+01	2.006E+01	0.000E+00	1.395E+01	1.727E+00
1.200E+02	1.261E+01	2.133E+01	5.140E+01	1.893E+01	0.000E+00	1.408E+01	1.732E+00
1.300E+02	1.340E+01	2.264E+01	5.346E+01	1.788E+01	0.000E+00	1.422E+01	1.743E+00
1.400E+02	1.428E+01	2.396E+01	5.632E+01	1.669E+01	0.000E+00	1.437E+01	1.757E+00
1.500E+02	1.522E+01	2.539E+01	5.912E+01	1.548E+01	0.000E+00	1.454E+01	1.773E+00

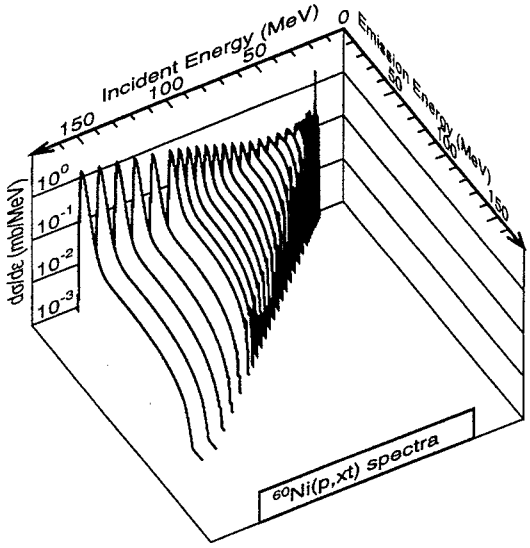

p + 60Ni nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
p
n
γ
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
10^1
10^0
0
50
100
150
Incident Energy (MeV)

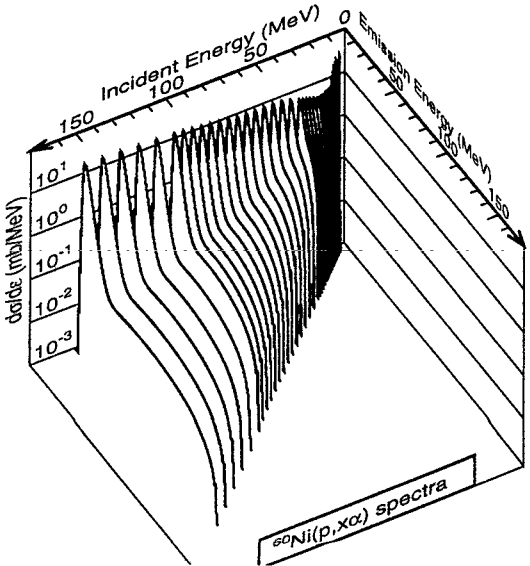
p + ^{60}Ni angle-integrated emission spectra

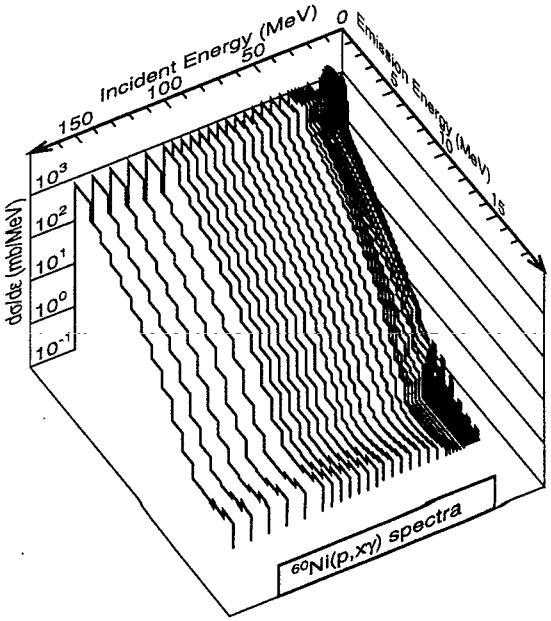




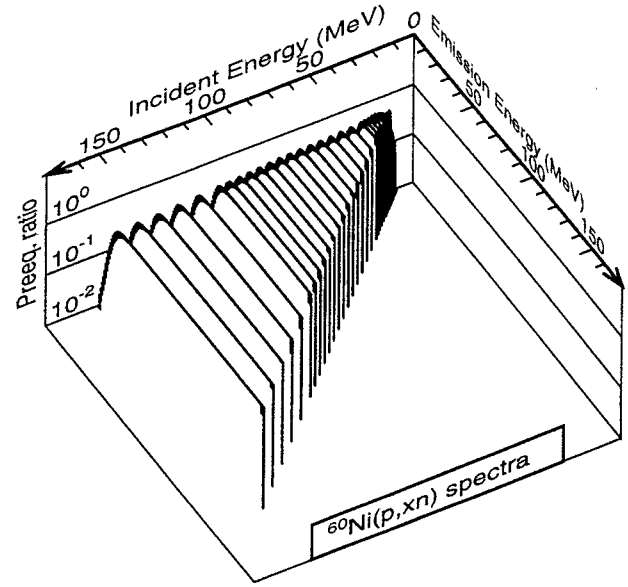


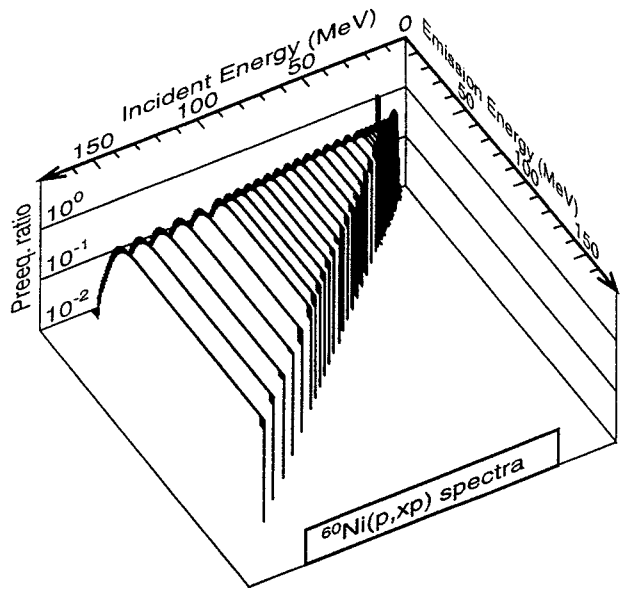


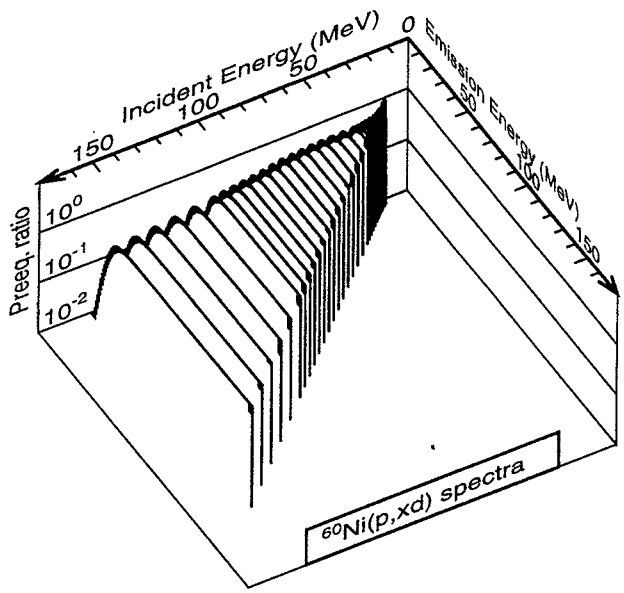


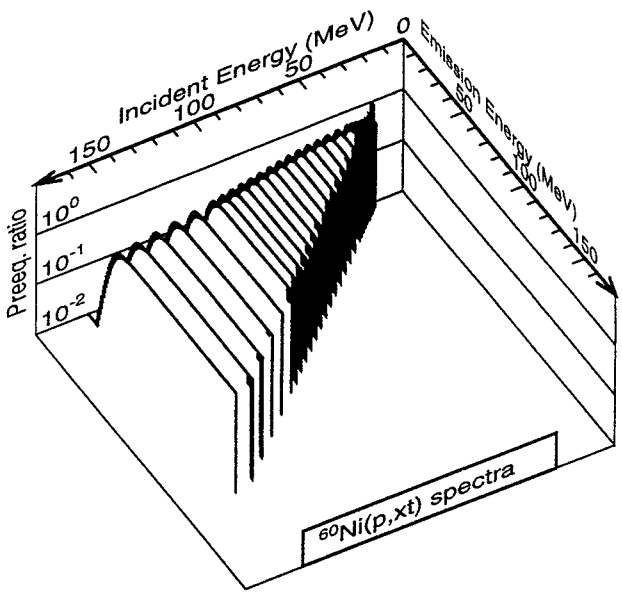


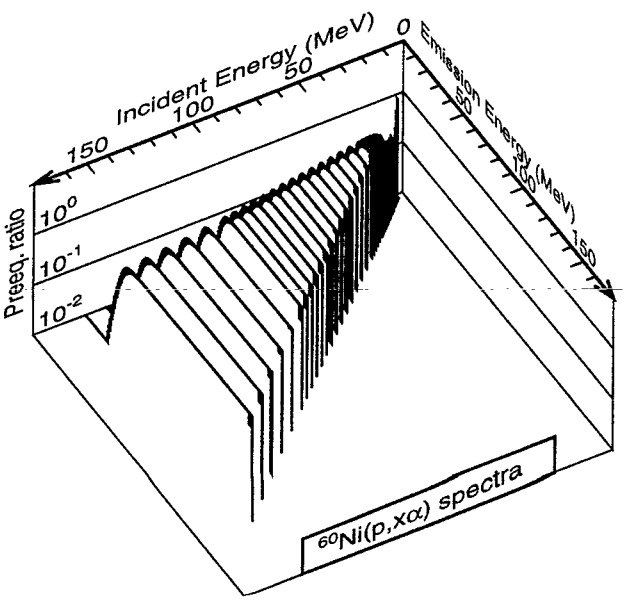
p + ^{60}Ni Kalbach preequilibrium ratios

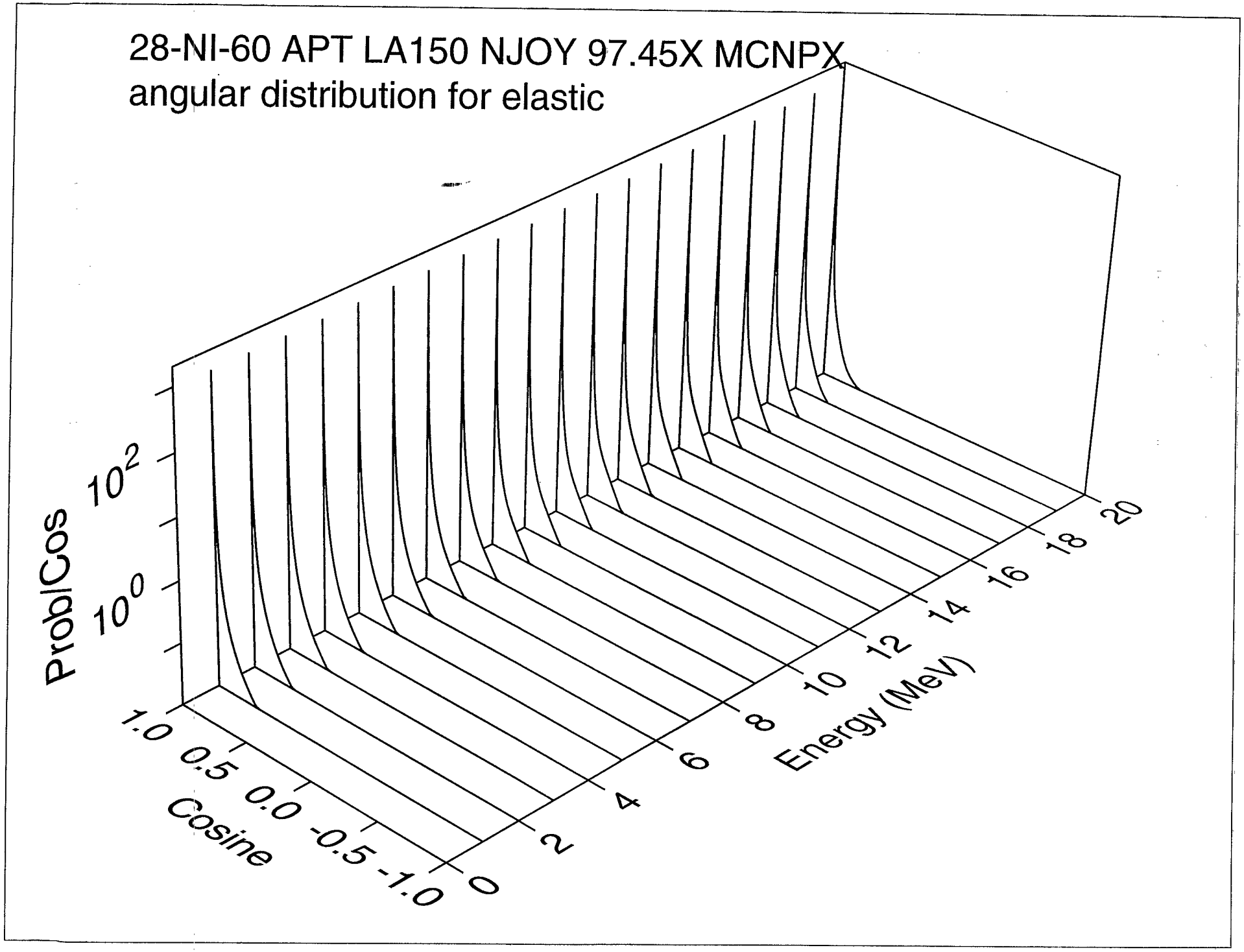


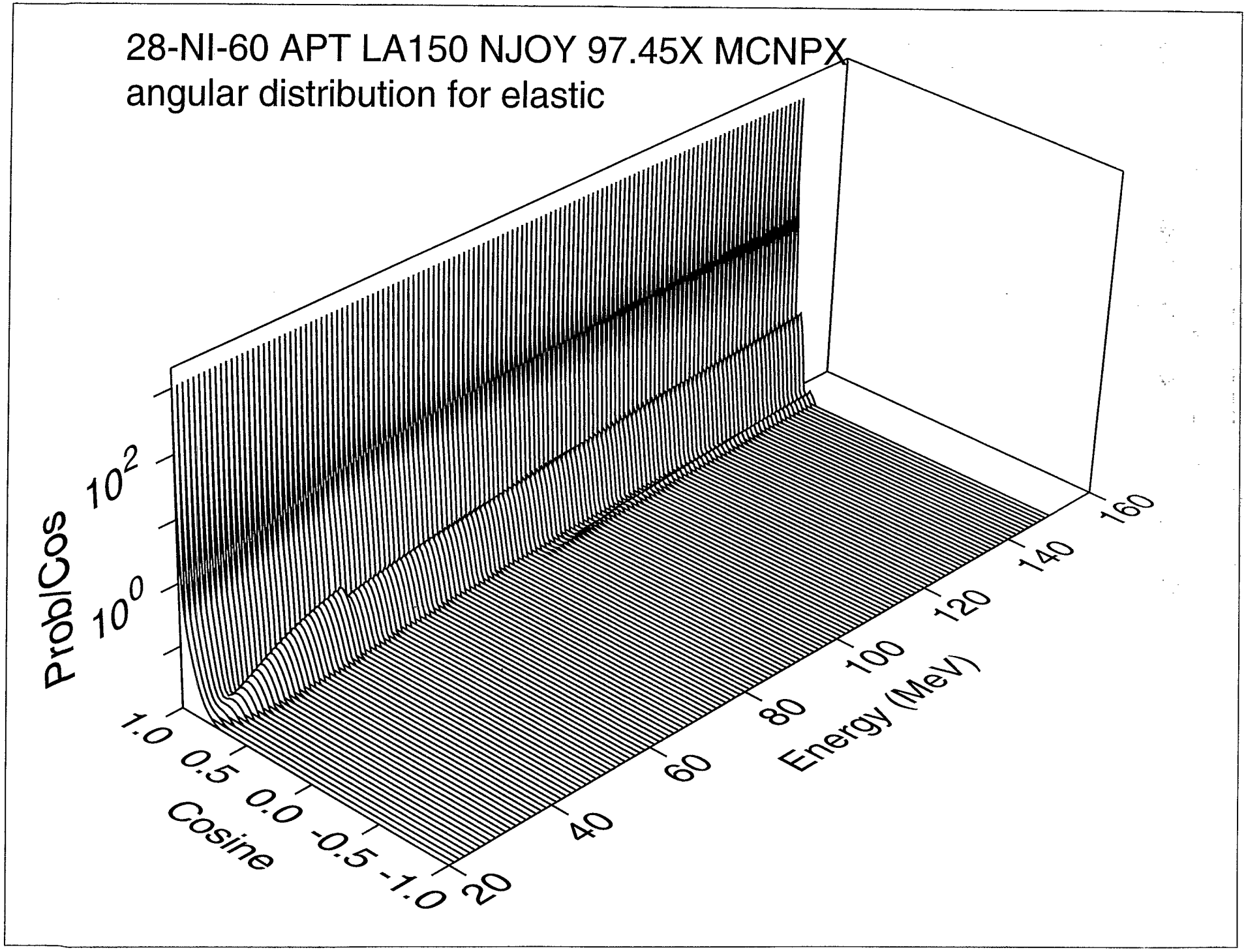


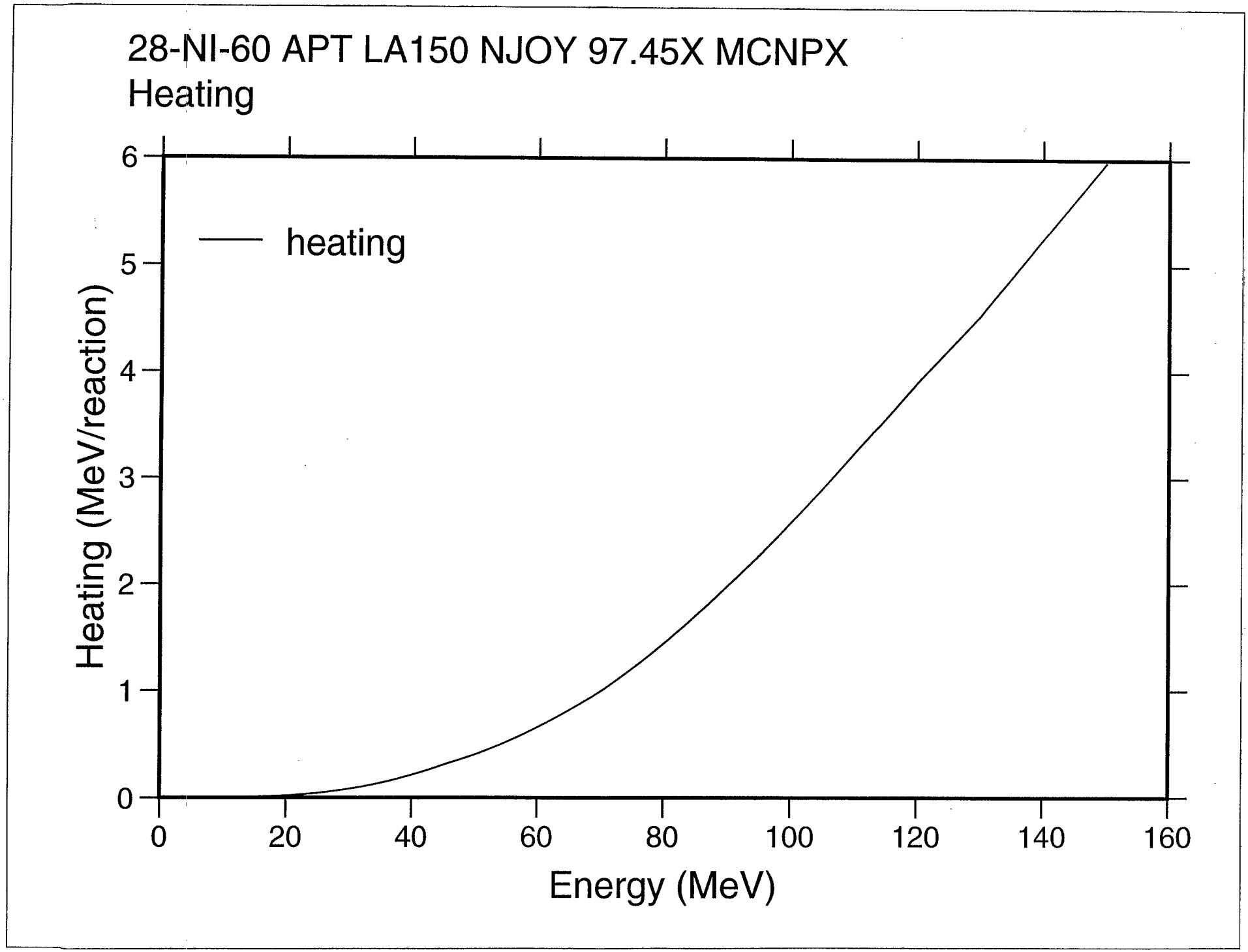







28-NI-60 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
0
2
4
6
8
10
12
14
16
18
20


28-NI-60 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
ProbCos
10^2
10^0
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


28-NI-60 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
1
2
3
4
5
6
0
20
40
60
80
100
120
140
160

EVALUATION OF p + 61Ni CROSS SECTIONS FOR THE ENERGY RANGE 1 to 150 MeV

S. Chiba, M. B. Chadwick, P. G. Young, and A. J. Koning

24 September 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident proton energy range from 1 to 150 MeV. The evaluation utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above are:

MF=3	MT= 2	Integral of nuclear plus interference components of the elastic scattering cross section
	MT= 5	Sum of binary (p,n') and (p,x) reactions
MF=6	MT= 2	Elastic (p,p) angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
	MT= 5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Ni58 and p + Ni58 reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic proton angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Gilbert and Cameron [Gi65] and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged- particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray

transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

DETAILS OF THE p + 61Ni ANALYSIS

The neutron optical model potential was adjusted to reproduce the measured total cross section data (Ci68, Pe73, Sc73, La83, Sm92, Di97) and s-wave strength function (Mu81). The total cross section data for natural Ni and Ni-58 were used because there was no data for Ni-61. These data were transformed to the Ni-61 cross section according to A*(2/3) law.

The parameter estimation was carried out based on Marquart-Bayesian approach (Sm91), where ECIS95 code was used for the optical model calculation. We have employed the energy dependence of the optical potential similar to Delaroche's work(De89). The initial potential parameters were adopted from Koning and Delaroche (Ko97). Total of 7 parameters concerning the central potential depth were estimated with associated covariance matrix, while the geometircal parameters were fixed to the result of a similar search for n + Ni-58. Presently obtained potential was used for the calculation of neutron transmission coefficients in the energy region above 20 MeV. Below 20 MeV, the Harper neutron potential (Ha82) was used for the calculation of transmission coefficients.

The proton optical potential was also searched for to obtain a good description of proton-total reaction cross section as predicted by Wellisch-Axen systematic (We96) above 50 MeV. The parameter estimation was carried out by the Marquart-Bayesian approach similar to the neutron OMP, but trying to seek the best parameter to reproduce the reaction cross sections compiled by Carlson (Ca96) and Wellisch values. The experimental data in Carlson (Ca96) was scaled for Ni-61 according to A**(2/3) law. In this search, the geometrical parameters were fixed to be same as the neutron potential. The present potential gives a good description of the proton total reaction cross section from 10 MeV to 250 MeV. However, after some trial and error to reproduce both the elastic scattering and reaction cross section data for Ni-58, we have employed the following combination of proton potentials:

0 to 5 MeV	:	Harper potential (Ha82)
6 to 47 MeV	:	Koning and Delaroche (Ko97)
48 to 260 MeV	:	Present OMP

For deuterons, the Lohr-Haeberli [Lo74] global potential was used; for alpha particles the McFadden-Satchler [Mc66] potential was used; and for tritons the Beccheti-Greenlees [Be71] potential was used. The He-3 channel was ignored.

The direct collective inelastic scattering to the following levels in Ni-61 was considered by the DWBA-mode calculation of ECIS95:

Jpi	Ex(MeV)	Deformation length
1/2-	0.2830	0.31703
5/2-	0.9086	0.54912
7/2-	1.0152	0.63407
3/2-	1.0996	0.44835

The deformation lengths were estimated assuming a weak-coupling of

3/2- neutron hole to the excited 2+ core in Ni-62.

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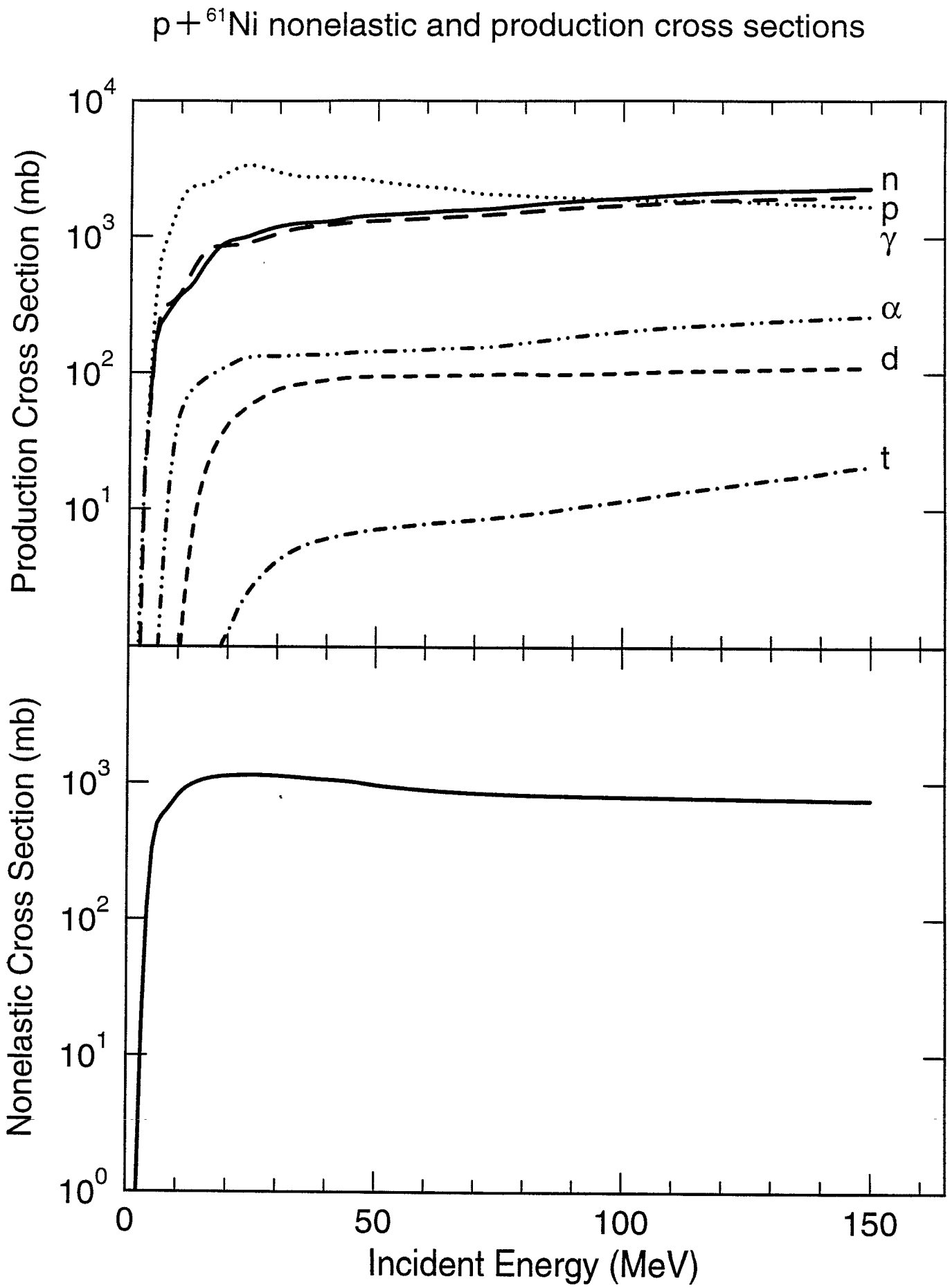
28061 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+00	9.226E-04	0.000E+00	0.000E+00	5.281E-04	0.000E+00	0.000E+00	0.000E+00	3.812E-12	1.079E-03
3.000E+00	1.774E-02	0.000E+00	0.000E+00	1.703E-02	0.000E+00	0.000E+00	0.000E+00	4.959E-08	1.892E-02
4.000E+00	1.186E-01	0.000E+00	6.504E-02	5.309E-02	0.000E+00	0.000E+00	0.000E+00	5.440E-06	7.616E-02
5.000E+00	3.296E-01	0.000E+00	1.660E-01	1.630E-01	0.000E+00	0.000E+00	0.000E+00	1.814E-04	3.391E-01
6.000E+00	5.006E-01	0.000E+00	2.286E-01	2.704E-01	0.000E+00	0.000E+00	0.000E+00	1.153E-03	6.676E-01
7.000E+00	5.768E-01	0.000E+00	2.600E-01	3.113E-01	8.482E-09	0.000E+00	0.000E+00	5.044E-03	8.976E-01
8.000E+00	6.358E-01	0.000E+00	2.965E-01	3.230E-01	6.349E-06	0.000E+00	0.000E+00	1.579E-02	1.136E+00
9.000E+00	7.118E-01	0.000E+00	3.339E-01	3.455E-01	1.163E-04	0.000E+00	0.000E+00	3.173E-02	1.454E+00
1.000E+01	7.966E-01	0.000E+00	3.707E-01	3.818E-01	5.744E-04	0.000E+00	0.000E+00	4.846E-02	1.809E+00
1.100E+01	8.720E-01	0.000E+00	3.989E-01	4.452E-01	1.890E-03	0.000E+00	0.000E+00	6.170E-02	2.098E+00
1.200E+01	9.311E-01	0.000E+00	4.303E-01	5.259E-01	4.372E-03	1.206E-08	0.000E+00	7.130E-02	2.273E+00
1.300E+01	9.769E-01	0.000E+00	4.781E-01	6.141E-01	8.050E-03	3.221E-07	0.000E+00	7.833E-02	2.345E+00
1.400E+01	1.015E+00	0.000E+00	5.477E-01	6.983E-01	1.263E-02	1.872E-05	0.000E+00	8.401E-02	2.358E+00
1.500E+01	1.046E+00	0.000E+00	6.276E-01	7.680E-01	1.768E-02	1.354E-04	0.000E+00	8.998E-02	2.399E+00
1.600E+01	1.072E+00	0.000E+00	6.998E-01	8.217E-01	2.291E-02	3.629E-04	0.000E+00	9.491E-02	2.481E+00
1.700E+01	1.092E+00	0.000E+00	7.770E-01	8.454E-01	2.807E-02	6.183E-04	0.000E+00	9.927E-02	2.600E+00
1.800E+01	1.106E+00	0.000E+00	8.458E-01	8.538E-01	3.312E-02	8.572E-04	0.000E+00	1.041E-01	2.737E+00
1.900E+01	1.117E+00	0.000E+00	8.984E-01	8.581E-01	3.780E-02	1.095E-03	0.000E+00	1.089E-01	2.891E+00
2.000E+01	1.124E+00	0.000E+00	9.309E-01	8.653E-01	4.291E-02	1.279E-03	0.000E+00	1.134E-01	2.996E+00
2.200E+01	1.135E+00	0.000E+00	9.718E-01	8.752E-01	5.016E-02	1.857E-03	0.000E+00	1.244E-01	3.242E+00
2.400E+01	1.141E+00	0.000E+00	1.015E+00	9.074E-01	5.773E-02	2.465E-03	0.000E+00	1.302E-01	3.343E+00
2.600E+01	1.142E+00	0.000E+00	1.077E+00	9.530E-01	6.397E-02	3.061E-03	0.000E+00	1.331E-01	3.264E+00
2.800E+01	1.137E+00	0.000E+00	1.136E+00	1.005E+00	7.043E-02	3.642E-03	0.000E+00	1.332E-01	3.105E+00
3.000E+01	1.127E+00	0.000E+00	1.186E+00	1.060E+00	7.609E-02	4.201E-03	0.000E+00	1.332E-01	2.950E+00
3.500E+01	1.094E+00	0.000E+00	1.260E+00	1.165E+00	8.357E-02	5.339E-03	0.000E+00	1.366E-01	2.743E+00
4.000E+01	1.059E+00	0.000E+00	1.298E+00	1.218E+00	8.904E-02	6.097E-03	0.000E+00	1.374E-01	2.735E+00
4.500E+01	1.027E+00	0.000E+00	1.391E+00	1.281E+00	9.317E-02	6.661E-03	0.000E+00	1.423E-01	2.685E+00
5.000E+01	9.668E-01	0.000E+00	1.443E+00	1.311E+00	9.443E-02	7.128E-03	0.000E+00	1.446E-01	2.538E+00
5.500E+01	9.246E-01	0.000E+00	1.475E+00	1.338E+00	9.471E-02	7.465E-03	0.000E+00	1.458E-01	2.413E+00
6.000E+01	8.920E-01	0.000E+00	1.514E+00	1.371E+00	9.542E-02	7.821E-03	0.000E+00	1.486E-01	2.326E+00
6.500E+01	8.665E-01	0.000E+00	1.559E+00	1.405E+00	9.625E-02	8.109E-03	0.000E+00	1.520E-01	2.253E+00
7.000E+01	8.474E-01	0.000E+00	1.589E+00	1.442E+00	9.709E-02	8.372E-03	0.000E+00	1.537E-01	2.098E+00
7.500E+01	8.332E-01	0.000E+00	1.638E+00	1.484E+00	9.823E-02	8.743E-03	0.000E+00	1.587E-01	2.050E+00
8.000E+01	8.227E-01	0.000E+00	1.708E+00	1.533E+00	9.887E-02	9.175E-03	0.000E+00	1.676E-01	2.007E+00
8.500E+01	8.147E-01	0.000E+00	1.776E+00	1.589E+00	9.767E-02	9.683E-03	0.000E+00	1.769E-01	1.968E+00
9.000E+01	8.083E-01	0.000E+00	1.841E+00	1.645E+00	9.864E-02	1.038E-02	0.000E+00	1.873E-01	1.955E+00
9.500E+01	8.029E-01	0.000E+00	1.902E+00	1.691E+00	9.988E-02	1.099E-02	0.000E+00	1.958E-01	1.926E+00
1.000E+02	7.980E-01	0.000E+00	1.948E+00	1.729E+00	1.010E-01	1.164E-02	0.000E+00	2.033E-01	1.903E+00
1.100E+02	7.892E-01	0.000E+00	2.055E+00	1.808E+00	1.036E-01	1.325E-02	0.000E+00	2.189E-01	1.881E+00
1.200E+02	7.806E-01	0.000E+00	2.140E+00	1.870E+00	1.053E-01	1.484E-02	0.000E+00	2.304E-01	1.861E+00
1.300E+02	7.722E-01	0.000E+00	2.210E+00	1.928E+00	1.077E-01	1.673E-02	0.000E+00	2.425E-01	1.799E+00
1.400E+02	7.637E-01	0.000E+00	2.257E+00	1.975E+00	1.093E-01	1.856E-02	0.000E+00	2.522E-01	1.756E+00
1.500E+02	7.554E-01	0.000E+00	2.289E+00	2.018E+00	1.100E-01	2.066E-02	0.000E+00	2.618E-01	1.701E+00

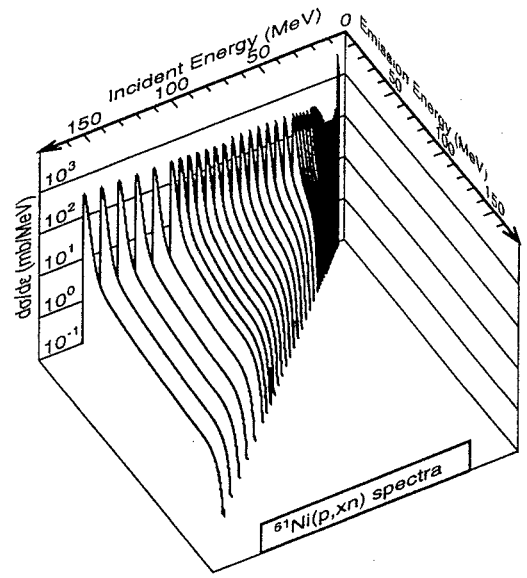
28061 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

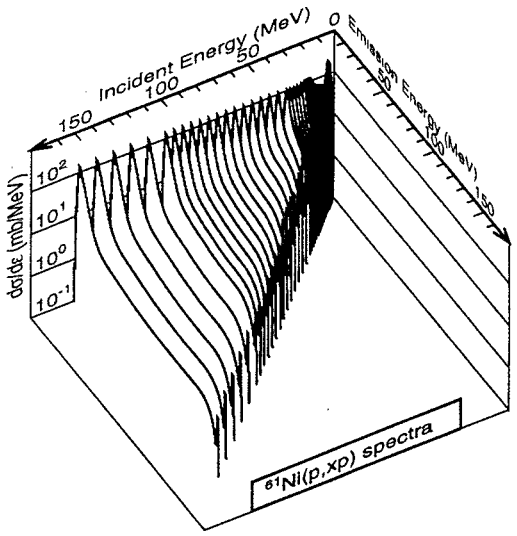
Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+00	0.000E+00	1.882E+00	0.000E+00	0.000E+00	0.000E+00	2.168E+00	2.057E+00
3.000E+00	0.000E+00	2.727E+00	0.000E+00	0.000E+00	0.000E+00	3.137E+00	4.953E-01
4.000E+00	8.062E-01	3.301E+00	0.000E+00	0.000E+00	0.000E+00	4.020E+00	5.412E-01
5.000E+00	1.102E+00	4.029E+00	0.000E+00	0.000E+00	0.000E+00	4.937E+00	8.206E-01
6.000E+00	1.412E+00	4.705E+00	0.000E+00	0.000E+00	0.000E+00	5.745E+00	9.920E-01
7.000E+00	1.757E+00	5.234E+00	1.185E+00	0.000E+00	0.000E+00	6.550E+00	1.175E+00
8.000E+00	2.045E+00	5.676E+00	2.130E+00	0.000E+00	0.000E+00	7.341E+00	1.341E+00
9.000E+00	2.308E+00	5.946E+00	3.057E+00	0.000E+00	0.000E+00	8.000E+00	1.494E+00
1.000E+01	2.533E+00	6.093E+00	3.751E+00	0.000E+00	0.000E+00	8.511E+00	1.637E+00
1.100E+01	2.708E+00	6.062E+00	4.345E+00	0.000E+00	0.000E+00	8.904E+00	1.745E+00
1.200E+01	2.793E+00	5.954E+00	4.879E+00	9.944E-01	0.000E+00	9.181E+00	1.814E+00
1.300E+01	2.762E+00	5.863E+00	5.321E+00	1.861E+00	0.000E+00	9.380E+00	1.827E+00
1.400E+01	2.647E+00	5.814E+00	5.887E+00	2.730E+00	0.000E+00	9.511E+00	1.781E+00
1.500E+01	2.560E+00	5.818E+00	6.470E+00	3.485E+00	0.000E+00	9.580E+00	1.712E+00
1.600E+01	2.515E+00	5.999E+00	7.061E+00	4.064E+00	0.000E+00	9.620E+00	1.643E+00
1.700E+01	2.512E+00	6.252E+00	7.663E+00	4.558E+00	0.000E+00	9.640E+00	1.592E+00
1.800E+01	2.556E+00	6.547E+00	8.276E+00	5.060E+00	0.000E+00	9.679E+00	1.577E+00
1.900E+01	2.637E+00	6.829E+00	8.880E+00	5.511E+00	0.000E+00	9.754E+00	1.591E+00
2.000E+01	2.791E+00	7.121E+00	9.462E+00	5.903E+00	0.000E+00	9.869E+00	1.698E+00
2.200E+01	3.105E+00	7.708E+00	1.058E+01	6.773E+00	0.000E+00	1.006E+01	1.781E+00
2.400E+01	3.359E+00	8.189E+00	1.168E+01	7.662E+00	0.000E+00	1.032E+01	1.835E+00
2.600E+01	3.543E+00	8.594E+00	1.267E+01	8.526E+00	0.000E+00	1.057E+01	1.829E+00
2.800E+01	3.713E+00	8.966E+00	1.377E+01	9.337E+00	0.000E+00	1.078E+01	1.796E+00

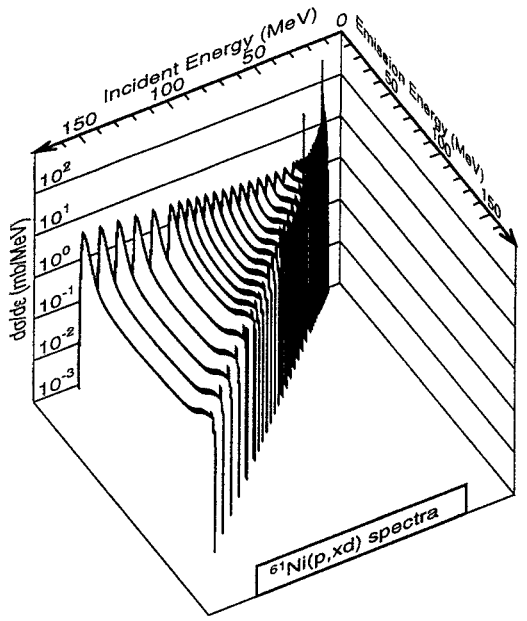
3.000E+01	3.920E+00	9.327E+00	1.488E+01	1.009E+01	0.000E+00	1.095E+01	1.770E+00
3.500E+01	4.512E+00	1.039E+01	1.756E+01	1.193E+01	0.000E+00	1.127E+01	1.763E+00
4.000E+01	5.139E+00	1.161E+01	2.041E+01	1.364E+01	0.000E+00	1.163E+01	1.784E+00
4.500E+01	5.617E+00	1.251E+01	2.323E+01	1.505E+01	0.000E+00	1.191E+01	1.789E+00
5.000E+01	6.013E+00	1.317E+01	2.585E+01	1.635E+01	0.000E+00	1.213E+01	1.803E+00
5.500E+01	6.458E+00	1.401E+01	2.827E+01	1.754E+01	0.000E+00	1.234E+01	1.813E+00
6.000E+01	6.884E+00	1.473E+01	3.053E+01	1.845E+01	0.000E+00	1.251E+01	1.803E+00
6.500E+01	7.298E+00	1.543E+01	3.286E+01	1.925E+01	0.000E+00	1.265E+01	1.808E+00
7.000E+01	7.785E+00	1.610E+01	3.513E+01	1.993E+01	0.000E+00	1.282E+01	1.714E+00
7.500E+01	8.206E+00	1.672E+01	3.718E+01	2.027E+01	0.000E+00	1.293E+01	1.707E+00
8.000E+01	8.525E+00	1.723E+01	3.903E+01	2.029E+01	0.000E+00	1.299E+01	1.719E+00
8.500E+01	8.859E+00	1.773E+01	4.006E+01	2.018E+01	0.000E+00	1.306E+01	1.741E+00
9.000E+01	9.169E+00	1.815E+01	4.126E+01	1.970E+01	0.000E+00	1.312E+01	1.745E+00
9.500E+01	9.497E+00	1.867E+01	4.286E+01	1.940E+01	0.000E+00	1.319E+01	1.760E+00
1.000E+02	9.865E+00	1.925E+01	4.438E+01	1.903E+01	0.000E+00	1.328E+01	1.757E+00
1.100E+02	1.047E+01	2.032E+01	4.701E+01	1.802E+01	0.000E+00	1.342E+01	1.766E+00
1.200E+02	1.114E+01	2.152E+01	4.942E+01	1.708E+01	0.000E+00	1.360E+01	1.767E+00
1.300E+02	1.176E+01	2.264E+01	5.161E+01	1.595E+01	0.000E+00	1.375E+01	1.780E+00
1.400E+02	1.246E+01	2.384E+01	5.362E+01	1.484E+01	0.000E+00	1.389E+01	1.757E+00
1.500E+02	1.319E+01	2.500E+01	5.441E+01	1.378E+01	0.000E+00	1.404E+01	1.759E+00

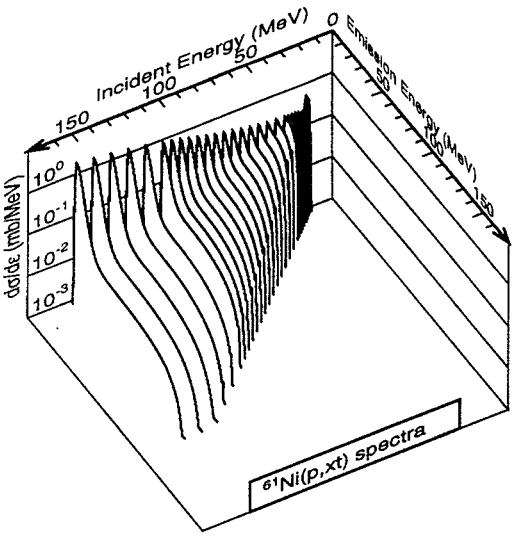

p + 61Ni nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
n
p
γ
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
10^1
10^0
0
50
100
150
Incident Energy (MeV)

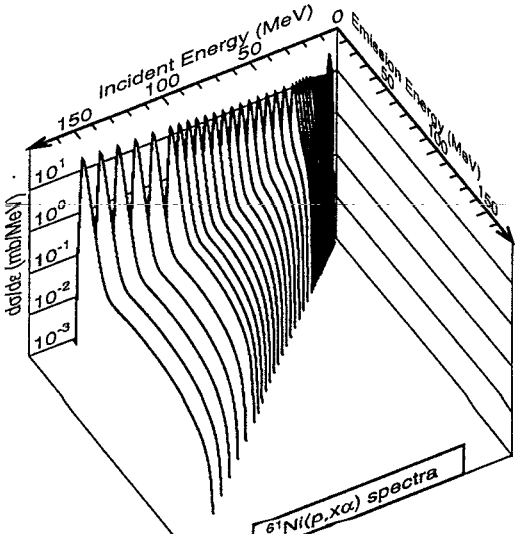
p + ^{61}Ni angle-integrated emission spectra

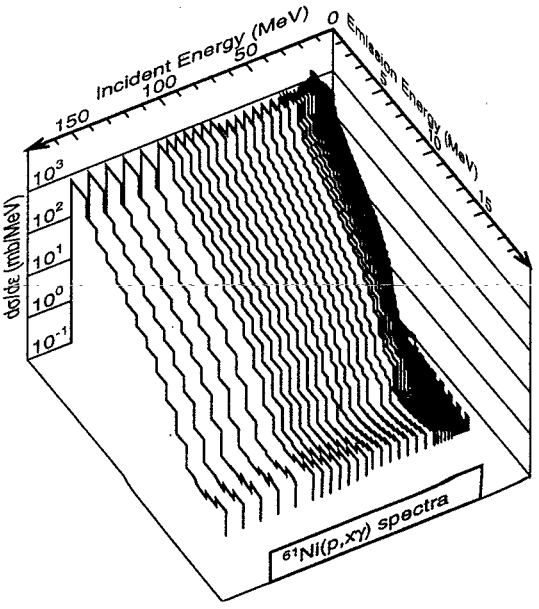




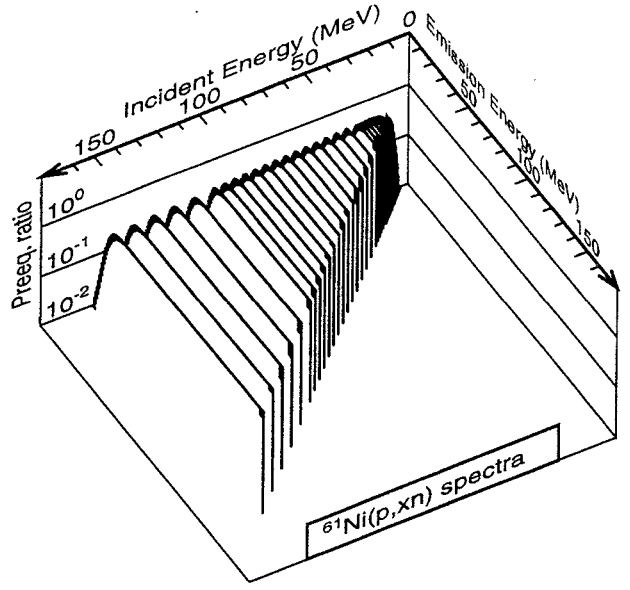


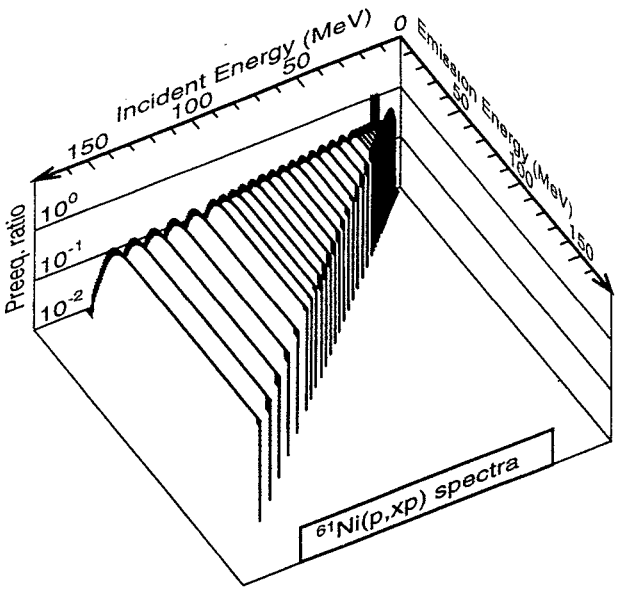


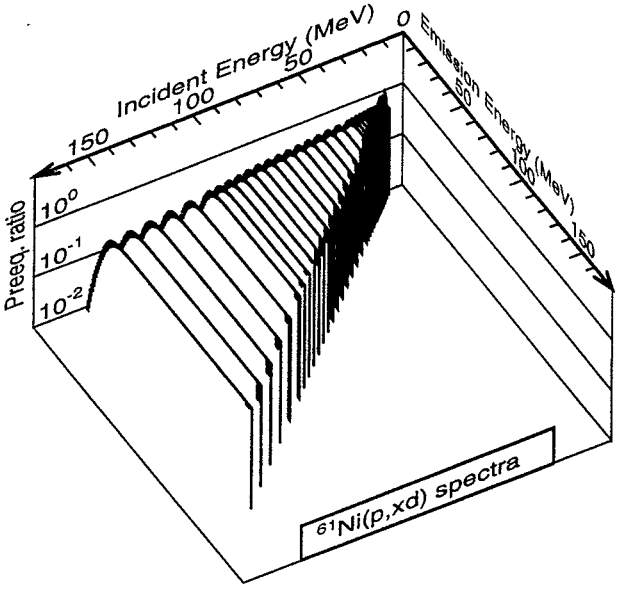


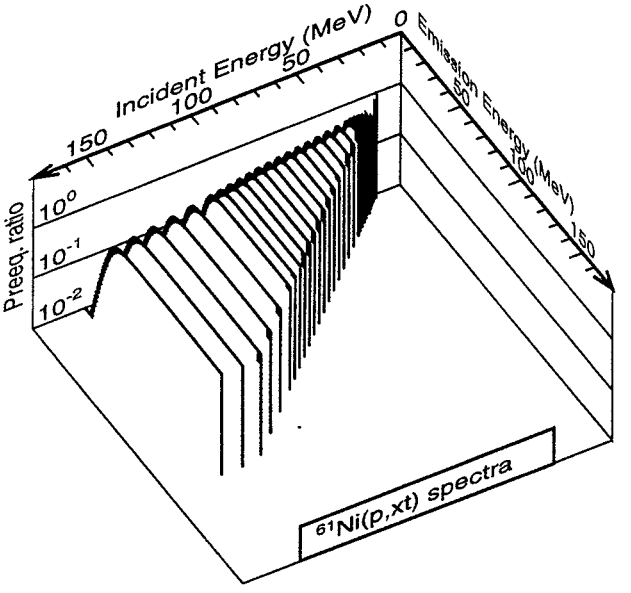


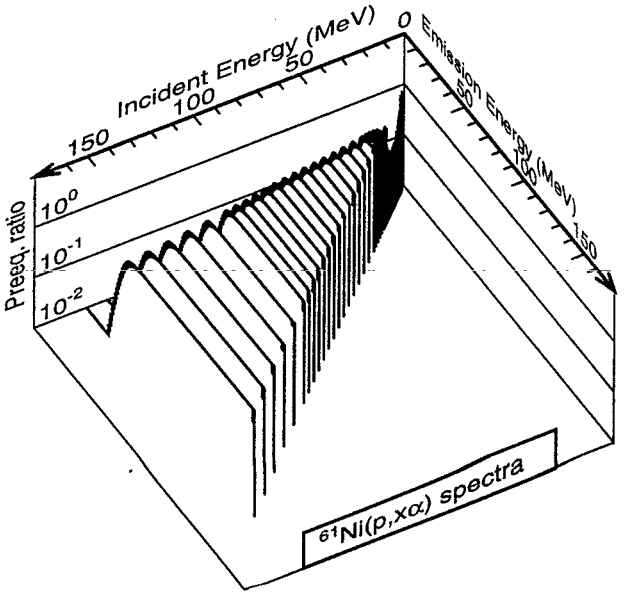
p + ^{61}Ni Kalbach preequilibrium ratios

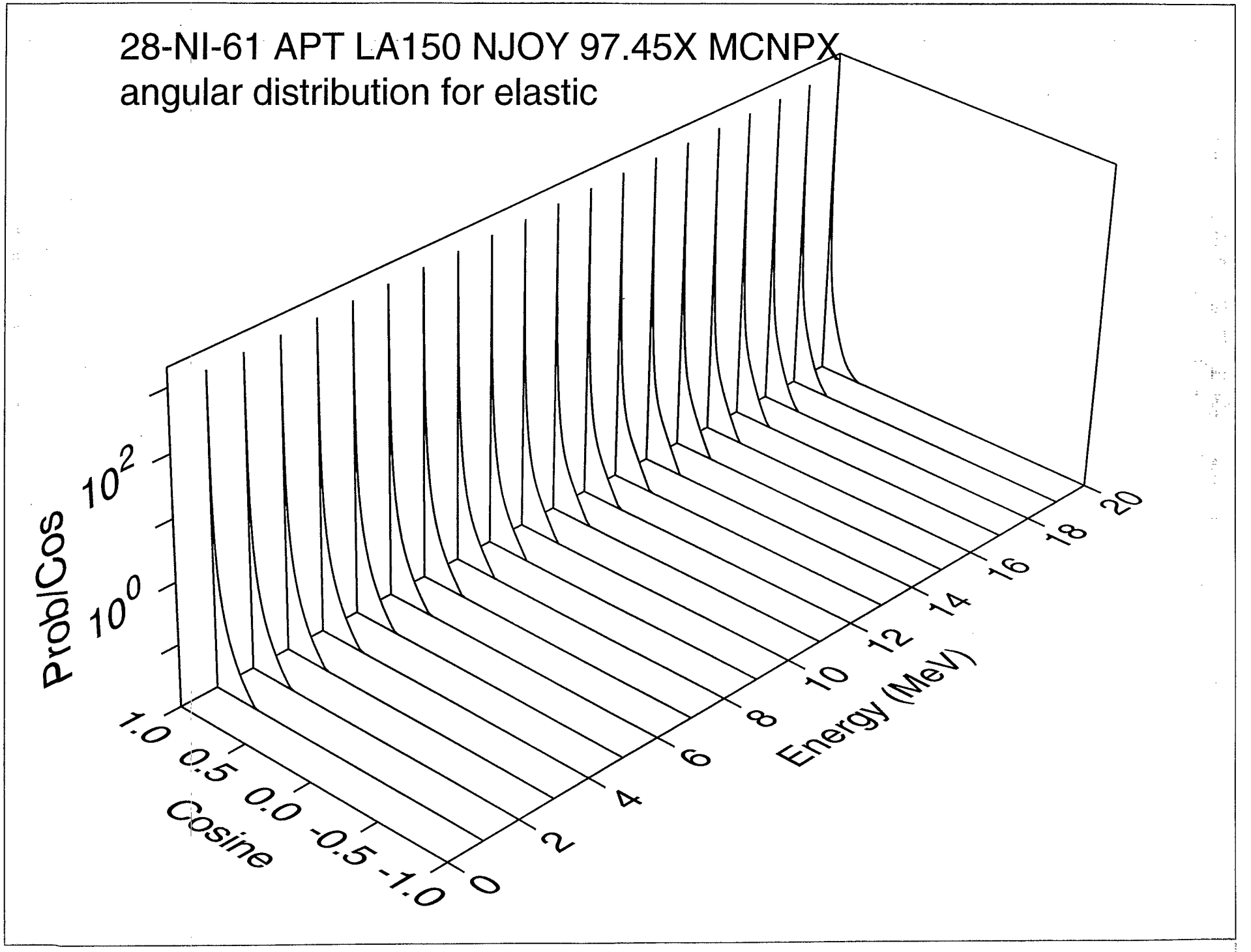


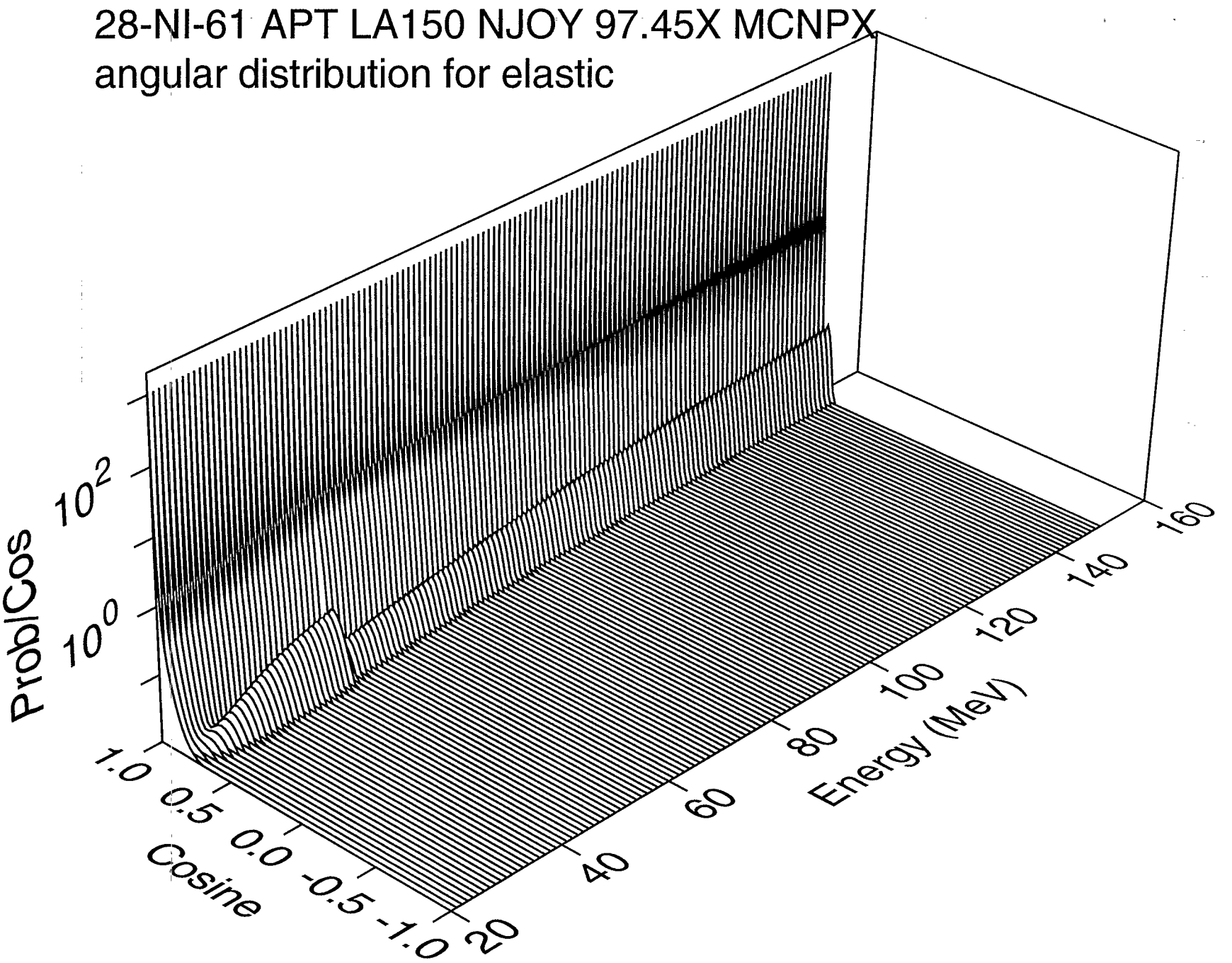


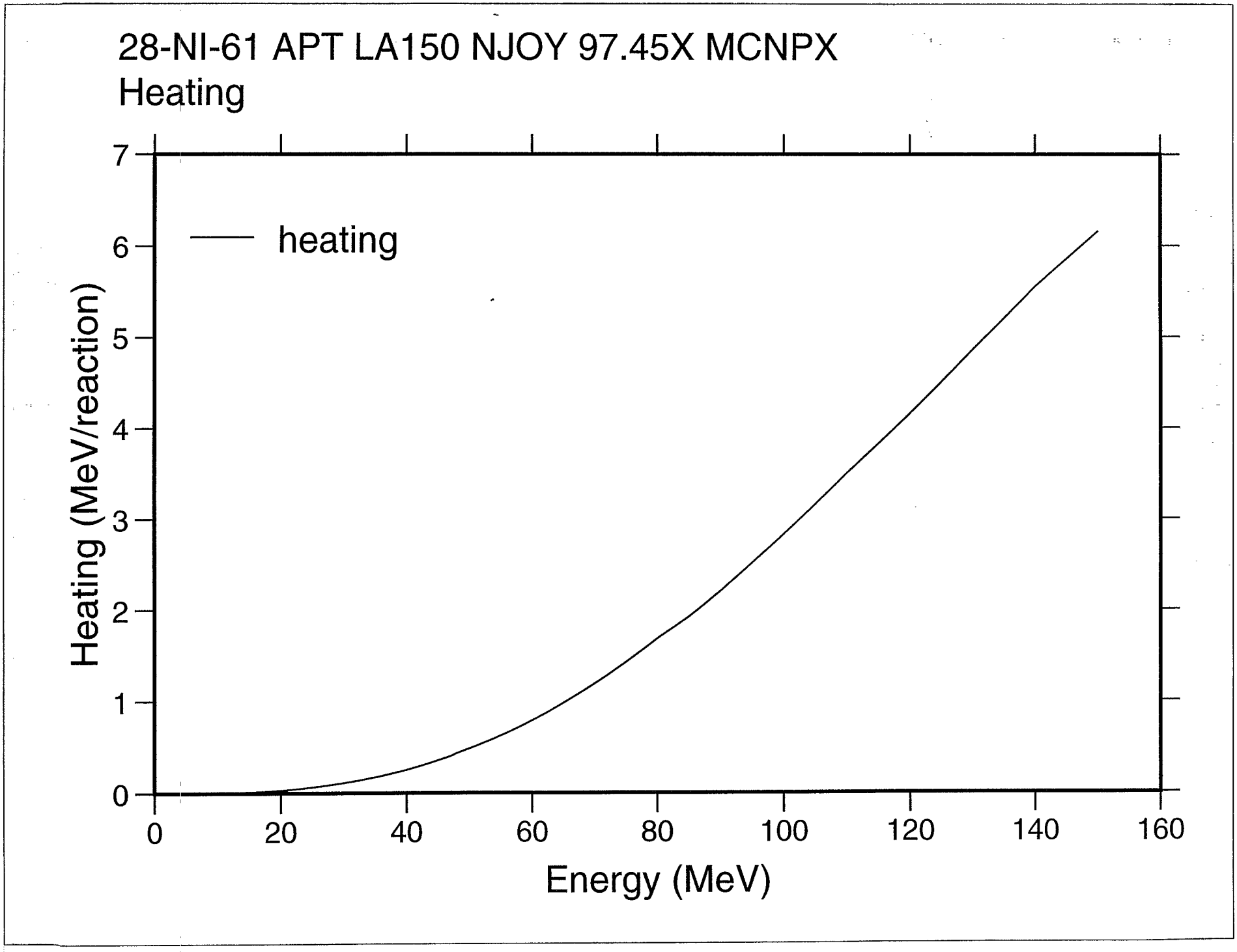







28-NI-61 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
1.0
0.5
0.0
-0.5
-1.0
Cosine
0
2
4
6
8
10
12
14
16
18
20
Energy (MeV)


28-NI-61 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


28-NI-61 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
1
2
3
4
5
6
7
0
20
40
60
80
100
120
140
160

EVALUATION OF p + 62Ni CROSS SECTIONS FOR THE ENERGY RANGE 1 to 150 MeV

S. Chiba, M. B. Chadwick, P. G. Young, and A. J. Koning

24 September 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident proton energy range from 1 to 150 MeV. The evaluation utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above are:

MF=3	MT= 2	Integral of nuclear plus interference components of the elastic scattering cross section
	MT= 5	Sum of binary (p,n') and (p,x) reactions
MF=6	MT= 2	Elastic (p,p) angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
	MT= 5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Ni58 and p + Ni58 reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic proton angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Gilbert and Cameron [Gi65] and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged- particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray

transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

DETAILS OF THE p + 62Ni ANALYSIS

The neutron optical model potential was adjusted to reproduce the measured total cross section data (Ci68, Pe73, Sc73, La83, Di97, Fa66, Du67) and s-wave strength function (Mu81). The data for natural Ni and Ni-58 were also used because there was not enough data for Ni-62 above MeV region. The total cross section data for natural Ni and Ni-58 were transformed to the Ni-62 cross section according to A*(2/3) law.

The parameter estimation was carried out based on Marquart-Bayesian approach (Sm91), where ECIS95 Ra96) code was used for the optical model calculation. We have employed the energy dependence of the optical potential similar to Delaroche's work(De89). The initial potential parameters were adopted from Koning and Delaroche (Ko97). Total of 7 parameters concerning the central potential depth were estimated with associated covariance matrix, while the geometircal parameters were fixed to the result of a similar search for n + Ni-58. Presently obtained potential was used for the calculation of neutron transmission coefficients in the energy region above 20 MeV. Below 20 MeV, the Harper neutron potential (Ha82) was used for the calculation of transmission coefficients.

The proton optical potential was also searched for to obtain a good description of proton-total reaction cross section as predicted by Wellisch-Axen systematic (We96) above 50 MeV. The parameter estimation was carried out by the Marquart-Bayesian approach similar to the neutron OMP, but trying to seek the best parameter to reproduce the reaction cross sections compiled by Carlson (Ca96) and Wellisch values. The experimental data in Carlson (Ca96) was scaled for Ni-62 according to A**(2/3) law. In this search, the geometrical parameters were fixed to be same as the neutron potential. The present potential gives a good description of the proton total reaction cross section from 10 MeV to 250 MeV. However, after some trial and error to reproduce both the elastic scattering and reaction cross section data for Ni-58, we have employed the following combination of proton potentials:

0 to 5 MeV	:	Harper potential (Ha82)
6 to 47 MeV	:	Koning and Delaroche (Ko97)
48 to 260 MeV	:	Present OMP

For deuterons, the Lohr-Haeberli [Lo74] global potential was used; for alpha particles the McFadden-Satchler [Mc66] potential was used; and for tritons the Beccheti-Greenlees [Be71] potential was used. The He-3 channel was ignored.

The direct collective inelastic scattering to the following levels in Ni-62 was considered by the DWBA-mode calculation of ECIS95 (Ra96):

Jpi	Ex(MeV)	Deformation length
2+	1.173	1.008
3-	3.757	0.83

The data deformation length for the 2+ state was retrieved from

the literature (Ra87). For the 3- level, it was estimated to be an average of the quantity for Ni-58 and Ni-60.

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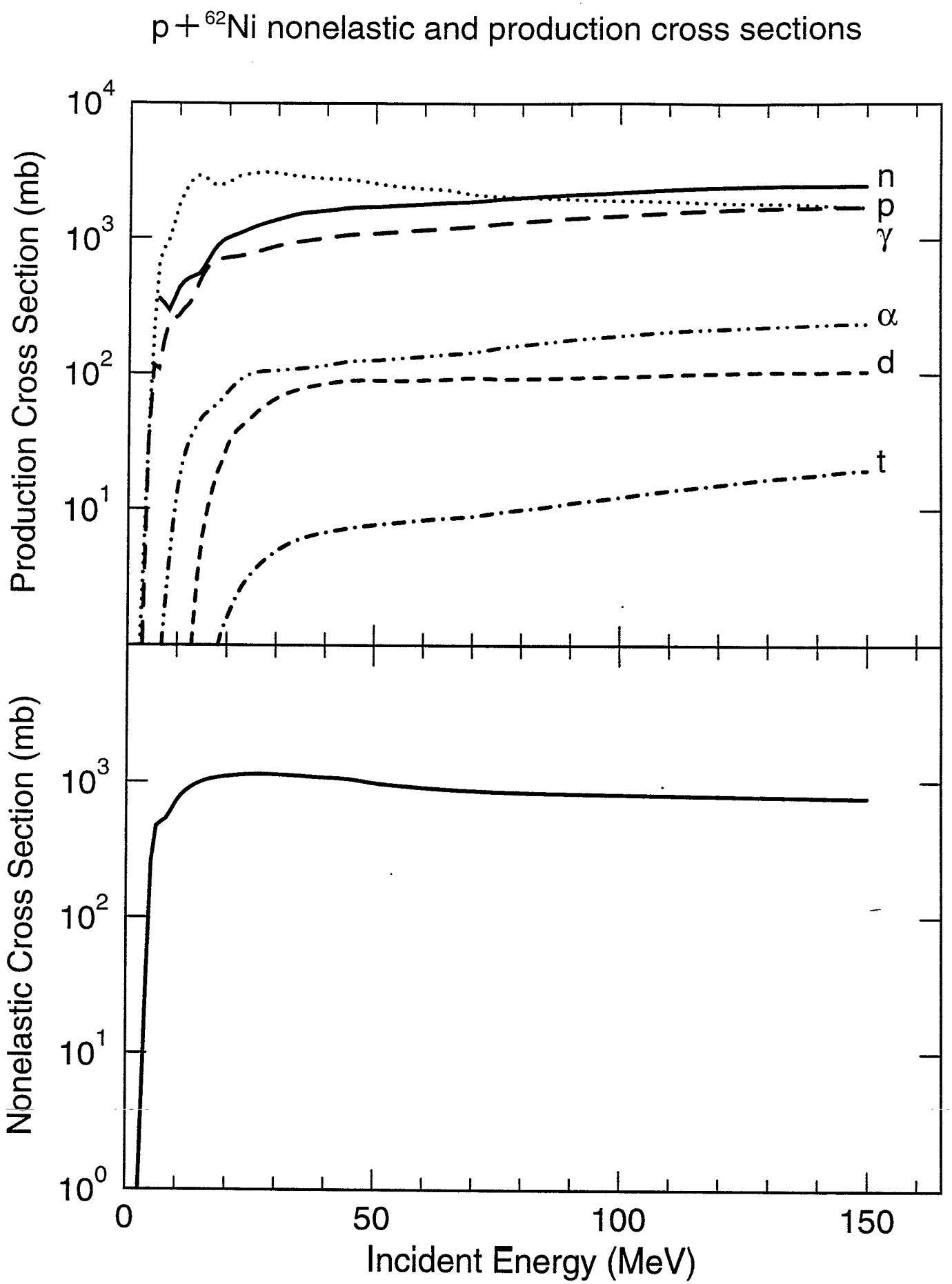
28062 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+00	4.579E-04	0.000E+00	0.000E+00	6.196E-08	0.000E+00	0.000E+00	0.000E+00	7.819E-09	6.632E-04
3.000E+00	2.922E-03	0.000E+00	0.000E+00	1.363E-03	0.000E+00	0.000E+00	0.000E+00	4.612E-08	3.525E-03
4.000E+00	3.402E-02	0.000E+00	0.000E+00	3.201E-02	0.000E+00	0.000E+00	0.000E+00	8.014E-06	3.532E-02
4.808E+00	2.155E-01	0.000E+00	1.180E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
5.000E+00	2.599E-01	0.000E+00	1.423E-01	1.159E-01	0.000E+00	0.000E+00	0.000E+00	1.878E-04	2.078E-01
6.000E+00	4.690E-01	0.000E+00	3.593E-01	1.088E-01	0.000E+00	0.000E+00	0.000E+00	3.877E-04	6.613E-01
7.000E+00	5.055E-01	0.000E+00	3.296E-01	1.743E-01	0.000E+00	0.000E+00	0.000E+00	1.225E-03	8.332E-01
8.000E+00	5.371E-01	0.000E+00	2.958E-01	2.376E-01	0.000E+00	0.000E+00	0.000E+00	3.296E-03	9.756E-01
9.000E+00	6.147E-01	0.000E+00	3.524E-01	2.543E-01	0.000E+00	0.000E+00	0.000E+00	7.629E-03	1.307E+00
1.000E+01	7.147E-01	0.000E+00	4.289E-01	2.706E-01	2.434E-08	0.000E+00	0.000E+00	1.470E-02	1.750E+00
1.100E+01	7.987E-01	0.000E+00	4.737E-01	3.018E-01	1.377E-05	5.342E-14	0.000E+00	2.260E-02	2.138E+00
1.200E+01	8.613E-01	0.000E+00	5.033E-01	3.275E-01	2.246E-04	8.543E-08	0.000E+00	2.977E-02	2.494E+00
1.300E+01	9.128E-01	0.000E+00	5.230E-01	3.674E-01	1.150E-03	5.569E-06	0.000E+00	3.628E-02	2.793E+00
1.400E+01	9.584E-01	0.000E+00	5.417E-01	4.622E-01	3.207E-03	3.936E-05	0.000E+00	4.189E-02	2.890E+00
1.500E+01	9.975E-01	0.000E+00	6.075E-01	5.489E-01	6.495E-03	1.217E-04	0.000E+00	4.771E-02	2.846E+00
1.600E+01	1.028E+00	0.000E+00	6.977E-01	6.225E-01	1.000E-02	2.845E-04	0.000E+00	5.149E-02	2.649E+00
1.700E+01	1.052E+00	0.000E+00	8.010E-01	6.693E-01	1.397E-02	5.532E-04	0.000E+00	5.507E-02	2.486E+00
1.800E+01	1.070E+00	0.000E+00	8.886E-01	6.913E-01	1.849E-02	9.027E-04	0.000E+00	5.939E-02	2.431E+00
1.900E+01	1.084E+00	0.000E+00	9.564E-01	7.049E-01	2.266E-02	1.281E-03	0.000E+00	6.481E-02	2.489E+00
2.000E+01	1.096E+00	0.000E+00	9.999E-01	7.162E-01	2.887E-02	1.574E-03	0.000E+00	7.194E-02	2.555E+00
2.200E+01	1.115E+00	0.000E+00	1.067E+00	7.313E-01	3.776E-02	2.321E-03	0.000E+00	8.577E-02	2.852E+00
2.400E+01	1.129E+00	0.000E+00	1.144E+00	7.556E-01	4.350E-02	3.043E-03	0.000E+00	9.611E-02	2.955E+00
2.600E+01	1.136E+00	0.000E+00	1.224E+00	7.896E-01	5.124E-02	3.707E-03	0.000E+00	1.013E-01	3.023E+00
2.800E+01	1.136E+00	0.000E+00	1.295E+00	8.296E-01	5.848E-02	4.336E-03	0.000E+00	1.031E-01	3.066E+00
3.000E+01	1.130E+00	0.000E+00	1.359E+00	8.698E-01	6.486E-02	4.918E-03	0.000E+00	1.042E-01	3.011E+00
3.500E+01	1.105E+00	0.000E+00	1.511E+00	9.392E-01	7.629E-02	6.043E-03	0.000E+00	1.083E-01	2.828E+00
4.000E+01	1.074E+00	0.000E+00	1.578E+00	9.951E-01	8.294E-02	6.730E-03	0.000E+00	1.139E-01	2.728E+00
4.500E+01	1.045E+00	0.000E+00	1.658E+00	1.051E+00	8.758E-02	7.255E-03	0.000E+00	1.225E-01	2.671E+00
5.000E+01	9.787E-01	0.000E+00	1.688E+00	1.075E+00	8.795E-02	7.632E-03	0.000E+00	1.246E-01	2.520E+00
5.500E+01	9.371E-01	0.000E+00	1.727E+00	1.109E+00	8.738E-02	7.944E-03	0.000E+00	1.287E-01	2.385E+00
6.000E+01	9.056E-01	0.000E+00	1.764E+00	1.140E+00	8.849E-02	8.265E-03	0.000E+00	1.329E-01	2.306E+00
6.500E+01	8.806E-01	0.000E+00	1.813E+00	1.172E+00	8.956E-02	8.544E-03	0.000E+00	1.381E-01	2.240E+00
7.000E+01	8.615E-01	0.000E+00	1.844E+00	1.211E+00	9.214E-02	8.803E-03	0.000E+00	1.428E-01	2.084E+00
7.500E+01	8.472E-01	0.000E+00	1.921E+00	1.265E+00	9.051E-02	9.383E-03	0.000E+00	1.538E-01	2.021E+00
8.000E+01	8.362E-01	0.000E+00	1.985E+00	1.309E+00	9.074E-02	9.861E-03	0.000E+00	1.625E-01	1.991E+00
8.500E+01	8.276E-01	0.000E+00	2.043E+00	1.354E+00	9.177E-02	1.038E-02	0.000E+00	1.706E-01	1.965E+00
9.000E+01	8.205E-01	0.000E+00	2.105E+00	1.402E+00	9.316E-02	1.108E-02	0.000E+00	1.796E-01	1.949E+00
9.500E+01	8.144E-01	0.000E+00	2.155E+00	1.443E+00	9.433E-02	1.166E-02	0.000E+00	1.861E-01	1.928E+00
1.000E+02	8.088E-01	0.000E+00	2.204E+00	1.482E+00	9.527E-02	1.229E-02	0.000E+00	1.924E-01	1.918E+00
1.100E+02	7.987E-01	0.000E+00	2.299E+00	1.556E+00	9.781E-02	1.376E-02	0.000E+00	2.058E-01	1.879E+00
1.200E+02	7.891E-01	0.000E+00	2.375E+00	1.615E+00	1.002E-01	1.516E-02	0.000E+00	2.162E-01	1.822E+00
1.300E+02	7.797E-01	0.000E+00	2.441E+00	1.665E+00	1.028E-01	1.674E-02	0.000E+00	2.255E-01	1.805E+00
1.400E+02	7.706E-01	0.000E+00	2.482E+00	1.705E+00	1.031E-01	1.804E-02	0.000E+00	2.323E-01	1.781E+00
1.500E+02	7.617E-01	0.000E+00	2.507E+00	1.737E+00	1.043E-01	1.948E-02	0.000E+00	2.383E-01	1.735E+00

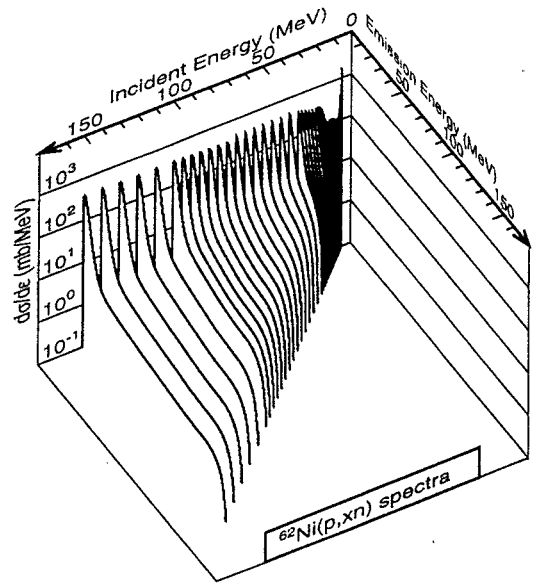
28062 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

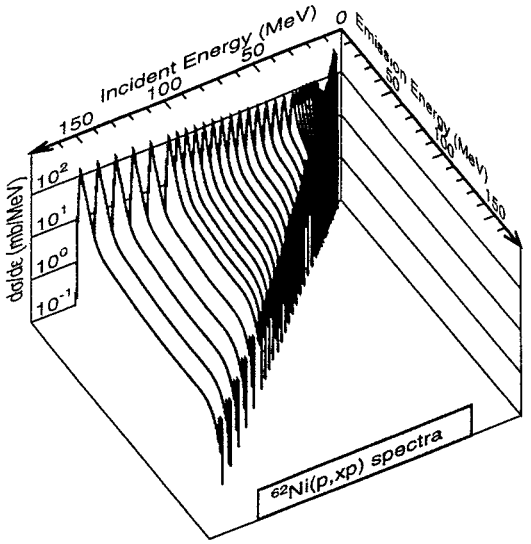
Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+00	0.000E+00	7.385E-01	0.000E+00	0.000E+00	0.000E+00	2.080E+00	3.960E+00
3.000E+00	0.000E+00	1.723E+00	0.000E+00	0.000E+00	0.000E+00	3.012E+00	3.153E+00
4.000E+00	0.000E+00	2.684E+00	0.000E+00	0.000E+00	0.000E+00	3.938E+00	1.518E+00
4.808E+00	1.233E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
5.000E+00	9.429E-02	3.489E+00	0.000E+00	0.000E+00	0.000E+00	4.853E+00	9.263E-01
6.000E+00	7.227E-01	4.196E+00	0.000E+00	0.000E+00	0.000E+00	5.687E+00	5.787E-01
7.000E+00	1.241E+00	5.069E+00	0.000E+00	0.000E+00	0.000E+00	6.429E+00	7.728E-01
8.000E+00	1.662E+00	5.940E+00	0.000E+00	0.000E+00	0.000E+00	7.094E+00	9.484E-01
9.000E+00	2.015E+00	6.319E+00	0.000E+00	0.000E+00	0.000E+00	7.690E+00	1.091E+00
1.000E+01	2.311E+00	6.522E+00	1.376E+00	0.000E+00	0.000E+00	8.147E+00	1.223E+00
1.100E+01	2.498E+00	6.836E+00	2.364E+00	8.466E-03	0.000E+00	8.503E+00	1.396E+00
1.200E+01	2.702E+00	7.114E+00	3.085E+00	1.701E+00	0.000E+00	8.778E+00	1.549E+00
1.300E+01	2.869E+00	7.039E+00	3.822E+00	2.622E+00	0.000E+00	9.009E+00	1.674E+00
1.400E+01	2.979E+00	6.518E+00	4.426E+00	3.463E+00	0.000E+00	9.191E+00	1.739E+00
1.500E+01	2.904E+00	6.017E+00	5.054E+00	3.977E+00	0.000E+00	9.328E+00	1.760E+00
1.600E+01	2.737E+00	6.106E+00	5.752E+00	4.389E+00	0.000E+00	9.428E+00	1.707E+00
1.700E+01	2.604E+00	6.344E+00	6.354E+00	4.777E+00	0.000E+00	9.462E+00	1.616E+00
1.800E+01	2.588E+00	6.678E+00	6.968E+00	5.181E+00	0.000E+00	9.427E+00	1.547E+00
1.900E+01	2.663E+00	7.002E+00	7.531E+00	5.659E+00	0.000E+00	9.388E+00	1.515E+00
2.000E+01	2.793E+00	7.369E+00	8.196E+00	6.124E+00	0.000E+00	9.346E+00	1.546E+00
2.200E+01	3.063E+00	8.058E+00	9.439E+00	7.079E+00	0.000E+00	9.477E+00	1.611E+00
2.400E+01	3.300E+00	8.677E+00	1.048E+01	8.006E+00	0.000E+00	9.735E+00	1.678E+00

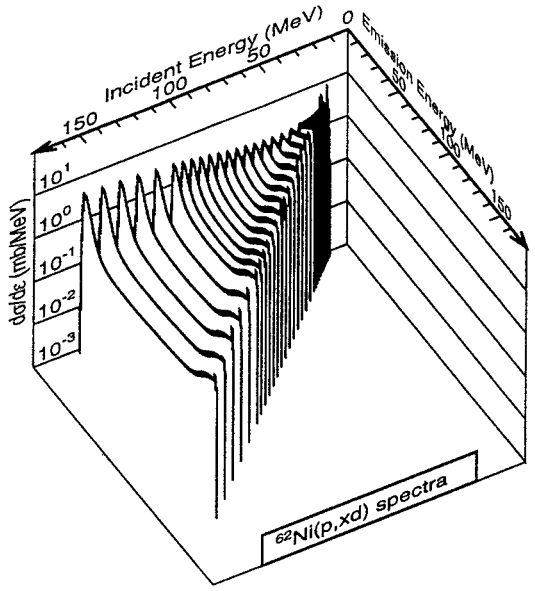
2.600E+01	3.472E+00	9.245E+00	1.160E+01	8.888E+00	0.000E+00	9.992E+00	1.684E+00
2.800E+01	3.636E+00	9.780E+00	1.270E+01	9.696E+00	0.000E+00	1.020E+01	1.716E+00
3.000E+01	3.809E+00	1.031E+01	1.383E+01	1.046E+01	0.000E+00	1.033E+01	1.729E+00
3.500E+01	4.234E+00	1.176E+01	1.673E+01	1.235E+01	0.000E+00	1.059E+01	1.689E+00
4.000E+01	4.781E+00	1.324E+01	1.971E+01	1.412E+01	0.000E+00	1.086E+01	1.657E+00
4.500E+01	5.265E+00	1.429E+01	2.273E+01	1.563E+01	0.000E+00	1.111E+01	1.667E+00
5.000E+01	5.666E+00	1.505E+01	2.543E+01	1.689E+01	0.000E+00	1.135E+01	1.693E+00
5.500E+01	6.069E+00	1.602E+01	2.785E+01	1.809E+01	0.000E+00	1.156E+01	1.703E+00
6.000E+01	6.469E+00	1.694E+01	3.033E+01	1.900E+01	0.000E+00	1.173E+01	1.702E+00
6.500E+01	6.857E+00	1.773E+01	3.276E+01	1.979E+01	0.000E+00	1.190E+01	1.689E+00
7.000E+01	7.280E+00	1.841E+01	3.556E+01	2.028E+01	0.000E+00	1.206E+01	1.654E+00
7.500E+01	7.571E+00	1.885E+01	3.678E+01	2.017E+01	0.000E+00	1.218E+01	1.665E+00
8.000E+01	7.916E+00	1.944E+01	3.847E+01	2.012E+01	0.000E+00	1.230E+01	1.674E+00
8.500E+01	8.263E+00	2.002E+01	4.027E+01	1.997E+01	0.000E+00	1.242E+01	1.680E+00
9.000E+01	8.583E+00	2.054E+01	4.177E+01	1.955E+01	0.000E+00	1.253E+01	1.693E+00
9.500E+01	8.942E+00	2.115E+01	4.338E+01	1.927E+01	0.000E+00	1.265E+01	1.715E+00
1.000E+02	9.293E+00	2.178E+01	4.478E+01	1.892E+01	0.000E+00	1.277E+01	1.733E+00
1.100E+02	9.958E+00	2.296E+01	4.733E+01	1.802E+01	0.000E+00	1.297E+01	1.712E+00
1.200E+02	1.061E+01	2.429E+01	5.005E+01	1.709E+01	0.000E+00	1.317E+01	1.734E+00
1.300E+02	1.125E+01	2.563E+01	5.235E+01	1.590E+01	0.000E+00	1.337E+01	1.739E+00
1.400E+02	1.197E+01	2.711E+01	5.409E+01	1.485E+01	0.000E+00	1.356E+01	1.742E+00
1.500E+02	1.270E+01	2.860E+01	5.614E+01	1.383E+01	0.000E+00	1.373E+01	1.754E+00

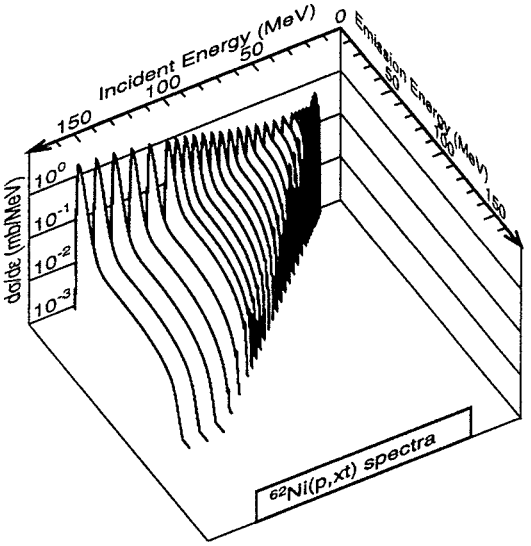

p + 62Ni nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
n
p
γ
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
10^1
10^0
0
50
100
150
Incident Energy (MeV)

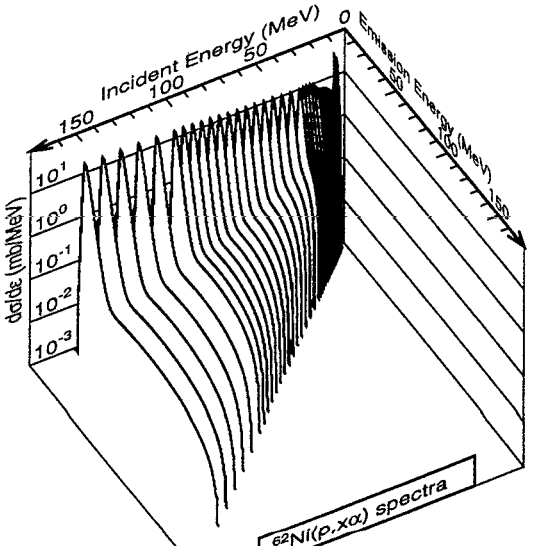
p + ^{62}Ni angle-integrated emission spectra

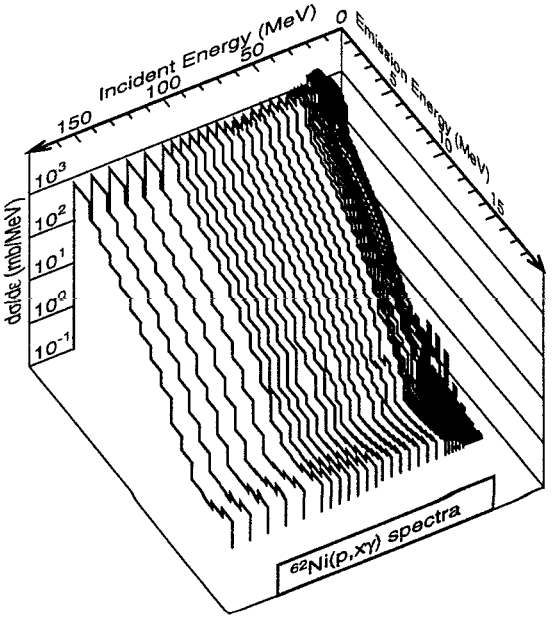




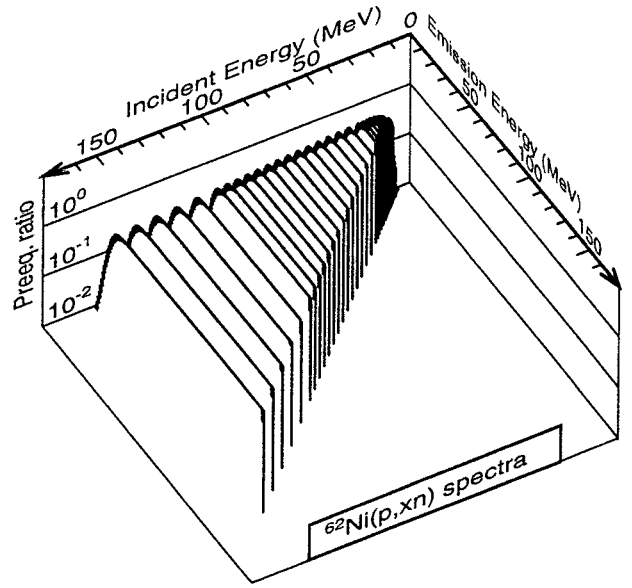


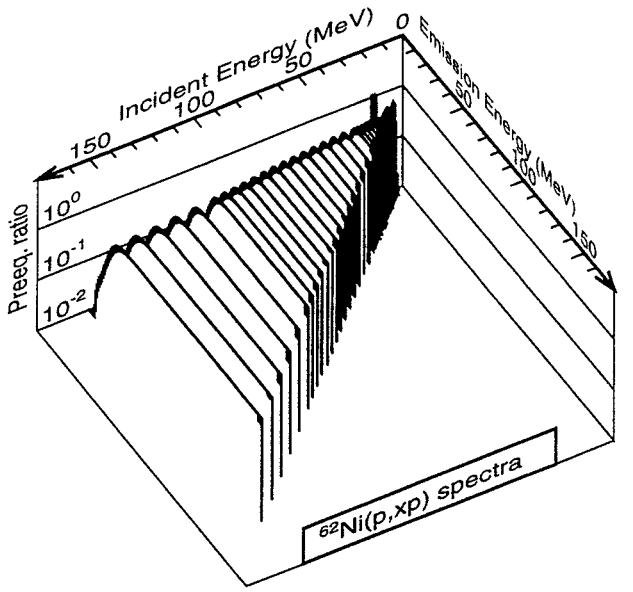


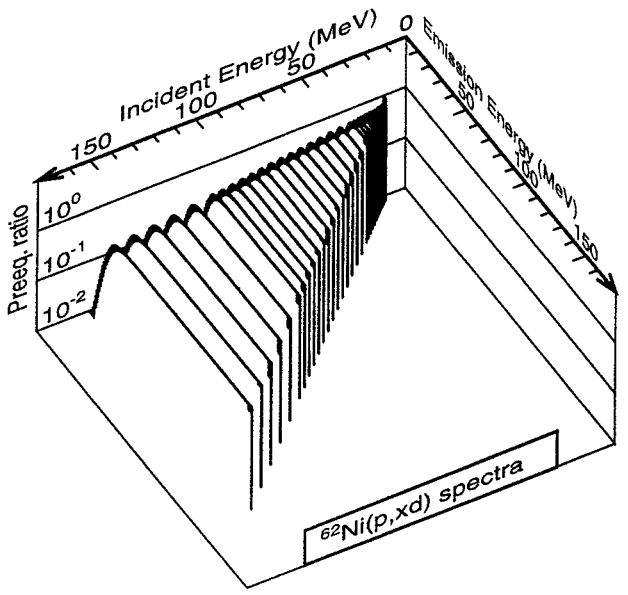


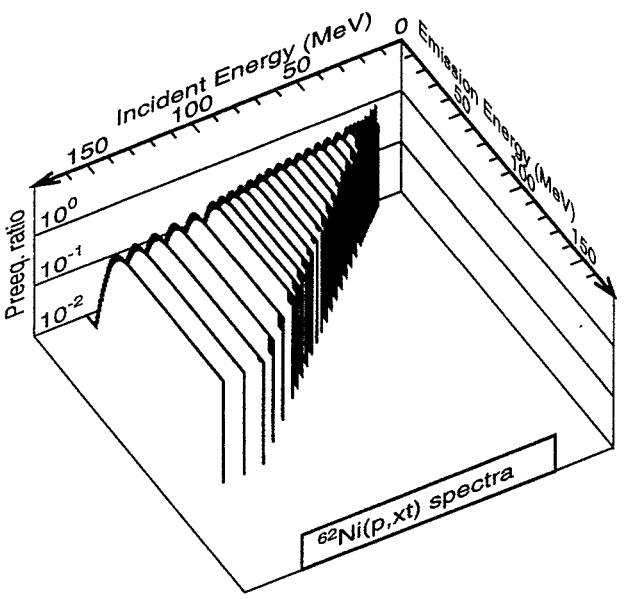


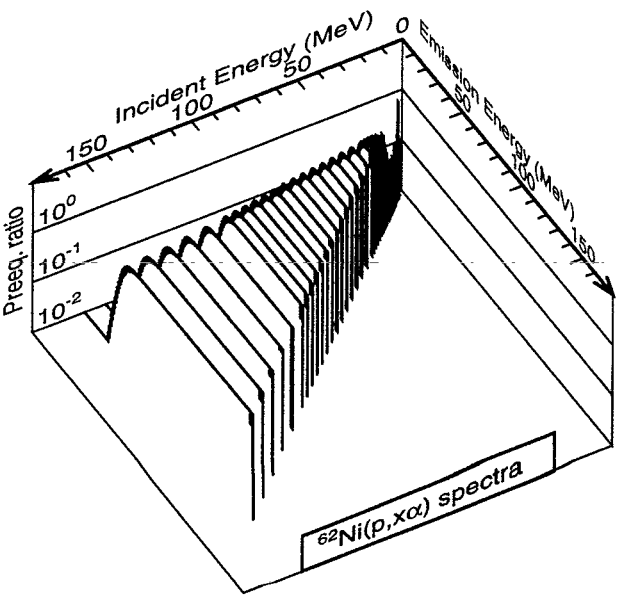
p + ^{62}Ni Kalbach preequilibrium ratios

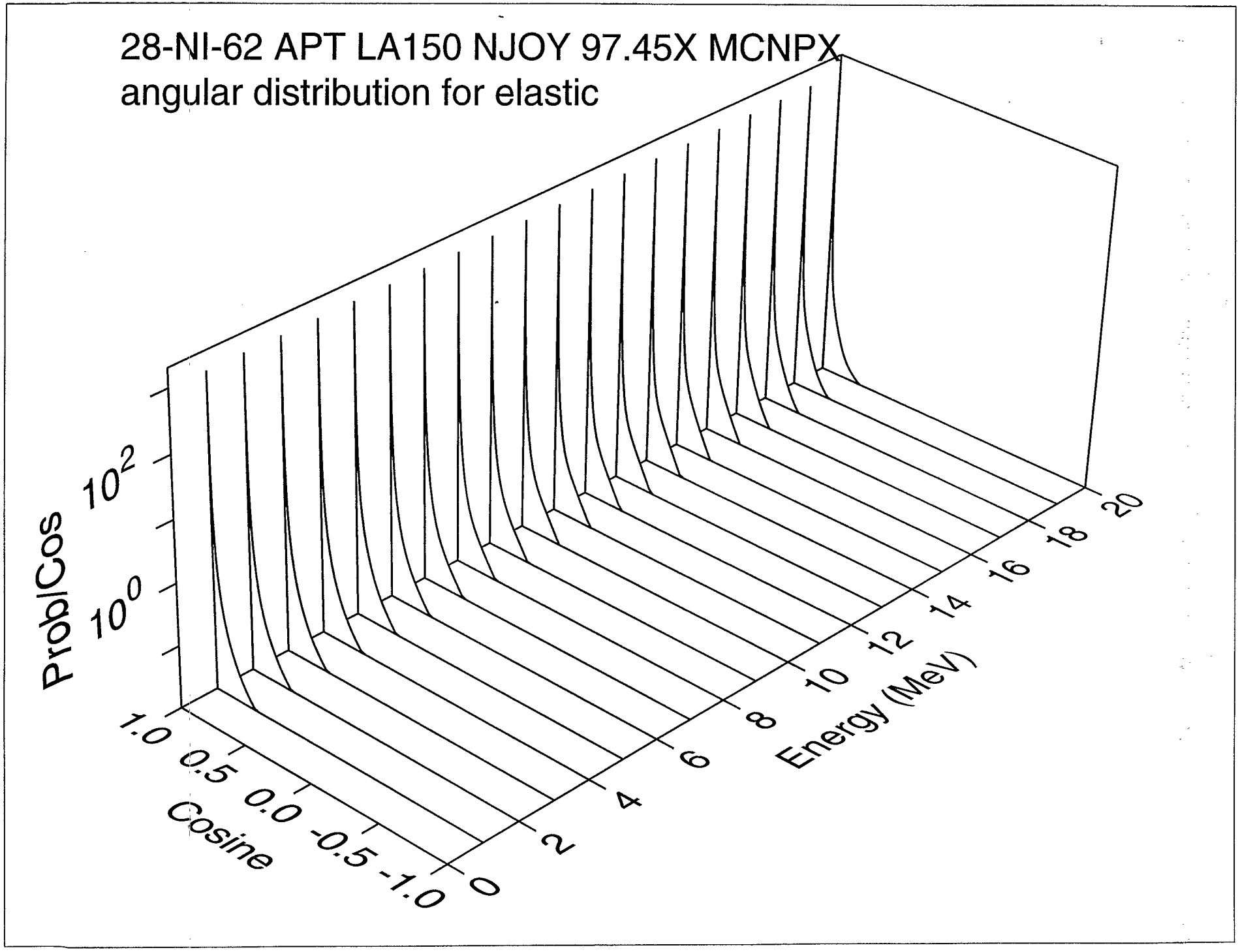


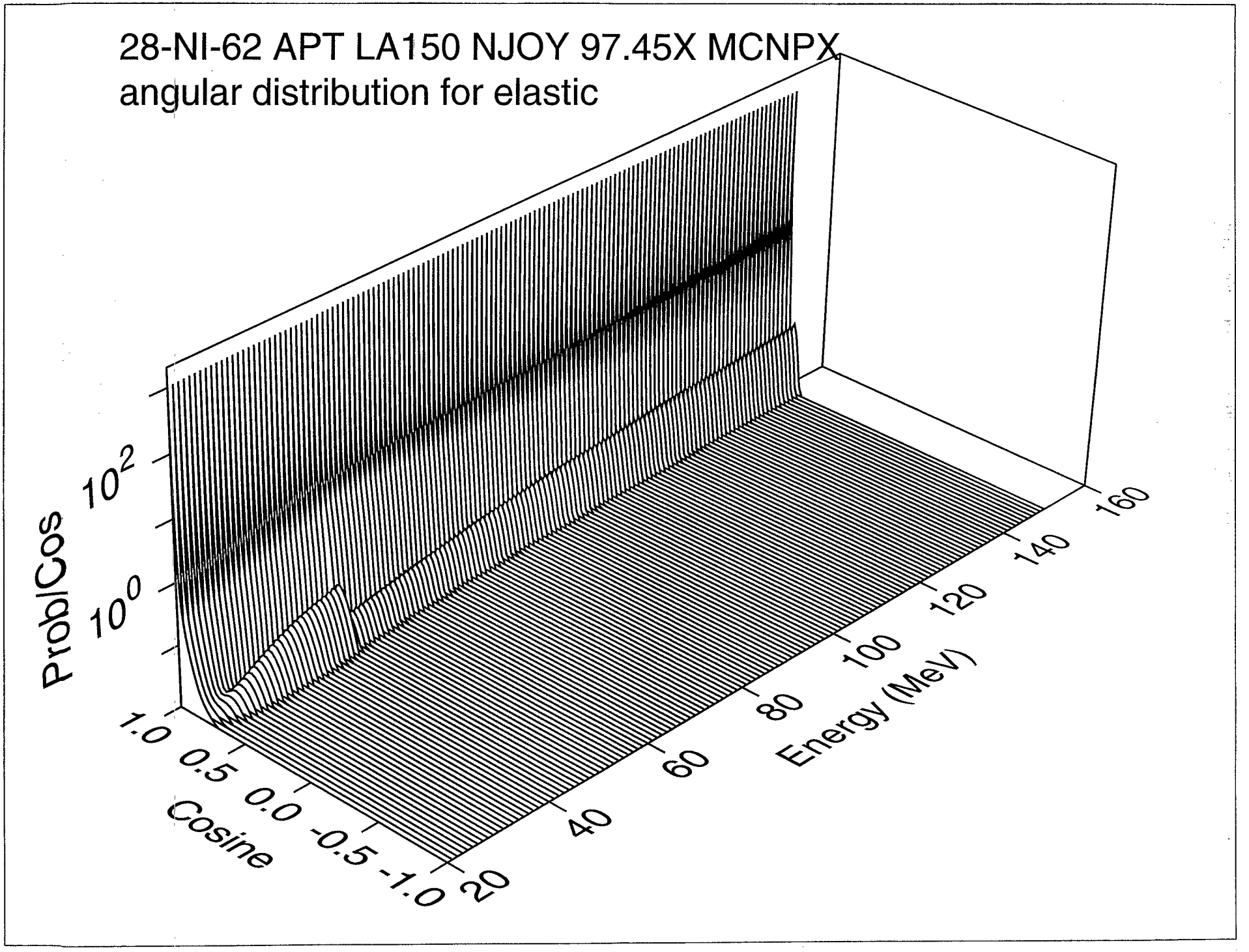


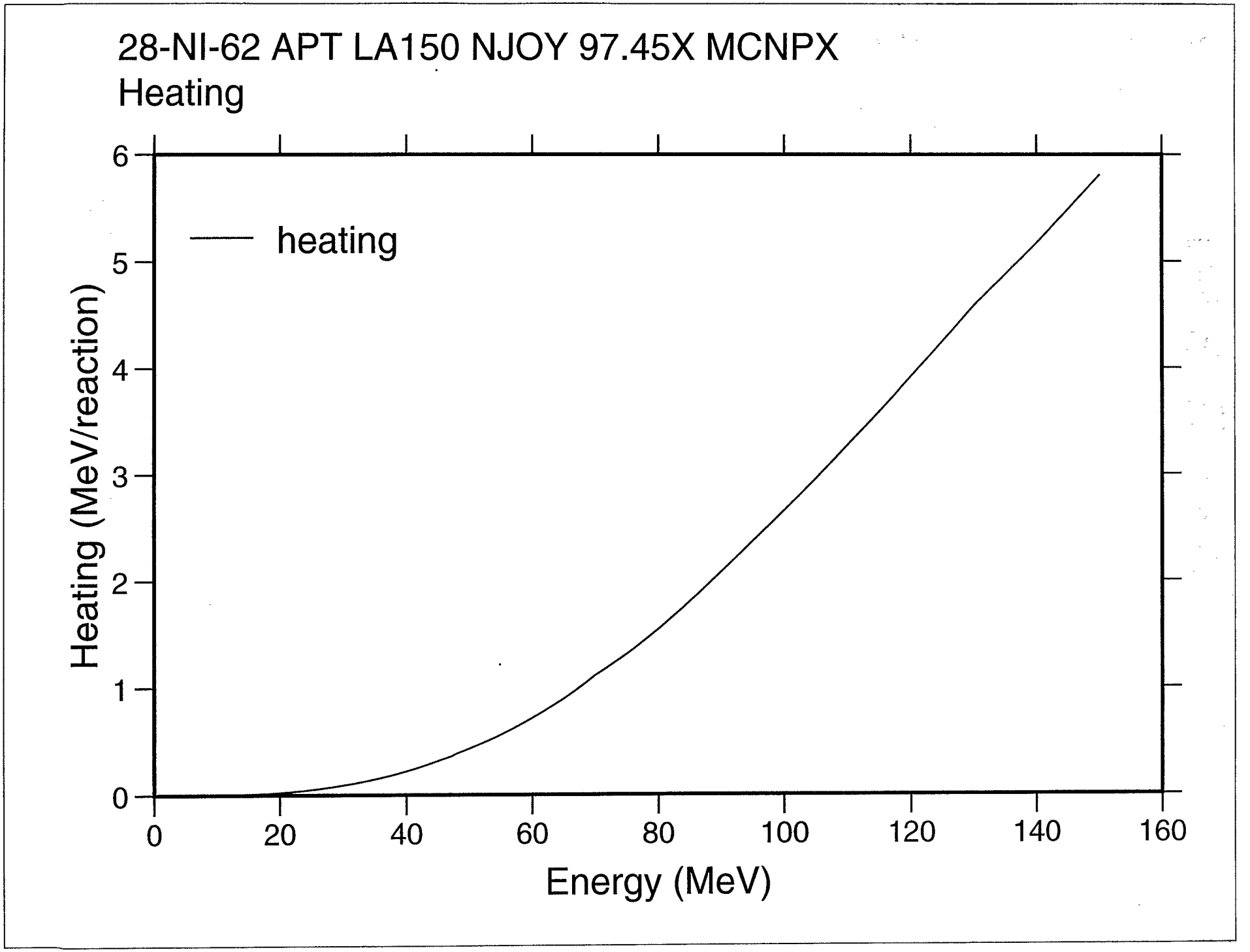







28-NI-62 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
1.0
0.5
0.0
-0.5
-1.0
Cosine
0
2
4
6
8
10
12
14
16
18
20
Energy (MeV)


28-NI-62 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


28-NI-62 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
1
2
3
4
5
6
0
20
40
60
80
100
120
140
160

EVALUATION OF p + 64Ni CROSS SECTIONS FOR THE ENERGY RANGE 1 to 150 MeV

S. Chiba, M. B. Chadwick, P. G. Young, and A. J. Koning

24 September 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident proton energy range from 1 to 150 MeV. The evaluation utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above are:

MF=3	MT= 2	Integral of nuclear plus interference components of the elastic scattering cross section
	MT= 5	Sum of binary (p,n') and (p,x) reactions
MF=6	MT= 2	Elastic (p,p) angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
	MT= 5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Ni58 and p + Ni58 reactions (Ch97). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic proton angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Gilbert and Cameron [Gi65] and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged- particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray

transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

DETAILS OF THE p + 64Ni ANALYSIS

The neutron optical model potential was adjusted to reproduce the measured total cross section data (Ci68, Pe73, Sc73, La83, Di97, Fa66, Du67) and s-wave strength function (Mu81). The data for natural Ni were also used because there was not enough data for Ni-64 at MeV region. The data for natural Ni were transformed to the Ni-64 cross section according to A*(2/3) law. The parameter estimation was carried out based on Marquart-Bayesian approach (Sm91), where ECIS95 code was used for the optical model calculation. We have employed the energy dependence of the optical potential similar to Delaroche's work(De89). The initial potential parameters were adopted from Koning and Delaroche (Ko97). Total of 7 parameters concerning the central potential depth were estimated with associated covariance matrix, while the geometrical parameters were fixed to the result of a similar search for n + Ni-58. Presently obtained potential was used for the calculation of neutron transmission coefficients in the energy region above 20 MeV. Below 20 MeV, the Harper neutron potential (Ha82) was used for the calculation of transmission coefficients.

The proton optical potential was also searched for to obtain a good description of proton-total reaction cross section as predicted by Wellisch-Axen systematic (We96) above 50 MeV. The parameter estimation was carried out by the Marquart-Bayesian approach similar to the neutron OMP, but trying to seek the best parameter to reproduce the reaction cross sections compiled by Carlson (Ca96) and Wellisch values. The experimental data in Carlson (Ca96) was scaled for Ni-64 according to A**(2/3) law. In this search, the geometrical parameters were fixed to be same as the neutron potential. The present potential gives a good description of the proton total reaction cross section from 10 MeV to 250 MeV. However, after some trial and error to reproduce both the elastic scattering and reaction cross section data for Ni-58, we have employed the following combination of proton potentials:

0 to 5 MeV	:	Harper potential (Ha82)
6 to 47 MeV	:	Koning and Delaroche (Ko97)
48 to 260 MeV	:	Present OMP

For deuterons, the Lohr-Haeberli [Lo74] global potential was used; for alpha particles the McFadden-Satchler [Mc66] potential was used; and for tritons the Beccheti-Greenlees [Be71] potential was used. The He-3 channel was ignored.

The direct collective inelastic scattering to the following levels in Ni-64 was considered by the DWBA-mode calculation of ECIS95 (Ra96):

Jpi	Ex(MeV)	Deformation length
2+	1.3458	0.92149
3-	3.56	0.838

The data for 2+ was retrieved from the literature (Ra87). The deformation length for the 3- level scaled from that of Ni-62 according to A**(1/3) law.

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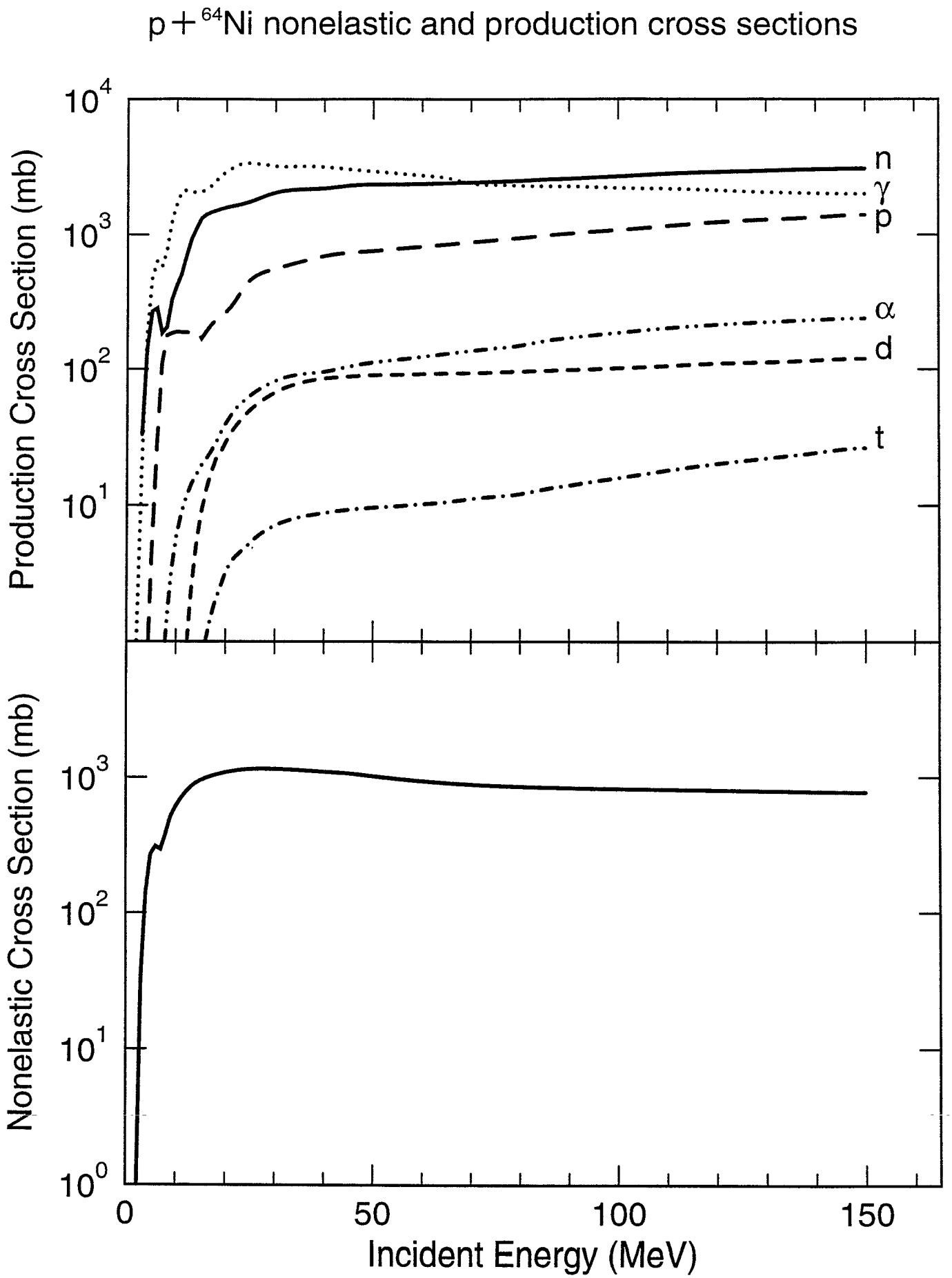
28064 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+00	7.871E-04	0.000E+00	0.000E+00	9.915E-09	0.000E+00	0.000E+00	0.000E+00	2.159E-11	1.021E-03
3.000E+00	3.316E-02	0.000E+00	3.307E-02	5.574E-06	0.000E+00	0.000E+00	0.000E+00	3.568E-08	2.022E-02
4.000E+00	1.407E-01	0.000E+00	1.402E-01	3.808E-04	0.000E+00	0.000E+00	0.000E+00	7.047E-07	1.834E-01
5.000E+00	2.719E-01	0.000E+00	2.674E-01	4.356E-03	0.000E+00	0.000E+00	0.000E+00	2.924E-05	4.743E-01
6.000E+00	3.096E-01	0.000E+00	2.820E-01	2.723E-02	0.000E+00	0.000E+00	0.000E+00	1.705E-04	6.377E-01
7.000E+00	2.947E-01	0.000E+00	1.846E-01	1.095E-01	0.000E+00	0.000E+00	0.000E+00	4.582E-04	5.771E-01
8.000E+00	3.822E-01	0.000E+00	2.040E-01	1.767E-01	0.000E+00	0.000E+00	0.000E+00	1.286E-03	7.804E-01
9.000E+00	5.154E-01	0.000E+00	3.280E-01	1.838E-01	4.607E-09	1.870E-08	0.000E+00	3.321E-03	1.284E+00
1.000E+01	6.088E-01	0.000E+00	4.145E-01	1.880E-01	5.214E-06	3.713E-08	0.000E+00	5.907E-03	1.715E+00
1.100E+01	6.941E-01	0.000E+00	5.135E-01	1.868E-01	1.161E-04	3.401E-06	0.000E+00	8.761E-03	2.103E+00
1.200E+01	7.757E-01	0.000E+00	7.069E-01	1.864E-01	7.273E-04	3.212E-05	0.000E+00	1.162E-02	2.141E+00
1.300E+01	8.498E-01	0.000E+00	9.296E-01	1.841E-01	2.338E-03	1.239E-04	0.000E+00	1.433E-02	2.085E+00
1.400E+01	9.089E-01	0.000E+00	1.118E+00	1.896E-01	5.037E-03	3.138E-04	0.000E+00	1.680E-02	2.046E+00
1.500E+01	9.522E-01	0.000E+00	1.318E+00	1.675E-01	8.681E-03	6.454E-04	0.000E+00	1.963E-02	2.080E+00
1.600E+01	9.866E-01	0.000E+00	1.406E+00	1.896E-01	1.285E-02	1.029E-03	0.000E+00	2.196E-02	2.162E+00
1.700E+01	1.016E+00	0.000E+00	1.464E+00	2.122E-01	1.729E-02	1.514E-03	0.000E+00	2.498E-02	2.305E+00
1.800E+01	1.042E+00	0.000E+00	1.507E+00	2.315E-01	2.183E-02	2.024E-03	0.000E+00	2.902E-02	2.513E+00
1.900E+01	1.066E+00	0.000E+00	1.549E+00	2.475E-01	2.476E-02	2.544E-03	0.000E+00	3.446E-02	2.740E+00
2.000E+01	1.087E+00	0.000E+00	1.586E+00	2.633E-01	2.923E-02	3.236E-03	0.000E+00	4.011E-02	2.903E+00
2.200E+01	1.121E+00	0.000E+00	1.644E+00	3.253E-01	3.811E-02	4.190E-03	0.000E+00	5.102E-02	3.214E+00
2.400E+01	1.145E+00	0.000E+00	1.708E+00	4.173E-01	4.622E-02	4.872E-03	0.000E+00	5.999E-02	3.372E+00
2.600E+01	1.156E+00	0.000E+00	1.806E+00	4.872E-01	5.378E-02	5.721E-03	0.000E+00	6.811E-02	3.339E+00
2.800E+01	1.158E+00	0.000E+00	1.928E+00	5.246E-01	6.078E-02	6.468E-03	0.000E+00	7.526E-02	3.278E+00
3.000E+01	1.154E+00	0.000E+00	2.034E+00	5.502E-01	6.709E-02	7.092E-03	0.000E+00	8.150E-02	3.200E+00
3.500E+01	1.132E+00	0.000E+00	2.144E+00	6.200E-01	7.849E-02	8.164E-03	0.000E+00	9.124E-02	3.180E+00
4.000E+01	1.102E+00	0.000E+00	2.183E+00	6.884E-01	8.484E-02	8.789E-03	0.000E+00	9.519E-02	3.137E+00
4.500E+01	1.071E+00	0.000E+00	2.283E+00	7.311E-01	8.758E-02	9.285E-03	0.000E+00	1.040E-01	3.018E+00
5.000E+01	1.020E+00	0.000E+00	2.327E+00	7.517E-01	8.973E-02	9.619E-03	0.000E+00	1.112E-01	2.905E+00
5.500E+01	9.747E-01	0.000E+00	2.335E+00	7.790E-01	9.049E-02	9.867E-03	0.000E+00	1.165E-01	2.808E+00
6.000E+01	9.377E-01	0.000E+00	2.352E+00	8.064E-01	9.158E-02	1.021E-02	0.000E+00	1.228E-01	2.713E+00
6.500E+01	9.079E-01	0.000E+00	2.382E+00	8.353E-01	9.260E-02	1.058E-02	0.000E+00	1.297E-01	2.602E+00
7.000E+01	8.850E-01	0.000E+00	2.412E+00	8.666E-01	9.341E-02	1.116E-02	0.000E+00	1.365E-01	2.362E+00
7.500E+01	8.677E-01	0.000E+00	2.449E+00	8.992E-01	9.470E-02	1.163E-02	0.000E+00	1.428E-01	2.316E+00
8.000E+01	8.547E-01	0.000E+00	2.488E+00	9.329E-01	9.598E-02	1.217E-02	0.000E+00	1.492E-01	2.289E+00
8.500E+01	8.447E-01	0.000E+00	2.552E+00	9.741E-01	9.690E-02	1.319E-02	0.000E+00	1.609E-01	2.271E+00
9.000E+01	8.368E-01	0.000E+00	2.598E+00	1.013E+00	9.849E-02	1.405E-02	0.000E+00	1.700E-01	2.279E+00
9.500E+01	8.302E-01	0.000E+00	2.653E+00	1.049E+00	1.002E-01	1.497E-02	0.000E+00	1.784E-01	2.254E+00
1.000E+02	8.244E-01	0.000E+00	2.704E+00	1.086E+00	1.020E-01	1.590E-02	0.000E+00	1.859E-01	2.224E+00
1.100E+02	8.143E-01	0.000E+00	2.804E+00	1.160E+00	1.055E-01	1.806E-02	0.000E+00	2.009E-01	2.177E+00
1.200E+02	8.049E-01	0.000E+00	2.895E+00	1.229E+00	1.097E-01	2.022E-02	0.000E+00	2.133E-01	2.122E+00
1.300E+02	7.959E-01	0.000E+00	2.971E+00	1.293E+00	1.122E-01	2.223E-02	0.000E+00	2.233E-01	2.065E+00
1.400E+02	7.871E-01	0.000E+00	3.029E+00	1.349E+00	1.163E-01	2.442E-02	0.000E+00	2.322E-01	2.024E+00
1.500E+02	7.785E-01	0.000E+00	3.065E+00	1.398E+00	1.194E-01	2.647E-02	0.000E+00	2.390E-01	2.000E+00

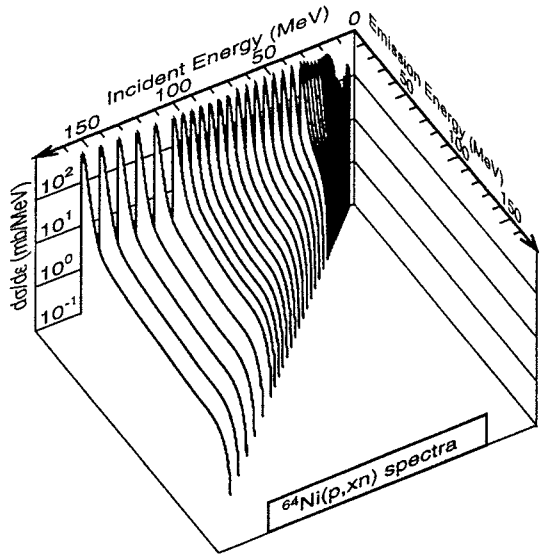
28064 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

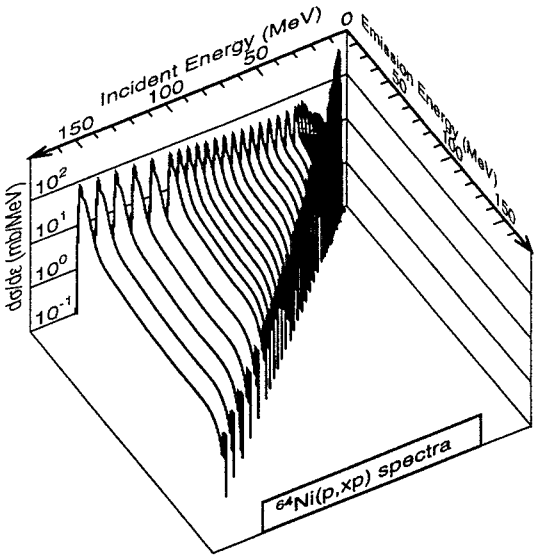
Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+00	0.000E+00	1.923E+00	0.000E+00	0.000E+00	0.000E+00	2.471E+00	4.571E+00
3.000E+00	2.947E-01	1.489E+00	0.000E+00	0.000E+00	0.000E+00	3.303E+00	2.120E-01
4.000E+00	9.391E-01	2.445E+00	0.000E+00	0.000E+00	0.000E+00	4.179E+00	3.661E-01
5.000E+00	1.382E+00	3.371E+00	0.000E+00	0.000E+00	0.000E+00	5.095E+00	5.817E-01
6.000E+00	1.701E+00	4.334E+00	0.000E+00	0.000E+00	0.000E+00	5.816E+00	8.072E-01
7.000E+00	1.968E+00	5.381E+00	0.000E+00	0.000E+00	0.000E+00	6.538E+00	1.022E+00
8.000E+00	2.172E+00	6.335E+00	0.000E+00	0.000E+00	0.000E+00	7.228E+00	1.146E+00
9.000E+00	2.276E+00	7.049E+00	1.282E+00	7.450E-01	0.000E+00	7.766E+00	1.281E+00
1.000E+01	2.411E+00	7.734E+00	2.208E+00	1.682E+00	0.000E+00	8.175E+00	1.410E+00
1.100E+01	2.443E+00	8.483E+00	3.083E+00	2.604E+00	0.000E+00	8.519E+00	1.518E+00
1.200E+01	2.236E+00	9.148E+00	3.791E+00	3.417E+00	0.000E+00	8.850E+00	1.520E+00
1.300E+01	2.131E+00	9.633E+00	4.453E+00	3.900E+00	0.000E+00	9.144E+00	1.481E+00
1.400E+01	2.136E+00	9.959E+00	5.105E+00	4.414E+00	0.000E+00	9.415E+00	1.422E+00
1.500E+01	2.210E+00	9.418E+00	5.768E+00	4.844E+00	0.000E+00	9.643E+00	1.371E+00
1.600E+01	2.346E+00	9.639E+00	6.425E+00	5.332E+00	0.000E+00	9.841E+00	1.344E+00
1.700E+01	2.497E+00	9.830E+00	7.088E+00	5.828E+00	0.000E+00	9.943E+00	1.362E+00
1.800E+01	2.657E+00	1.001E+01	7.736E+00	6.309E+00	0.000E+00	9.949E+00	1.400E+00
1.900E+01	2.799E+00	1.014E+01	8.281E+00	6.800E+00	0.000E+00	9.961E+00	1.446E+00
2.000E+01	2.951E+00	1.024E+01	8.866E+00	7.339E+00	0.000E+00	1.005E+01	1.569E+00
2.200E+01	3.180E+00	9.964E+00	1.007E+01	8.286E+00	0.000E+00	1.023E+01	1.651E+00
2.400E+01	3.347E+00	9.524E+00	1.120E+01	9.028E+00	0.000E+00	1.041E+01	1.656E+00
2.600E+01	3.439E+00	9.707E+00	1.232E+01	9.809E+00	0.000E+00	1.045E+01	1.637E+00
2.800E+01	3.519E+00	1.034E+01	1.342E+01	1.057E+01	0.000E+00	1.051E+01	1.555E+00

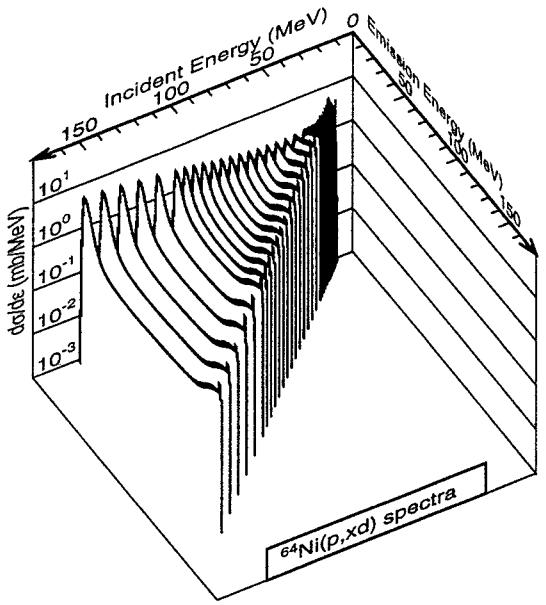
3.000E+01	3.639E+00	1.122E+01	1.456E+01	1.132E+01	0.000E+00	1.063E+01	1.483E+00
3.500E+01	4.089E+00	1.330E+01	1.746E+01	1.316E+01	0.000E+00	1.109E+01	1.459E+00
4.000E+01	4.549E+00	1.508E+01	2.037E+01	1.485E+01	0.000E+00	1.149E+01	1.496E+00
4.500E+01	4.900E+00	1.642E+01	2.304E+01	1.629E+01	0.000E+00	1.165E+01	1.508E+00
5.000E+01	5.247E+00	1.755E+01	2.579E+01	1.757E+01	0.000E+00	1.185E+01	1.521E+00
5.500E+01	5.601E+00	1.884E+01	2.833E+01	1.867E+01	0.000E+00	1.203E+01	1.533E+00
6.000E+01	5.952E+00	1.998E+01	3.074E+01	1.935E+01	0.000E+00	1.215E+01	1.544E+00
6.500E+01	6.279E+00	2.101E+01	3.306E+01	1.988E+01	0.000E+00	1.226E+01	1.545E+00
7.000E+01	6.637E+00	2.195E+01	3.503E+01	2.010E+01	0.000E+00	1.237E+01	1.514E+00
7.500E+01	6.993E+00	2.285E+01	3.713E+01	2.015E+01	0.000E+00	1.247E+01	1.523E+00
8.000E+01	7.351E+00	2.376E+01	3.912E+01	2.010E+01	0.000E+00	1.257E+01	1.533E+00
8.500E+01	7.635E+00	2.429E+01	4.029E+01	1.941E+01	0.000E+00	1.263E+01	1.565E+00
9.000E+01	7.968E+00	2.493E+01	4.178E+01	1.893E+01	0.000E+00	1.271E+01	1.585E+00
9.500E+01	8.272E+00	2.562E+01	4.316E+01	1.843E+01	0.000E+00	1.279E+01	1.585E+00
1.000E+02	8.580E+00	2.631E+01	4.445E+01	1.790E+01	0.000E+00	1.288E+01	1.611E+00
1.100E+02	9.155E+00	2.759E+01	4.626E+01	1.664E+01	0.000E+00	1.305E+01	1.625E+00
1.200E+02	9.693E+00	2.888E+01	4.814E+01	1.535E+01	0.000E+00	1.322E+01	1.598E+00
1.300E+02	1.026E+01	3.020E+01	4.911E+01	1.420E+01	0.000E+00	1.339E+01	1.626E+00
1.400E+02	1.079E+01	3.150E+01	5.059E+01	1.317E+01	0.000E+00	1.354E+01	1.619E+00
1.500E+02	1.138E+01	3.292E+01	5.183E+01	1.238E+01	0.000E+00	1.370E+01	1.647E+00

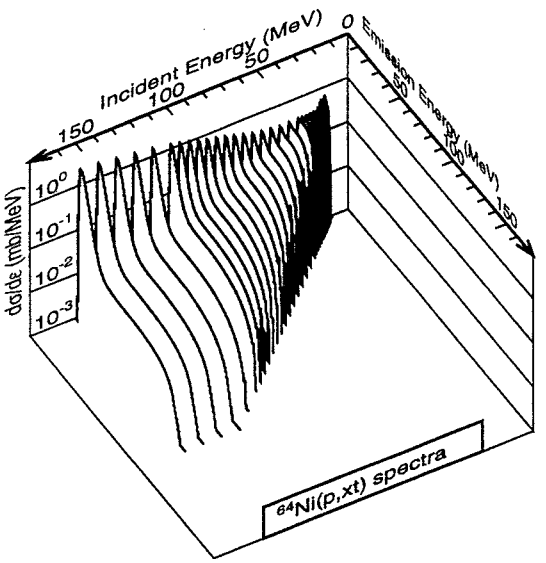

p + 64Ni nonelastic and production cross sections
Production Cross Section (mb)
Nonelastic Cross Section (mb)
Incident Energy (MeV)
n
γ
p
α
d
t
10^4
10^3
10^2
10^1
10^0
0
50
100
150

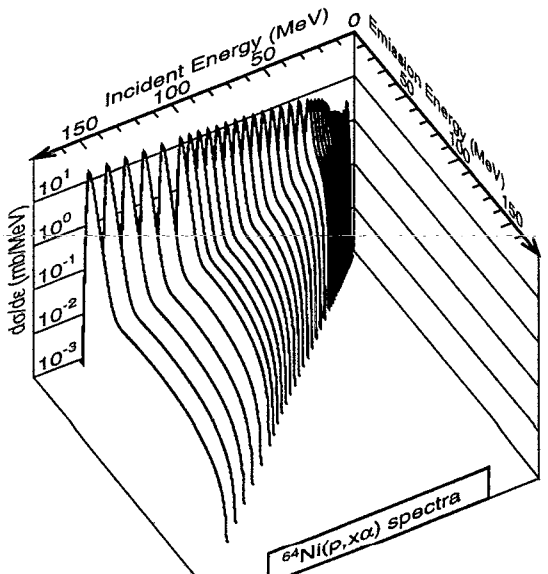
p + ^{64}Ni angle-integrated emission spectra

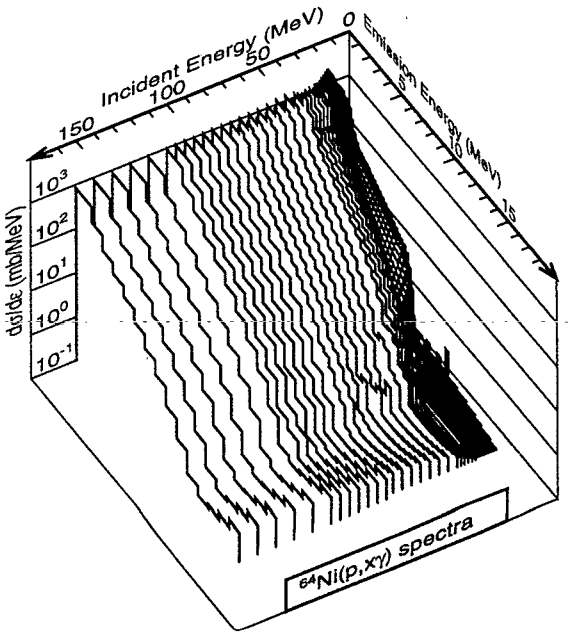




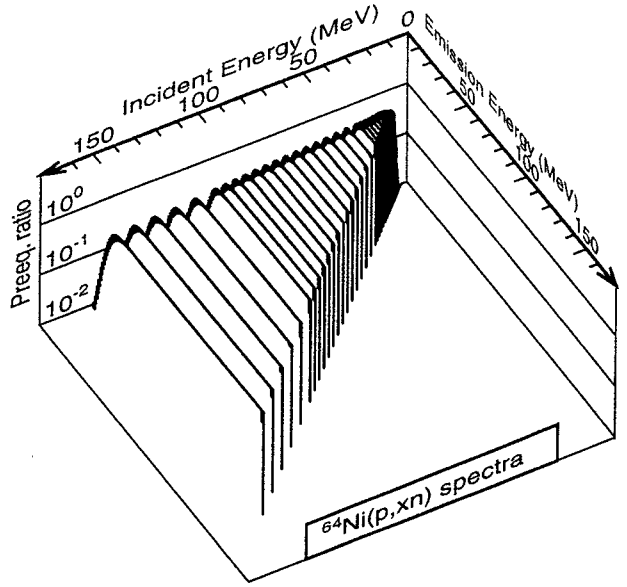


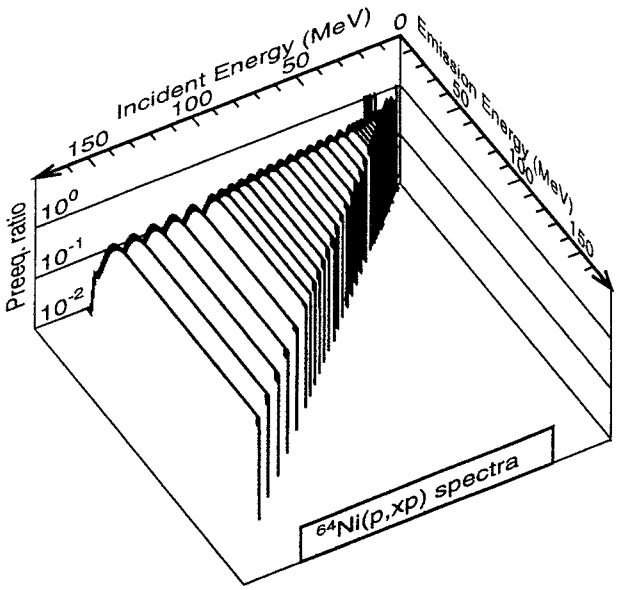


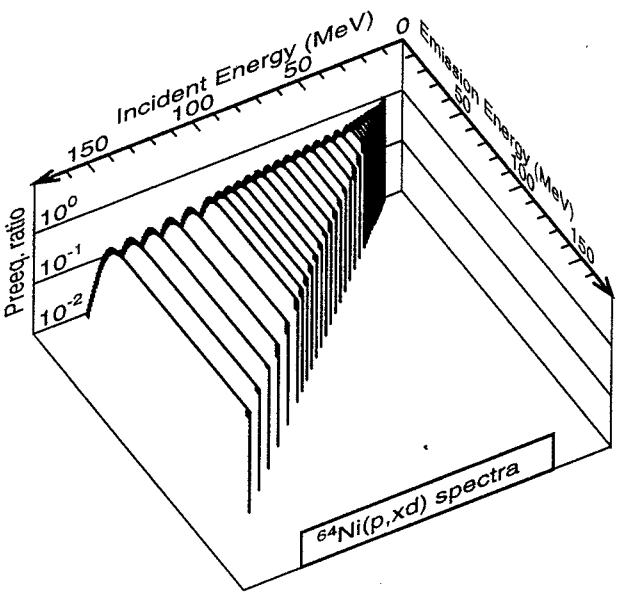


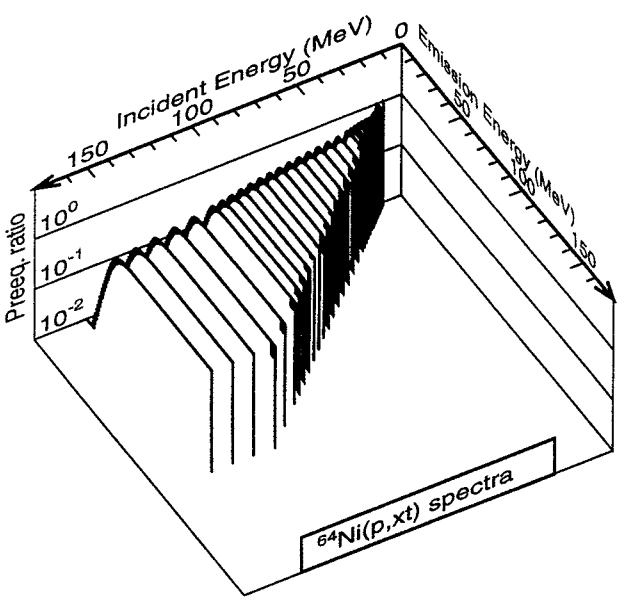


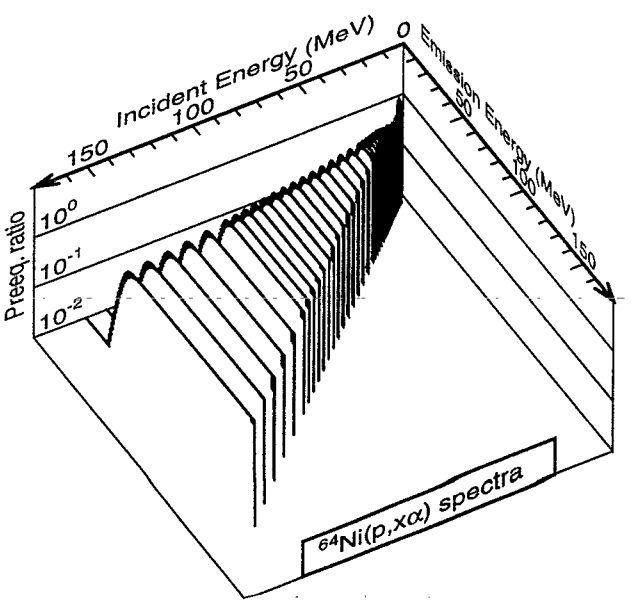
p + ^{64}Ni Kalbach preequilibrium ratios

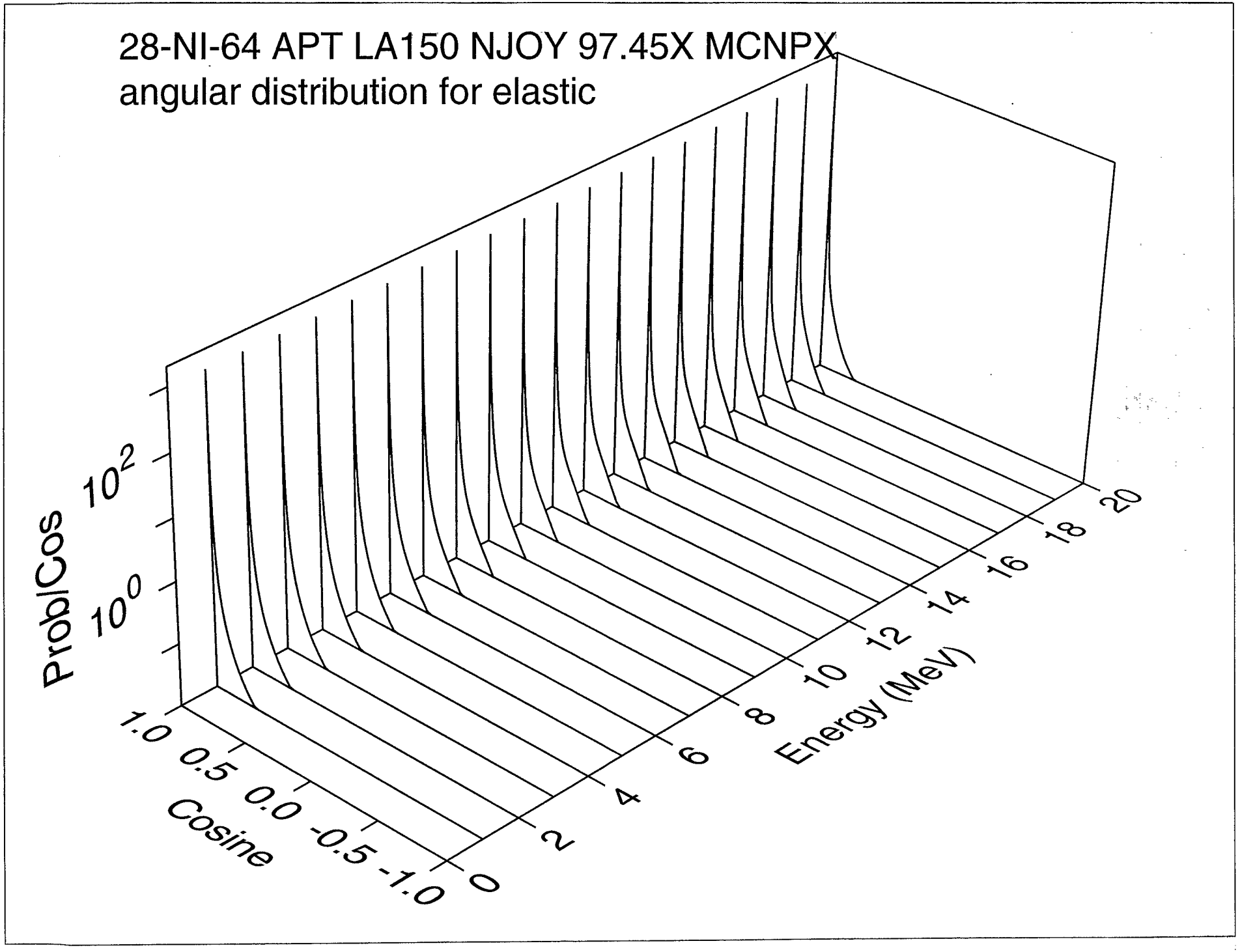


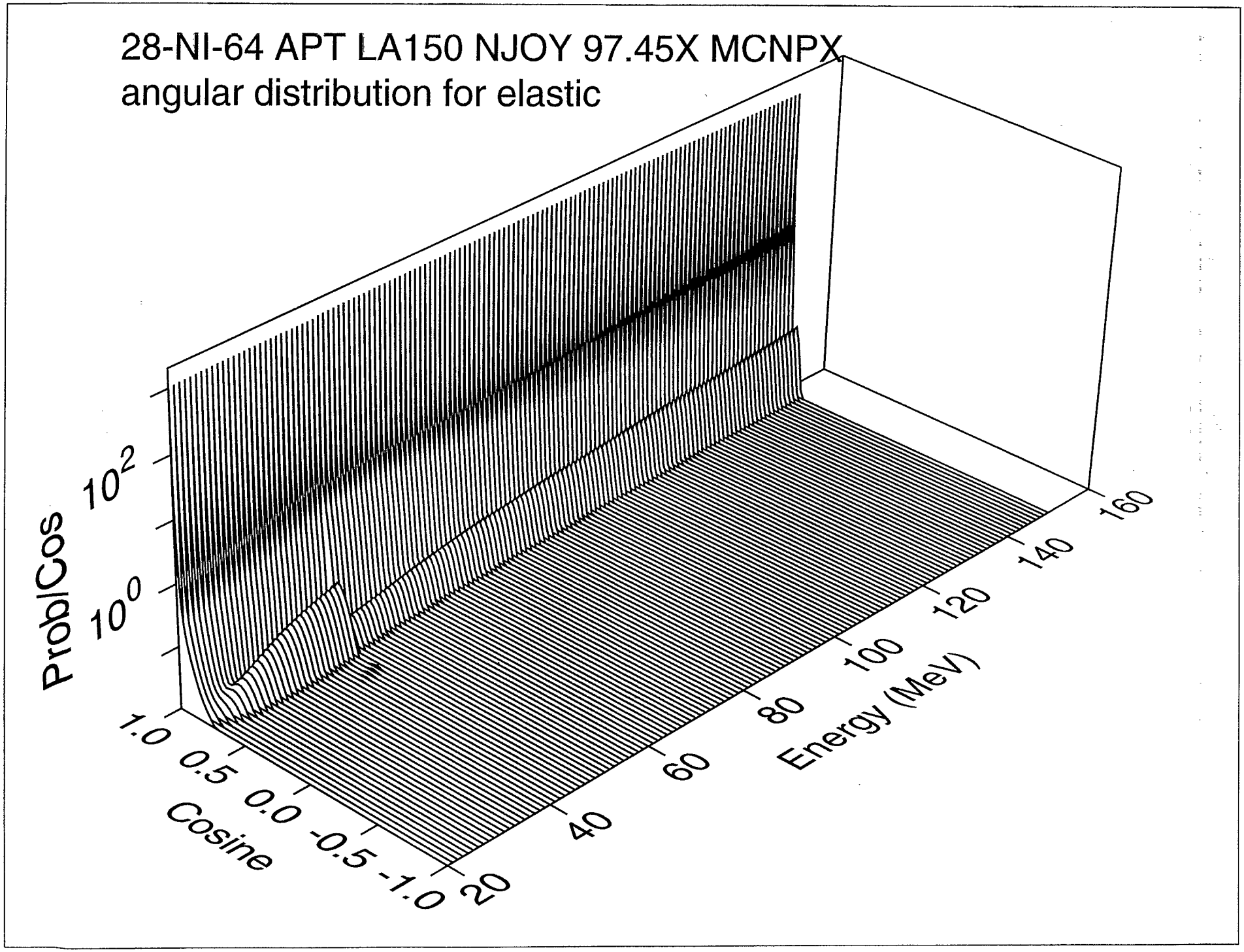


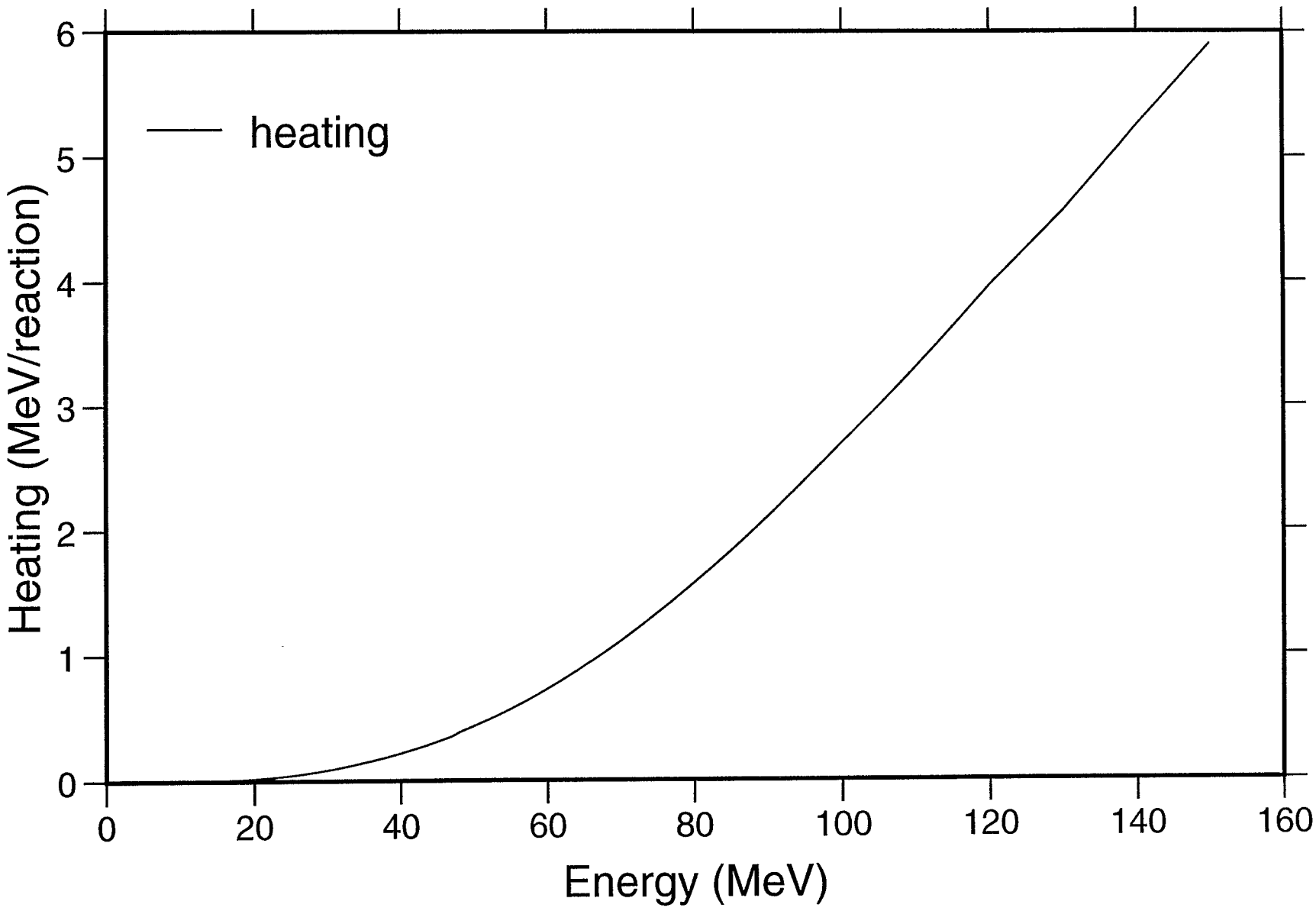







28-NI-64 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
1.0
0.5
0.0
-0.5
-1.0
Cosine
0
2
4
6
8
10
12
14
16
18
20
Energy (MeV)


28-NI-64 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
ProbCos
10^2
10^0
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


28-NI-64 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
1
2
3
4
5
6
0
20
40
60
80
100
120
140
160

EVALUATION OF p + 63Cu CROSS SECTIONS FOR THE ENERGY RANGE 1 to 150 MeV

A. J. Koning, M. B. Chadwick, and P. G. Young
15 February 1998

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident proton energy range from 1 to 150 MeV. The evaluation utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above are:

MF=3 MT=	2	Integral of nuclear plus interference components of the elastic scattering cross section
MT=	5	Sum of binary (p,n') and (p,x) reactions
MF=6 MT=	2	Elastic (p,p) angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
MT=	5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Cu63 and p + Cu63 reactions (Ch98). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic proton angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96a). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk et al. (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged- particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray

transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

SOME Cu-63 SPECIFIC INFORMATION CONCERNING THE EVAL.

This evaluation is documented in some detail in Ref. (Ko98b).

To obtain the neutron optical potential we used total cross section data from 1.2 to 4.5 MeV (Gu86) and from 5.3 to 600 MeV (Fi93), and elastic scattering angular distribution data from 1.6 to 96 MeV (Br50, Sa60, Ki74, El82, Gu86). The optical potential parameters were obtained using a combination of a grid search code and the interactive optical model viewer ECISVIEW [Ko97], both built around the coupled channels code ECIS96 [Ra94]. The energy dependence of the optical model parameters is as described in [Ko98]. This optical potential was used for the calculation, with ECIS96, of neutron transmission coefficients and DWBA cross sections for the entire energy region above 20 MeV.

Due to the lack of proton elastic scattering data in numerical form, we used a combination of global optical models for the proton channel. The Becchetti-Greenlees potential [Be69]was adopted below 47 MeV, and the non-relativistic version of the Madland potential [Ma88] above 47 MeV. At this particular energy point the two potentials join smoothly. The resulting proton reaction cross section was compared with the available experimental data as compiled by Carlson (Ca96). Finally, the calculated proton transmission coefficients were renormalized to the reaction cross sections obtained from fit by eye through the data points.

For deuterons, the Lohr-Haeberli global potential [Lo74] was used; for alpha particles the Moyen potential (MacFadden-Satchler [Ma66]) was used; and for tritons the Becchetti-Greenlees potential [Be71] was used. The He-3 channel was ignored.

Following Delaroche et al. [De82], we adopted the weak-coupling model for direct collective inelastic scattering for Cu-63, using Ni-64 as a basis. For the calculation of the cross sections, ECIS96 was used in DWBA mode. We used the following direct transitions for Cu-63 (ground state 3/2-) :

Jpi	Ex(MeV)	Deformation length/parameter
0.5-	0.669	Delta(2)=0.319
2.5-	0.962	Delta(2)=0.552
3.5-	1.327	Delta(2)=0.638
1.5-	1.547	Delta(2)=0.451
1.5-	3.382	Delta(3)=0.313
2.5-	3.632	Delta(3)=0.384
3.5-	3.882	Delta(3)=0.444
4.5-	4.132	Delta(3)=0.496

No measurements exist for proton-induced emission spectra above 20 MeV for Cu-63. However, for Cu-65 there exists 26.7 MeV (p,xn) and (p,xp) data by Holler et al (Ho85). This has been used to benchmark the Cu-65 data. The partial level density parameters have been slightly adjusted to obtain good agreement with these experimental data. Hence we also adopted these parameters for the whole energy region for Cu-63.

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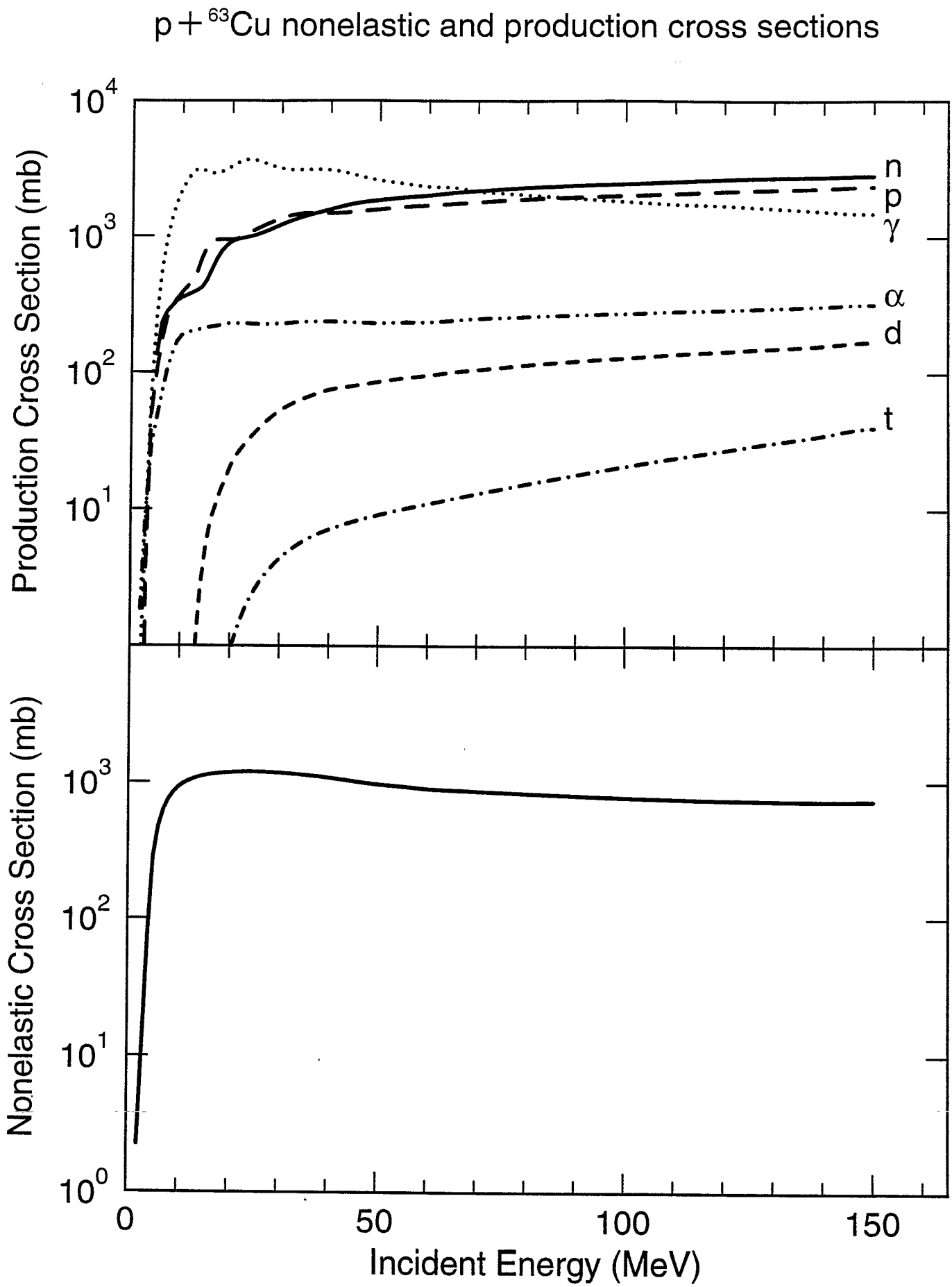
29063 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+00	2.235E-03	0.000E+00	0.000E+00	1.105E-10	0.000E+00	0.000E+00	0.000E+00	1.857E-03	8.471E-04
3.000E+00	1.392E-02	0.000E+00	0.000E+00	3.322E-03	0.000E+00	0.000E+00	0.000E+00	9.634E-03	7.641E-03
4.000E+00	7.938E-02	0.000E+00	0.000E+00	5.029E-02	0.000E+00	0.000E+00	0.000E+00	2.786E-02	6.962E-02
5.000E+00	2.823E-01	0.000E+00	1.351E-01	1.014E-01	0.000E+00	0.000E+00	0.000E+00	4.504E-02	2.549E-01
6.000E+00	4.716E-01	0.000E+00	2.314E-01	1.706E-01	0.000E+00	0.000E+00	0.000E+00	6.892E-02	5.640E-01
7.000E+00	6.262E-01	0.000E+00	2.770E-01	2.472E-01	0.000E+00	0.000E+00	0.000E+00	1.013E-01	9.452E-01
8.000E+00	7.479E-01	0.000E+00	3.048E-01	3.062E-01	0.000E+00	0.000E+00	0.000E+00	1.361E-01	1.364E+00
9.000E+00	8.448E-01	0.000E+00	3.342E-01	3.424E-01	0.000E+00	0.000E+00	0.000E+00	1.673E-01	1.784E+00
1.000E+01	9.205E-01	0.000E+00	3.515E-01	3.822E-01	1.177E-09	0.000E+00	0.000E+00	1.863E-01	2.199E+00
1.100E+01	9.775E-01	0.000E+00	3.651E-01	4.193E-01	4.061E-06	0.000E+00	0.000E+00	1.967E-01	2.572E+00
1.200E+01	1.019E+00	0.000E+00	3.799E-01	4.622E-01	1.328E-04	0.000E+00	0.000E+00	1.994E-01	2.888E+00
1.300E+01	1.055E+00	0.000E+00	3.956E-01	5.356E-01	8.980E-04	5.846E-09	0.000E+00	2.023E-01	3.096E+00
1.400E+01	1.085E+00	0.000E+00	4.184E-01	6.798E-01	2.661E-03	1.201E-06	0.000E+00	2.099E-01	3.076E+00
1.500E+01	1.110E+00	0.000E+00	4.729E-01	8.209E-01	5.209E-03	1.780E-05	0.000E+00	2.136E-01	2.956E+00
1.600E+01	1.130E+00	0.000E+00	5.642E-01	9.011E-01	8.259E-03	6.747E-05	0.000E+00	2.162E-01	2.877E+00
1.700E+01	1.145E+00	0.000E+00	6.722E-01	9.336E-01	1.064E-02	1.761E-04	0.000E+00	2.194E-01	2.878E+00
1.800E+01	1.156E+00	0.000E+00	7.715E-01	9.400E-01	1.367E-02	3.493E-04	0.000E+00	2.233E-01	2.966E+00
1.900E+01	1.165E+00	0.000E+00	8.468E-01	9.385E-01	1.681E-02	5.821E-04	0.000E+00	2.291E-01	3.088E+00
2.000E+01	1.173E+00	0.000E+00	9.031E-01	9.385E-01	2.068E-02	8.692E-04	0.000E+00	2.292E-01	3.234E+00
2.200E+01	1.184E+00	0.000E+00	9.598E-01	9.793E-01	2.736E-02	1.529E-03	0.000E+00	2.294E-01	3.560E+00
2.400E+01	1.190E+00	0.000E+00	9.964E-01	1.073E+00	3.324E-02	2.238E-03	0.000E+00	2.279E-01	3.638E+00
2.600E+01	1.188E+00	0.000E+00	1.052E+00	1.170E+00	3.985E-02	2.955E-03	0.000E+00	2.257E-01	3.495E+00
2.800E+01	1.181E+00	0.000E+00	1.126E+00	1.259E+00	4.640E-02	3.667E-03	0.000E+00	2.268E-01	3.280E+00
3.000E+01	1.171E+00	0.000E+00	1.211E+00	1.345E+00	5.261E-02	4.364E-03	0.000E+00	2.282E-01	3.123E+00
3.500E+01	1.133E+00	0.000E+00	1.407E+00	1.474E+00	6.488E-02	5.901E-03	0.000E+00	2.350E-01	3.060E+00
4.000E+01	1.084E+00	0.000E+00	1.579E+00	1.480E+00	7.464E-02	7.128E-03	0.000E+00	2.360E-01	3.052E+00
4.500E+01	1.024E+00	0.000E+00	1.746E+00	1.521E+00	7.991E-02	8.150E-03	0.000E+00	2.327E-01	2.816E+00
5.000E+01	9.713E-01	0.000E+00	1.842E+00	1.581E+00	8.552E-02	9.076E-03	0.000E+00	2.302E-01	2.570E+00
5.500E+01	9.361E-01	0.000E+00	1.921E+00	1.644E+00	9.091E-02	1.001E-02	0.000E+00	2.331E-01	2.427E+00
6.000E+01	8.993E-01	0.000E+00	1.987E+00	1.681E+00	9.517E-02	1.091E-02	0.000E+00	2.341E-01	2.310E+00
6.500E+01	8.797E-01	0.000E+00	2.084E+00	1.734E+00	1.007E-01	1.194E-02	0.000E+00	2.409E-01	2.270E+00
7.000E+01	8.633E-01	0.000E+00	2.154E+00	1.784E+00	1.049E-01	1.304E-02	0.000E+00	2.488E-01	2.132E+00
7.500E+01	8.472E-01	0.000E+00	2.223E+00	1.837E+00	1.096E-01	1.416E-02	0.000E+00	2.530E-01	2.071E+00
8.000E+01	8.320E-01	0.000E+00	2.288E+00	1.880E+00	1.144E-01	1.537E-02	0.000E+00	2.582E-01	2.012E+00
8.500E+01	8.175E-01	0.000E+00	2.342E+00	1.922E+00	1.183E-01	1.661E-02	0.000E+00	2.628E-01	1.963E+00
9.000E+01	8.041E-01	0.000E+00	2.391E+00	1.955E+00	1.218E-01	1.795E-02	0.000E+00	2.671E-01	1.916E+00
9.500E+01	7.917E-01	0.000E+00	2.436E+00	1.990E+00	1.263E-01	1.937E-02	0.000E+00	2.715E-01	1.873E+00
1.000E+02	7.803E-01	0.000E+00	2.476E+00	2.026E+00	1.301E-01	2.082E-02	0.000E+00	2.752E-01	1.836E+00
1.100E+02	7.613E-01	0.000E+00	2.553E+00	2.083E+00	1.382E-01	2.393E-02	0.000E+00	2.833E-01	1.756E+00
1.200E+02	7.473E-01	0.000E+00	2.634E+00	2.146E+00	1.444E-01	2.732E-02	0.000E+00	2.919E-01	1.693E+00
1.300E+02	7.388E-01	0.000E+00	2.714E+00	2.210E+00	1.526E-01	3.113E-02	0.000E+00	3.020E-01	1.617E+00
1.400E+02	7.355E-01	0.000E+00	2.780E+00	2.287E+00	1.608E-01	3.532E-02	0.000E+00	3.113E-01	1.552E+00
1.500E+02	7.386E-01	0.000E+00	2.850E+00	2.369E+00	1.707E-01	4.016E-02	0.000E+00	3.232E-01	1.503E+00

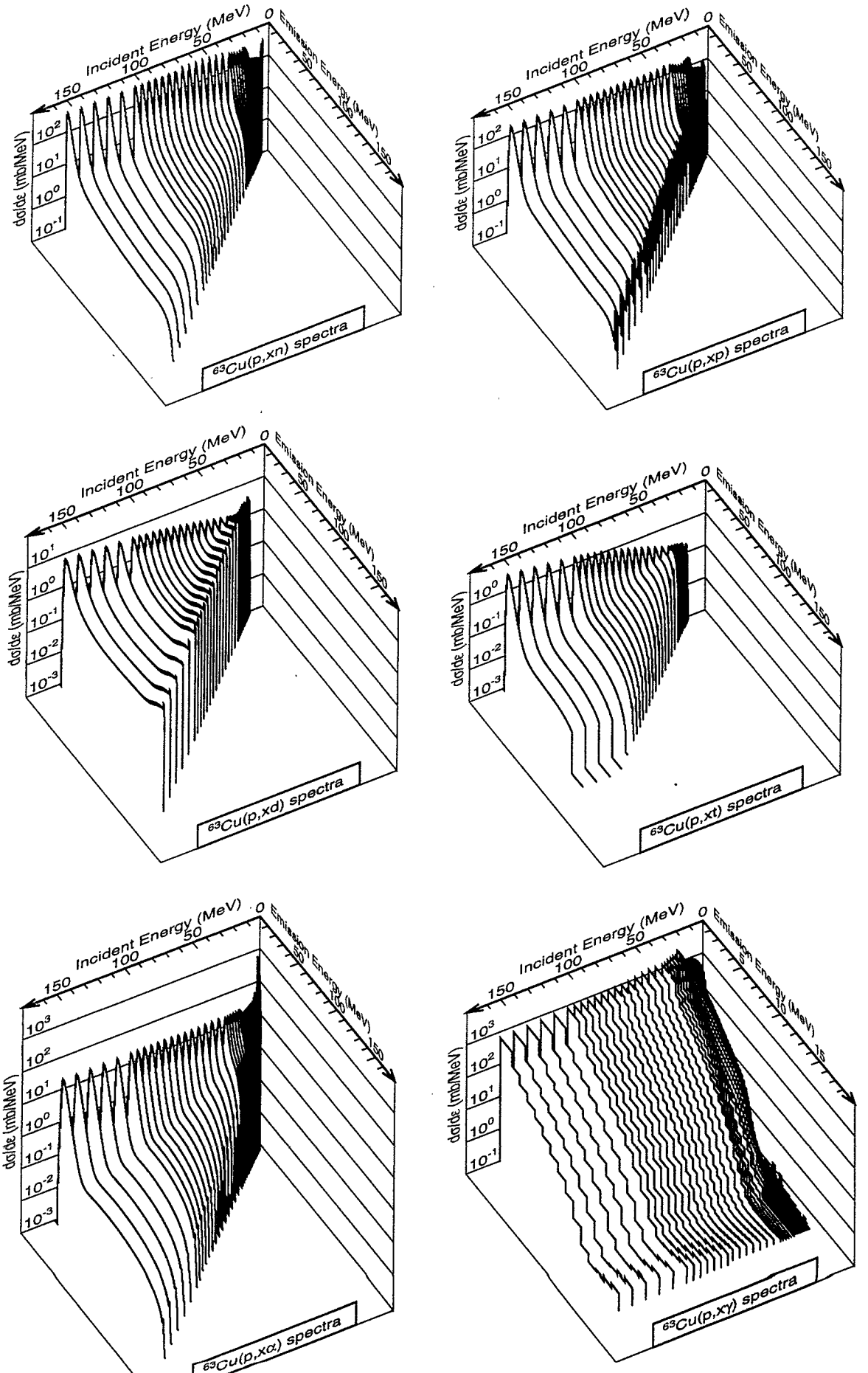
29063 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+00	0.000E+00	1.212E+00	0.000E+00	0.000E+00	0.000E+00	5.175E+00	2.951E+00
3.000E+00	0.000E+00	2.055E+00	0.000E+00	0.000E+00	0.000E+00	5.942E+00	1.584E+00
4.000E+00	0.000E+00	2.798E+00	0.000E+00	0.000E+00	0.000E+00	6.634E+00	1.129E+00
5.000E+00	4.816E-01	3.465E+00	0.000E+00	0.000E+00	0.000E+00	7.265E+00	8.693E-01
6.000E+00	1.105E+00	4.056E+00	0.000E+00	0.000E+00	0.000E+00	7.709E+00	9.763E-01
7.000E+00	1.553E+00	4.555E+00	0.000E+00	0.000E+00	0.000E+00	8.075E+00	1.148E+00
8.000E+00	1.855E+00	4.943E+00	0.000E+00	0.000E+00	0.000E+00	8.402E+00	1.308E+00
9.000E+00	2.041E+00	5.202E+00	0.000E+00	0.000E+00	0.000E+00	8.739E+00	1.483E+00
1.000E+01	2.153E+00	5.443E+00	1.135E+00	0.000E+00	0.000E+00	9.050E+00	1.645E+00
1.100E+01	2.200E+00	5.617E+00	2.016E+00	0.000E+00	0.000E+00	9.328E+00	1.788E+00
1.200E+01	2.274E+00	5.680E+00	2.812E+00	0.000E+00	0.000E+00	9.574E+00	1.902E+00
1.300E+01	2.342E+00	5.532E+00	3.563E+00	1.431E+00	0.000E+00	9.683E+00	1.967E+00
1.400E+01	2.380E+00	5.098E+00	4.259E+00	2.322E+00	0.000E+00	9.614E+00	1.912E+00
1.500E+01	2.309E+00	4.887E+00	4.959E+00	3.161E+00	0.000E+00	9.625E+00	1.776E+00
1.600E+01	2.190E+00	4.948E+00	5.642E+00	3.738E+00	0.000E+00	9.674E+00	1.615E+00
1.700E+01	2.130E+00	5.131E+00	6.239E+00	4.222E+00	0.000E+00	9.768E+00	1.463E+00
1.800E+01	2.151E+00	5.388E+00	6.852E+00	4.712E+00	0.000E+00	9.897E+00	1.360E+00
1.900E+01	2.245E+00	5.662E+00	7.459E+00	5.206E+00	0.000E+00	9.997E+00	1.314E+00
2.000E+01	2.375E+00	5.933E+00	8.130E+00	5.667E+00	0.000E+00	1.024E+01	1.361E+00
2.200E+01	2.698E+00	6.304E+00	9.348E+00	6.655E+00	0.000E+00	1.060E+01	1.424E+00
2.400E+01	2.979E+00	6.426E+00	1.041E+01	7.608E+00	0.000E+00	1.088E+01	1.475E+00
2.600E+01	3.182E+00	6.534E+00	1.151E+01	8.500E+00	0.000E+00	1.109E+01	1.503E+00
2.800E+01	3.318E+00	6.669E+00	1.259E+01	9.329E+00	0.000E+00	1.117E+01	1.513E+00

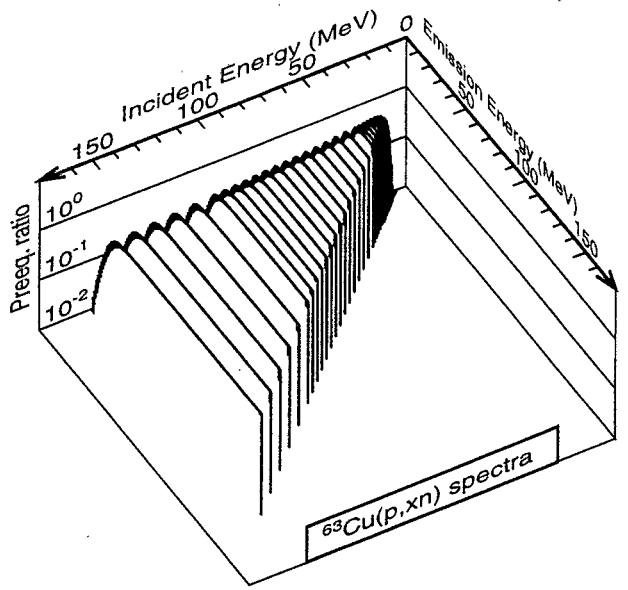
3.000E+01	3.463E+00	6.822E+00	1.366E+01	1.009E+01	0.000E+00	1.127E+01	1.487E+00
3.500E+01	3.882E+00	7.463E+00	1.629E+01	1.184E+01	0.000E+00	1.152E+01	1.472E+00
4.000E+01	4.267E+00	8.318E+00	1.893E+01	1.332E+01	0.000E+00	1.179E+01	1.495E+00
4.500E+01	4.594E+00	8.960E+00	2.105E+01	1.450E+01	0.000E+00	1.205E+01	1.507E+00
5.000E+01	4.962E+00	9.430E+00	2.324E+01	1.550E+01	0.000E+00	1.226E+01	1.516E+00
5.500E+01	5.336E+00	9.827E+00	2.512E+01	1.623E+01	0.000E+00	1.242E+01	1.523E+00
6.000E+01	5.686E+00	1.023E+01	2.684E+01	1.677E+01	0.000E+00	1.256E+01	1.532E+00
6.500E+01	6.011E+00	1.061E+01	2.841E+01	1.702E+01	0.000E+00	1.267E+01	1.532E+00
7.000E+01	6.387E+00	1.102E+01	2.962E+01	1.711E+01	0.000E+00	1.276E+01	1.566E+00
7.500E+01	6.735E+00	1.136E+01	3.100E+01	1.711E+01	0.000E+00	1.289E+01	1.587E+00
8.000E+01	7.060E+00	1.173E+01	3.219E+01	1.700E+01	0.000E+00	1.301E+01	1.590E+00
8.500E+01	7.391E+00	1.209E+01	3.332E+01	1.684E+01	0.000E+00	1.312E+01	1.602E+00
9.000E+01	7.715E+00	1.247E+01	3.425E+01	1.661E+01	0.000E+00	1.323E+01	1.596E+00
9.500E+01	8.035E+00	1.283E+01	3.523E+01	1.635E+01	0.000E+00	1.334E+01	1.589E+00
1.000E+02	8.354E+00	1.318E+01	3.629E+01	1.607E+01	0.000E+00	1.345E+01	1.593E+00
1.100E+02	8.985E+00	1.392E+01	3.807E+01	1.543E+01	0.000E+00	1.366E+01	1.623E+00
1.200E+02	9.606E+00	1.465E+01	3.912E+01	1.454E+01	0.000E+00	1.386E+01	1.644E+00
1.300E+02	1.022E+01	1.537E+01	4.015E+01	1.362E+01	0.000E+00	1.404E+01	1.641E+00
1.400E+02	1.089E+01	1.605E+01	4.131E+01	1.282E+01	0.000E+00	1.424E+01	1.649E+00
1.500E+02	1.160E+01	1.678E+01	4.199E+01	1.220E+01	0.000E+00	1.443E+01	1.663E+00

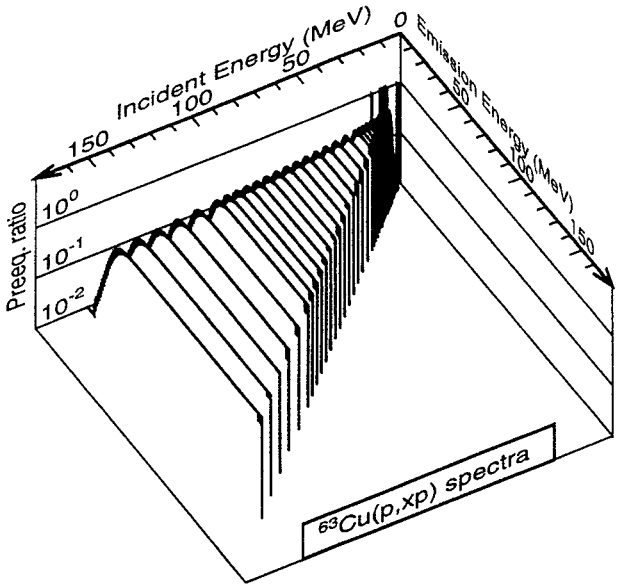

p + 63Cu nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
n
p
γ
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
10^1
10^0
0
50
100
150
Incident Energy (MeV)

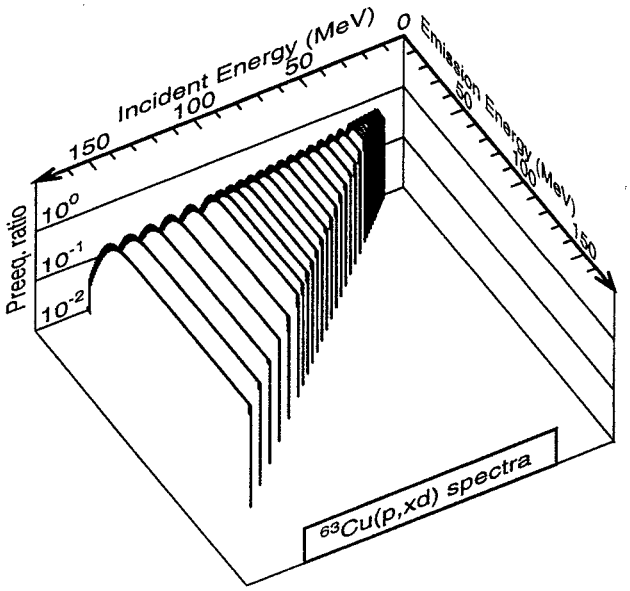
p + ^{63}Cu angle-integrated emission spectra

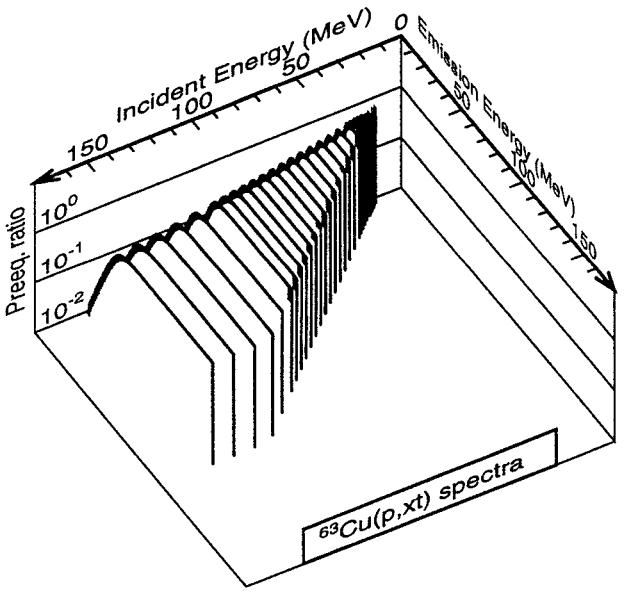


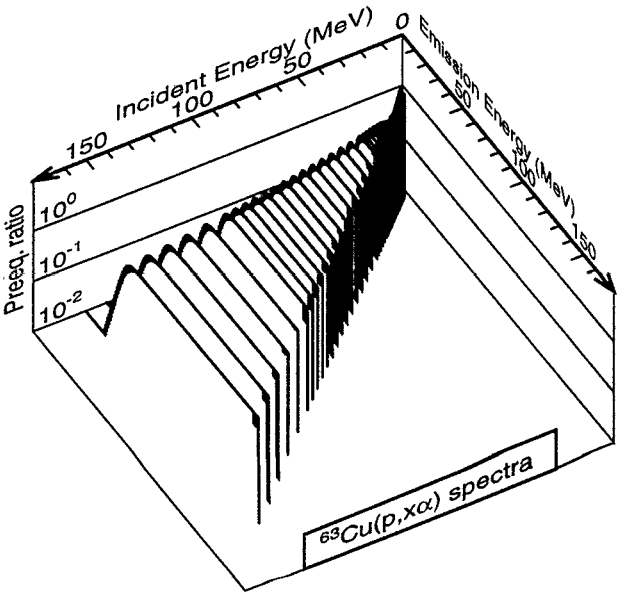
p + ^{63}Cu Kalbach preequilibrium ratios

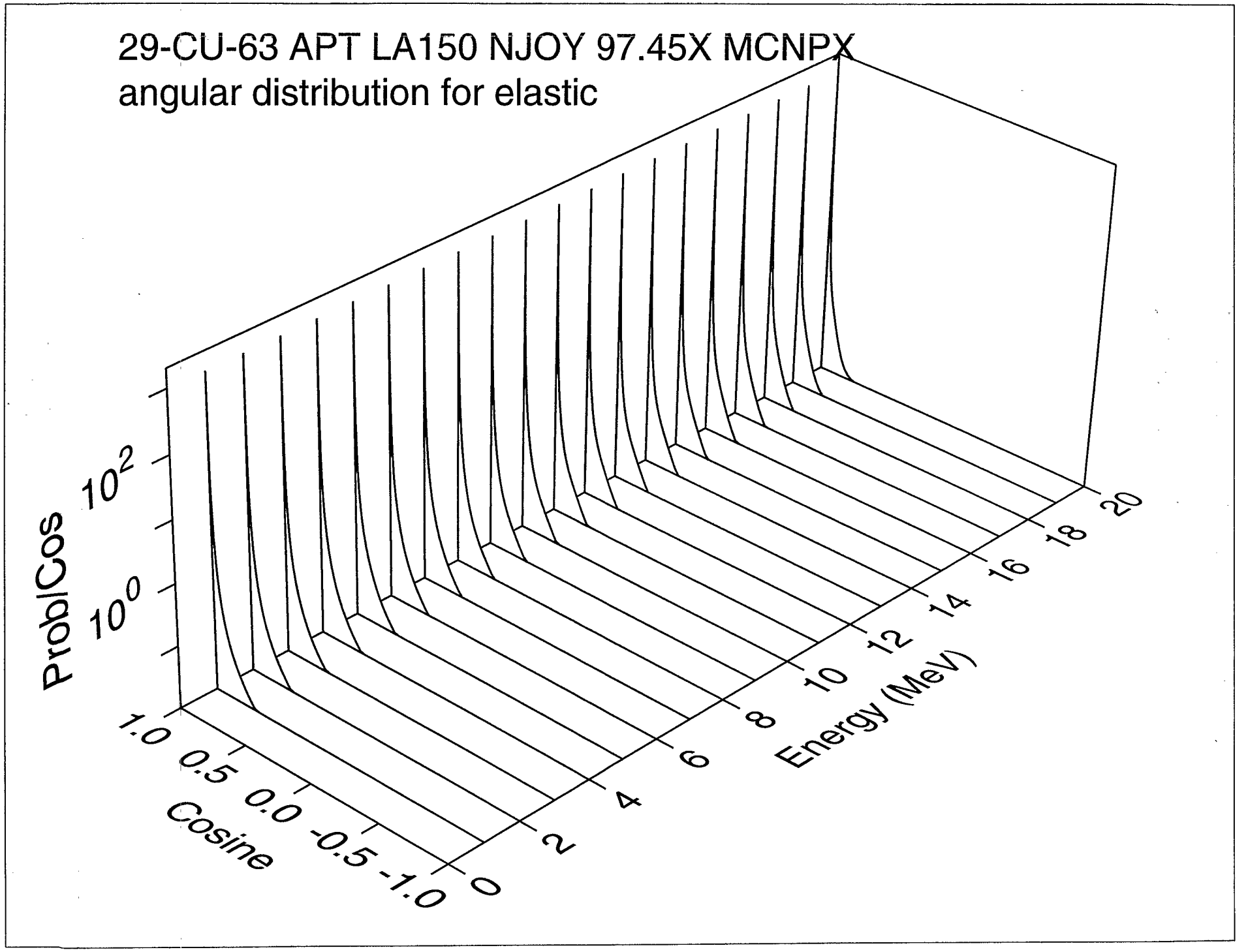


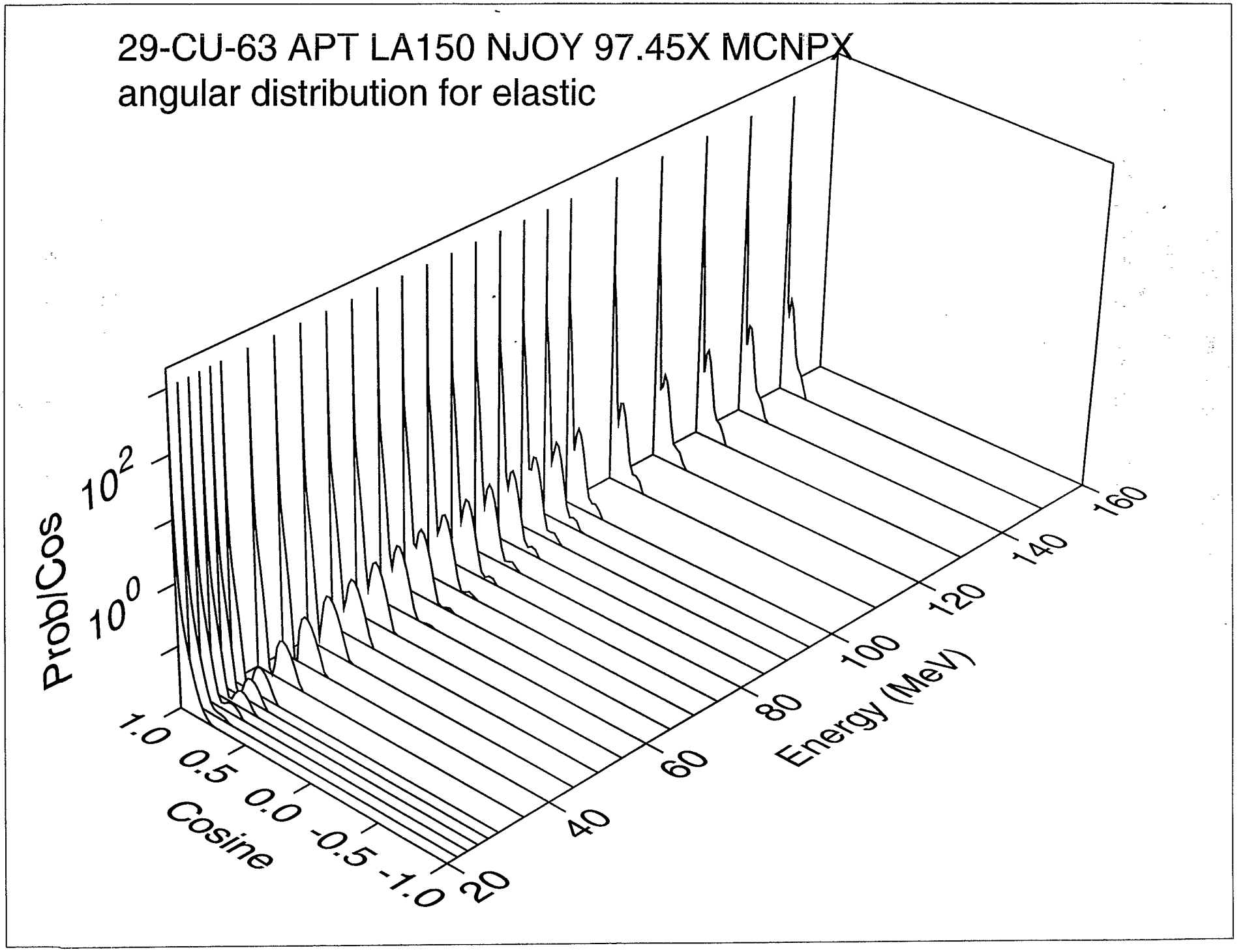


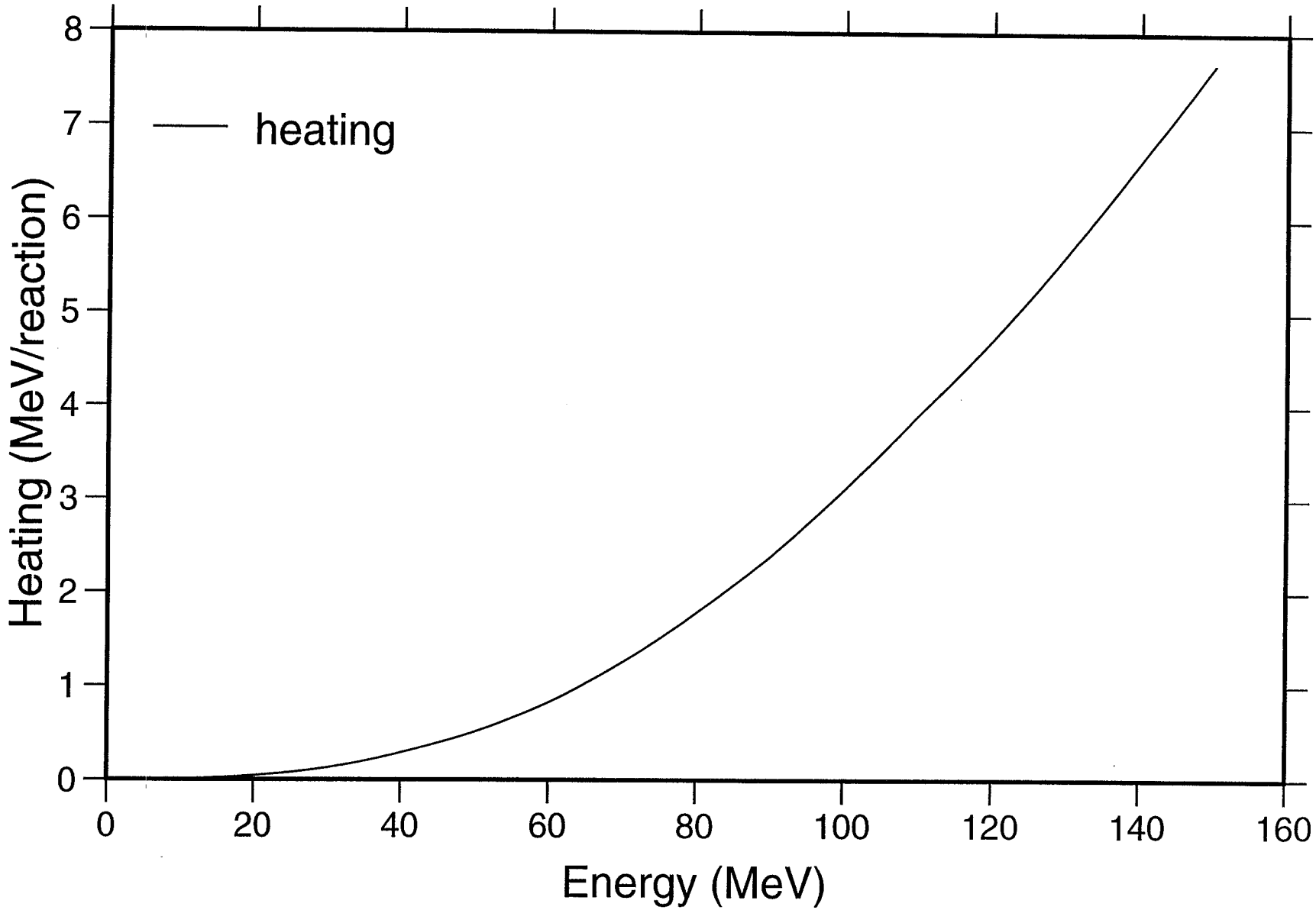







29-CU-63 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
1.0
0.5
0.0
-0.5
-1.0
Cosine
0
2
4
6
8
10
12
14
16
18
20
Energy (MeV)


29-CU-63 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


29-CU-63 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
1
2
3
4
5
6
7
8
0
20
40
60
80
100
120
140
160

EVALUATION OF p + 65Cu CROSS SECTIONS FOR THE ENERGY RANGE 1 to 150 MeV

A. J. Koning, M. B. Chadwick, and P. G. Young
15 February 1998

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident proton energy range from 1 to 150 MeV. The evaluation utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above are:

MF=3	MT= 2	Integral of nuclear plus interference components of the elastic scattering cross section
	MT= 5	Sum of binary (p,n') and (p,x) reactions
MF=6	MT= 2	Elastic (p,p) angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
	MT= 5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Cu65 and p + Cu65 reactions (Ch98). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic proton angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96a). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from

nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk et al. (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged- particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

SPECIFIC INFORMATION CONCERNING THE Cu-65 EVALUATION

This evaluation is documented in some detail in Ref. (Ko98b).

To obtain the neutron optical potential we used total cross section data from 1.2 to 4.5 MeV (Gu86) and from 5.3 to 600 MeV (Fi93), and elastic scattering angular distribution data from 1.6 to 96 MeV (Br50, Sa60, Ki74, El82, Gu86). The optical potential parameters were obtained using a combination of a grid search code and the interactive optical model viewer ECISVIEW [Ko97], both built around the coupled channels code ECIS96 [Ra94]. The energy dependence of the optical model parameters is as described in [Ko98]. This optical potential was used for the calculation, with ECIS96, of neutron transmission coefficients and DWBA cross sections for the entire energy region above 20 MeV.

Due to the lack of proton elastic scattering data in numerical form, we used a combination of global optical models for the proton channel. The Becchetti-Greenlees potential [Be69] was adopted below 47 MeV, and the non-relativistic version of the Madland potential [Ma88] above 47 MeV. At this particular energy point the two potentials join smoothly. The calculated proton transmission coefficients were then renormalized, to a reaction cross section value scaled by A**2/3 from our evaluated reaction cross section for Cu63, which we showed described experimental data well.

For deuterons, the Lohr-Haeberli global potential [Lo74] was used; for alpha particles the Moyen potential (MacFadden-Satchler [Ma66]) was used; and for tritons the Becchetti-Greenlees potential [Be71] was used. The He-3 channel was ignored.

Following Delaroche et al. [De82], we adopted the weak-coupling model for direct collective inelastic scattering for Cu-65, using Ni-64 as a basis. For the calculation of the cross sections, ECIS96 was used in DWBA mode. We used the following direct transitions for Cu-65 (ground state 3/2-) :

Jpi	Ex(MeV)	Deformation length/parameter
0.5-	0.771	Beta(2)=0.0566
2.5-	1.116	Beta(2)=0.0980
3.5-	1.481	Beta(2)=0.1132
1.5-	1.743	Beta(2)=0.0800
1.5-	3.185	Delta(3)=0.3167
2.5-	3.435	Delta(3)=0.3879
3.5-	3.685	Delta(3)=0.4479
4.5-	3.935	Delta(3)=0.5008

Two measurements exist for proton-induced emission spectra above 20 MeV for 65Cu: the 26.7 MeV (p,xn) and (p,xp) data by Holler et al (Ho85). The partial level density parameters have been slightly adjusted to obtain good agreement with these

experimental data (Ko98b).

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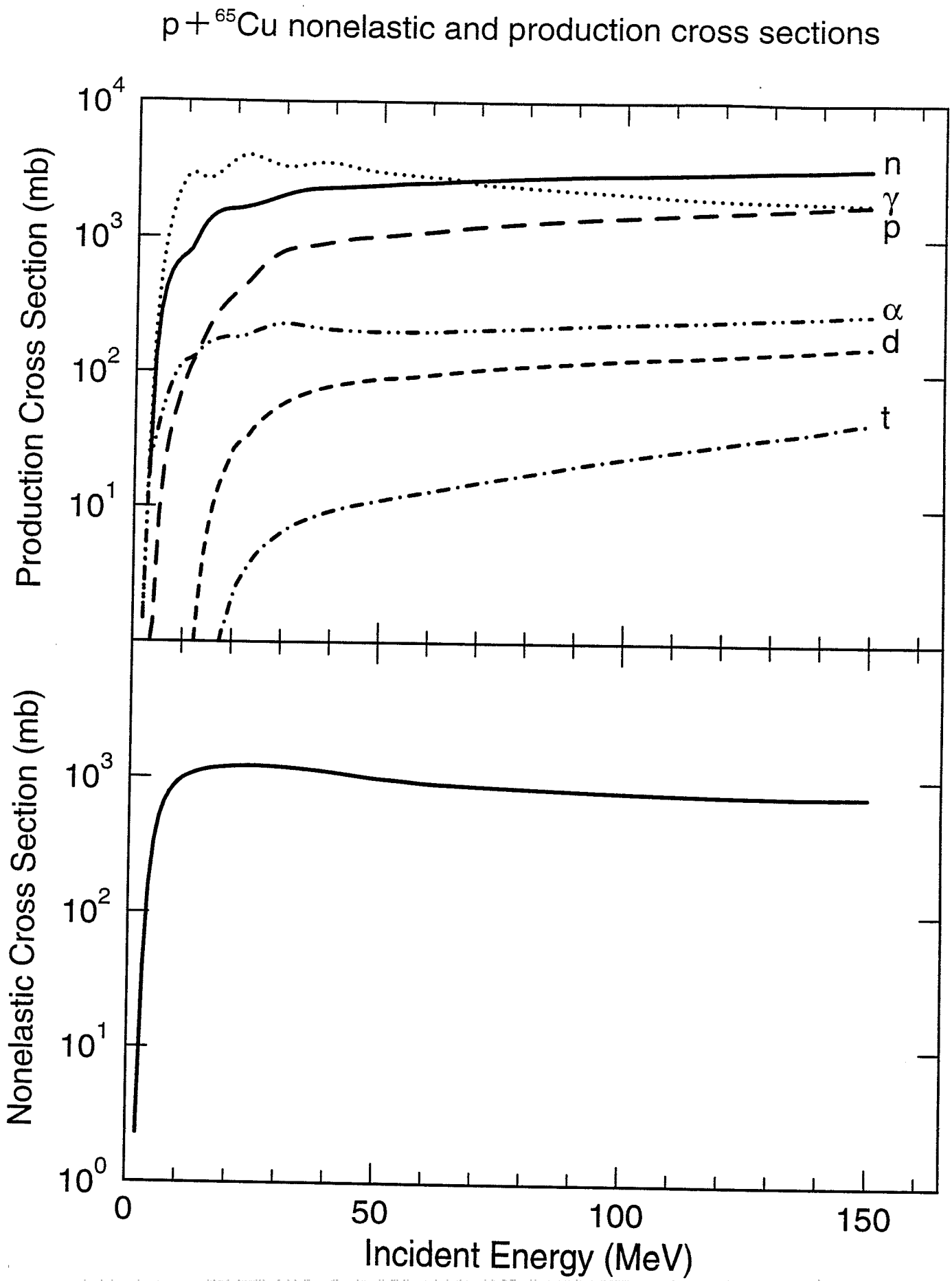
29065 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+00	2.282E-03	0.000E+00	0.000E+00	1.926E-11	0.000E+00	0.000E+00	0.000E+00	1.480E-03	1.607E-03
3.000E+00	3.883E-02	0.000E+00	1.671E-02	2.798E-05	0.000E+00	0.000E+00	0.000E+00	2.193E-02	2.746E-02
4.000E+00	1.582E-01	0.000E+00	1.266E-01	1.389E-03	0.000E+00	0.000E+00	0.000E+00	2.998E-02	1.992E-01
5.000E+00	3.355E-01	0.000E+00	2.831E-01	8.465E-03	0.000E+00	0.000E+00	0.000E+00	4.364E-02	5.426E-01
6.000E+00	5.117E-01	0.000E+00	4.310E-01	2.041E-02	0.000E+00	0.000E+00	0.000E+00	5.981E-02	9.836E-01
7.000E+00	6.583E-01	0.000E+00	5.468E-01	3.337E-02	0.000E+00	0.000E+00	0.000E+00	7.745E-02	1.435E+00
8.000E+00	7.746E-01	0.000E+00	6.295E-01	4.787E-02	0.000E+00	0.000E+00	0.000E+00	9.652E-02	1.996E+00
9.000E+00	8.688E-01	0.000E+00	6.914E-01	6.542E-02	2.277E-10	0.000E+00	0.000E+00	1.112E-01	2.400E+00
1.000E+01	9.432E-01	0.000E+00	7.367E-01	8.558E-02	1.398E-06	0.000E+00	0.000E+00	1.201E-01	2.780E+00
1.100E+01	9.999E-01	0.000E+00	7.983E-01	1.072E-01	6.998E-05	1.760E-09	0.000E+00	1.248E-01	2.963E+00
1.200E+01	1.041E+00	0.000E+00	9.424E-01	1.287E-01	5.860E-04	9.862E-07	0.000E+00	1.314E-01	2.905E+00
1.300E+01	1.078E+00	0.000E+00	1.116E+00	1.534E-01	1.909E-03	1.503E-05	0.000E+00	1.456E-01	2.758E+00
1.400E+01	1.108E+00	0.000E+00	1.267E+00	1.854E-01	4.144E-03	7.033E-05	0.000E+00	1.564E-01	2.688E+00
1.500E+01	1.134E+00	0.000E+00	1.389E+00	2.193E-01	7.076E-03	2.054E-04	0.000E+00	1.647E-01	2.722E+00
1.600E+01	1.154E+00	0.000E+00	1.480E+00	2.537E-01	1.044E-02	4.500E-04	0.000E+00	1.708E-01	2.847E+00
1.700E+01	1.169E+00	0.000E+00	1.538E+00	2.867E-01	1.405E-02	7.914E-04	0.000E+00	1.761E-01	3.044E+00
1.800E+01	1.181E+00	0.000E+00	1.573E+00	3.181E-01	1.776E-02	1.195E-03	0.000E+00	1.797E-01	3.280E+00
1.900E+01	1.190E+00	0.000E+00	1.591E+00	3.476E-01	2.150E-02	1.551E-03	0.000E+00	1.813E-01	3.548E+00
2.000E+01	1.198E+00	0.000E+00	1.598E+00	3.753E-01	2.676E-02	2.130E-03	0.000E+00	1.797E-01	3.728E+00
2.200E+01	1.209E+00	0.000E+00	1.639E+00	4.353E-01	3.073E-02	3.086E-03	0.000E+00	1.842E-01	4.021E+00
2.400E+01	1.215E+00	0.000E+00	1.707E+00	5.227E-01	3.787E-02	4.023E-03	0.000E+00	1.975E-01	3.924E+00
2.600E+01	1.213E+00	0.000E+00	1.796E+00	6.263E-01	4.472E-02	4.919E-03	0.000E+00	2.107E-01	3.666E+00
2.800E+01	1.206E+00	0.000E+00	1.904E+00	7.143E-01	5.137E-02	5.644E-03	0.000E+00	2.222E-01	3.423E+00
3.000E+01	1.195E+00	0.000E+00	2.021E+00	7.828E-01	5.753E-02	6.428E-03	0.000E+00	2.268E-01	3.272E+00
3.500E+01	1.157E+00	0.000E+00	2.232E+00	8.493E-01	6.983E-02	8.036E-03	0.000E+00	2.159E-01	3.443E+00
4.000E+01	1.107E+00	0.000E+00	2.294E+00	9.129E-01	7.862E-02	9.272E-03	0.000E+00	2.052E-01	3.495E+00
4.500E+01	1.046E+00	0.000E+00	2.345E+00	9.776E-01	8.472E-02	1.029E-02	0.000E+00	2.009E-01	3.190E+00
5.000E+01	9.917E-01	0.000E+00	2.404E+00	1.011E+00	8.934E-02	1.118E-02	0.000E+00	1.983E-01	2.983E+00
5.500E+01	9.557E-01	0.000E+00	2.478E+00	1.060E+00	9.174E-02	1.215E-02	0.000E+00	1.990E-01	2.874E+00
6.000E+01	9.182E-01	0.000E+00	2.511E+00	1.098E+00	9.577E-02	1.306E-02	0.000E+00	1.990E-01	2.770E+00
6.500E+01	8.982E-01	0.000E+00	2.586E+00	1.152E+00	1.005E-01	1.416E-02	0.000E+00	2.038E-01	2.685E+00
7.000E+01	8.814E-01	0.000E+00	2.637E+00	1.205E+00	1.051E-01	1.533E-02	0.000E+00	2.082E-01	2.470E+00
7.500E+01	8.650E-01	0.000E+00	2.693E+00	1.246E+00	1.093E-01	1.654E-02	0.000E+00	2.115E-01	2.412E+00
8.000E+01	8.494E-01	0.000E+00	2.745E+00	1.286E+00	1.129E-01	1.779E-02	0.000E+00	2.156E-01	2.343E+00
8.500E+01	8.347E-01	0.000E+00	2.789E+00	1.323E+00	1.162E-01	1.910E-02	0.000E+00	2.192E-01	2.286E+00
9.000E+01	8.210E-01	0.000E+00	2.838E+00	1.360E+00	1.193E-01	2.058E-02	0.000E+00	2.239E-01	2.221E+00
9.500E+01	8.083E-01	0.000E+00	2.871E+00	1.395E+00	1.225E-01	2.202E-02	0.000E+00	2.275E-01	2.172E+00
1.000E+02	7.967E-01	0.000E+00	2.901E+00	1.423E+00	1.255E-01	2.351E-02	0.000E+00	2.312E-01	2.125E+00
1.100E+02	7.773E-01	0.000E+00	2.977E+00	1.495E+00	1.306E-01	2.677E-02	0.000E+00	2.393E-01	2.013E+00
1.200E+02	7.630E-01	0.000E+00	3.047E+00	1.566E+00	1.369E-01	3.021E-02	0.000E+00	2.466E-01	1.946E+00
1.300E+02	7.543E-01	0.000E+00	3.127E+00	1.634E+00	1.438E-01	3.407E-02	0.000E+00	2.554E-01	1.899E+00
1.400E+02	7.510E-01	0.000E+00	3.221E+00	1.712E+00	1.504E-01	3.841E-02	0.000E+00	2.653E-01	1.869E+00
1.500E+02	7.541E-01	0.000E+00	3.324E+00	1.798E+00	1.588E-01	4.337E-02	0.000E+00	2.767E-01	1.854E+00

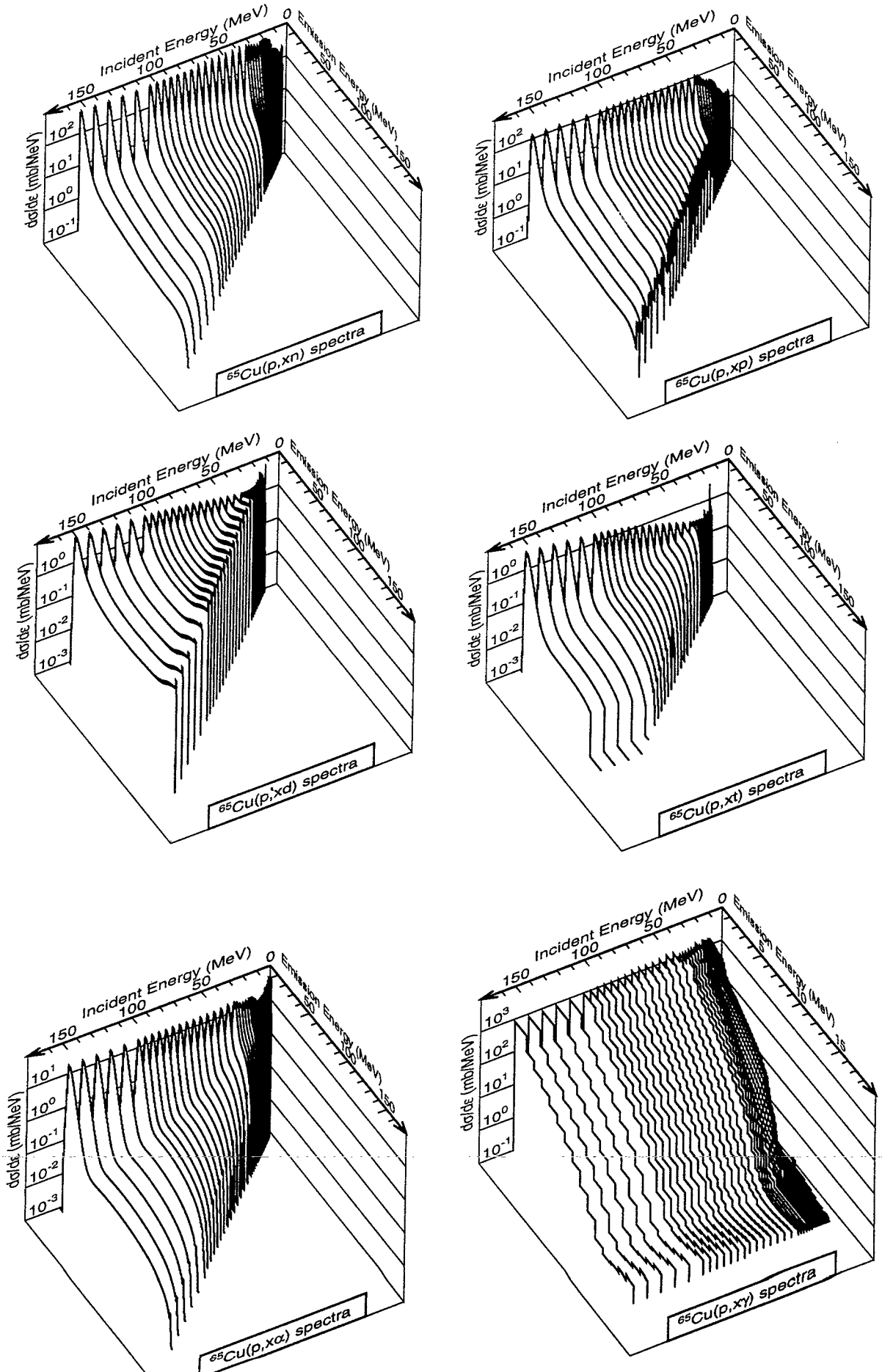
29065 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+00	0.000E+00	1.215E+00	0.000E+00	0.000E+00	0.000E+00	5.552E+00	3.288E+00
3.000E+00	6.392E-01	2.043E+00	0.000E+00	0.000E+00	0.000E+00	6.335E+00	6.762E-01
4.000E+00	1.141E+00	2.818E+00	0.000E+00	0.000E+00	0.000E+00	6.980E+00	5.917E-01
5.000E+00	1.515E+00	3.571E+00	0.000E+00	0.000E+00	0.000E+00	7.589E+00	8.074E-01
6.000E+00	1.750E+00	4.221E+00	0.000E+00	0.000E+00	0.000E+00	8.045E+00	1.042E+00
7.000E+00	1.928E+00	4.656E+00	0.000E+00	0.000E+00	0.000E+00	8.377E+00	1.272E+00
8.000E+00	2.054E+00	4.990E+00	0.000E+00	0.000E+00	0.000E+00	8.726E+00	1.434E+00
9.000E+00	2.143E+00	5.282E+00	1.106E+00	0.000E+00	0.000E+00	9.064E+00	1.617E+00
1.000E+01	2.212E+00	5.535E+00	1.942E+00	0.000E+00	0.000E+00	9.397E+00	1.794E+00
1.100E+01	2.199E+00	5.808E+00	2.743E+00	1.373E+00	0.000E+00	9.665E+00	1.963E+00
1.200E+01	2.050E+00	6.075E+00	3.551E+00	2.308E+00	0.000E+00	9.695E+00	1.991E+00
1.300E+01	1.971E+00	6.216E+00	4.340E+00	3.124E+00	0.000E+00	9.473E+00	1.926E+00
1.400E+01	1.962E+00	6.225E+00	5.020E+00	3.716E+00	0.000E+00	9.346E+00	1.802E+00
1.500E+01	1.988E+00	6.249E+00	5.699E+00	4.218E+00	0.000E+00	9.436E+00	1.643E+00
1.600E+01	2.056E+00	6.366E+00	6.364E+00	4.694E+00	0.000E+00	9.613E+00	1.504E+00
1.700E+01	2.160E+00	6.514E+00	7.014E+00	5.222E+00	0.000E+00	9.826E+00	1.419E+00
1.800E+01	2.269E+00	6.687E+00	7.640E+00	5.746E+00	0.000E+00	1.005E+01	1.383E+00
1.900E+01	2.408E+00	6.870E+00	8.254E+00	6.235E+00	0.000E+00	1.028E+01	1.393E+00
2.000E+01	2.549E+00	7.073E+00	8.971E+00	6.770E+00	0.000E+00	1.050E+01	1.509E+00
2.200E+01	2.763E+00	7.315E+00	9.834E+00	7.719E+00	0.000E+00	1.065E+01	1.580E+00
2.400E+01	2.918E+00	7.252E+00	1.097E+01	8.593E+00	0.000E+00	1.049E+01	1.621E+00
2.600E+01	3.045E+00	7.182E+00	1.208E+01	9.401E+00	0.000E+00	1.037E+01	1.630E+00
2.800E+01	3.167E+00	7.270E+00	1.318E+01	1.004E+01	0.000E+00	1.035E+01	1.599E+00

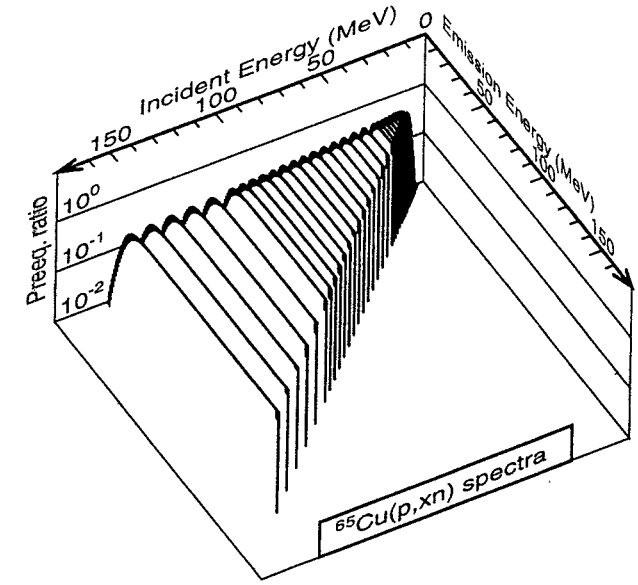
3.000E+01	3.283E+00	7.492E+00	1.428E+01	1.077E+01	0.000E+00	1.046E+01	1.552E+00
3.500E+01	3.657E+00	8.606E+00	1.702E+01	1.242E+01	0.000E+00	1.103E+01	1.421E+00
4.000E+01	4.129E+00	9.522E+00	1.969E+01	1.380E+01	0.000E+00	1.139E+01	1.443E+00
4.500E+01	4.516E+00	1.025E+01	2.223E+01	1.494E+01	0.000E+00	1.161E+01	1.455E+00
5.000E+01	4.864E+00	1.112E+01	2.453E+01	1.586E+01	0.000E+00	1.187E+01	1.451E+00
5.500E+01	5.210E+00	1.176E+01	2.615E+01	1.648E+01	0.000E+00	1.208E+01	1.450E+00
6.000E+01	5.566E+00	1.229E+01	2.810E+01	1.688E+01	0.000E+00	1.227E+01	1.441E+00
6.500E+01	5.896E+00	1.278E+01	2.980E+01	1.706E+01	0.000E+00	1.241E+01	1.446E+00
7.000E+01	6.270E+00	1.326E+01	3.147E+01	1.710E+01	0.000E+00	1.255E+01	1.501E+00
7.500E+01	6.604E+00	1.379E+01	3.292E+01	1.704E+01	0.000E+00	1.269E+01	1.504E+00
8.000E+01	6.932E+00	1.429E+01	3.435E+01	1.692E+01	0.000E+00	1.281E+01	1.524E+00
8.500E+01	7.252E+00	1.480E+01	3.571E+01	1.673E+01	0.000E+00	1.292E+01	1.513E+00
9.000E+01	7.558E+00	1.520E+01	3.658E+01	1.647E+01	0.000E+00	1.303E+01	1.525E+00
9.500E+01	7.877E+00	1.567E+01	3.784E+01	1.621E+01	0.000E+00	1.313E+01	1.544E+00
1.000E+02	8.192E+00	1.618E+01	3.903E+01	1.594E+01	0.000E+00	1.324E+01	1.547E+00
1.100E+02	8.792E+00	1.705E+01	4.031E+01	1.526E+01	0.000E+00	1.345E+01	1.579E+00
1.200E+02	9.383E+00	1.788E+01	4.234E+01	1.434E+01	0.000E+00	1.365E+01	1.596E+00
1.300E+02	9.952E+00	1.876E+01	4.375E+01	1.343E+01	0.000E+00	1.383E+01	1.599E+00
1.400E+02	1.053E+01	1.956E+01	4.492E+01	1.266E+01	0.000E+00	1.401E+01	1.595E+00
1.500E+02	1.111E+01	2.040E+01	4.584E+01	1.206E+01	0.000E+00	1.418E+01	1.587E+00

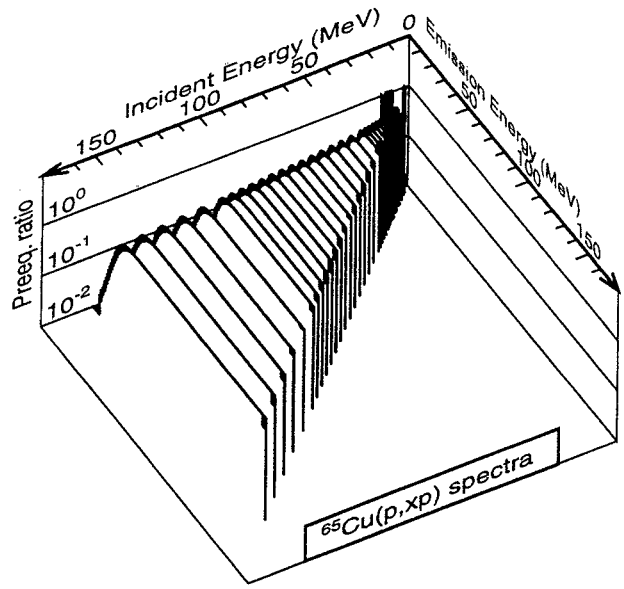

p + 65Cu nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
n
γ
p
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
10^1
10^0
0
50
100
150
Incident Energy (MeV)

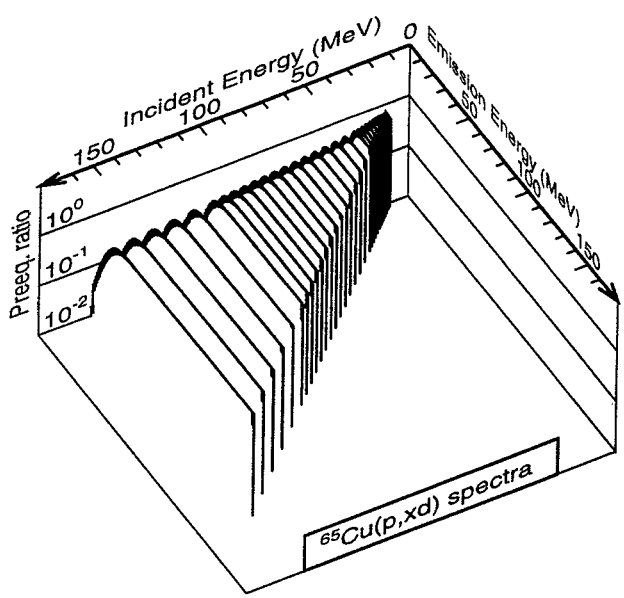
p + ^{65}Cu angle-integrated emission spectra

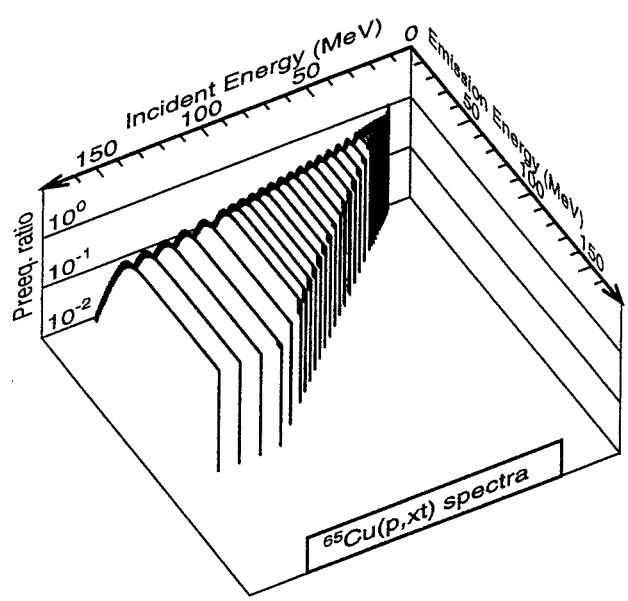


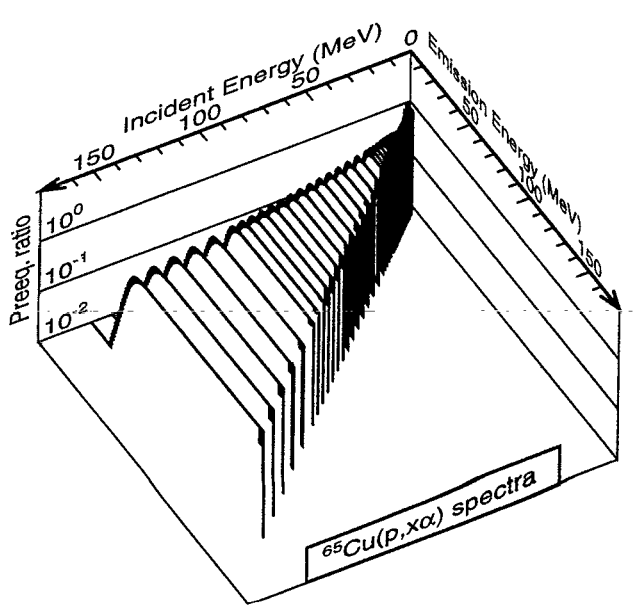
p + ^{65}Cu Kalbach preequilibrium ratios

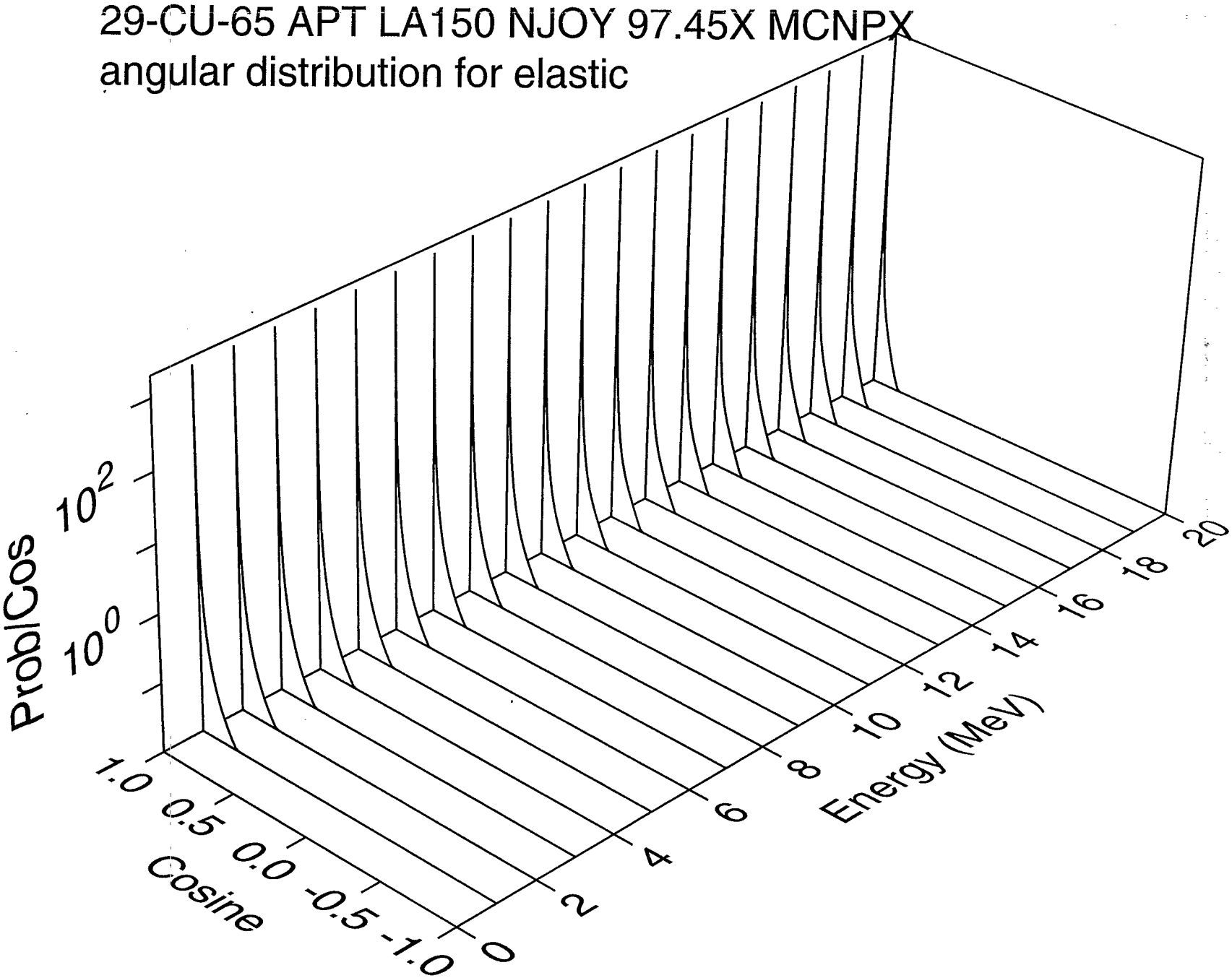


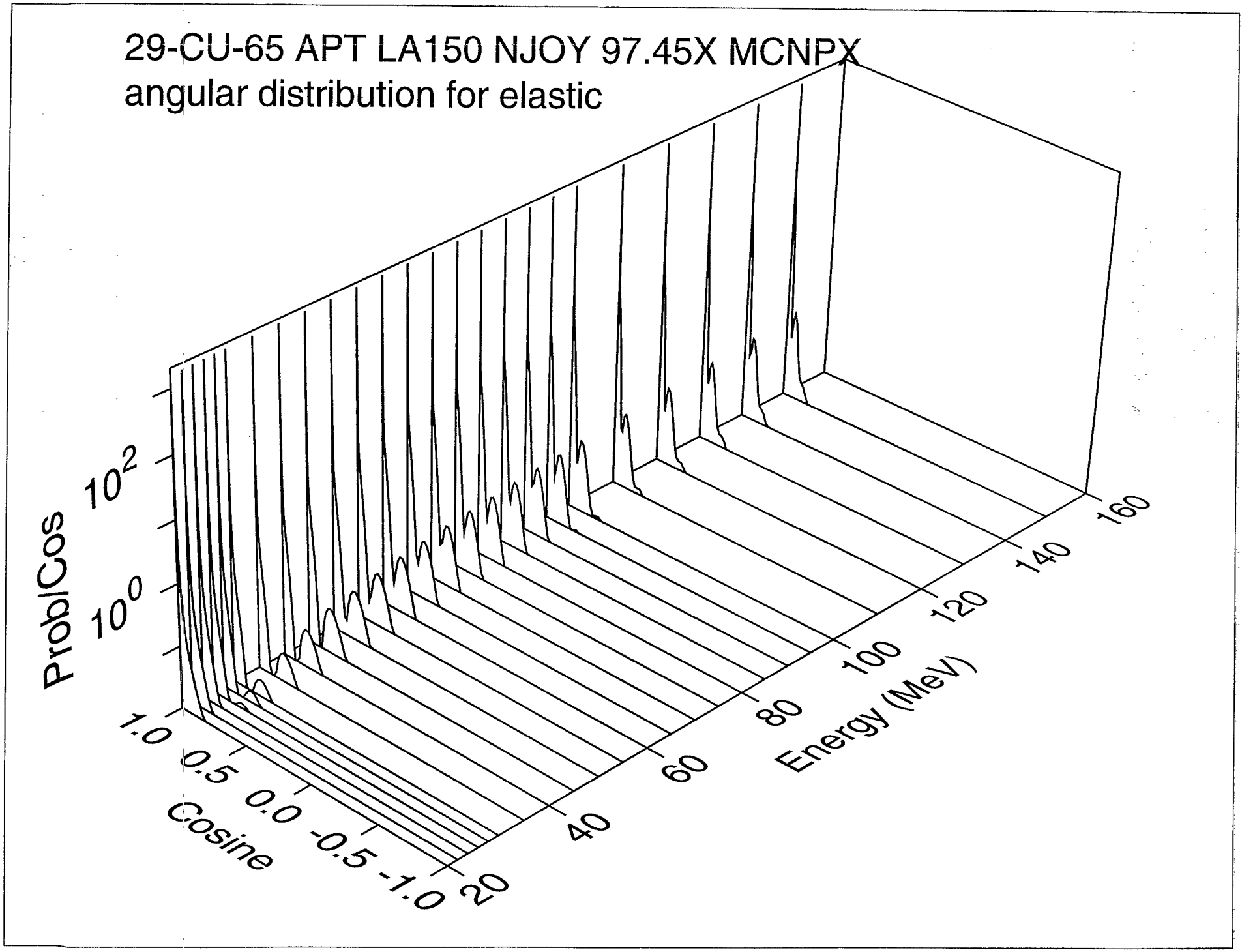


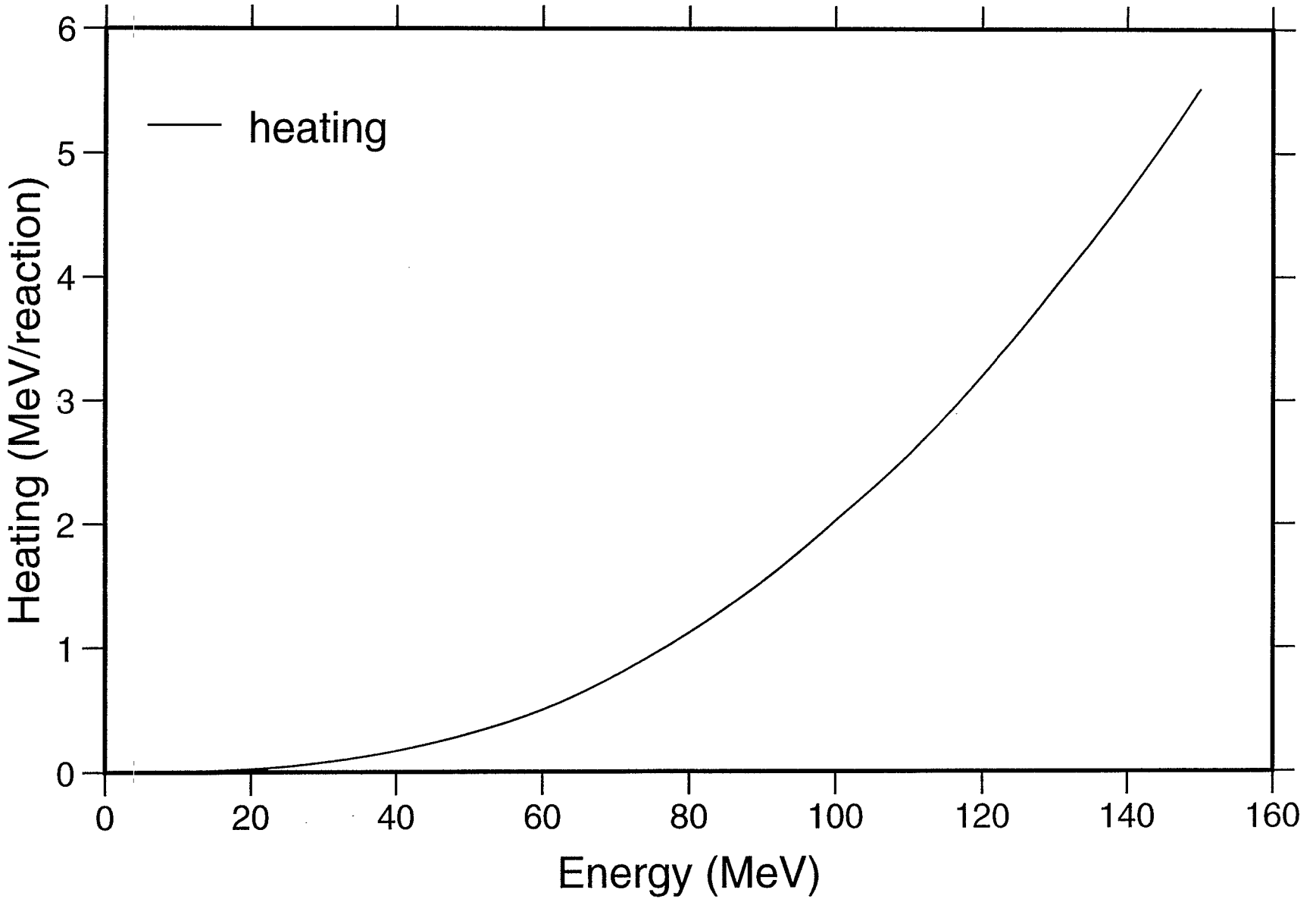







29-CU-65 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
1.0
0.5
0.0
-0.5
-1.0
Cosine
0
2
4
6
8
10
12
14
16
18
20
Energy (MeV)


29-CU-65 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


29-CU-65 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
1
2
3
4
5
6
0
20
40
60
80
100
120
140
160

EVALUATION OF p + 93Nb CROSS SECTIONS FOR THE ENERGY RANGE 1 to 150 MeV

M. B. Chadwick, and P. G. Young
10 December 1997

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident proton energy range from 1 to 150 MeV. The evaluation utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data above are:

MF=3	MT= 2	Integral of nuclear plus interference components of the elastic scattering cross section
	MT= 5	Sum of binary (p,n') and (p,x) reactions
MF=6	MT= 2	Elastic (p,p) angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
	MT= 5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n +93Nb and p +93Nb reactions (Ch98). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic proton angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96a). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. All other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation utilizes the LCT=3 option approved at the November, 1996, CSEWG meeting.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk et al. (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged- particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission

coefficients were calculated using the Kopecky-Uhl model (Ko90).

SPECIFIC INFORMATION CONCERNING THE NB-93 EVALUATION

The following optical potentials were used in the GNASH calculations. For incident neutrons, the Wilmore-Hodgson potential was used below 15 MeV, and the Madland potential (Ma88) was used at higher energies. For incident protons, the Becchetti-Greenlees (Be69) potential was used up to 50 MeV, above which the Madland potential (Ma88) was used. In both cases, the matching energy between the potentials was chosen to result in continuity of the reaction cross section. For protons at 50 MeV the reaction cross section (and transmission coefficients) was renormalized slightly to smoothen the transition between the potentials. The Perey (Pe63) potential was used for indident deuterons. For tritons, the Becchetti-Greenlees (Be71) was used up to 80 MeV, above which the Watanabe potential was used. The Moyen (McFadden Satchler) (Mc66) potential was used for alpha particles over the whole energy range.

Direct inelastic scattering to low-lying states in Nb93 was determined as follows. Coherent excitation of 2+ and 3- vibrations were assumed to be fragmented over Nb93 states, after coupling these excitations with the 4.5+ core. The magnitudes of the deformation lengths of 2+ and 3- excitations was obtained by fitting values of 34 and 46 mb respectively at 14 MeV, obtained in ref. (Ch93) and accounting for measurements well. This strength was then fragmented over Nb states. For the 3- excitation, the 7 states are in the "continuum" region of the GNASH calculation at approximately 2.5 MeV, with spins 1.5-,2.5-, ..,7.5-. For the 2+, the 5 states (2.5+,3.5+,...6.5+) near 1 MeV were assumed to be those whose inelastic cross section in the existing ENDF <20 MeV file are significant (note that the ENDF file below 20 MeV appears to incorporate inelastic information only up to 5 MeV for many states, after which a value of zero at 20 MeV was inserted).

Experimental data is used to benchmark the calculations. For incident neutrons, experimental neutron emission spectra data exist at 20 and 26 MeV by Marcinkowski (Ma83). For incident protons, spectra data exist at 14 and 26 MeV by Watanabe et al. (Wa97), and at 65 MeV by Sakai et al (Sa80). Our evaluation agrees reasonably well with these measurements.

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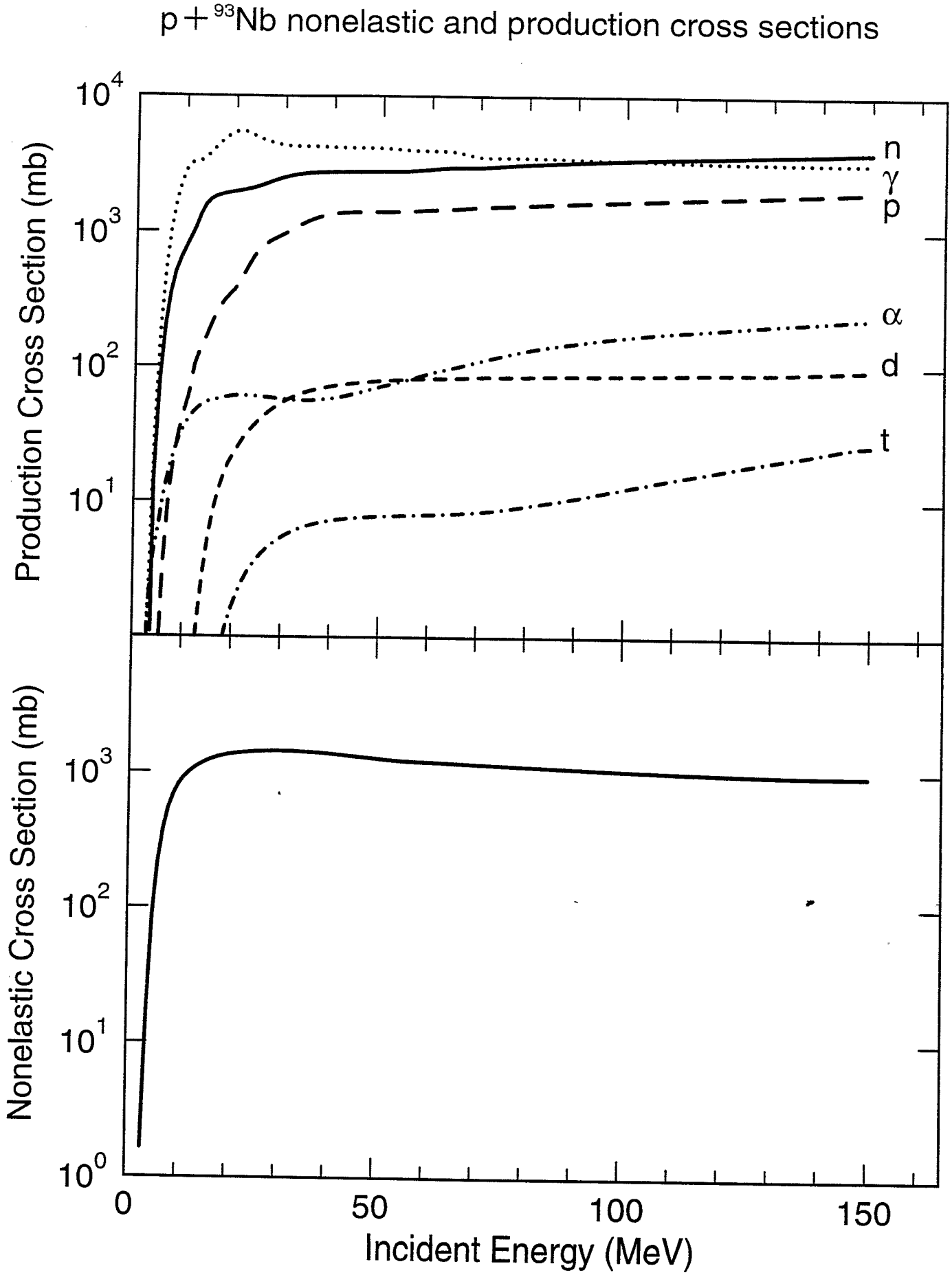
= TARGET 1000Z+A (if A=0 then elemental)
= PROJECTILE 1000Z+A
lastic, elastic, and Production cross sections for A<5 ejectiles in barns:

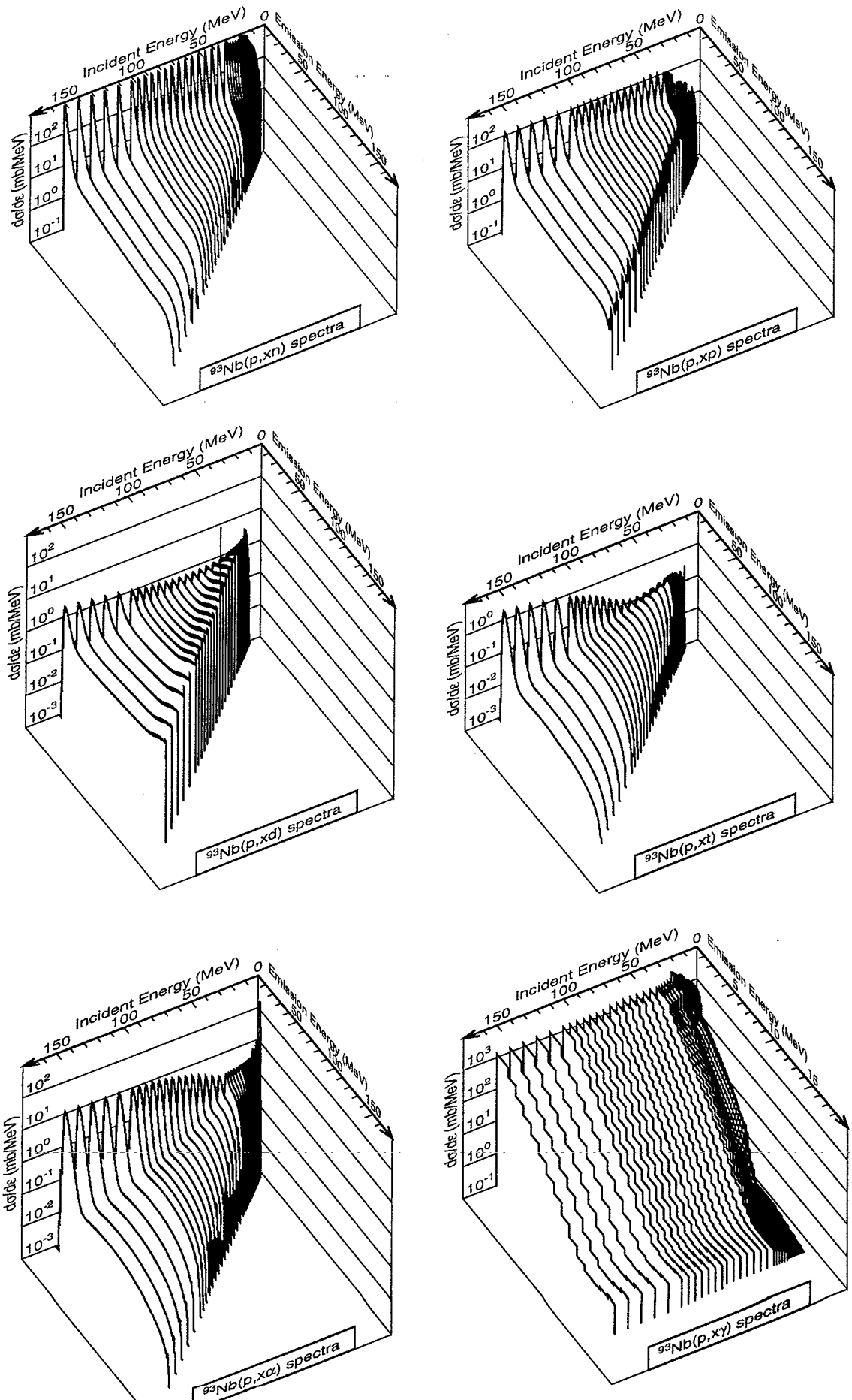
ſY	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
E+00	1.858E-05	0.000E+00	3.450E-09	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.602E-05	1.312E-05
E+00	1.640E-03	0.000E+00	2.361E-06	8.393E-10	0.000E+00	0.000E+00	0.000E+00	1.559E-03	1.015E-03
E+00	1.851E-02	0.000E+00	1.427E-02	3.074E-05	0.000E+00	0.000E+00	0.000E+00	4.055E-03	2.668E-02
E+00	8.703E-02	0.000E+00	7.961E-02	5.689E-04	0.000E+00	0.000E+00	0.000E+00	6.442E-03	1.729E-01
E+00	2.125E-01	0.000E+00	1.972E-01	3.368E-03	0.000E+00	0.000E+00	0.000E+00	1.117E-02	5.063E-01
E+00	3.762E-01	0.000E+00	3.477E-01	1.047E-02	0.000E+00	0.000E+00	0.000E+00	1.687E-02	1.026E+00
E+00	5.440E-01	0.000E+00	4.984E-01	2.121E-02	6.825E-09	0.000E+00	0.000E+00	2.297E-02	1.649E+00
+00	6.884E-01	0.000E+00	6.243E-01	3.300E-02	3.445E-08	0.000E+00	0.000E+00	2.967E-02	2.278E+00
+01	8.139E-01	0.000E+00	7.471E-01	4.670E-02	1.190E-06	2.836E-11	0.000E+00	3.581E-02	2.849E+00
+01	9.107E-01	0.000E+00	8.931E-01	6.336E-02	3.370E-05	1.963E-08	0.000E+00	4.144E-02	3.175E+00
+01	9.901E-01	0.000E+00	1.066E+00	1.020E-01	3.745E-04	2.668E-07	0.000E+00	4.600E-02	3.264E+00
-01	1.060E+00	0.000E+00	1.334E+00	1.300E-01	1.249E-03	5.230E-06	0.000E+00	4.977E-02	3.325E+00
01	1.122E+00	0.000E+00	1.561E+00	1.552E-01	2.765E-03	3.748E-05	0.000E+00	5.271E-02	3.518E+00
01	1.175E+00	0.000E+00	1.707E+00	1.903E-01	5.253E-03	1.299E-04	0.000E+00	5.505E-02	3.815E+00
01	1.222E+00	0.000E+00	1.795E+00	2.321E-01	8.276E-03	2.976E-04	0.000E+00	5.587E-02	4.178E+00
01	1.261E+00	0.000E+00	1.851E+00	2.731E-01	1.168E-02	5.515E-04	0.000E+00	5.730E-02	4.540E+00
01	1.294E+00	0.000E+00	1.891E+00	3.093E-01	1.530E-02	8.755E-04	0.000E+00	5.849E-02	4.886E+00
01	1.322E+00	0.000E+00	1.923E+00	3.401E-01	1.901E-02	1.253E-03	0.000E+00	5.937E-02	5.205E+00
1	1.345E+00	0.000E+00	1.951E+00	3.713E-01	2.213E-02	1.639E-03	0.000E+00	6.012E-02	5.386E+00
1	1.378E+00	0.000E+00	2.014E+00	4.894E-01	2.917E-02	2.498E-03	0.000E+00	6.041E-02	5.415E+00
1	1.401E+00	0.000E+00	2.094E+00	6.591E-01	3.584E-02	3.338E-03	0.000E+00	6.003E-02	5.019E+00
1	1.419E+00	0.000E+00	2.217E+00	7.891E-01	4.230E-02	4.111E-03	0.000E+00	5.927E-02	4.671E+00
1	1.431E+00	0.000E+00	2.359E+00	8.776E-01	4.850E-02	4.801E-03	0.000E+00	5.822E-02	4.442E+00
.	1.434E+00	0.000E+00	2.486E+00	9.566E-01	5.420E-02	5.400E-03	0.000E+00	5.718E-02	4.274E+00
	1.419E+00	0.000E+00	2.681E+00	1.197E+00	6.499E-02	6.527E-03	0.000E+00	5.623E-02	4.200E+00
	1.383E+00	0.000E+00	2.739E+00	1.354E+00	7.143E-02	7.221E-03	0.000E+00	5.840E-02	4.141E+00
	1.329E+00	0.000E+00	2.759E+00	1.393E+00	7.577E-02	7.607E-03	0.000E+00	6.354E-02	4.116E+00
	1.276E+00	0.000E+00	2.775E+00	1.399E+00	7.859E-02	7.815E-03	0.000E+00	7.096E-02	4.108E+00
	1.229E+00	0.000E+00	2.796E+00	1.412E+00	8.061E-02	7.935E-03	0.000E+00	7.904E-02	4.005E+00
	1.207E+00	0.000E+00	2.893E+00	1.448E+00	8.206E-02	8.060E-03	0.000E+00	8.928E-02	3.948E+00
	1.186E+00	0.000E+00	2.978E+00	1.477E+00	8.274E-02	8.218E-03	0.000E+00	9.884E-02	3.880E+00
	1.165E+00	0.000E+00	2.996E+00	1.524E+00	8.445E-02	8.445E-03	0.000E+00	1.100E-01	3.572E+00
	1.144E+00	0.000E+00	3.081E+00	1.551E+00	8.487E-02	8.825E-03	0.000E+00	1.220E-01	3.544E+00
	1.123E+00	0.000E+00	3.161E+00	1.579E+00	8.520E-02	9.391E-03	0.000E+00	1.338E-01	3.532E+00
	.102E+00	0.000E+00	3.229E+00	1.610E+00	8.594E-02	1.005E-02	0.000E+00	1.435E-01	3.515E+00
	.083E+00	0.000E+00	3.291E+00	1.639E+00	8.638E-02	1.082E-02	0.000E+00	1.523E-01	3.468E+00
	.065E+00	0.000E+00	3.351E+00	1.666E+00	8.693E-02	1.178E-02	0.000E+00	1.612E-01	3.425E+00
	.048E+00	0.000E+00	3.402E+00	1.691E+00	8.752E-02	1.276E-02	0.000E+00	1.686E-01	3.410E+00
	.018E+00	0.000E+00	3.501E+00	1.749E+00	8.833E-02	1.504E-02	0.000E+00	1.829E-01	3.333E+00
	937E-01	0.000E+00	3.587E+00	1.803E+00	9.019E-02	1.754E-02	0.000E+00	1.952E-01	3.278E+00
	757E-01	0.000E+00	3.685E+00	1.864E+00	9.092E-02	2.045E-02	0.000E+00	2.082E-01	3.246E+00
	654E-01	0.000E+00	3.793E+00	1.929E+00	9.375E-02	2.367E-02	0.000E+00	2.211E-01	3.246E+00
	610E-01	0.000E+00	3.889E+00	1.997E+00	9.635E-02	2.677E-02	0.000E+00	2.317E-01	3.240E+00

: 1000Z+A (if A=0 then elemental)
:TILE 1000Z+A
ssion energies for A<5 ejectiles in MeV:

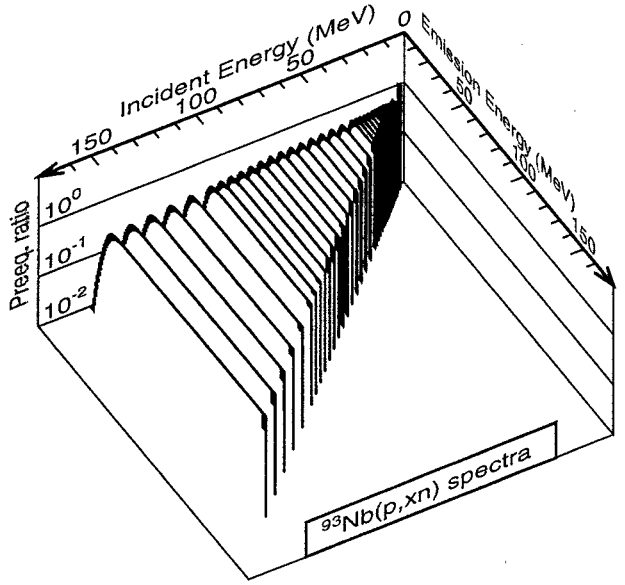
tron	proton	deuteron	triton	helium3	alpha	gamma
37E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	7.014E+00	2.159E+00
38E-01	2.381E+00	0.000E+00	0.000E+00	0.000E+00	8.033E+00	1.956E+00
7E+00	2.922E+00	0.000E+00	0.000E+00	0.000E+00	8.868E+00	1.096E+00
8E+00	3.760E+00	0.000E+00	0.000E+00	0.000E+00	9.666E+00	1.240E+00
5E+00	4.455E+00	0.000E+00	0.000E+00	0.000E+00	1.023E+01	1.392E+00
5E+00	5.031E+00	0.000E+00	0.000E+00	0.000E+00	1.076E+01	1.519E+00
LE+00	5.583E+00	1.211E+00	0.000E+00	0.000E+00	1.124E+01	1.650E+00
E+00	6.106E+00	2.127E+00	0.000E+00	0.000E+00	1.168E+01	1.770E+00
E+00	6.620E+00	2.868E+00	1.568E+00	0.000E+00	1.209E+01	1.857E+00
E+00	7.068E+00	3.946E+00	2.526E+00	0.000E+00	1.249E+01	1.892E+00
E+00	6.533E+00	4.735E+00	3.329E+00	0.000E+00	1.288E+01	1.867E+00
E+00	6.875E+00	5.452E+00	4.262E+00	0.000E+00	1.324E+01	1.614E+00
+00	7.433E+00	6.173E+00	4.825E+00	0.000E+00	1.357E+01	1.376E+00
+00	7.813E+00	6.930E+00	5.354E+00	0.000E+00	1.390E+01	1.257E+00
+00	8.100E+00	7.638E+00	5.943E+00	0.000E+00	1.415E+01	1.236E+00
+00	8.394E+00	8.334E+00	6.527E+00	0.000E+00	1.444E+01	1.264E+00
+00	8.739E+00	9.009E+00	7.084E+00	0.000E+00	1.472E+01	1.317E+00
+00	9.122E+00	9.670E+00	7.620E+00	0.000E+00	1.500E+01	1.380E+00
-00	9.450E+00	1.026E+01	8.108E+00	0.000E+00	1.529E+01	1.525E+00
00	9.224E+00	1.151E+01	9.111E+00	0.000E+00	1.582E+01	1.584E+00
00	8.927E+00	1.273E+01	1.008E+01	0.000E+00	1.633E+01	1.625E+00
00	9.177E+00	1.393E+01	1.101E+01	0.000E+00	1.683E+01	1.675E+00
00	9.697E+00	1.511E+01	1.195E+01	0.000E+00	1.732E+01	1.688E+00

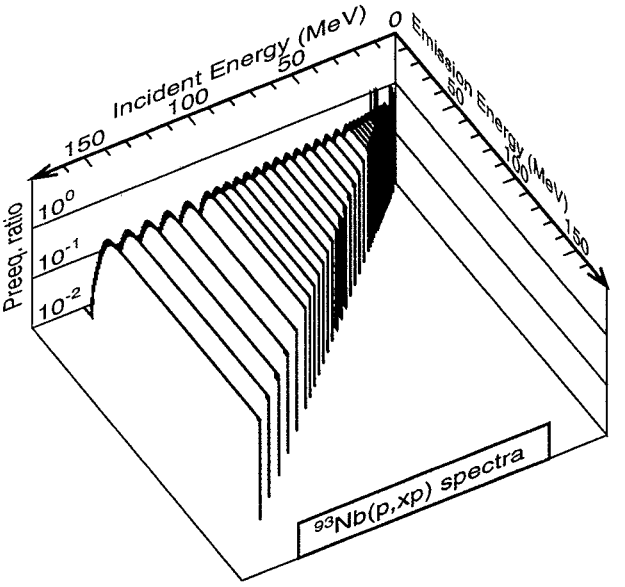

p + 93Nb nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
n
γ
p
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
10^1
10^0
0
50
100
150
Incident Energy (MeV)

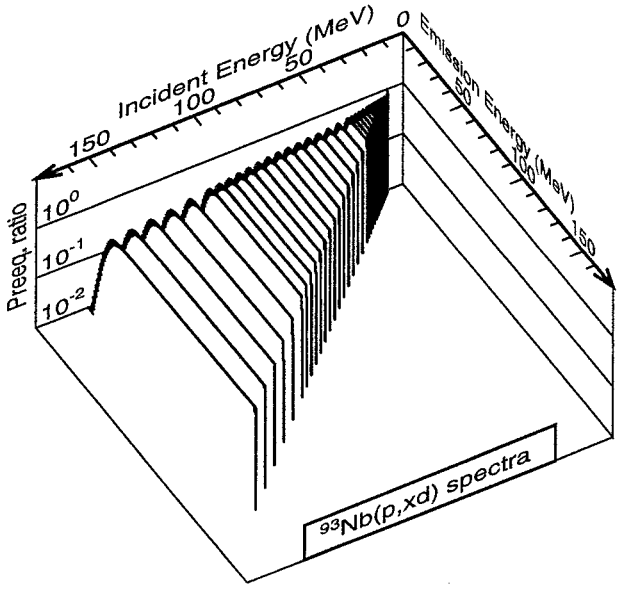
p + ^{93}Nb angle-integrated emission spectra

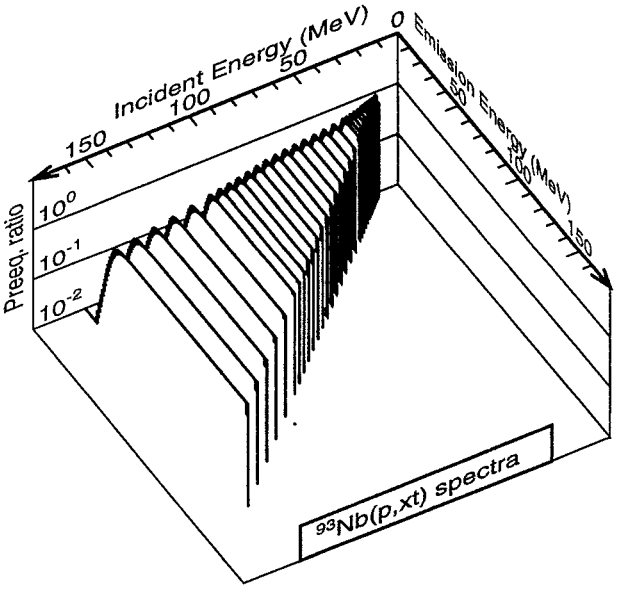


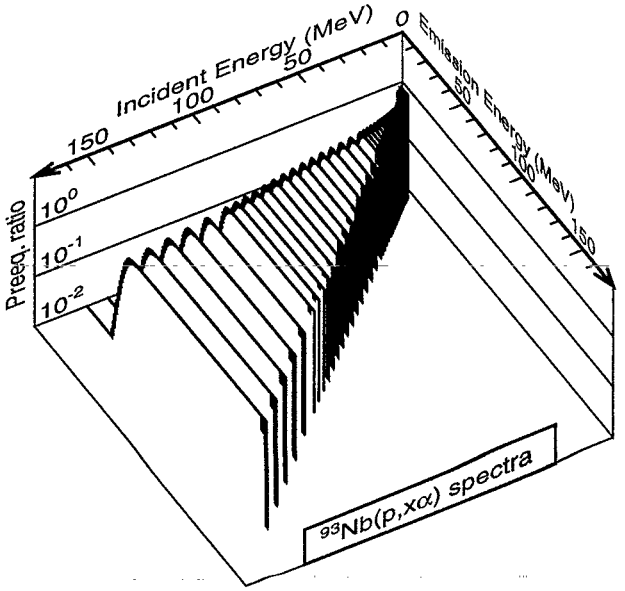
p + ^{93}Nb Kalbach preequilibrium ratios

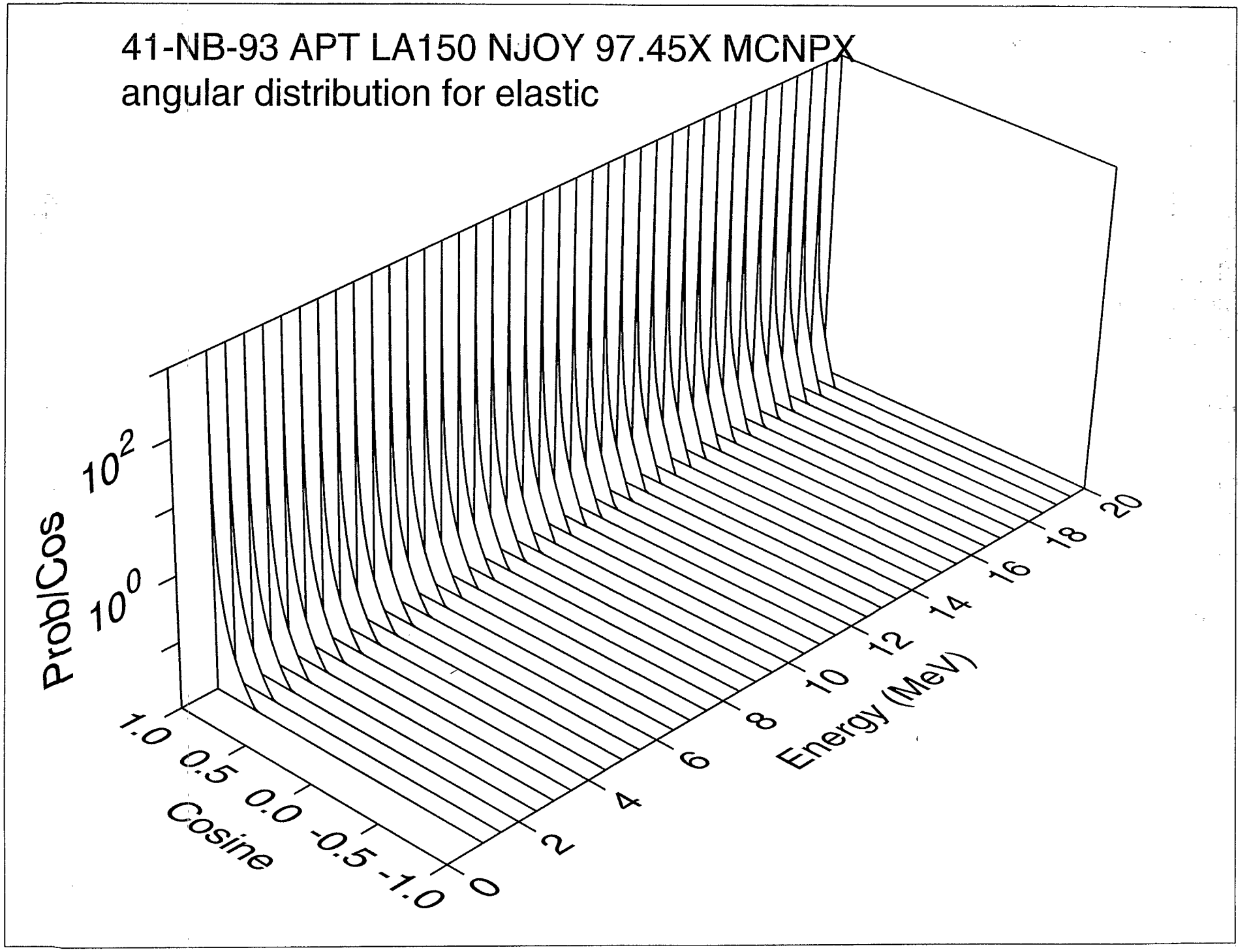


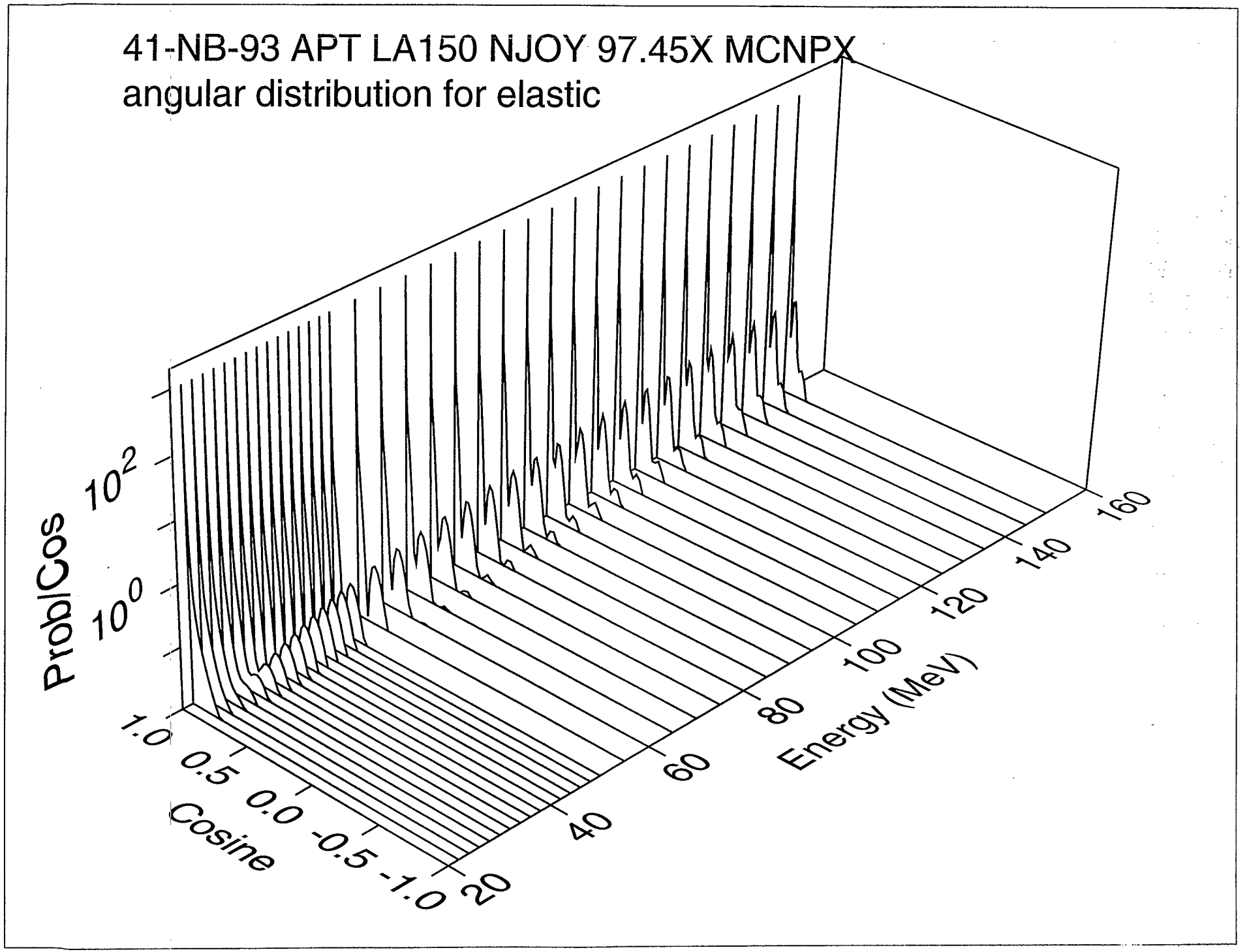


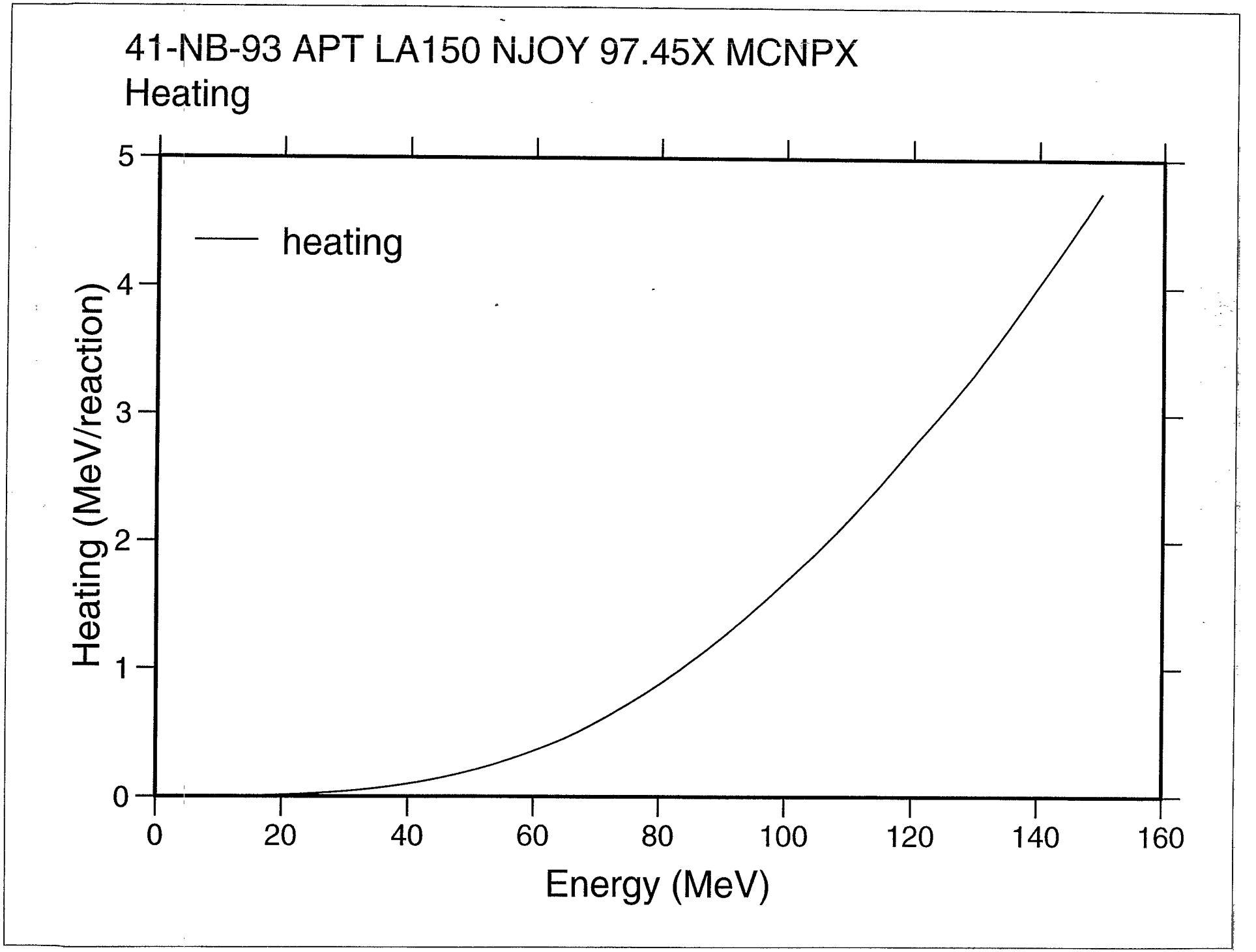







41-NB-93 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
0
2
4
6
8
10
12
14
16
18
20


41-NB-93 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


41-NB-93 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
1
2
3
4
5
0
20
40
60
80
100
120
140
160

EVALUATION OF p + 182W CROSS SECTIONS FOR THE ENERGY RANGE 2 to 150 MeV

M. B. Chadwick and P. G. Young
17 October 1996

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 2 to 150 MeV.

The evaluation utilizes MF = 3 [MT=2 and MT=5] and MF=6 [MT=2 and MT=5] to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced with non-negligible cross sections (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data are:

MF=3	MT= 2	Integral of nuclear plus interference components of the elastic scattering cross section
	MT= 5	Sum of binary (n,n') and (n,x) reactions
MF=6	MT= 2	Elastic angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
	MT= 5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + W, n + Ta, p + Ta, and p + W reactions (Ch96a). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Coupled-channels and spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A coupled-channels neutron optical model potential based on earlier work to 100 MeV (Yo90) is utilized to 80 MeV, and the global spherical optical model potential of Madland (Ma88) is used at higher energies. For protons, the Beccetti-Greenlees potential (Be69) is utilized below 20 MeV, and the Madland Semmering potential (Ma88) at higher energies. The Perey potential (Pe63) is used for deuterons, and the Beccetti-Greenlees potential (Be71) for tritons. The ECIS79 code (Ra72) was used for the coupled-channels optical model calculations, and the SCAT2 code (Be92) was utilized for the spherical optical model calculations. Minor normalizations were made to the reaction cross sections and transmission coefficients to produce

agreement with the (sparse) measurements for W and values inferred from systematics of proton and neutron reaction cross sections from measurements on other targets. The same reaction cross sections are used for both proton- and neutron-induced reactions on W isotopes.

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96b). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. Note that all other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation requires a modification of the original ENDF-6 format, i.e., we use LCT=3 with LAW 1 to indicate that data for the heavy recoils are in the lab system but all other reactions are in the cm system.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed above. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

MT=2 elastic scattering data in MF=3 and MF=6 are based on optical model calculations with the SCAT2 code (Be92). We have made use of the "nuclear-plus-interference" option in MF=6, which corresponds to LAW=5, LTP=12, and the appropriate integrated cross section is stored in MF=3. Note that because of the interference effect, the tabulations in both MF=6 and MF=3 can be negative at some energies and angles.

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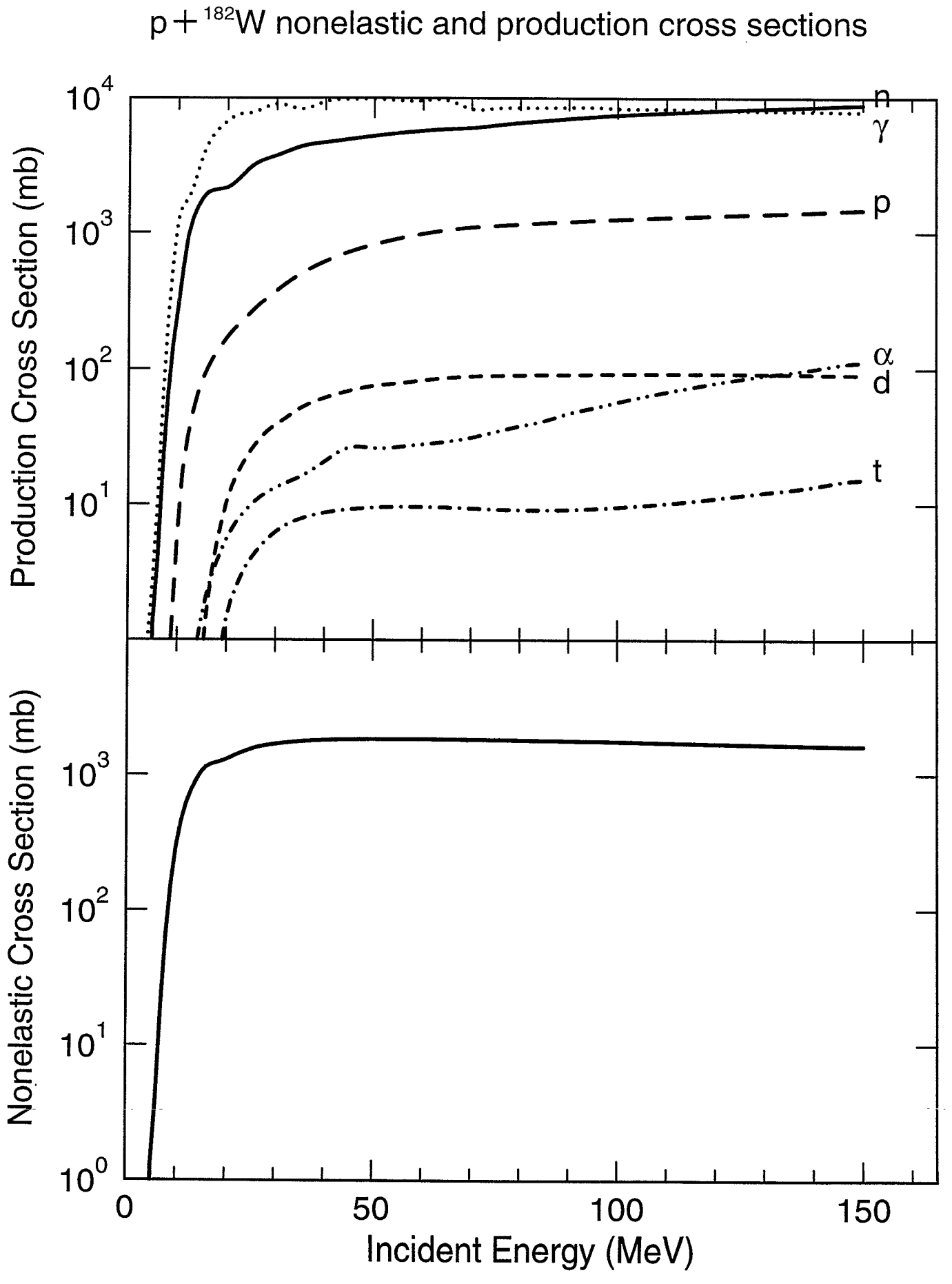
74182 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
3.000E+00	1.000E-20	0.000E+00	0.000E+00	1.000E-20	0.000E+00	0.000E+00	0.000E+00	1.000E-20	1.000E-20
4.000E+00	1.689E-05	0.000E+00	1.541E-05	1.331E-10	0.000E+00	0.000E+00	0.000E+00	5.747E-08	2.231E-05
5.000E+00	1.289E-03	0.000E+00	1.270E-03	4.128E-08	0.000E+00	0.000E+00	0.000E+00	2.003E-07	2.634E-03
6.000E+00	3.940E-03	0.000E+00	3.903E-03	1.121E-06	0.000E+00	0.000E+00	0.000E+00	7.011E-07	1.033E-02
7.000E+00	1.915E-02	0.000E+00	1.898E-02	2.025E-05	0.000E+00	0.000E+00	0.000E+00	2.755E-06	6.049E-02
8.000E+00	6.458E-02	0.000E+00	6.391E-02	2.493E-04	2.651E-08	0.000E+00	0.000E+00	8.261E-06	2.309E-01
9.000E+00	1.537E-01	0.000E+00	1.514E-01	1.537E-03	2.334E-08	0.000E+00	0.000E+00	2.275E-05	6.109E-01
1.000E+01	2.875E-01	0.000E+00	2.803E-01	6.137E-03	2.346E-08	2.661E-11	0.000E+00	5.772E-05	1.249E+00
1.100E+01	4.462E-01	0.000E+00	5.365E-01	1.741E-02	1.072E-06	1.305E-08	0.000E+00	1.319E-04	1.630E+00
1.200E+01	6.053E-01	0.000E+00	9.314E-01	3.079E-02	5.354E-06	3.105E-07	0.000E+00	2.761E-04	1.733E+00
1.300E+01	7.529E-01	0.000E+00	1.266E+00	4.657E-02	3.091E-05	1.471E-06	0.000E+00	5.347E-04	2.164E+00
1.400E+01	8.956E-01	0.000E+00	1.546E+00	6.449E-02	1.687E-04	8.511E-06	0.000E+00	9.410E-04	2.865E+00
1.500E+01	1.033E+00	0.000E+00	1.794E+00	8.283E-02	6.508E-04	3.806E-05	0.000E+00	1.504E-03	3.727E+00
1.600E+01	1.135E+00	0.000E+00	1.969E+00	1.004E-01	1.660E-03	1.234E-04	0.000E+00	2.194E-03	4.559E+00
1.700E+01	1.188E+00	0.000E+00	2.045E+00	1.176E-01	3.140E-03	2.987E-04	0.000E+00	2.959E-03	5.218E+00
1.800E+01	1.221E+00	0.000E+00	2.082E+00	1.344E-01	5.098E-03	5.651E-04	0.000E+00	3.763E-03	5.793E+00
1.900E+01	1.250E+00	0.000E+00	2.109E+00	1.515E-01	7.416E-03	9.227E-04	0.000E+00	4.610E-03	6.341E+00
2.000E+01	1.289E+00	0.000E+00	2.154E+00	1.703E-01	1.038E-02	1.454E-03	0.000E+00	5.548E-03	6.723E+00
2.200E+01	1.394E+00	0.000E+00	2.438E+00	2.058E-01	1.618E-02	2.474E-03	0.000E+00	7.427E-03	7.518E+00
2.400E+01	1.492E+00	0.000E+00	2.893E+00	2.426E-01	2.213E-02	3.532E-03	0.000E+00	9.126E-03	7.663E+00
2.600E+01	1.577E+00	0.000E+00	3.287E+00	2.860E-01	2.820E-02	4.476E-03	0.000E+00	1.069E-02	7.996E+00
2.800E+01	1.638E+00	0.000E+00	3.536E+00	3.288E-01	3.406E-02	5.432E-03	0.000E+00	1.206E-02	8.619E+00
3.000E+01	1.681E+00	0.000E+00	3.746E+00	3.747E-01	3.867E-02	6.287E-03	0.000E+00	1.328E-02	9.052E+00
3.500E+01	1.756E+00	0.000E+00	4.369E+00	5.007E-01	5.124E-02	7.832E-03	0.000E+00	1.595E-02	8.304E+00
4.000E+01	1.800E+00	0.000E+00	4.679E+00	6.181E-01	6.122E-02	8.724E-03	0.000E+00	2.074E-02	9.398E+00
4.500E+01	1.822E+00	0.000E+00	4.939E+00	7.301E-01	6.906E-02	9.235E-03	0.000E+00	2.626E-02	9.786E+00
5.000E+01	1.830E+00	0.000E+00	5.223E+00	8.258E-01	7.523E-02	9.509E-03	0.000E+00	2.594E-02	9.811E+00
5.500E+01	1.832E+00	0.000E+00	5.492E+00	9.112E-01	7.861E-02	9.627E-03	0.000E+00	2.651E-02	9.593E+00
6.000E+01	1.830E+00	0.000E+00	5.712E+00	9.860E-01	8.277E-02	9.631E-03	0.000E+00	2.777E-02	9.573E+00
6.500E+01	1.826E+00	0.000E+00	5.895E+00	1.052E+00	8.629E-02	9.558E-03	0.000E+00	2.909E-02	9.640E+00
7.000E+01	1.819E+00	0.000E+00	6.018E+00	1.101E+00	8.868E-02	9.403E-03	0.000E+00	3.120E-02	8.282E+00
7.500E+01	1.809E+00	0.000E+00	6.298E+00	1.133E+00	8.956E-02	9.243E-03	0.000E+00	3.445E-02	8.391E+00
8.000E+01	1.799E+00	0.000E+00	6.569E+00	1.160E+00	9.024E-02	9.153E-03	0.000E+00	3.790E-02	8.482E+00
8.500E+01	1.788E+00	0.000E+00	6.803E+00	1.188E+00	9.099E-02	9.146E-03	0.000E+00	4.155E-02	8.493E+00
9.000E+01	1.778E+00	0.000E+00	7.040E+00	1.214E+00	9.098E-02	9.221E-03	0.000E+00	4.717E-02	8.521E+00
9.500E+01	1.768E+00	0.000E+00	7.261E+00	1.240E+00	9.172E-02	9.379E-03	0.000E+00	5.161E-02	8.539E+00
1.000E+02	1.756E+00	0.000E+00	7.466E+00	1.264E+00	9.218E-02	9.615E-03	0.000E+00	5.699E-02	8.368E+00
1.100E+02	1.727E+00	0.000E+00	7.791E+00	1.308E+00	9.253E-02	1.025E-02	0.000E+00	6.800E-02	8.302E+00
1.200E+02	1.699E+00	0.000E+00	8.090E+00	1.348E+00	9.264E-02	1.116E-02	0.000E+00	7.934E-02	8.163E+00
1.300E+02	1.672E+00	0.000E+00	8.364E+00	1.387E+00	9.225E-02	1.233E-02	0.000E+00	9.022E-02	8.033E+00
1.400E+02	1.648E+00	0.000E+00	8.620E+00	1.430E+00	9.156E-02	1.367E-02	0.000E+00	1.010E-01	7.998E+00
1.500E+02	1.631E+00	0.000E+00	8.875E+00	1.479E+00	9.077E-02	1.524E-02	0.000E+00	1.124E-01	7.903E+00

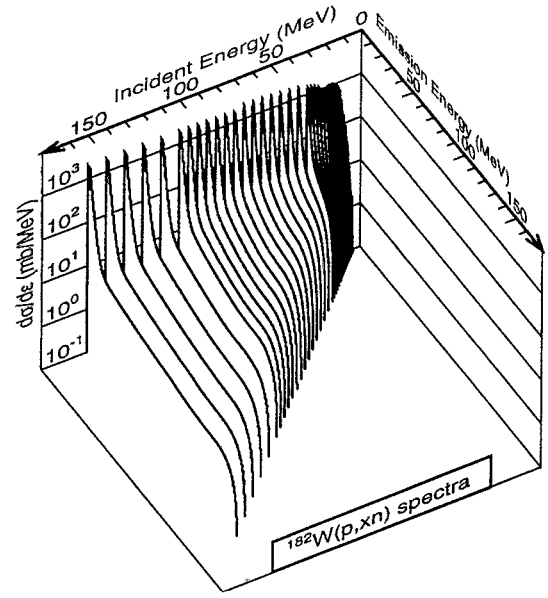
74182 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

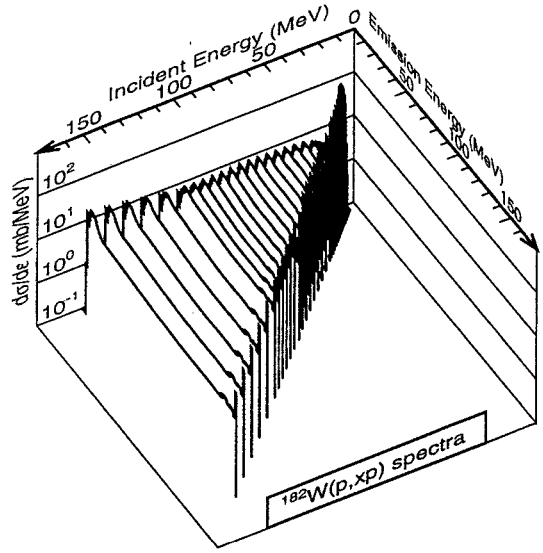
Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
3.000E+00	0.000E+00	9.107E-05	0.000E+00	0.000E+00	0.000E+00	8.778E+00	3.256E+00
4.000E+00	2.345E-01	3.860E+00	0.000E+00	0.000E+00	0.000E+00	9.859E+00	4.083E-01
5.000E+00	5.591E-01	4.686E+00	0.000E+00	0.000E+00	0.000E+00	1.063E+01	4.520E-01
6.000E+00	9.410E-01	5.666E+00	0.000E+00	0.000E+00	0.000E+00	1.141E+01	5.707E-01
7.000E+00	1.125E+00	6.657E+00	0.000E+00	0.000E+00	0.000E+00	1.231E+01	7.306E-01
8.000E+00	1.197E+00	7.657E+00	1.989E+00	0.000E+00	0.000E+00	1.294E+01	8.820E-01
9.000E+00	1.216E+00	8.623E+00	2.982E+00	0.000E+00	0.000E+00	1.374E+01	1.032E+00
1.000E+01	1.276E+00	9.583E+00	3.954E+00	3.302E+00	0.000E+00	1.445E+01	1.136E+00
1.100E+01	1.149E+00	1.053E+01	4.727E+00	4.280E+00	0.000E+00	1.518E+01	1.116E+00
1.200E+01	1.112E+00	1.141E+01	5.454E+00	4.874E+00	0.000E+00	1.600E+01	8.256E-01
1.300E+01	1.219E+00	1.224E+01	6.508E+00	5.523E+00	0.000E+00	1.676E+01	6.502E-01
1.400E+01	1.355E+00	1.301E+01	7.444E+00	6.577E+00	0.000E+00	1.744E+01	6.457E-01
1.500E+01	1.474E+00	1.370E+01	8.329E+00	7.407E+00	0.000E+00	1.804E+01	7.098E-01
1.600E+01	1.573E+00	1.435E+01	9.127E+00	8.195E+00	0.000E+00	1.859E+01	7.928E-01
1.700E+01	1.664E+00	1.498E+01	9.881E+00	8.894E+00	0.000E+00	1.912E+01	8.764E-01
1.800E+01	1.755E+00	1.558E+01	1.063E+01	9.527E+00	0.000E+00	1.960E+01	9.520E-01
1.900E+01	1.853E+00	1.616E+01	1.135E+01	1.012E+01	0.000E+00	2.005E+01	1.013E+00
2.000E+01	1.951E+00	1.681E+01	1.210E+01	1.080E+01	0.000E+00	2.045E+01	1.162E+00
2.200E+01	2.078E+00	1.782E+01	1.346E+01	1.188E+01	0.000E+00	2.114E+01	1.167E+00
2.400E+01	2.142E+00	1.865E+01	1.479E+01	1.291E+01	0.000E+00	2.191E+01	1.041E+00
2.600E+01	2.254E+00	1.944E+01	1.609E+01	1.382E+01	0.000E+00	2.269E+01	9.417E-01
2.800E+01	2.404E+00	2.007E+01	1.737E+01	1.482E+01	0.000E+00	2.342E+01	9.332E-01
3.000E+01	2.545E+00	2.083E+01	1.851E+01	1.581E+01	0.000E+00	2.410E+01	9.512E-01
3.500E+01	2.844E+00	2.290E+01	2.174E+01	1.813E+01	0.000E+00	2.557E+01	9.732E-01

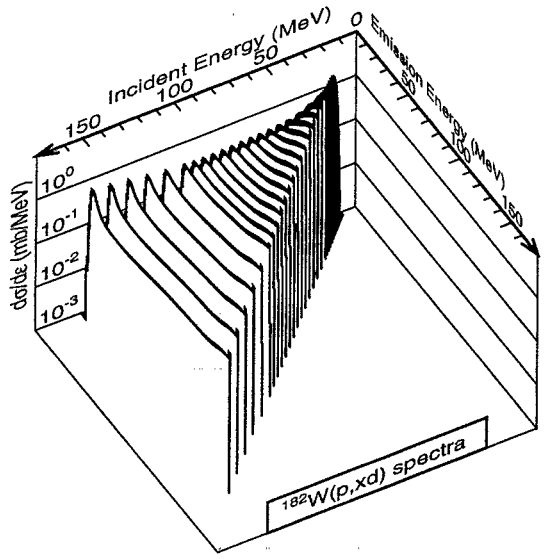
4.000E+01	3.230E+00	2.520E+01	2.502E+01	2.034E+01	0.000E+00	2.478E+01	1.001E+00
4.500E+01	3.599E+00	2.759E+01	2.828E+01	2.255E+01	0.000E+00	2.402E+01	1.007E+00
5.000E+01	3.911E+00	2.989E+01	3.147E+01	2.475E+01	0.000E+00	2.606E+01	9.733E-01
5.500E+01	4.200E+00	3.221E+01	3.432E+01	2.692E+01	0.000E+00	2.745E+01	9.702E-01
6.000E+01	4.490E+00	3.447E+01	3.739E+01	2.907E+01	0.000E+00	2.831E+01	9.718E-01
6.500E+01	4.784E+00	3.664E+01	4.042E+01	3.119E+01	0.000E+00	2.901E+01	9.861E-01
7.000E+01	5.105E+00	3.884E+01	4.349E+01	3.313E+01	0.000E+00	2.924E+01	1.235E+00
7.500E+01	5.263E+00	4.084E+01	4.646E+01	3.474E+01	0.000E+00	2.889E+01	1.223E+00
8.000E+01	5.418E+00	4.282E+01	4.939E+01	3.607E+01	0.000E+00	2.854E+01	1.219E+00
8.500E+01	5.595E+00	4.476E+01	5.231E+01	3.712E+01	0.000E+00	2.819E+01	1.228E+00
9.000E+01	5.761E+00	4.663E+01	5.499E+01	3.781E+01	0.000E+00	2.716E+01	1.229E+00
9.500E+01	5.935E+00	4.832E+01	5.782E+01	3.821E+01	0.000E+00	2.683E+01	1.231E+00
1.000E+02	6.098E+00	5.006E+01	6.058E+01	3.823E+01	0.000E+00	2.632E+01	1.235E+00
1.100E+02	6.424E+00	5.356E+01	6.593E+01	3.754E+01	0.000E+00	2.546E+01	1.229E+00
1.200E+02	6.750E+00	5.681E+01	7.099E+01	3.601E+01	0.000E+00	2.481E+01	1.231E+00
1.300E+02	7.077E+00	5.981E+01	7.556E+01	3.401E+01	0.000E+00	2.440E+01	1.239E+00
1.400E+02	7.415E+00	6.250E+01	7.974E+01	3.193E+01	0.000E+00	2.405E+01	1.242E+00
1.500E+02	7.758E+00	6.492E+01	8.353E+01	2.983E+01	0.000E+00	2.373E+01	1.260E+00

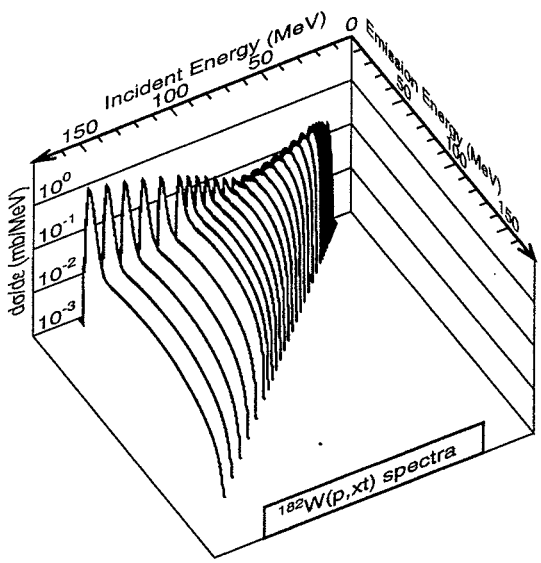

p + 182W nonelastic and production cross sections
Production Cross Section (mb)
Nonelastic Cross Section (mb)
Incident Energy (MeV)
n
γ
p
α
d
t
10^4
10^3
10^2
10^1
10^0
0
50
100
150

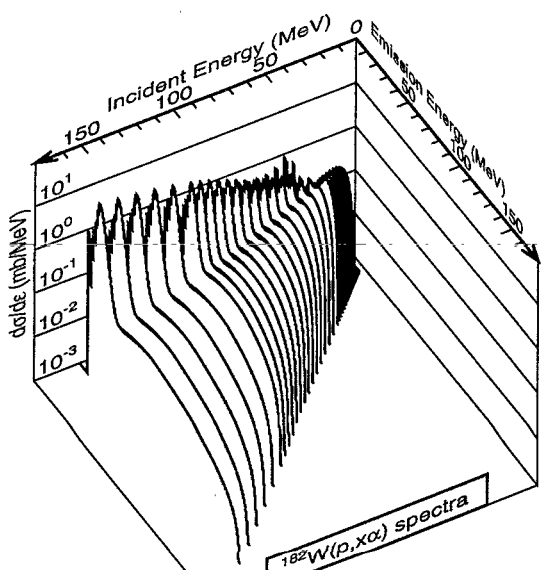
p + ^{182}W angle-integrated emission spectra

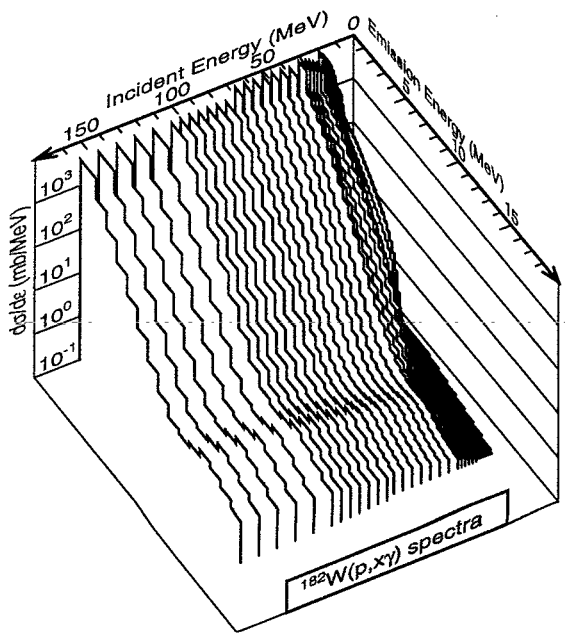




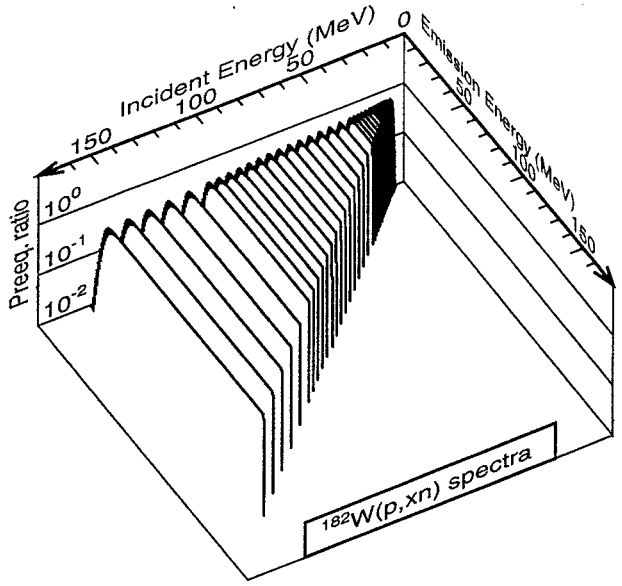


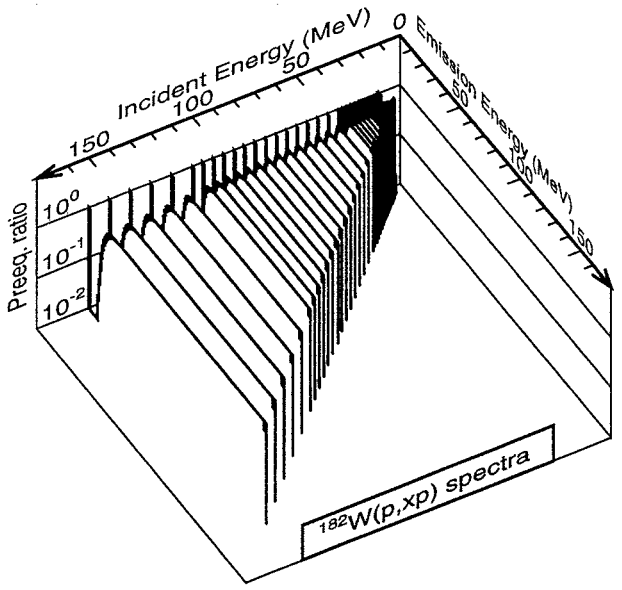


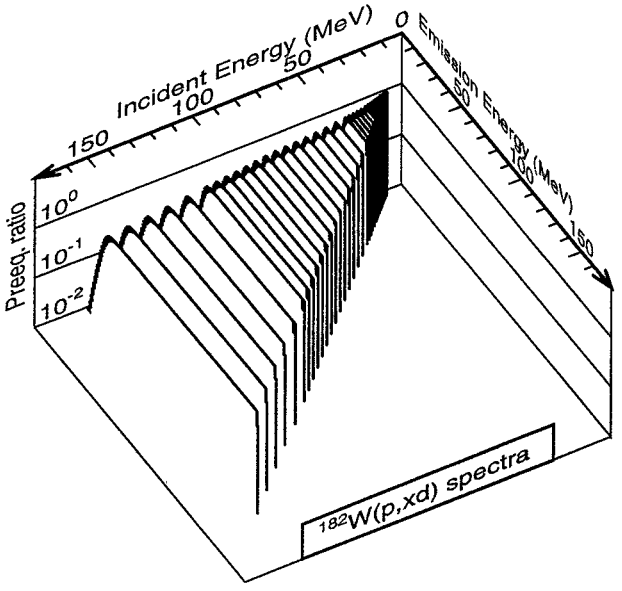


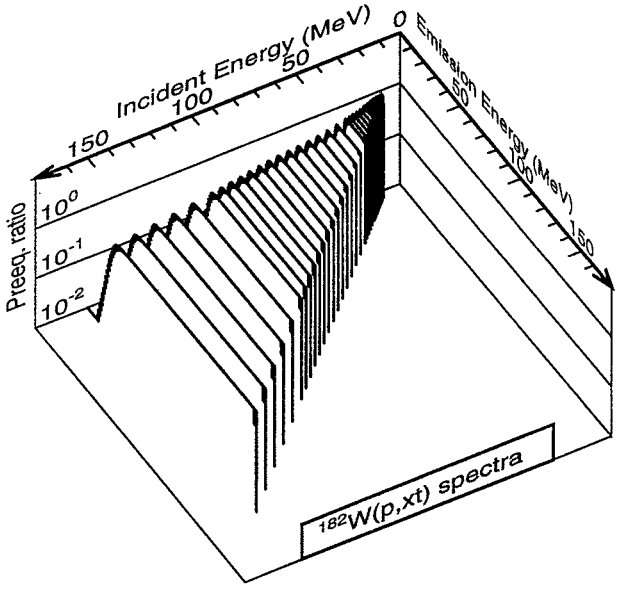


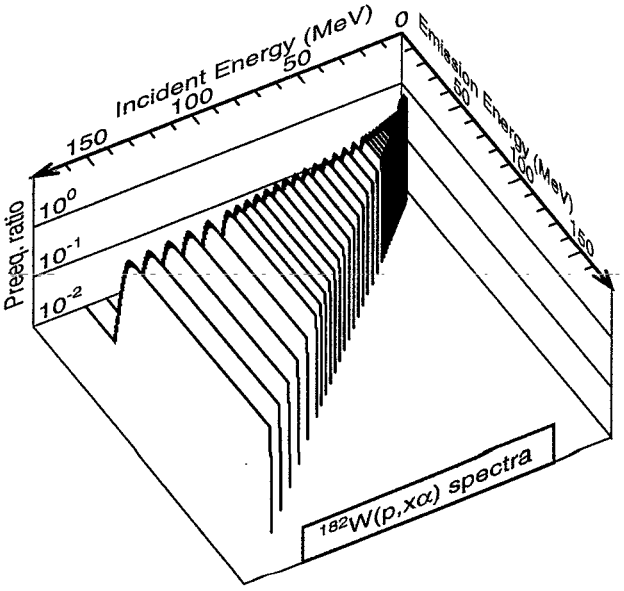
p + ^{182}W Kalbach preequilibrium ratios

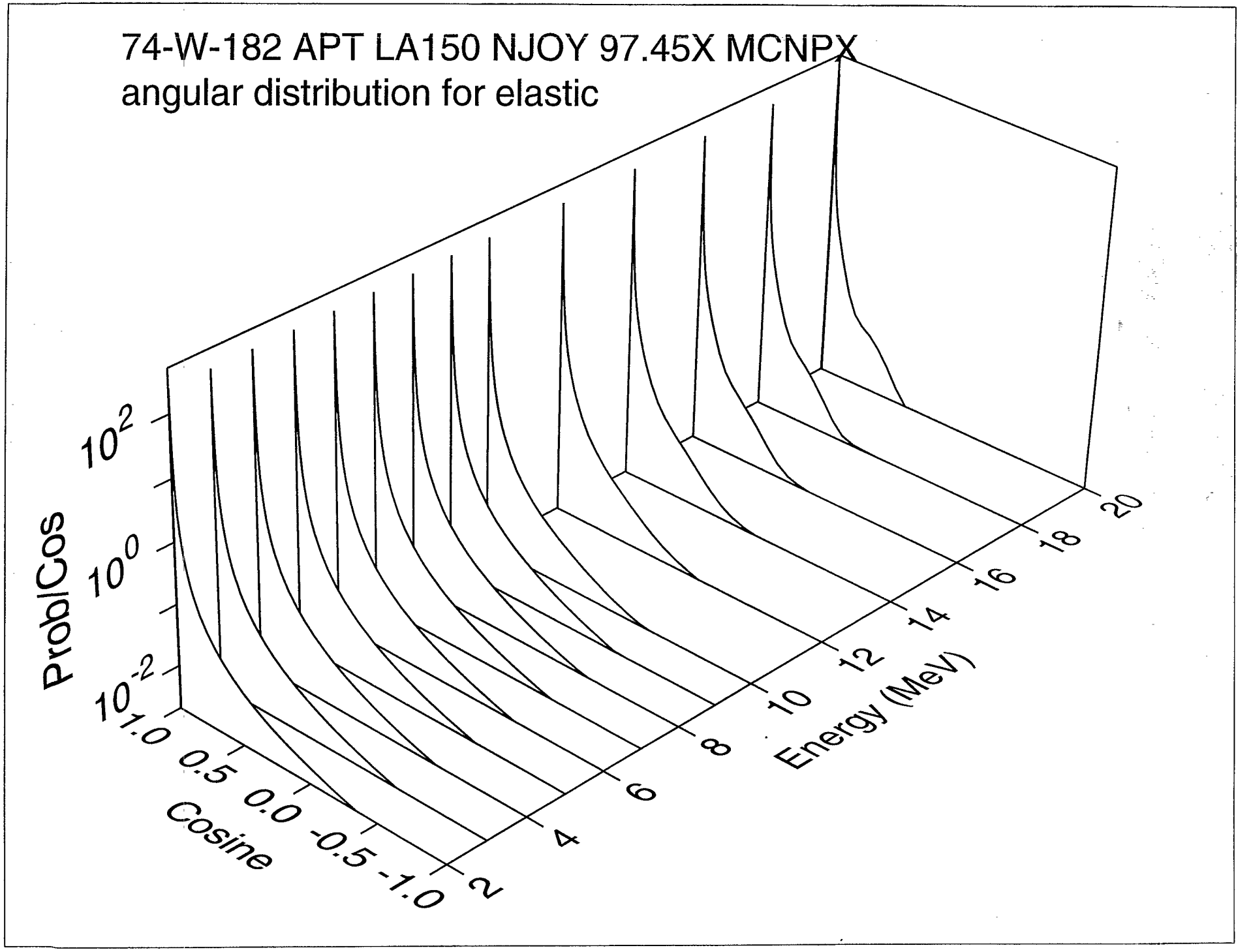


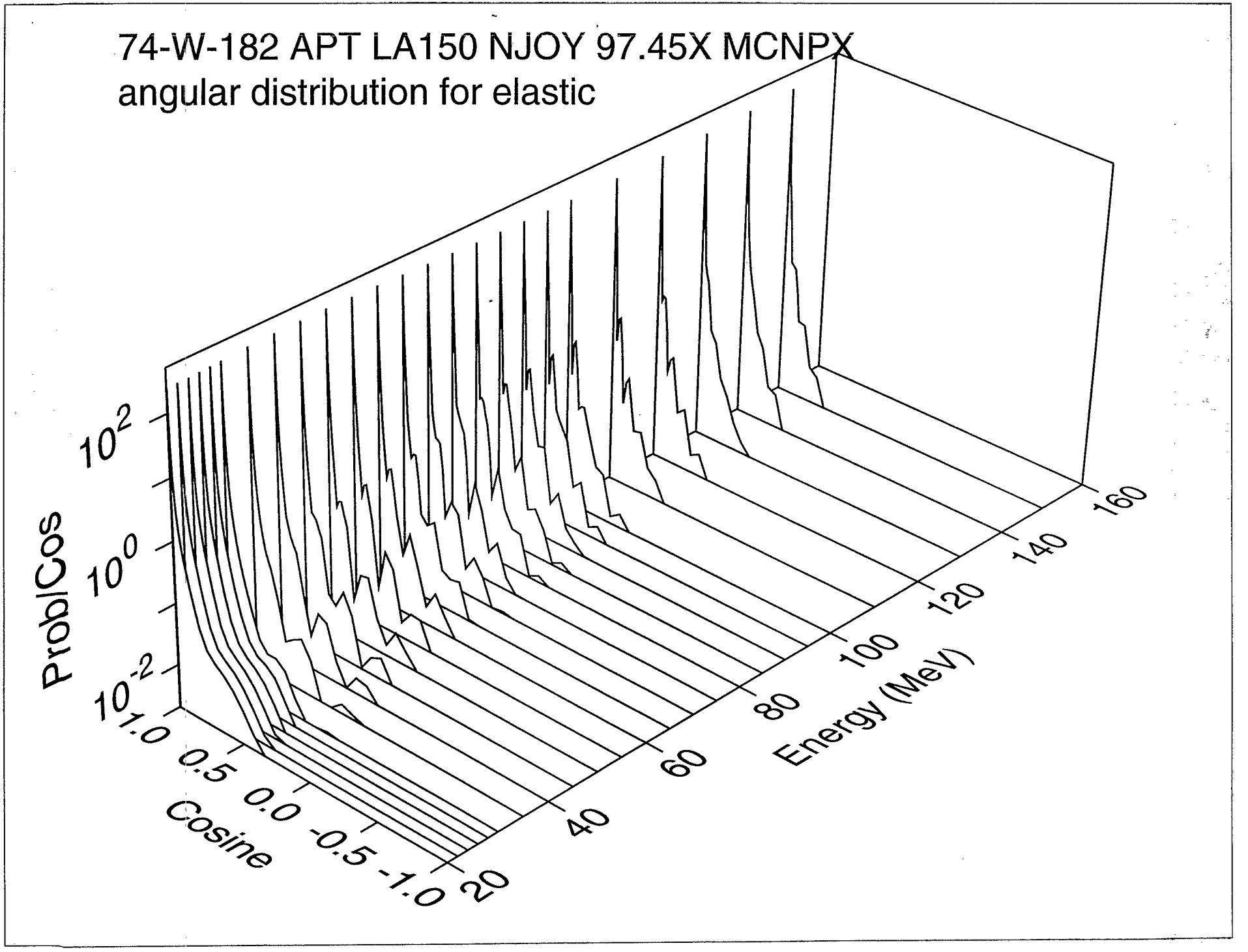


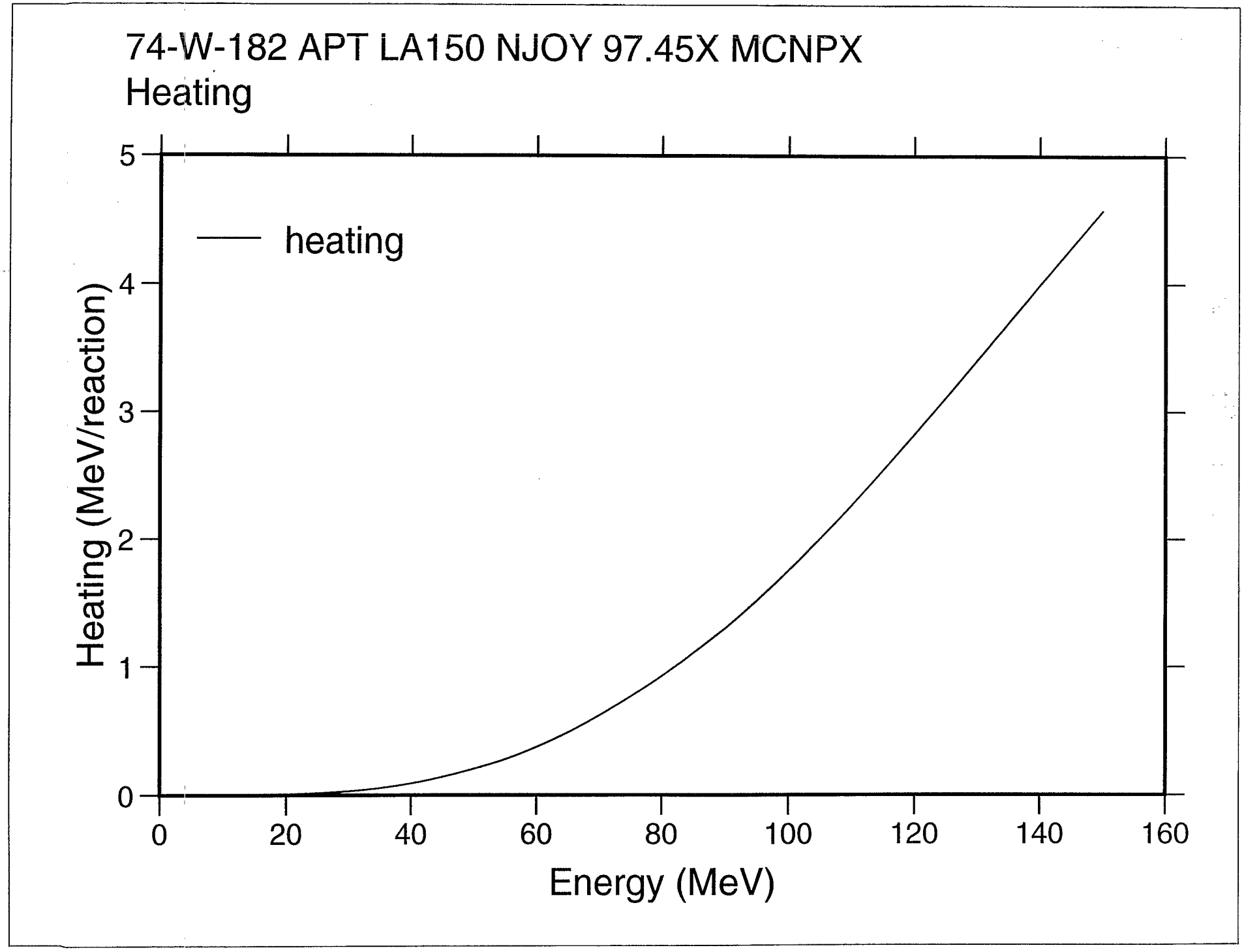







74-W-182 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
2
4
6
8
10
12
14
16
18
20


74-W-182 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
10^{-2}
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


74-W-182 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
1
2
3
4
5
0
20
40
60
80
100
120
140
160

EVALUATION OF p + 183W CROSS SECTIONS FOR THE ENERGY RANGE 2 to 150 MeV

M. B. Chadwick and P. G. Young
17 October 1996

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 2 to 150 MeV.

The evaluation utilizes MF = 3 [MT=2 and MT=5] and MF=6 [MT=2 and MT=5] to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced with non-negligible cross sections (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data are:

MF=3 MT=	2	Integral of nuclear plus interference components of the elastic scattering cross section
MT=	5	Sum of binary (n,n') and (n,x) reactions
MF=6 MT=	2	Elastic angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
MT=	5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + W, n + Ta, p + Ta, and p + W reactions (Ch96a). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Coupled-channels and spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A coupled-channels neutron optical model potential based on earlier work to 100 MeV (Yo90) is utilized to 80 MeV, and the global spherical optical model potential of Madland (Ma88) is used at higher energies. For protons, the Beccetti-Greenlees potential (Be69) is utilized below 20 MeV, and the Madland Semmering potential (Ma88) at higher energies. The Perey potential (Pe63) is used for deuterons, and the Beccetti-Greenlees potential (Be71) for tritons. The ECIS79 code (Ra72) was used for the coupled-channels optical model calculations, and the SCAT2 code (Be92) was utilized for the spherical optical model calculations. Minor normalizations were made to the reaction cross sections and transmission coefficients to produce

agreement with the (sparse) measurements for W and values inferred from systematics of proton and neutron reaction cross sections from measurements on other targets. The same reaction cross sections are used for both proton- and neutron-induced reactions on W isotopes.

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96b). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. Note that all other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation requires a modification of the original ENDF-6 format, i.e., we use LCT=3 with LAW 1 to indicate that data for the heavy recoils are in the lab system but all other reactions are in the cm system.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed above. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

MT=2 elastic scattering data in MF=3 and MF=6 are based on optical model calculations with the SCAT2 code (Be92). We have made use of the "nuclear-plus-interference" option in MF=6, which corresponds to LAW=5, LTP=12, and the appropriate integrated cross section is stored in MF=3. Note that because of the interference effect, the tabulations in both MF=6 and MF=3 can be negative at some energies and angles.

****

REFERENCES

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74183 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

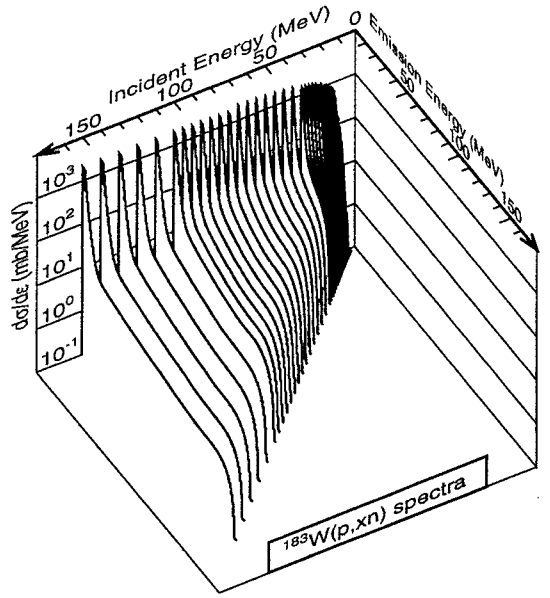
Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
3.000E+00	1.000E-20	0.000E+00	1.000E-20	1.000E-20	0.000E+00	0.000E+00	0.000E+00	1.000E-20	1.000E-20
4.000E+00	1.689E-05	0.000E+00	1.650E-05	1.633E-11	0.000E+00	0.000E+00	0.000E+00	2.253E-07	3.642E-05
5.000E+00	1.289E-03	0.000E+00	1.278E-03	2.453E-08	0.000E+00	0.000E+00	0.000E+00	4.925E-07	3.490E-03
6.000E+00	3.940E-03	0.000E+00	3.913E-03	1.476E-07	3.025E-12	0.000E+00	0.000E+00	1.898E-06	1.241E-02
7.000E+00	1.915E-02	0.000E+00	1.903E-02	2.053E-05	1.766E-12	0.000E+00	0.000E+00	5.759E-06	6.954E-02
8.000E+00	6.458E-02	0.000E+00	6.408E-02	2.649E-04	1.438E-09	0.000E+00	0.000E+00	1.555E-05	2.586E-01
9.000E+00	1.537E-01	0.000E+00	1.516E-01	1.630E-03	6.623E-07	4.726E-14	0.000E+00	4.296E-05	6.760E-01
1.000E+01	2.875E-01	0.000E+00	2.837E-01	6.481E-03	4.575E-06	2.222E-10	0.000E+00	1.134E-04	1.356E+00
1.100E+01	4.462E-01	0.000E+00	5.781E-01	1.811E-02	2.180E-05	1.214E-07	0.000E+00	2.397E-04	1.712E+00
1.200E+01	6.053E-01	0.000E+00	9.431E-01	3.178E-02	1.264E-04	8.638E-07	0.000E+00	4.580E-04	2.001E+00
1.300E+01	7.529E-01	0.000E+00	1.260E+00	4.788E-02	5.182E-04	4.237E-06	0.000E+00	8.214E-04	2.526E+00
1.400E+01	8.956E-01	0.000E+00	1.530E+00	6.632E-02	1.444E-03	2.238E-05	0.000E+00	1.354E-03	3.271E+00
1.500E+01	1.033E+00	0.000E+00	1.773E+00	8.540E-02	2.943E-03	8.204E-05	0.000E+00	2.046E-03	4.151E+00
1.600E+01	1.135E+00	0.000E+00	1.943E+00	1.037E-01	5.011E-03	2.259E-04	0.000E+00	2.848E-03	4.727E+00
1.700E+01	1.188E+00	0.000E+00	2.023E+00	1.215E-01	7.508E-03	4.707E-04	0.000E+00	3.693E-03	5.294E+00
1.800E+01	1.221E+00	0.000E+00	2.145E+00	1.387E-01	1.016E-02	8.153E-04	0.000E+00	4.543E-03	5.477E+00
1.900E+01	1.250E+00	0.000E+00	2.361E+00	1.562E-01	1.307E-02	1.249E-03	0.000E+00	5.406E-03	5.318E+00
2.000E+01	1.289E+00	0.000E+00	2.588E+00	1.750E-01	1.701E-02	1.788E-03	0.000E+00	6.316E-03	4.922E+00
2.200E+01	1.394E+00	0.000E+00	3.021E+00	2.115E-01	2.357E-02	2.923E-03	0.000E+00	8.032E-03	5.269E+00
2.400E+01	1.492E+00	0.000E+00	3.330E+00	2.487E-01	2.989E-02	4.065E-03	0.000E+00	9.573E-03	6.383E+00
2.600E+01	1.577E+00	0.000E+00	3.556E+00	2.926E-01	3.615E-02	5.171E-03	0.000E+00	1.100E-02	7.599E+00
2.800E+01	1.638E+00	0.000E+00	3.728E+00	3.362E-01	4.002E-02	6.158E-03	0.000E+00	1.227E-02	8.650E+00
3.000E+01	1.681E+00	0.000E+00	3.905E+00	3.822E-01	4.560E-02	7.020E-03	0.000E+00	1.341E-02	9.240E+00
3.500E+01	1.756E+00	0.000E+00	4.500E+00	5.059E-01	5.775E-02	8.517E-03	0.000E+00	1.562E-02	9.283E+00
4.000E+01	1.800E+00	0.000E+00	4.900E+00	6.202E-01	6.722E-02	9.352E-03	0.000E+00	1.739E-02	9.533E+00
4.500E+01	1.822E+00	0.000E+00	5.237E+00	7.299E-01	7.462E-02	9.810E-03	0.000E+00	1.915E-02	9.530E+00
5.000E+01	1.830E+00	0.000E+00	5.447E+00	8.230E-01	8.043E-02	1.005E-02	0.000E+00	2.305E-02	9.886E+00
5.500E+01	1.832E+00	0.000E+00	5.664E+00	9.055E-01	8.513E-02	1.012E-02	0.000E+00	2.557E-02	9.852E+00
6.000E+01	1.830E+00	0.000E+00	5.886E+00	9.782E-01	8.885E-02	1.010E-02	0.000E+00	2.643E-02	9.695E+00
6.500E+01	1.826E+00	0.000E+00	6.094E+00	1.042E+00	9.174E-02	1.001E-02	0.000E+00	2.736E-02	9.553E+00
7.000E+01	1.819E+00	0.000E+00	6.297E+00	1.078E+00	9.287E-02	9.812E-03	0.000E+00	2.993E-02	7.972E+00
7.500E+01	1.809E+00	0.000E+00	6.575E+00	1.108E+00	9.352E-02	9.669E-03	0.000E+00	3.267E-02	8.019E+00
8.000E+01	1.799E+00	0.000E+00	6.842E+00	1.134E+00	9.396E-02	9.602E-03	0.000E+00	3.593E-02	8.075E+00
8.500E+01	1.788E+00	0.000E+00	7.078E+00	1.161E+00	9.452E-02	9.620E-03	0.000E+00	3.930E-02	8.130E+00
9.000E+01	1.778E+00	0.000E+00	7.314E+00	1.184E+00	9.488E-02	9.723E-03	0.000E+00	4.301E-02	8.139E+00
9.500E+01	1.768E+00	0.000E+00	7.538E+00	1.208E+00	9.539E-02	9.910E-03	0.000E+00	4.695E-02	8.106E+00
1.000E+02	1.756E+00	0.000E+00	7.746E+00	1.231E+00	9.517E-02	1.018E-02	0.000E+00	5.153E-02	8.080E+00
1.100E+02	1.727E+00	0.000E+00	8.061E+00	1.272E+00	9.506E-02	1.089E-02	0.000E+00	6.113E-02	8.070E+00
1.200E+02	1.699E+00	0.000E+00	8.352E+00	1.310E+00	9.461E-02	1.187E-02	0.000E+00	7.201E-02	7.952E+00
1.300E+02	1.672E+00	0.000E+00	8.613E+00	1.346E+00	9.388E-02	1.312E-02	0.000E+00	8.315E-02	7.631E+00
1.400E+02	1.648E+00	0.000E+00	8.866E+00	1.383E+00	9.287E-02	1.457E-02	0.000E+00	9.334E-02	7.508E+00
1.500E+02	1.631E+00	0.000E+00	9.119E+00	1.425E+00	9.184E-02	1.618E-02	0.000E+00	1.030E-01	7.481E+00

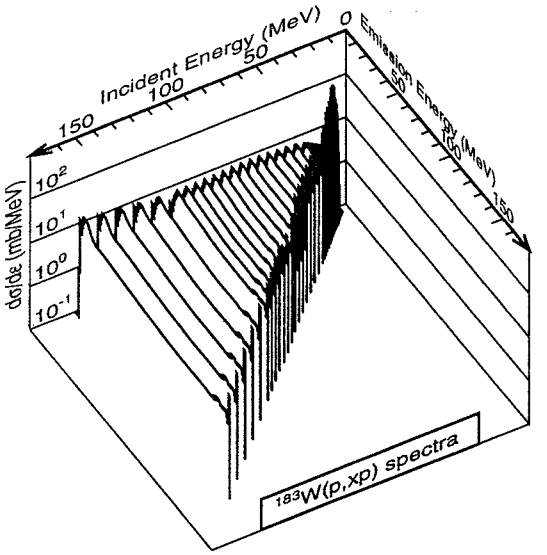
74183 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

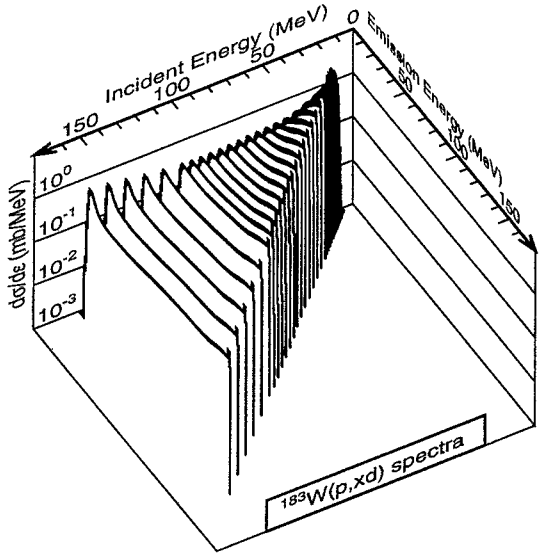
Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
3.000E+00	7.640E-01	9.008E-05	0.000E+00	0.000E+00	0.000E+00	9.134E+00	1.959E+00
4.000E+00	9.864E-01	3.753E+00	0.000E+00	0.000E+00	0.000E+00	1.033E+01	8.071E-01
5.000E+00	1.095E+00	4.683E+00	0.000E+00	0.000E+00	0.000E+00	1.090E+01	9.718E-01
6.000E+00	1.137E+00	5.165E+00	1.988E+00	0.000E+00	0.000E+00	1.192E+01	1.139E+00
7.000E+00	1.158E+00	6.725E+00	2.673E+00	0.000E+00	0.000E+00	1.263E+01	1.230E+00
8.000E+00	1.208E+00	7.712E+00	3.665E+00	0.000E+00	0.000E+00	1.334E+01	1.343E+00
9.000E+00	1.302E+00	8.713E+00	4.678E+00	8.108E-04	0.000E+00	1.376E+01	1.421E+00
1.000E+01	1.404E+00	9.668E+00	5.343E+00	3.628E+00	0.000E+00	1.407E+01	1.473E+00
1.100E+01	1.218E+00	1.061E+01	6.284E+00	4.625E+00	0.000E+00	1.509E+01	1.259E+00
1.200E+01	1.232E+00	1.148E+01	7.261E+00	5.201E+00	0.000E+00	1.615E+01	9.020E-01
1.300E+01	1.361E+00	1.229E+01	8.144E+00	6.129E+00	0.000E+00	1.702E+01	7.052E-01
1.400E+01	1.496E+00	1.304E+01	8.938E+00	7.052E+00	0.000E+00	1.770E+01	6.810E-01
1.500E+01	1.608E+00	1.368E+01	9.628E+00	7.852E+00	0.000E+00	1.830E+01	7.283E-01
1.600E+01	1.699E+00	1.433E+01	1.037E+01	8.587E+00	0.000E+00	1.885E+01	8.531E-01
1.700E+01	1.797E+00	1.496E+01	1.109E+01	9.227E+00	0.000E+00	1.938E+01	9.235E-01
1.800E+01	1.840E+00	1.557E+01	1.179E+01	9.829E+00	0.000E+00	1.987E+01	9.463E-01
1.900E+01	1.837E+00	1.616E+01	1.248E+01	1.040E+01	0.000E+00	2.035E+01	8.831E-01
2.000E+01	1.861E+00	1.680E+01	1.319E+01	1.098E+01	0.000E+00	2.081E+01	9.036E-01
2.200E+01	1.985E+00	1.784E+01	1.455E+01	1.204E+01	0.000E+00	2.168E+01	8.435E-01
2.400E+01	2.150E+00	1.870E+01	1.588E+01	1.307E+01	0.000E+00	2.250E+01	8.740E-01
2.600E+01	2.322E+00	1.950E+01	1.719E+01	1.409E+01	0.000E+00	2.327E+01	9.476E-01
2.800E+01	2.501E+00	2.020E+01	1.826E+01	1.508E+01	0.000E+00	2.397E+01	1.016E+00
3.000E+01	2.657E+00	2.098E+01	1.954E+01	1.606E+01	0.000E+00	2.460E+01	1.044E+00
3.500E+01	2.963E+00	2.312E+01	2.277E+01	1.835E+01	0.000E+00	2.623E+01	9.270E-01

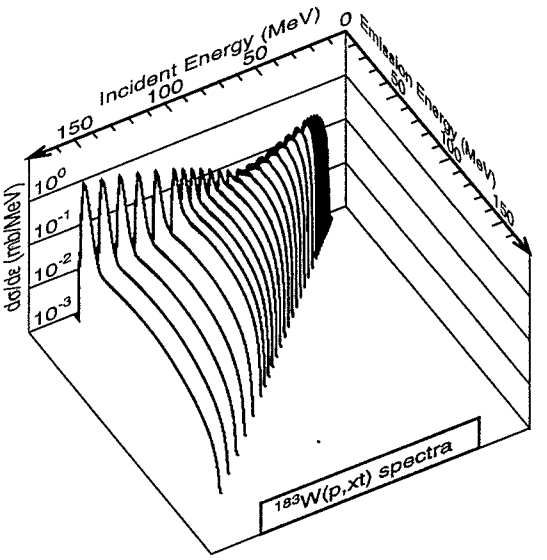
4.000E+01	3.299E+00	2.546E+01	2.605E+01	2.056E+01	0.000E+00	2.763E+01	9.193E-01
4.500E+01	3.624E+00	2.791E+01	2.932E+01	2.277E+01	0.000E+00	2.859E+01	9.126E-01
5.000E+01	3.970E+00	3.020E+01	3.252E+01	2.496E+01	0.000E+00	2.759E+01	9.371E-01
5.500E+01	4.278E+00	3.255E+01	3.569E+01	2.711E+01	0.000E+00	2.775E+01	9.435E-01
6.000E+01	4.559E+00	3.484E+01	3.878E+01	2.922E+01	0.000E+00	2.883E+01	9.369E-01
6.500E+01	4.834E+00	3.706E+01	4.179E+01	3.128E+01	0.000E+00	2.971E+01	9.369E-01
7.000E+01	5.077E+00	3.932E+01	4.485E+01	3.302E+01	0.000E+00	2.956E+01	1.181E+00
7.500E+01	5.237E+00	4.140E+01	4.785E+01	3.453E+01	0.000E+00	2.932E+01	1.184E+00
8.000E+01	5.393E+00	4.345E+01	5.082E+01	3.575E+01	0.000E+00	2.891E+01	1.171E+00
8.500E+01	5.566E+00	4.544E+01	5.376E+01	3.669E+01	0.000E+00	2.854E+01	1.181E+00
9.000E+01	5.728E+00	4.739E+01	5.666E+01	3.727E+01	0.000E+00	2.813E+01	1.185E+00
9.500E+01	5.897E+00	4.920E+01	5.952E+01	3.758E+01	0.000E+00	2.772E+01	1.191E+00
1.000E+02	6.056E+00	5.104E+01	6.216E+01	3.752E+01	0.000E+00	2.721E+01	1.200E+00
1.100E+02	6.384E+00	5.468E+01	6.754E+01	3.674E+01	0.000E+00	2.625E+01	1.217E+00
1.200E+02	6.708E+00	5.807E+01	7.257E+01	3.518E+01	0.000E+00	2.537E+01	1.232E+00
1.300E+02	7.040E+00	6.125E+01	7.719E+01	3.322E+01	0.000E+00	2.473E+01	1.265E+00
1.400E+02	7.373E+00	6.418E+01	8.140E+01	3.115E+01	0.000E+00	2.438E+01	1.276E+00
1.500E+02	7.713E+00	6.689E+01	8.529E+01	2.920E+01	0.000E+00	2.418E+01	1.279E+00

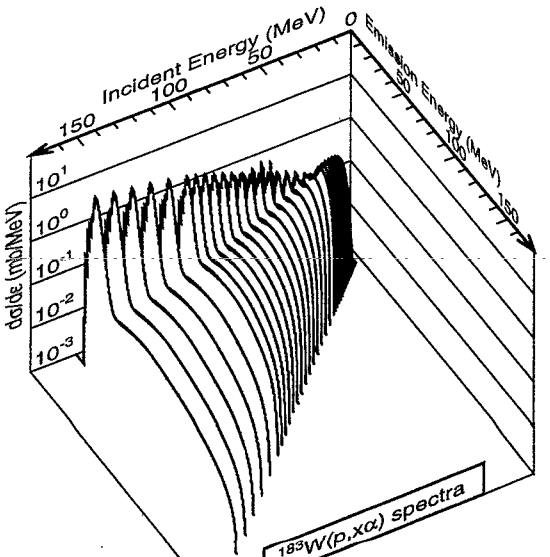
p + ^{183}W angle-integrated emission spectra

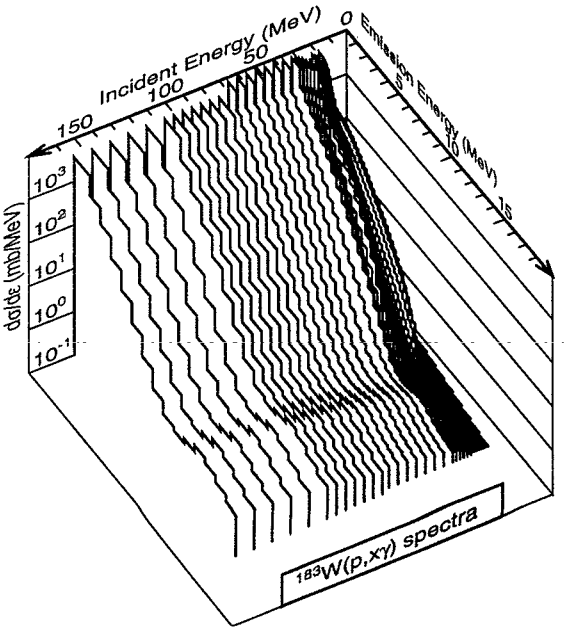




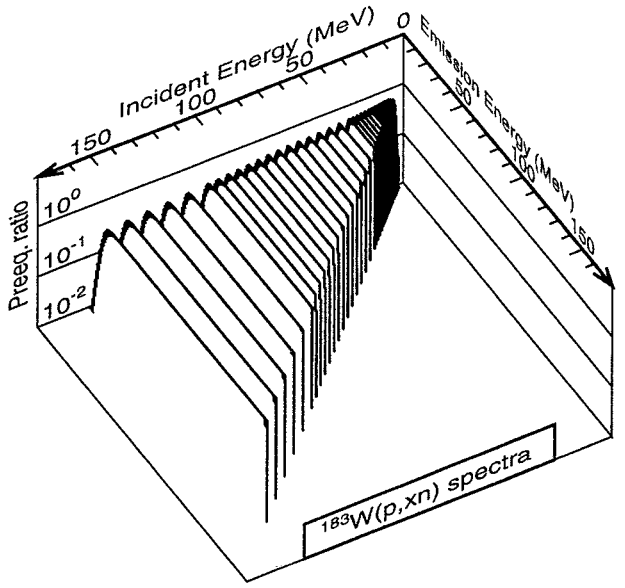


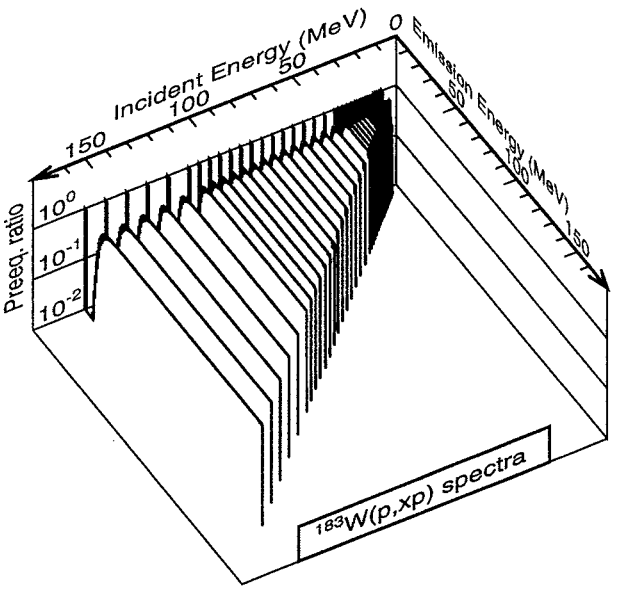


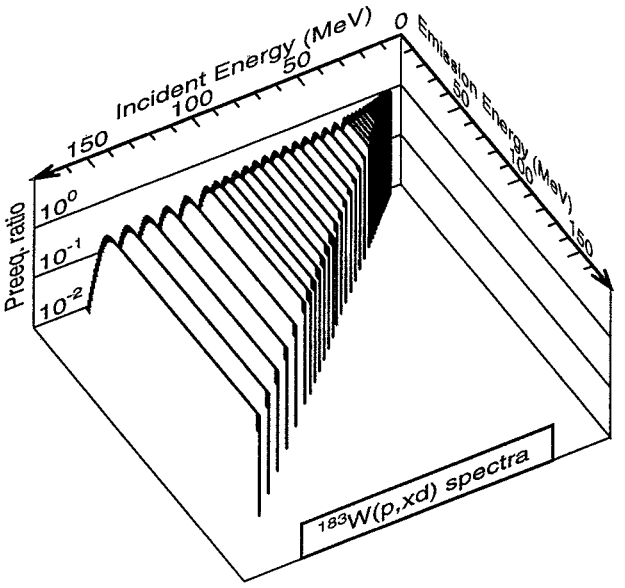


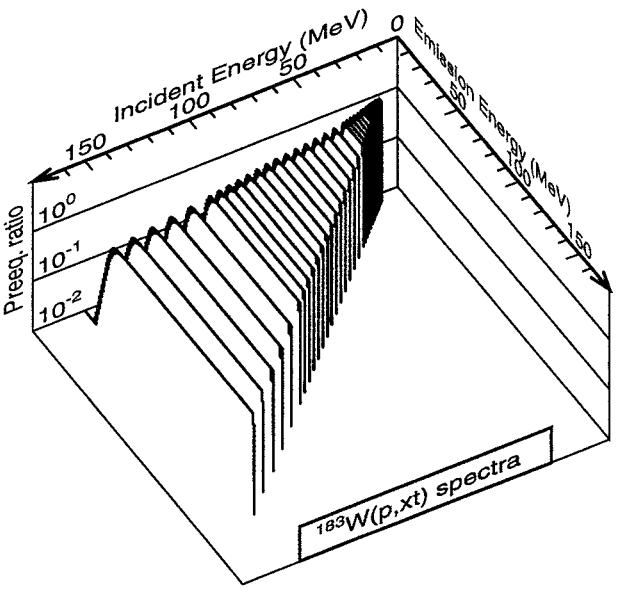


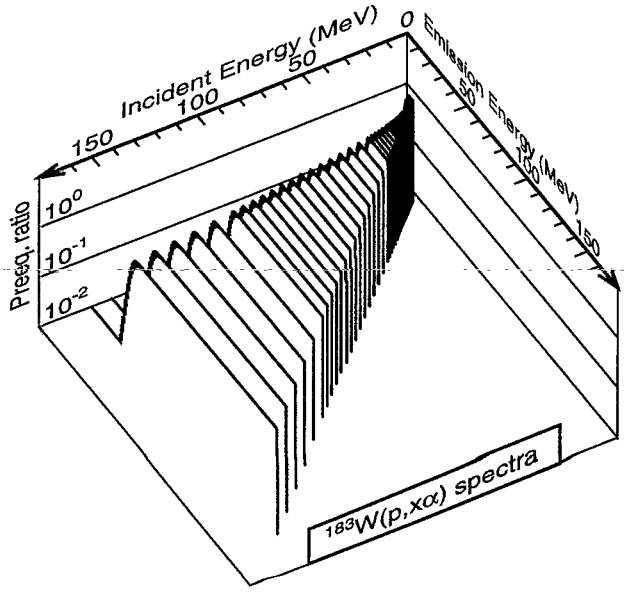
p + ^{183}W Kalbach preequilibrium ratios

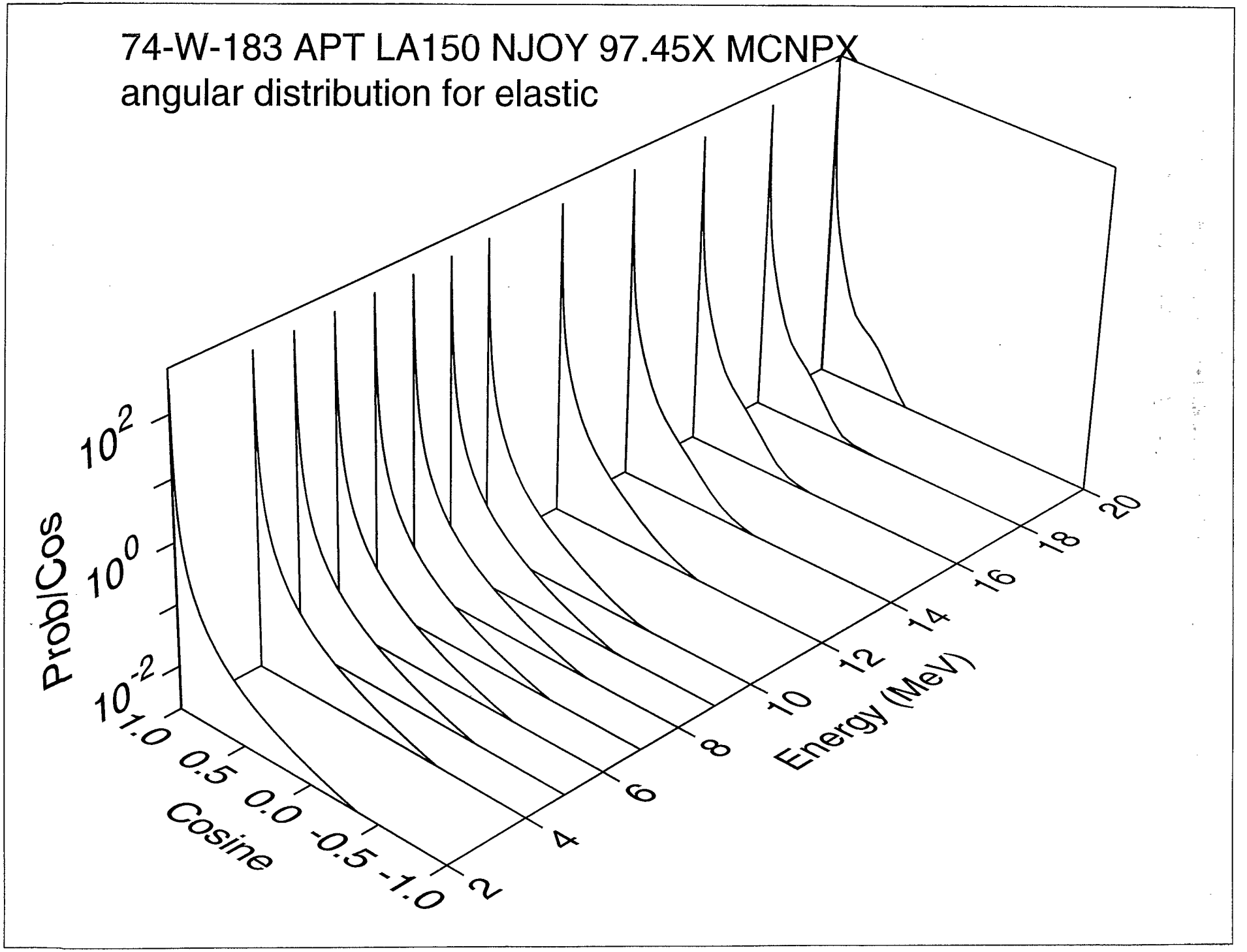


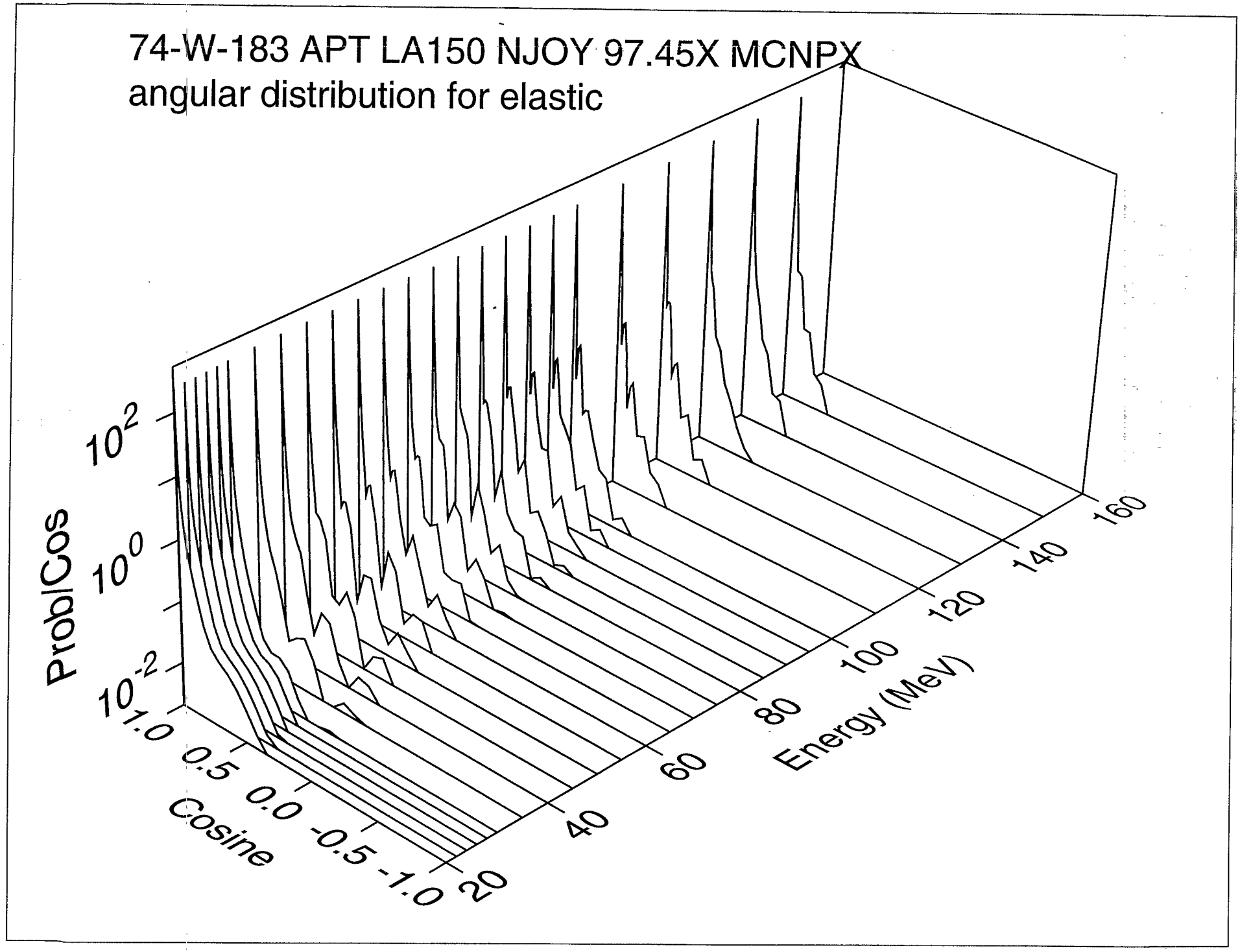


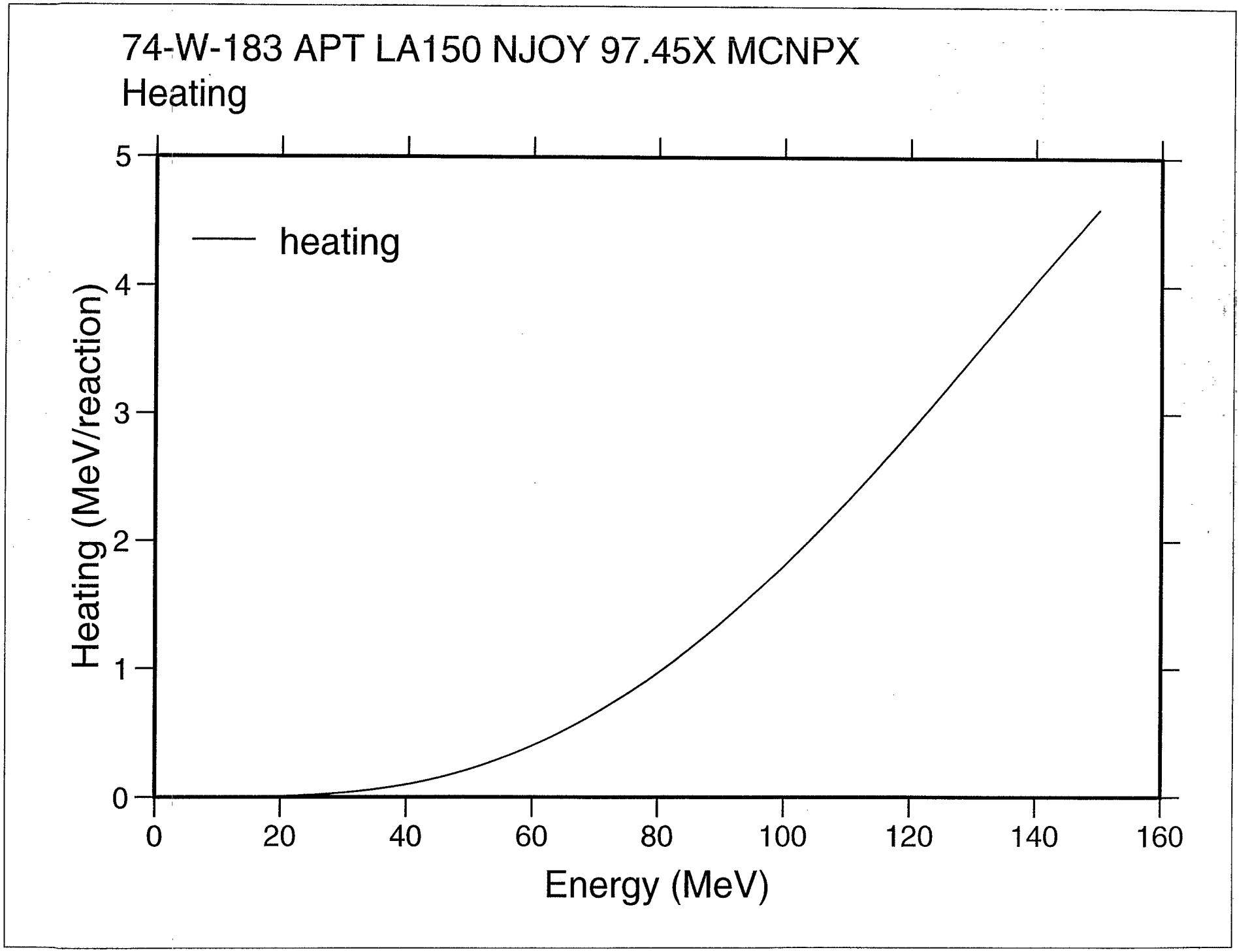







74-W-183 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
2
4
6
8
10
12
14
16
18
20


74-W-183 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
10^{-2}
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


74-W-183 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
1
2
3
4
5
0
20
40
60
80
100
120
140
160

EVALUATION OF p + 184W CROSS SECTIONS FOR THE ENERGY RANGE 2 to 150 MeV

M. B. Chadwick and P. G. Young
17 October 1996

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 2 to 150 MeV.

The evaluation utilizes MF = 3 [MT=2 and MT=5] and MF=6 [MT=2 and MT=5] to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced with non-negligible cross sections (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data are:

MF=3	MT= 2	Integral of nuclear plus interference components of the elastic scattering cross section
	MT= 5	Sum of binary (n,n') and (n,x) reactions
MF=6	MT= 2	Elastic angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
	MT= 5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + W, n + Ta, p + Ta, and p + W reactions (Ch96a). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Coupled-channels and spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A coupled-channels neutron optical model potential based on earlier work to 100 MeV (Yo90) is utilized to 80 MeV, and the global spherical optical model potential of Madland (Ma88) is used at higher energies. For protons, the Beccetti-Greenlees potential (Be69) is utilized below 20 MeV, and the Madland Semmering potential (Ma88) at higher energies. The Perey potential (Pe63) is used for deuterons, and the Beccetti-Greenlees potential (Be71) for tritons. The ECIS79 code (Ra72) was used for the coupled-channels optical model calculations, and the SCAT2 code (Be92) was utilized for the spherical optical model calculations. Minor normalizations were made to the reaction cross sections and transmission coefficients to produce

agreement with the (sparse) measurements for W and values inferred from systematics of proton and neutron reaction cross sections from measurements on other targets. The same reaction cross sections are used for both proton- and neutron-induced reactions on W isotopes.

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96b). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. Note that all other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation requires a modification of the original ENDF-6 format, i.e., we use LCT=3 with LAW 1 to indicate that data for the heavy recoils are in the lab system but all other reactions are in the cm system.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed above. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

MT=2 elastic scattering data in MF=3 and MF=6 are based on optical model calculations with the SCAT2 code (Be92). We have made use of the "nuclear-plus-interference" option in MF=6, which corresponds to LAW=5, LTP=12, and the appropriate integrated cross section is stored in MF=3. Note that because of the interference effect, the tabulations in both MF=6 and MF=3 can be negative at some energies and angles.

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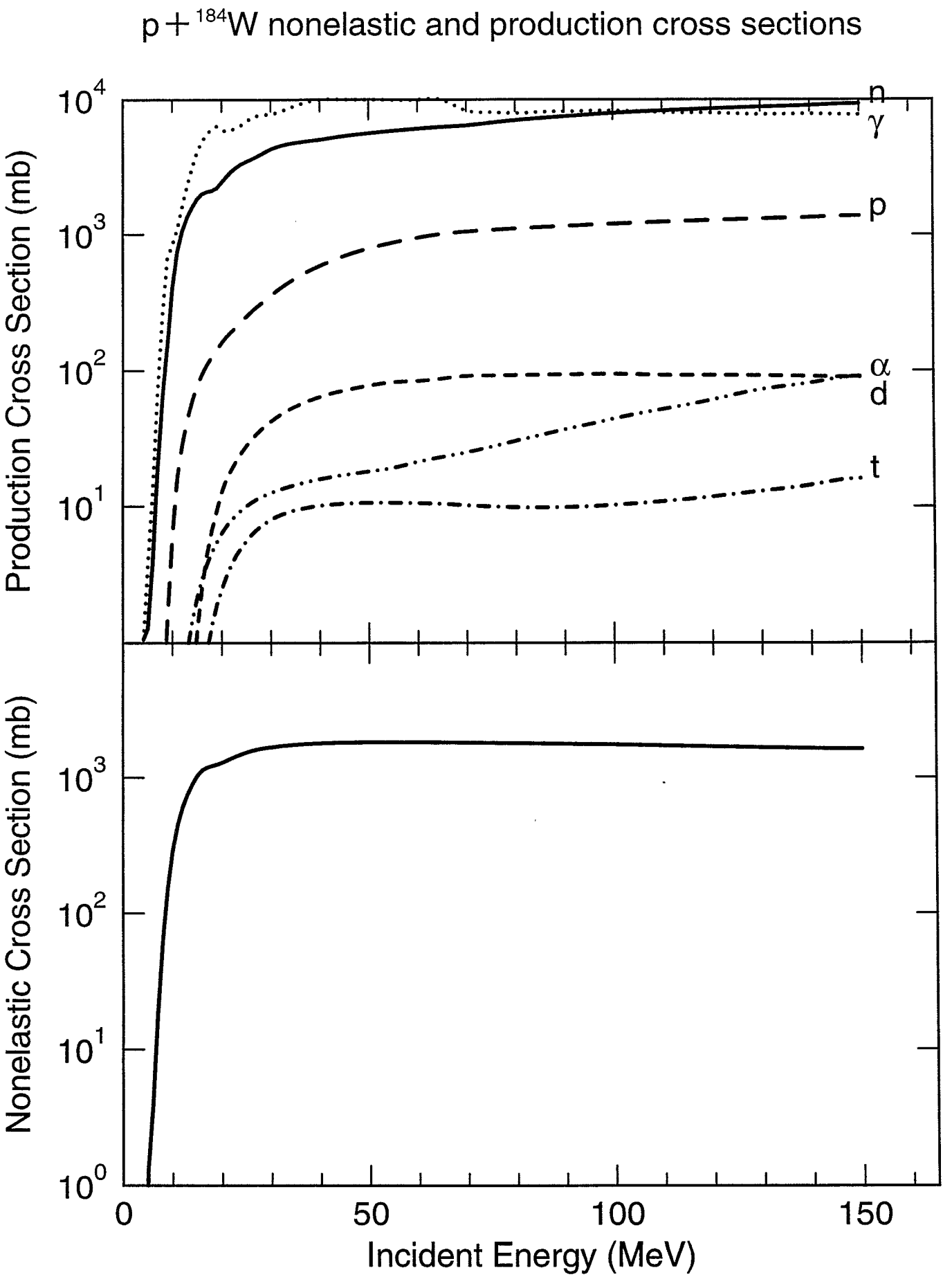
74184 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
3.000E+00	1.000E-20	0.000E+00	1.000E-20	1.000E-20	0.000E+00	0.000E+00	0.000E+00	1.000E-20	1.000E-20
4.000E+00	1.689E-05	0.000E+00	1.633E-05	6.767E-12	0.000E+00	0.000E+00	0.000E+00	3.598E-07	3.679E-05
5.000E+00	1.289E-03	0.000E+00	1.276E-03	9.543E-09	0.000E+00	0.000E+00	0.000E+00	6.990E-07	3.542E-03
6.000E+00	3.940E-03	0.000E+00	3.907E-03	1.056E-06	0.000E+00	0.000E+00	0.000E+00	2.690E-06	1.259E-02
7.000E+00	1.915E-02	0.000E+00	1.902E-02	1.872E-05	0.000E+00	0.000E+00	0.000E+00	7.414E-06	6.997E-02
8.000E+00	6.458E-02	0.000E+00	6.407E-02	2.431E-04	7.388E-10	0.000E+00	0.000E+00	1.920E-05	2.606E-01
9.000E+00	1.537E-01	0.000E+00	1.549E-01	1.531E-03	1.200E-09	1.270E-08	0.000E+00	4.724E-05	6.632E-01
1.000E+01	2.875E-01	0.000E+00	4.069E-01	6.053E-03	4.048E-07	6.240E-08	0.000E+00	1.119E-04	8.353E-01
1.100E+01	4.462E-01	0.000E+00	7.440E-01	1.652E-02	3.774E-06	6.657E-07	0.000E+00	2.449E-04	1.088E+00
1.200E+01	6.053E-01	0.000E+00	1.061E+00	2.889E-02	1.235E-05	3.070E-06	0.000E+00	4.865E-04	1.606E+00
1.300E+01	7.529E-01	0.000E+00	1.336E+00	4.341E-02	8.508E-05	1.648E-05	0.000E+00	8.787E-04	2.288E+00
1.400E+01	8.956E-01	0.000E+00	1.590E+00	5.981E-02	3.853E-04	6.862E-05	0.000E+00	1.433E-03	3.106E+00
1.500E+01	1.033E+00	0.000E+00	1.828E+00	7.714E-02	1.201E-03	2.079E-04	0.000E+00	2.134E-03	4.025E+00
1.600E+01	1.135E+00	0.000E+00	1.997E+00	9.397E-02	2.550E-03	4.752E-04	0.000E+00	2.934E-03	4.886E+00
1.700E+01	1.188E+00	0.000E+00	2.070E+00	1.102E-01	4.409E-03	8.560E-04	0.000E+00	3.772E-03	5.553E+00
1.800E+01	1.221E+00	0.000E+00	2.112E+00	1.258E-01	6.682E-03	1.334E-03	0.000E+00	4.614E-03	6.109E+00
1.900E+01	1.250E+00	0.000E+00	2.209E+00	1.417E-01	9.250E-03	1.888E-03	0.000E+00	5.465E-03	6.367E+00
2.000E+01	1.289E+00	0.000E+00	2.441E+00	1.601E-01	1.272E-02	2.467E-03	0.000E+00	6.347E-03	5.976E+00
2.200E+01	1.394E+00	0.000E+00	2.933E+00	1.936E-01	1.878E-02	3.759E-03	0.000E+00	7.960E-03	5.974E+00
2.400E+01	1.492E+00	0.000E+00	3.323E+00	2.284E-01	2.483E-02	4.992E-03	0.000E+00	9.360E-03	6.486E+00
2.600E+01	1.577E+00	0.000E+00	3.605E+00	2.699E-01	3.094E-02	6.149E-03	0.000E+00	1.064E-02	7.282E+00
2.800E+01	1.638E+00	0.000E+00	3.924E+00	3.110E-01	3.678E-02	7.144E-03	0.000E+00	1.170E-02	7.687E+00
3.000E+01	1.681E+00	0.000E+00	4.279E+00	3.554E-01	4.236E-02	7.991E-03	0.000E+00	1.261E-02	7.805E+00
3.500E+01	1.756E+00	0.000E+00	4.786E+00	4.762E-01	5.462E-02	9.383E-03	0.000E+00	1.442E-02	9.021E+00
4.000E+01	1.800E+00	0.000E+00	5.060E+00	5.880E-01	6.437E-02	1.013E-02	0.000E+00	1.591E-02	9.989E+00
4.500E+01	1.822E+00	0.000E+00	5.378E+00	6.970E-01	7.176E-02	1.050E-02	0.000E+00	1.712E-02	9.982E+00
5.000E+01	1.830E+00	0.000E+00	5.643E+00	7.910E-01	7.762E-02	1.063E-02	0.000E+00	1.816E-02	9.958E+00
5.500E+01	1.832E+00	0.000E+00	5.891E+00	8.734E-01	8.233E-02	1.064E-02	0.000E+00	1.933E-02	9.931E+00
6.000E+01	1.830E+00	0.000E+00	6.107E+00	9.468E-01	8.405E-02	1.056E-02	0.000E+00	2.136E-02	9.984E+00
6.500E+01	1.826E+00	0.000E+00	6.299E+00	1.011E+00	8.749E-02	1.043E-02	0.000E+00	2.323E-02	9.981E+00
7.000E+01	1.819E+00	0.000E+00	6.455E+00	1.051E+00	9.135E-02	1.019E-02	0.000E+00	2.512E-02	8.279E+00
7.500E+01	1.809E+00	0.000E+00	6.749E+00	1.082E+00	9.204E-02	9.979E-03	0.000E+00	2.757E-02	8.036E+00
8.000E+01	1.799E+00	0.000E+00	7.036E+00	1.108E+00	9.252E-02	9.852E-03	0.000E+00	3.047E-02	7.908E+00
8.500E+01	1.788E+00	0.000E+00	7.280E+00	1.134E+00	9.311E-02	9.817E-03	0.000E+00	3.351E-02	8.090E+00
9.000E+01	1.778E+00	0.000E+00	7.500E+00	1.157E+00	9.349E-02	9.871E-03	0.000E+00	3.692E-02	8.147E+00
9.500E+01	1.768E+00	0.000E+00	7.723E+00	1.181E+00	9.402E-02	1.001E-02	0.000E+00	4.045E-02	8.207E+00
1.000E+02	1.756E+00	0.000E+00	7.929E+00	1.201E+00	9.427E-02	1.025E-02	0.000E+00	4.433E-02	8.257E+00
1.100E+02	1.727E+00	0.000E+00	8.261E+00	1.240E+00	9.263E-02	1.089E-02	0.000E+00	5.199E-02	8.015E+00
1.200E+02	1.699E+00	0.000E+00	8.556E+00	1.275E+00	9.241E-02	1.183E-02	0.000E+00	6.106E-02	7.954E+00
1.300E+02	1.672E+00	0.000E+00	8.823E+00	1.308E+00	9.186E-02	1.303E-02	0.000E+00	7.261E-02	7.758E+00
1.400E+02	1.648E+00	0.000E+00	9.084E+00	1.342E+00	9.089E-02	1.446E-02	0.000E+00	8.119E-02	7.842E+00
1.500E+02	1.631E+00	0.000E+00	9.350E+00	1.379E+00	8.960E-02	1.610E-02	0.000E+00	9.087E-02	7.725E+00

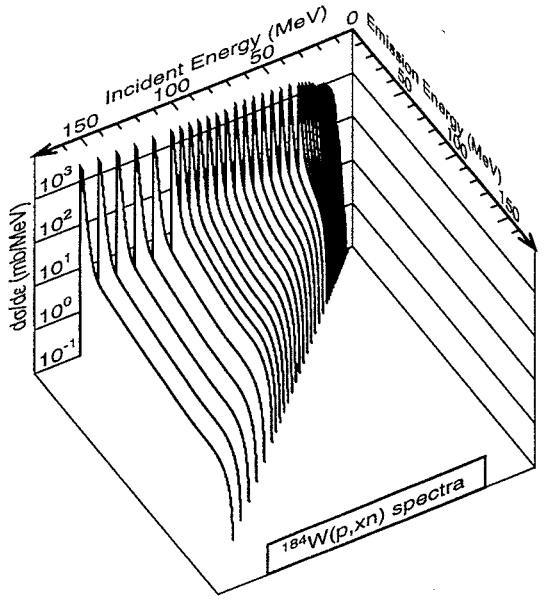
74184 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

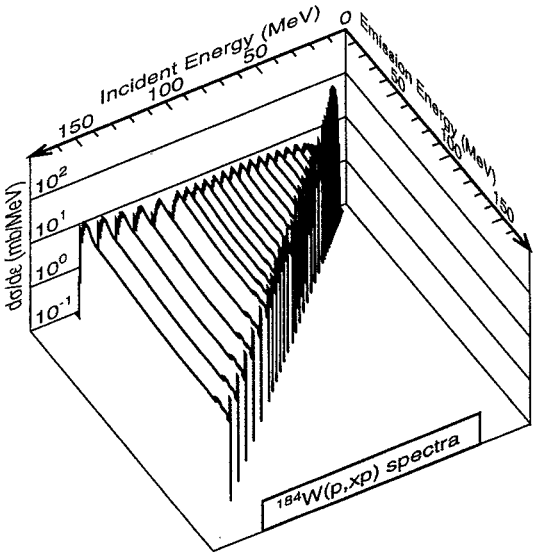
Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
3.000E+00	4.682E-01	8.911E-05	0.000E+00	0.000E+00	0.000E+00	9.511E+00	3.419E-01
4.000E+00	8.397E-01	3.658E+00	0.000E+00	0.000E+00	0.000E+00	1.047E+01	4.571E-01
5.000E+00	1.026E+00	4.621E+00	0.000E+00	0.000E+00	0.000E+00	1.108E+01	6.590E-01
6.000E+00	1.097E+00	5.689E+00	0.000E+00	0.000E+00	0.000E+00	1.210E+01	8.384E-01
7.000E+00	1.120E+00	6.682E+00	0.000E+00	0.000E+00	0.000E+00	1.279E+01	9.975E-01
8.000E+00	1.170E+00	7.671E+00	2.733E+00	0.000E+00	0.000E+00	1.362E+01	1.135E+00
9.000E+00	1.240E+00	8.648E+00	3.592E+00	3.711E+00	0.000E+00	1.441E+01	1.223E+00
1.000E+01	1.090E+00	9.608E+00	4.536E+00	4.531E+00	0.000E+00	1.518E+01	1.094E+00
1.100E+01	1.144E+00	1.055E+01	5.225E+00	5.057E+00	0.000E+00	1.598E+01	7.907E-01
1.200E+01	1.267E+00	1.143E+01	5.986E+00	5.749E+00	0.000E+00	1.672E+01	6.986E-01
1.300E+01	1.389E+00	1.226E+01	7.032E+00	6.794E+00	0.000E+00	1.740E+01	7.443E-01
1.400E+01	1.492E+00	1.302E+01	7.946E+00	7.525E+00	0.000E+00	1.802E+01	8.252E-01
1.500E+01	1.579E+00	1.373E+01	8.792E+00	8.301E+00	0.000E+00	1.859E+01	9.079E-01
1.600E+01	1.665E+00	1.438E+01	9.562E+00	8.995E+00	0.000E+00	1.912E+01	9.837E-01
1.700E+01	1.762E+00	1.500E+01	1.031E+01	9.634E+00	0.000E+00	1.962E+01	1.050E+00
1.800E+01	1.865E+00	1.560E+01	1.105E+01	1.024E+01	0.000E+00	2.008E+01	1.104E+00
1.900E+01	1.925E+00	1.619E+01	1.177E+01	1.081E+01	0.000E+00	2.052E+01	1.111E+00
2.000E+01	1.909E+00	1.685E+01	1.255E+01	1.131E+01	0.000E+00	2.100E+01	1.082E+00
2.200E+01	1.989E+00	1.789E+01	1.391E+01	1.238E+01	0.000E+00	2.190E+01	9.193E-01
2.400E+01	2.132E+00	1.874E+01	1.524E+01	1.341E+01	0.000E+00	2.277E+01	8.523E-01
2.600E+01	2.290E+00	1.944E+01	1.654E+01	1.442E+01	0.000E+00	2.360E+01	8.908E-01
2.800E+01	2.403E+00	2.018E+01	1.783E+01	1.542E+01	0.000E+00	2.439E+01	9.013E-01
3.000E+01	2.492E+00	2.096E+01	1.911E+01	1.640E+01	0.000E+00	2.516E+01	8.548E-01
3.500E+01	2.856E+00	2.307E+01	2.234E+01	1.868E+01	0.000E+00	2.696E+01	8.568E-01

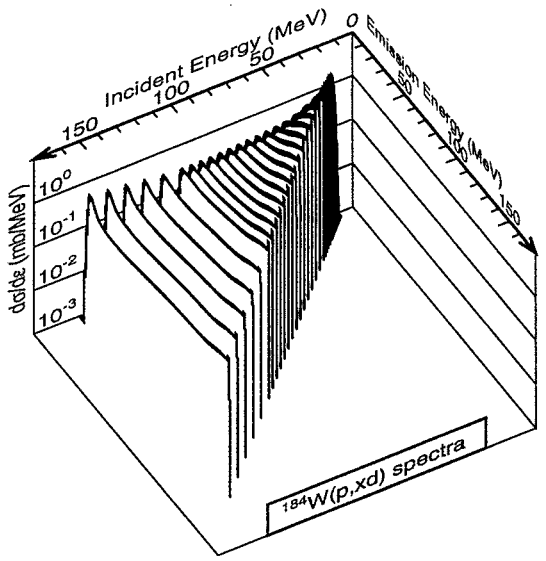
4.000E+01	3.247E+00	2.534E+01	2.562E+01	2.092E+01	0.000E+00	2.846E+01	9.348E-01
4.500E+01	3.576E+00	2.777E+01	2.888E+01	2.315E+01	0.000E+00	2.983E+01	9.077E-01
5.000E+01	3.883E+00	3.012E+01	3.209E+01	2.537E+01	0.000E+00	3.105E+01	8.824E-01
5.500E+01	4.169E+00	3.247E+01	3.523E+01	2.755E+01	0.000E+00	3.193E+01	8.838E-01
6.000E+01	4.452E+00	3.476E+01	3.792E+01	2.967E+01	0.000E+00	3.182E+01	8.999E-01
6.500E+01	4.726E+00	3.699E+01	4.099E+01	3.175E+01	0.000E+00	3.182E+01	9.062E-01
7.000E+01	5.001E+00	3.926E+01	4.453E+01	3.360E+01	0.000E+00	3.175E+01	1.161E+00
7.500E+01	5.150E+00	4.137E+01	4.753E+01	3.519E+01	0.000E+00	3.126E+01	1.168E+00
8.000E+01	5.294E+00	4.348E+01	5.050E+01	3.648E+01	0.000E+00	3.060E+01	1.173E+00
8.500E+01	5.460E+00	4.554E+01	5.345E+01	3.751E+01	0.000E+00	3.002E+01	1.171E+00
9.000E+01	5.633E+00	4.755E+01	5.636E+01	3.816E+01	0.000E+00	2.938E+01	1.184E+00
9.500E+01	5.799E+00	4.943E+01	5.923E+01	3.853E+01	0.000E+00	2.884E+01	1.179E+00
1.000E+02	5.957E+00	5.136E+01	6.204E+01	3.852E+01	0.000E+00	2.828E+01	1.184E+00
1.100E+02	6.274E+00	5.523E+01	6.685E+01	3.776E+01	0.000E+00	2.738E+01	1.202E+00
1.200E+02	6.592E+00	5.880E+01	7.196E+01	3.616E+01	0.000E+00	2.642E+01	1.210E+00
1.300E+02	6.915E+00	6.215E+01	7.667E+01	3.410E+01	0.000E+00	2.522E+01	1.234E+00
1.400E+02	7.237E+00	6.529E+01	8.094E+01	3.190E+01	0.000E+00	2.500E+01	1.212E+00
1.500E+02	7.563E+00	6.826E+01	8.466E+01	2.978E+01	0.000E+00	2.464E+01	1.219E+00

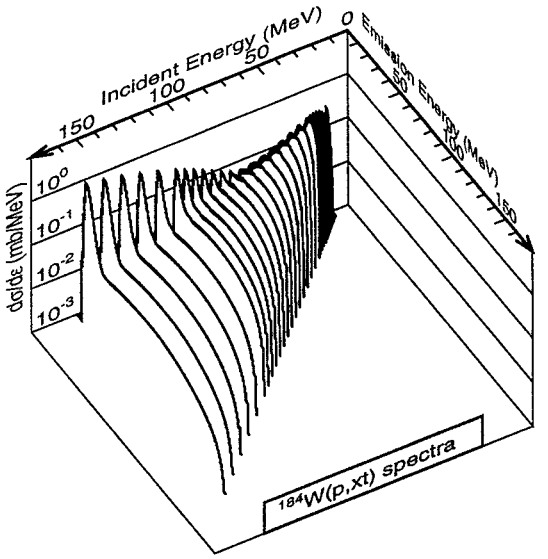

p + 184W nonelastic and production cross sections
Production Cross Section (mb)
Nonelastic Cross Section (mb)
Incident Energy (MeV)
n
γ
p
α
d
t
10^4
10^3
10^2
10^1
10^0
0
50
100
150

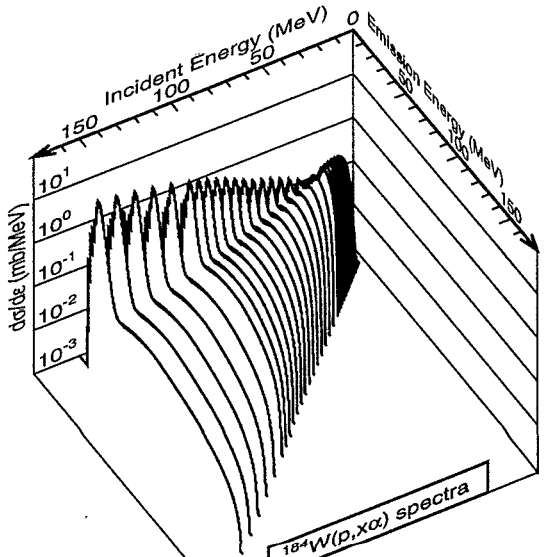
p + ^{184}W angle-integrated emission spectra

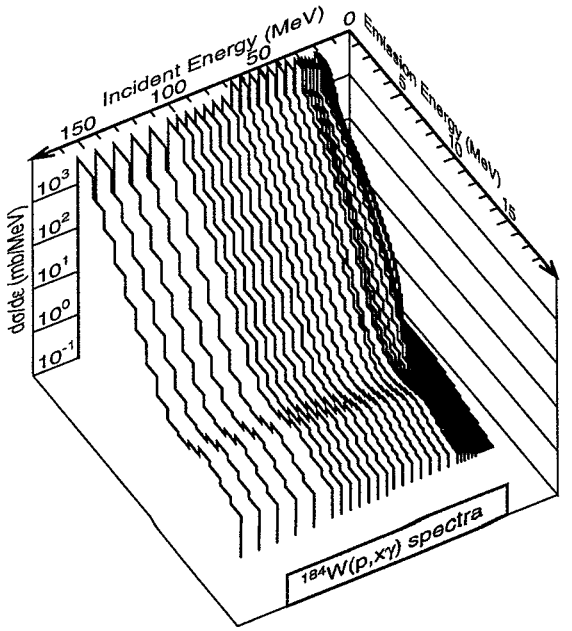




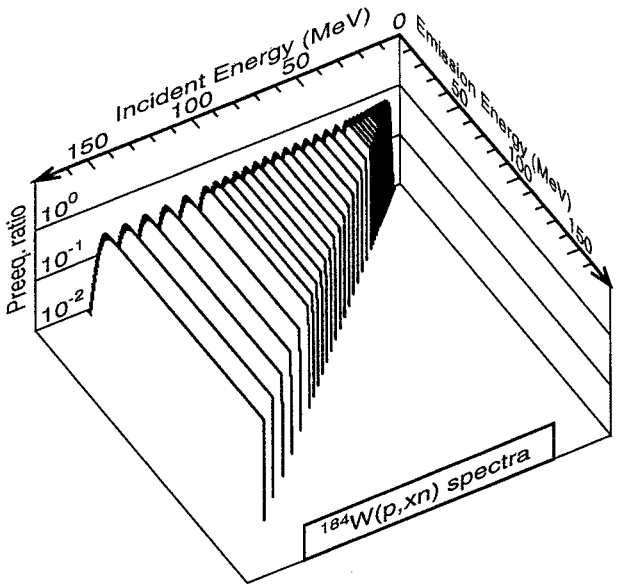


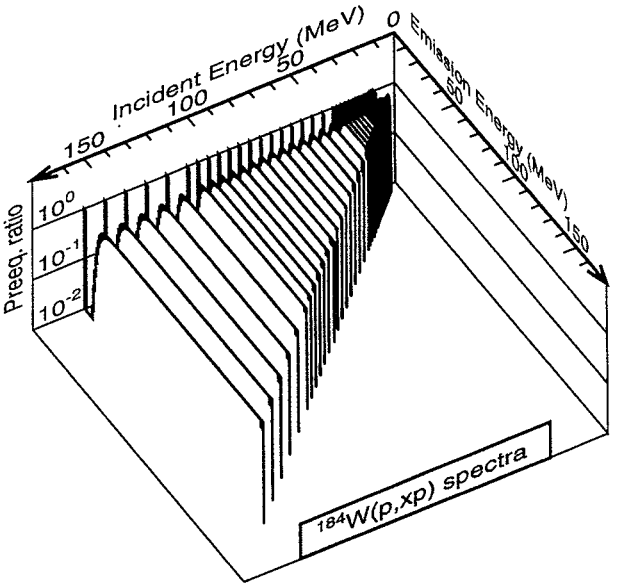


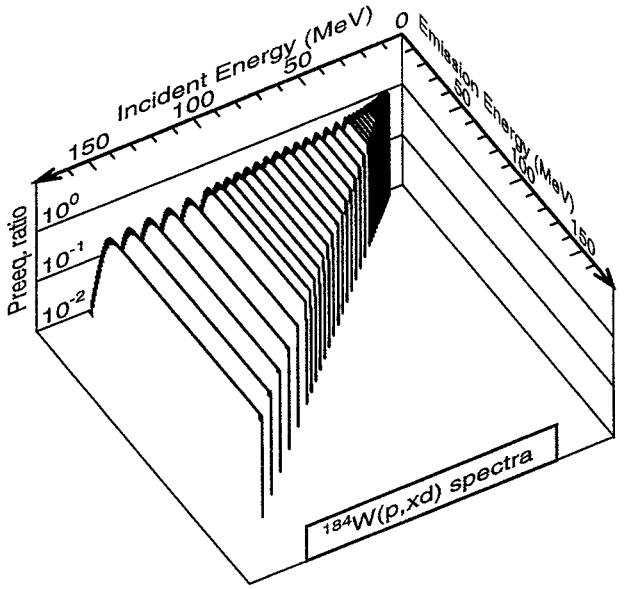


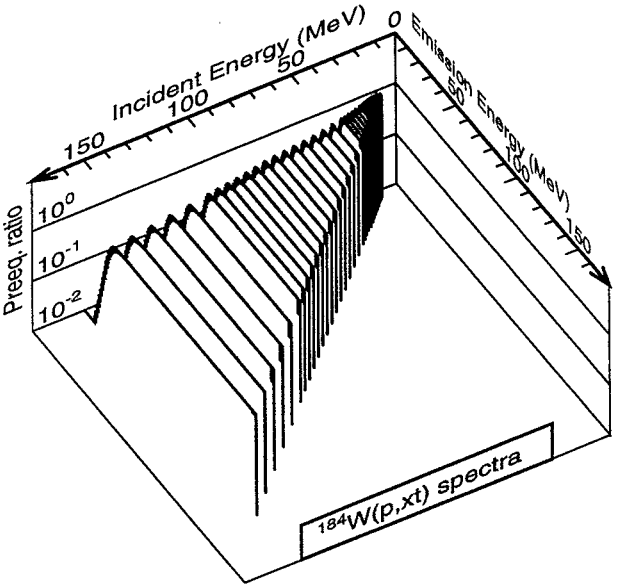


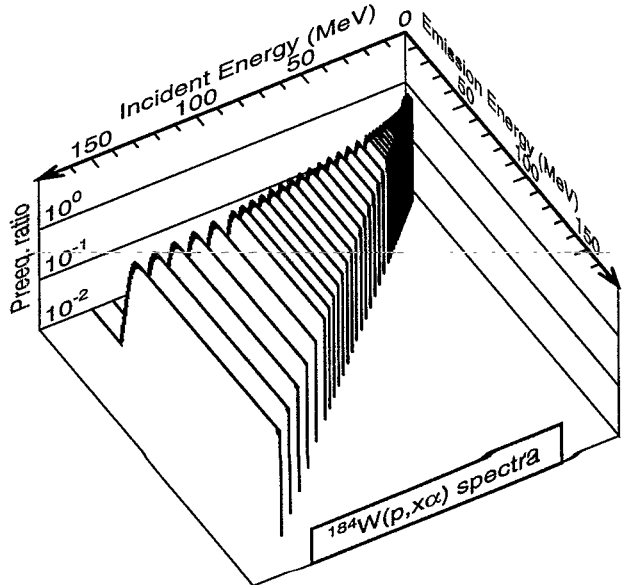
p + ^{184}W Kalbach preequilibrium ratios

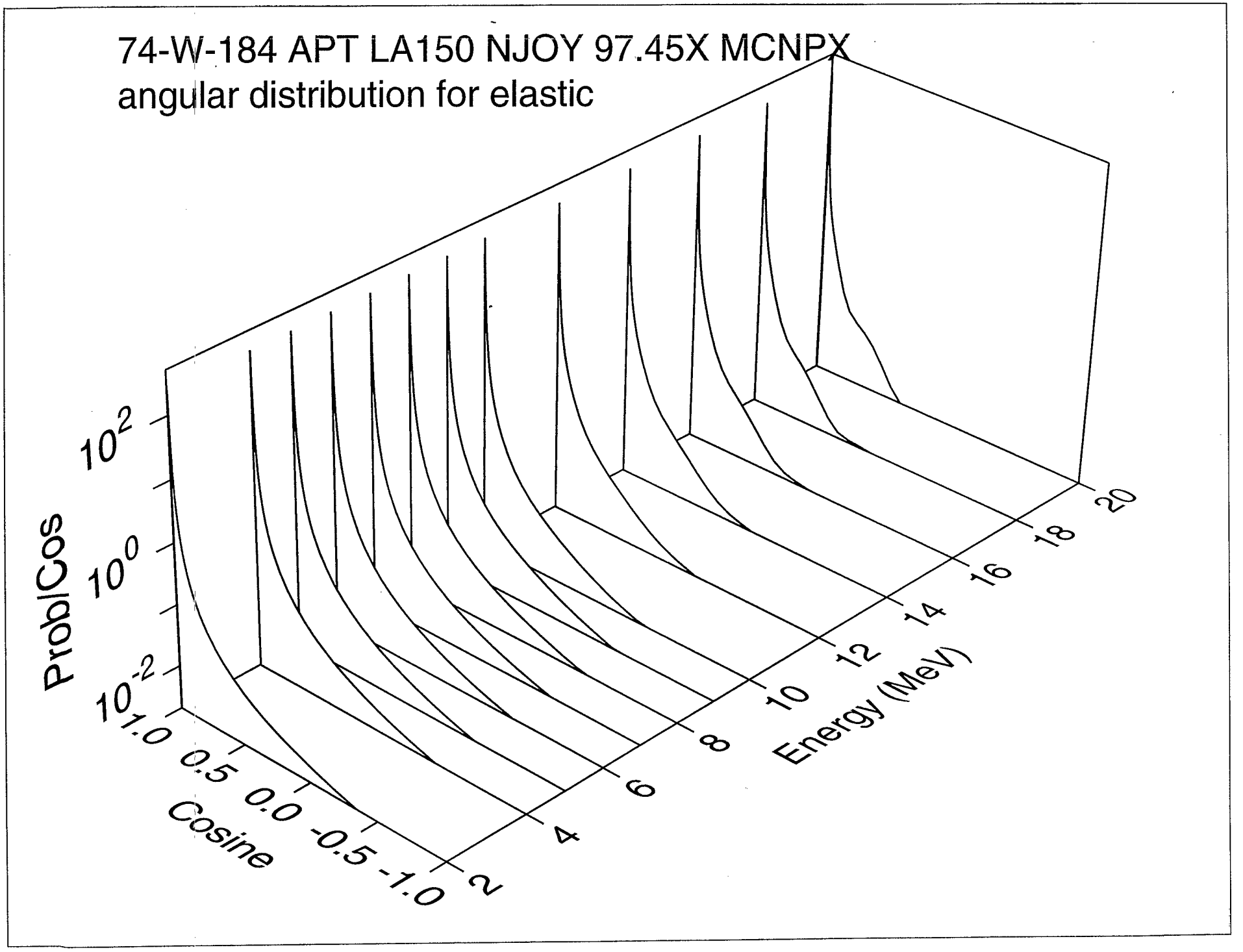


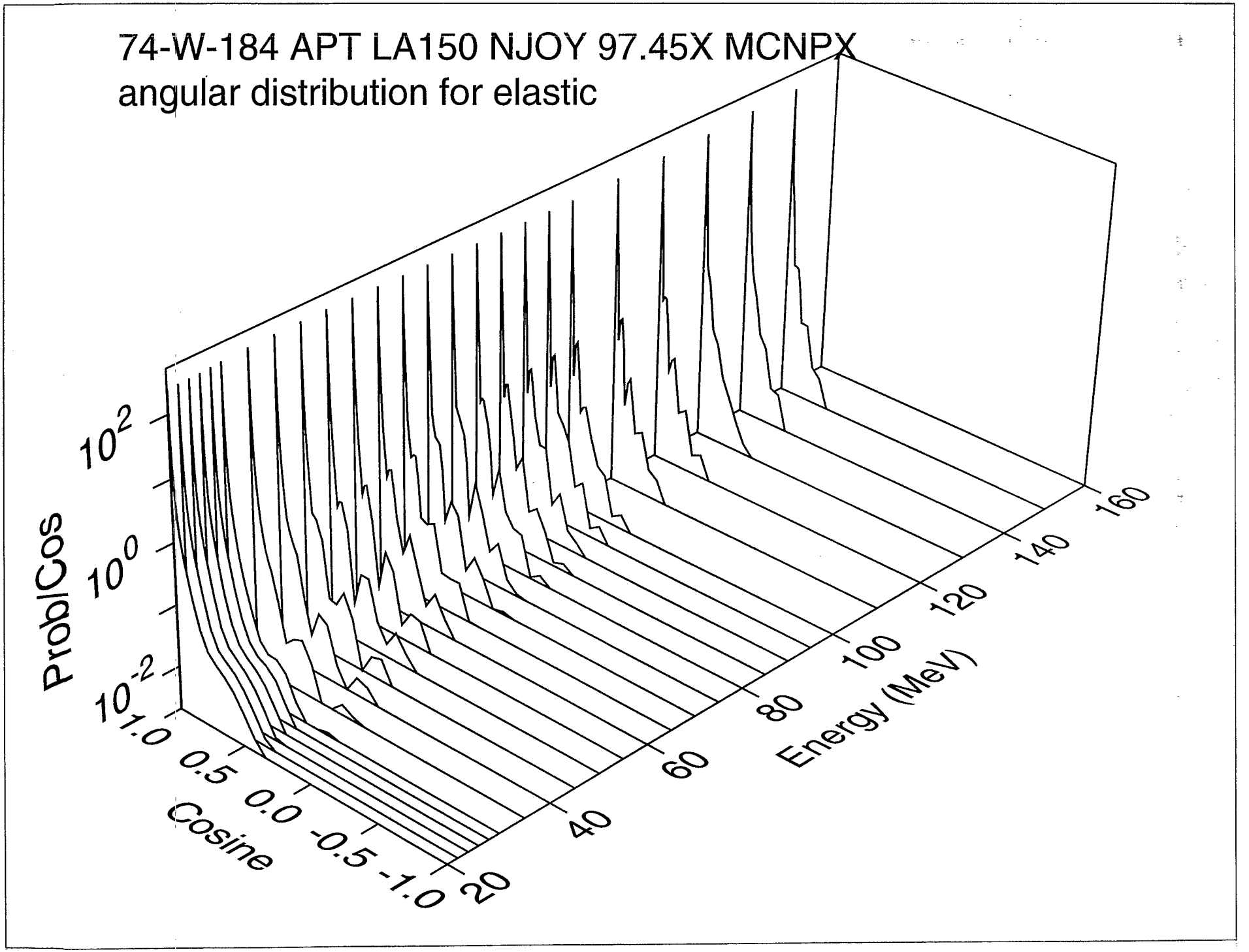


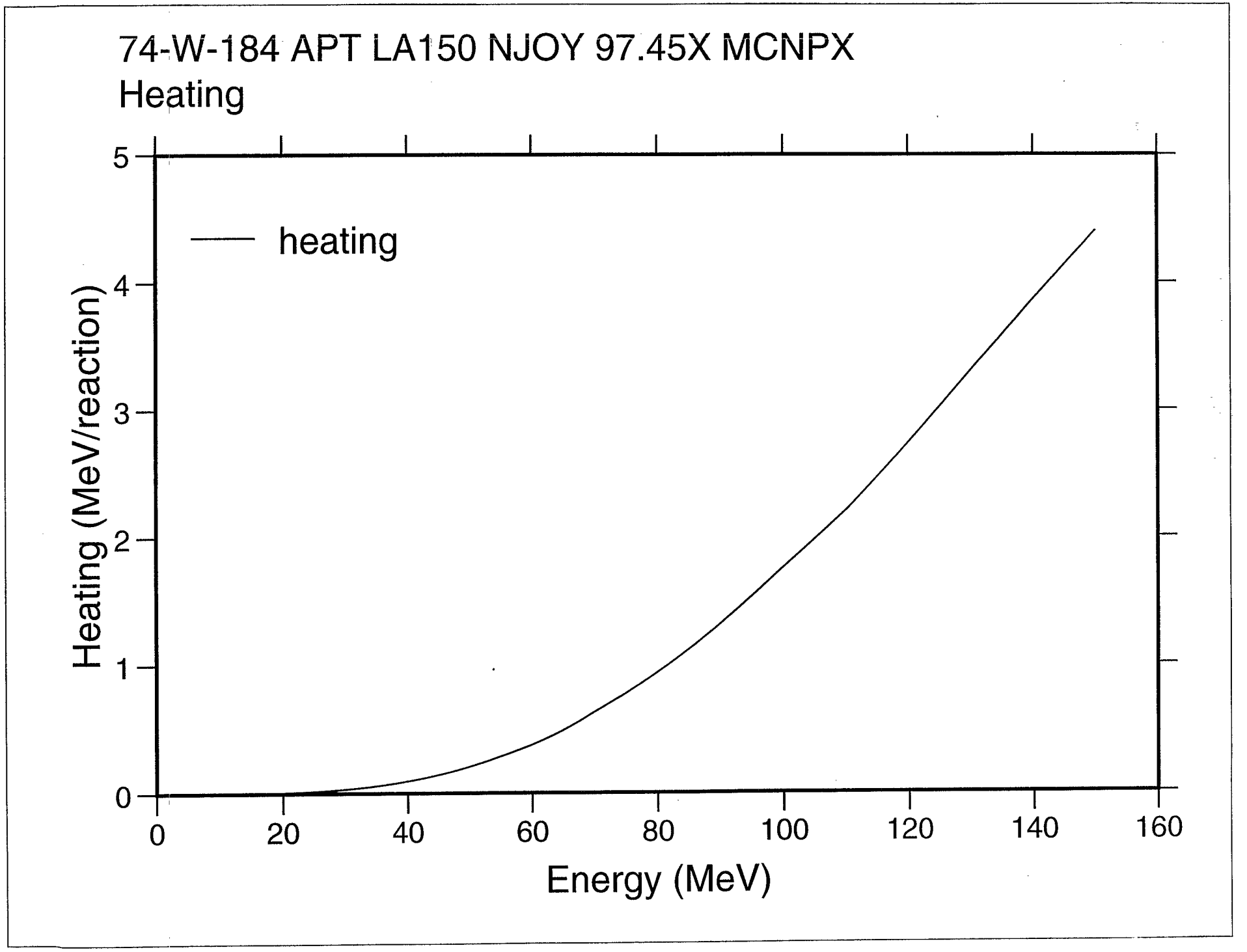







74-W-184 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
ProbCos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
2
4
6
8
10
12
14
16
18
20


74-W-184 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
20
40
60
80
100
120
140
160


74-W-184 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
1
2
3
4
5
0
20
40
60
80
100
120
140
160

EVALUATION OF p + 186W CROSS SECTIONS FOR THE ENERGY RANGE 2 to 150 MeV

M. B. Chadwick and P. G. Young
17 October 1996

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 2 to 150 MeV.

The evaluation utilizes MF = 3 [MT=2 and MT=5] and MF=6 [MT=2 and MT=5] to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced with non-negligible cross sections (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data are:

MF=3 MT=	2	Integral of nuclear plus interference components of the elastic scattering cross section
MT=	5	Sum of binary (n,n') and (n,x) reactions
MF=6 MT=	2	Elastic angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
MT=	5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + W, n + Ta, p + Ta, and p + W reactions (Ch96a). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Coupled-channels and spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A coupled-channels neutron optical model potential based on earlier work to 100 MeV (Yo90) is utilized to 80 MeV, and the global spherical optical model potential of Madland (Ma88) is used at higher energies. For protons, the Beccetti-Greenlees potential (Be69) is utilized below 20 MeV, and the Madland Semmering potential (Ma88) at higher energies. The Perey potential (Pe63) is used for deuterons, and the Beccetti-Greenlees potential (Be71) for tritons. The ECIS79 code (Ra72) was used for the coupled-channels optical model calculations, and the SCAT2 code (Be92) was utilized for the spherical optical model calculations. Minor normalizations were made to the reaction cross sections and transmission coefficients to produce

agreement with the (sparse) measurements for W and values inferred from systematics of proton and neutron reaction cross sections from measurements on other targets. The same reaction cross sections are used for both proton- and neutron-induced reactions on W isotopes.

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96b). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. Note that all other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation requires a modification of the original ENDF-6 format, i.e., we use LCT=3 with LAW 1 to indicate that data for the heavy recoils are in the lab system but all other reactions are in the cm system.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed above. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

MT=2 elastic scattering data in MF=3 and MF=6 are based on optical model calculations with the SCAT2 code (Be92). We have made use of the "nuclear-plus-interference" option in MF=6, which corresponds to LAW=5, LTP=12, and the appropriate integrated cross section is stored in MF=3. Note that because of the interference effect, the tabulations in both MF=6 and MF=3 can be negative at some energies and angles.

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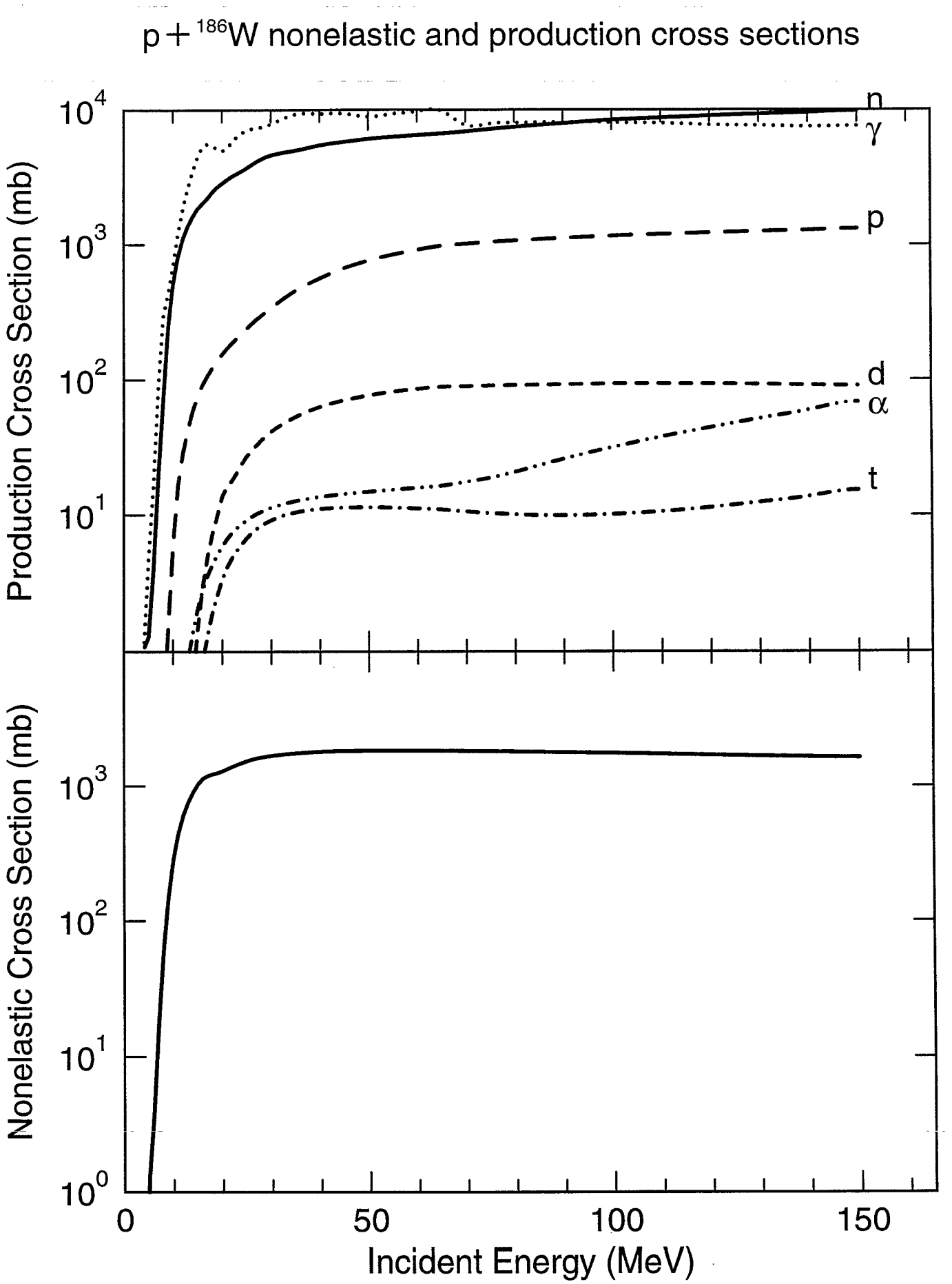
74186 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
3.000E+00	1.000E-20	0.000E+00	1.000E-20	1.000E-20	0.000E+00	0.000E+00	0.000E+00	1.000E-20	1.000E-20
4.000E+00	1.689E-05	0.000E+00	1.645E-05	9.521E-13	0.000E+00	0.000E+00	0.000E+00	3.831E-07	4.946E-05
5.000E+00	1.289E-03	0.000E+00	1.284E-03	1.758E-09	0.000E+00	0.000E+00	0.000E+00	7.398E-07	4.675E-03
6.000E+00	3.940E-03	0.000E+00	3.925E-03	1.020E-06	0.000E+00	0.000E+00	0.000E+00	2.887E-06	1.608E-02
7.000E+00	1.915E-02	0.000E+00	1.908E-02	1.847E-05	0.000E+00	0.000E+00	0.000E+00	7.533E-06	8.843E-02
8.000E+00	6.458E-02	0.000E+00	7.117E-02	2.419E-04	1.432E-12	1.530E-11	0.000E+00	1.945E-05	2.867E-01
9.000E+00	1.537E-01	0.000E+00	2.381E-01	1.527E-03	1.184E-09	6.821E-09	0.000E+00	4.690E-05	4.269E-01
1.000E+01	2.875E-01	0.000E+00	5.032E-01	6.033E-03	5.992E-07	4.078E-07	0.000E+00	1.107E-04	6.851E-01
1.100E+01	4.462E-01	0.000E+00	8.019E-01	1.644E-02	4.431E-06	2.016E-06	0.000E+00	2.416E-04	1.170E+00
1.200E+01	6.053E-01	0.000E+00	1.094E+00	2.858E-02	2.055E-05	1.084E-05	0.000E+00	4.772E-04	1.827E+00
1.300E+01	7.529E-01	0.000E+00	1.358E+00	4.276E-02	1.262E-04	4.940E-05	0.000E+00	8.553E-04	2.597E+00
1.400E+01	8.956E-01	0.000E+00	1.608E+00	5.877E-02	5.237E-04	1.643E-04	0.000E+00	1.383E-03	3.487E+00
1.500E+01	1.033E+00	0.000E+00	1.845E+00	7.528E-02	1.466E-03	4.118E-04	0.000E+00	2.046E-03	4.471E+00
1.600E+01	1.135E+00	0.000E+00	2.022E+00	9.147E-02	2.928E-03	7.997E-04	0.000E+00	2.798E-03	5.347E+00
1.700E+01	1.188E+00	0.000E+00	2.204E+00	1.069E-01	4.903E-03	1.313E-03	0.000E+00	3.578E-03	5.605E+00
1.800E+01	1.221E+00	0.000E+00	2.453E+00	1.216E-01	7.242E-03	1.913E-03	0.000E+00	4.345E-03	5.377E+00
1.900E+01	1.250E+00	0.000E+00	2.683E+00	1.367E-01	9.856E-03	2.581E-03	0.000E+00	5.110E-03	5.198E+00
2.000E+01	1.289E+00	0.000E+00	2.865E+00	1.538E-01	1.363E-02	3.371E-03	0.000E+00	5.913E-03	4.959E+00
2.200E+01	1.394E+00	0.000E+00	3.221E+00	1.853E-01	1.795E-02	4.822E-03	0.000E+00	7.374E-03	5.774E+00
2.400E+01	1.492E+00	0.000E+00	3.528E+00	2.177E-01	2.394E-02	6.142E-03	0.000E+00	8.613E-03	6.752E+00
2.600E+01	1.577E+00	0.000E+00	3.928E+00	2.570E-01	3.001E-02	7.347E-03	0.000E+00	9.710E-03	7.248E+00
2.800E+01	1.638E+00	0.000E+00	4.349E+00	2.958E-01	3.583E-02	8.353E-03	0.000E+00	1.059E-02	7.464E+00
3.000E+01	1.681E+00	0.000E+00	4.643E+00	3.383E-01	4.142E-02	9.172E-03	0.000E+00	1.132E-02	7.884E+00
3.500E+01	1.756E+00	0.000E+00	5.030E+00	4.547E-01	5.328E-02	1.046E-02	0.000E+00	1.269E-02	9.306E+00
4.000E+01	1.800E+00	0.000E+00	5.490E+00	5.650E-01	6.307E-02	1.109E-02	0.000E+00	1.365E-02	9.380E+00
4.500E+01	1.822E+00	0.000E+00	5.818E+00	6.718E-01	7.069E-02	1.136E-02	0.000E+00	1.433E-02	9.415E+00
5.000E+01	1.830E+00	0.000E+00	6.116E+00	7.644E-01	7.657E-02	1.140E-02	0.000E+00	1.488E-02	8.897E+00
5.500E+01	1.832E+00	0.000E+00	6.335E+00	8.458E-01	8.149E-02	1.131E-02	0.000E+00	1.540E-02	9.357E+00
6.000E+01	1.830E+00	0.000E+00	6.525E+00	9.180E-01	8.536E-02	1.115E-02	0.000E+00	1.591E-02	9.741E+00
6.500E+01	1.826E+00	0.000E+00	6.718E+00	9.814E-01	8.857E-02	1.094E-02	0.000E+00	1.647E-02	9.891E+00
7.000E+01	1.819E+00	0.000E+00	6.943E+00	1.015E+00	8.933E-02	1.058E-02	0.000E+00	1.757E-02	7.722E+00
7.500E+01	1.809E+00	0.000E+00	7.226E+00	1.046E+00	9.024E-02	1.029E-02	0.000E+00	1.889E-02	7.918E+00
8.000E+01	1.799E+00	0.000E+00	7.482E+00	1.072E+00	9.087E-02	1.008E-02	0.000E+00	2.085E-02	8.010E+00
8.500E+01	1.788E+00	0.000E+00	7.734E+00	1.096E+00	9.143E-02	9.964E-03	0.000E+00	2.337E-02	8.122E+00
9.000E+01	1.778E+00	0.000E+00	7.966E+00	1.120E+00	9.208E-02	9.933E-03	0.000E+00	2.599E-02	8.111E+00
9.500E+01	1.768E+00	0.000E+00	8.210E+00	1.141E+00	9.256E-02	9.996E-03	0.000E+00	2.887E-02	8.127E+00
1.000E+02	1.756E+00	0.000E+00	8.419E+00	1.162E+00	9.318E-02	1.013E-02	0.000E+00	3.173E-02	8.049E+00
1.100E+02	1.727E+00	0.000E+00	8.755E+00	1.196E+00	9.318E-02	1.060E-02	0.000E+00	3.785E-02	7.992E+00
1.200E+02	1.699E+00	0.000E+00	9.055E+00	1.226E+00	9.277E-02	1.137E-02	0.000E+00	4.445E-02	7.747E+00
1.300E+02	1.672E+00	0.000E+00	9.330E+00	1.254E+00	9.202E-02	1.244E-02	0.000E+00	5.159E-02	7.662E+00
1.400E+02	1.648E+00	0.000E+00	9.590E+00	1.283E+00	9.095E-02	1.374E-02	0.000E+00	5.954E-02	7.546E+00
1.500E+02	1.631E+00	0.000E+00	9.848E+00	1.315E+00	8.981E-02	1.528E-02	0.000E+00	6.829E-02	7.610E+00

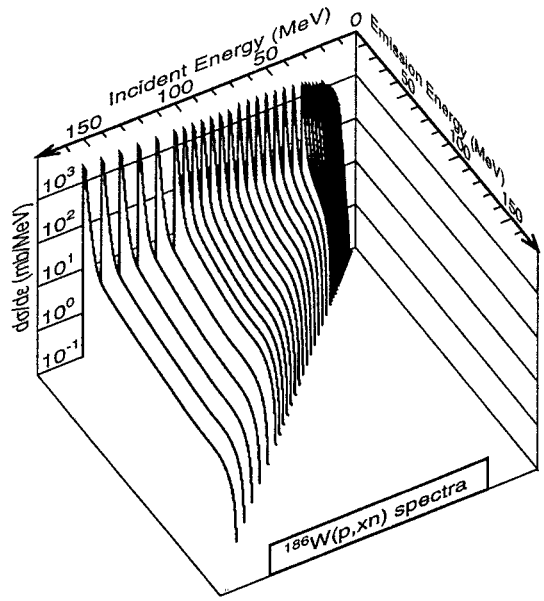
74186 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

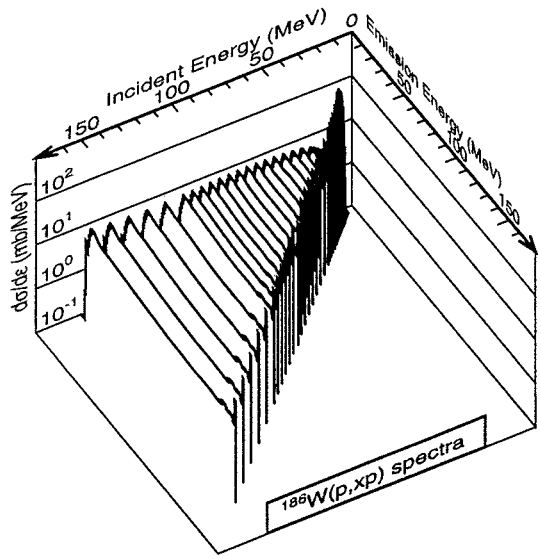
Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
3.000E+00	1.232E+00	8.721E-05	0.000E+00	0.000E+00	0.000E+00	9.447E+00	3.132E-01
4.000E+00	1.062E+00	3.586E+00	0.000E+00	0.000E+00	0.000E+00	1.049E+01	5.330E-01
5.000E+00	1.159E+00	4.536E+00	0.000E+00	0.000E+00	0.000E+00	1.115E+01	7.001E-01
6.000E+00	1.198E+00	5.710E+00	0.000E+00	0.000E+00	0.000E+00	1.217E+01	8.597E-01
7.000E+00	1.218E+00	6.699E+00	0.000E+00	0.000E+00	0.000E+00	1.284E+01	9.765E-01
8.000E+00	1.168E+00	7.682E+00	2.565E+00	3.338E+00	0.000E+00	1.371E+01	1.077E+00
9.000E+00	1.057E+00	8.657E+00	3.601E+00	4.051E+00	0.000E+00	1.451E+01	9.112E-01
1.000E+01	1.155E+00	9.619E+00	4.611E+00	4.742E+00	0.000E+00	1.530E+01	7.055E-01
1.100E+01	1.278E+00	1.056E+01	5.329E+00	5.337E+00	0.000E+00	1.609E+01	6.947E-01
1.200E+01	1.379E+00	1.146E+01	6.294E+00	6.375E+00	0.000E+00	1.682E+01	7.747E-01
1.300E+01	1.463E+00	1.230E+01	7.275E+00	7.238E+00	0.000E+00	1.750E+01	8.649E-01
1.400E+01	1.547E+00	1.308E+01	8.164E+00	8.033E+00	0.000E+00	1.812E+01	9.379E-01
1.500E+01	1.640E+00	1.380E+01	8.985E+00	8.747E+00	0.000E+00	1.869E+01	1.000E+00
1.600E+01	1.740E+00	1.446E+01	9.732E+00	9.384E+00	0.000E+00	1.922E+01	1.040E+00
1.700E+01	1.779E+00	1.510E+01	1.048E+01	9.985E+00	0.000E+00	1.973E+01	1.021E+00
1.800E+01	1.779E+00	1.572E+01	1.121E+01	1.056E+01	0.000E+00	2.023E+01	9.183E-01
1.900E+01	1.810E+00	1.631E+01	1.193E+01	1.111E+01	0.000E+00	2.071E+01	7.989E-01
2.000E+01	1.869E+00	1.699E+01	1.273E+01	1.169E+01	0.000E+00	2.119E+01	8.545E-01
2.200E+01	2.033E+00	1.805E+01	1.387E+01	1.274E+01	0.000E+00	2.212E+01	8.437E-01
2.400E+01	2.186E+00	1.880E+01	1.520E+01	1.376E+01	0.000E+00	2.302E+01	9.046E-01
2.600E+01	2.286E+00	1.963E+01	1.651E+01	1.477E+01	0.000E+00	2.390E+01	9.025E-01
2.800E+01	2.376E+00	2.038E+01	1.780E+01	1.576E+01	0.000E+00	2.476E+01	8.445E-01
3.000E+01	2.503E+00	2.115E+01	1.909E+01	1.672E+01	0.000E+00	2.561E+01	8.141E-01
3.500E+01	2.899E+00	2.327E+01	2.229E+01	1.899E+01	0.000E+00	2.762E+01	8.928E-01

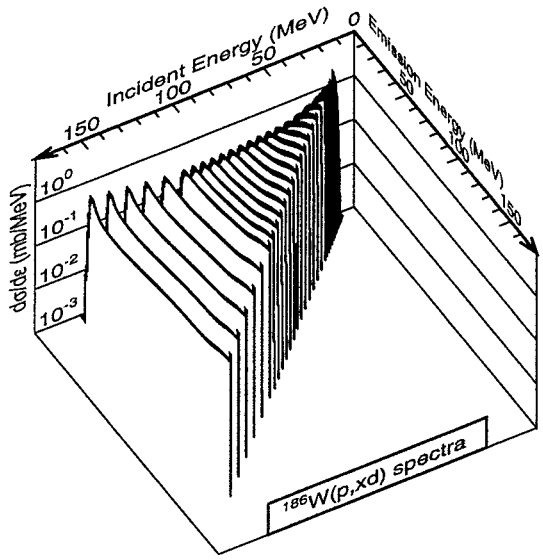
4.000E+01	3.201E+00	2.556E+01	2.560E+01	2.124E+01	0.000E+00	2.950E+01	8.622E-01
4.500E+01	3.519E+00	2.800E+01	2.890E+01	2.349E+01	0.000E+00	3.127E+01	8.435E-01
5.000E+01	3.801E+00	3.038E+01	3.213E+01	2.573E+01	0.000E+00	3.291E+01	8.642E-01
5.500E+01	4.088E+00	3.275E+01	3.533E+01	2.795E+01	0.000E+00	3.439E+01	8.690E-01
6.000E+01	4.369E+00	3.507E+01	3.845E+01	3.012E+01	0.000E+00	3.571E+01	8.727E-01
6.500E+01	4.631E+00	3.732E+01	4.153E+01	3.226E+01	0.000E+00	3.682E+01	8.741E-01
7.000E+01	4.849E+00	3.964E+01	4.454E+01	3.415E+01	0.000E+00	3.677E+01	1.142E+00
7.500E+01	5.004E+00	4.178E+01	4.758E+01	3.587E+01	0.000E+00	3.644E+01	1.131E+00
8.000E+01	5.164E+00	4.395E+01	5.058E+01	3.734E+01	0.000E+00	3.541E+01	1.129E+00
8.500E+01	5.318E+00	4.609E+01	5.356E+01	3.853E+01	0.000E+00	3.405E+01	1.131E+00
9.000E+01	5.480E+00	4.819E+01	5.651E+01	3.944E+01	0.000E+00	3.291E+01	1.131E+00
9.500E+01	5.627E+00	5.018E+01	5.942E+01	3.997E+01	0.000E+00	3.187E+01	1.131E+00
1.000E+02	5.782E+00	5.222E+01	6.235E+01	4.022E+01	0.000E+00	3.102E+01	1.133E+00
1.100E+02	6.084E+00	5.631E+01	6.789E+01	3.975E+01	0.000E+00	2.952E+01	1.138E+00
1.200E+02	6.390E+00	6.020E+01	7.310E+01	3.826E+01	0.000E+00	2.837E+01	1.153E+00
1.300E+02	6.698E+00	6.386E+01	7.794E+01	3.614E+01	0.000E+00	2.743E+01	1.161E+00
1.400E+02	7.012E+00	6.728E+01	8.239E+01	3.379E+01	0.000E+00	2.658E+01	1.169E+00
1.500E+02	7.335E+00	7.055E+01	8.650E+01	3.145E+01	0.000E+00	2.586E+01	1.180E+00

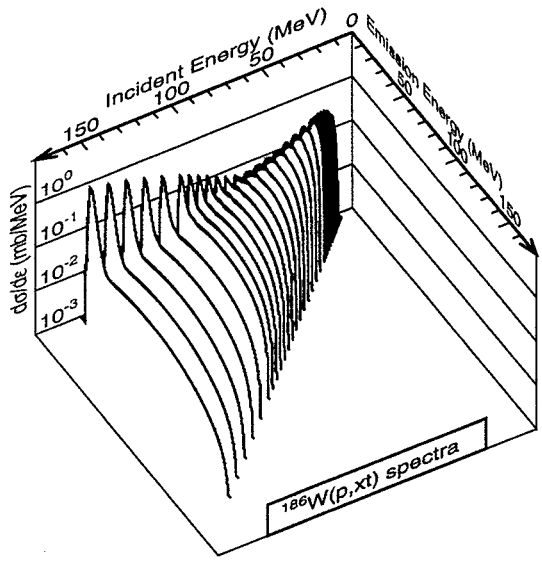

p + 186W nonelastic and production cross sections
Production Cross Section (mb)
Nonelastic Cross Section (mb)
Incident Energy (MeV)
n
γ
p
d
α
t
10^4
10^3
10^2
10^1
10^0
0
50
100
150

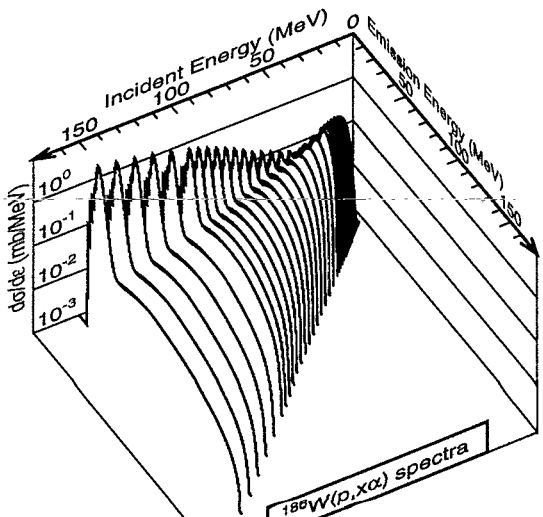
p + ^{186}W angle-integrated emission spectra

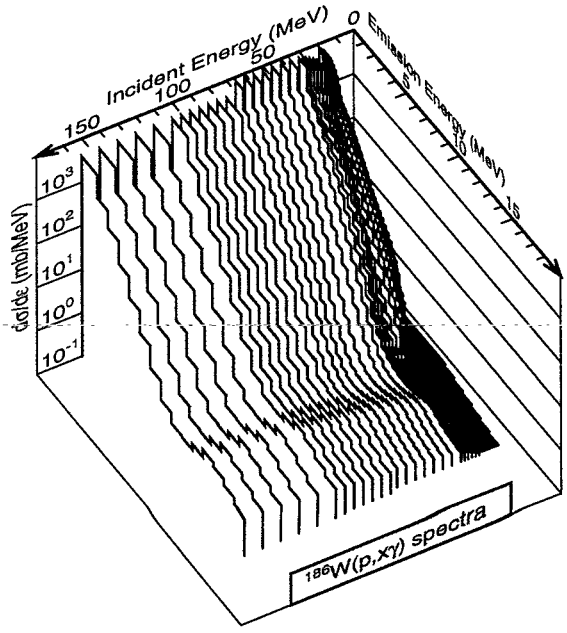




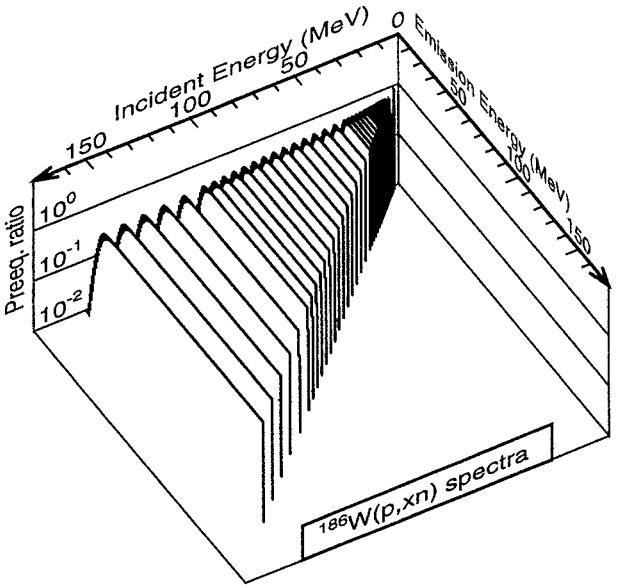


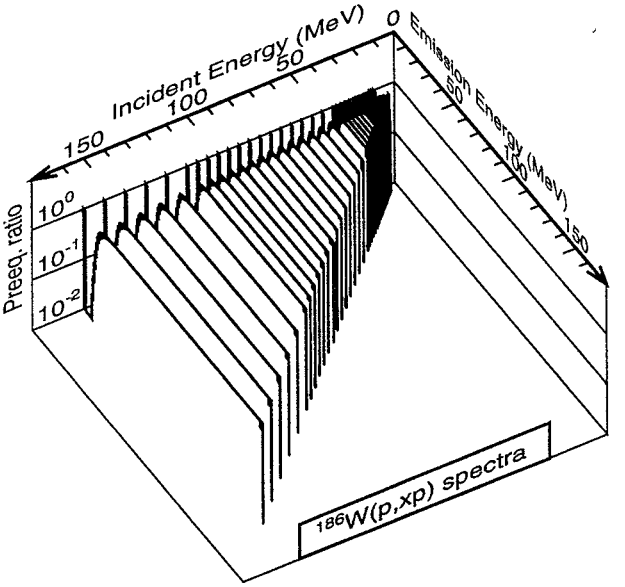


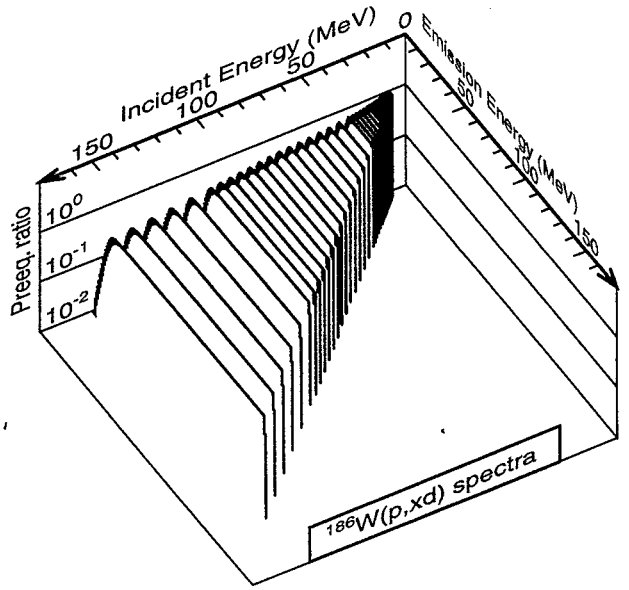


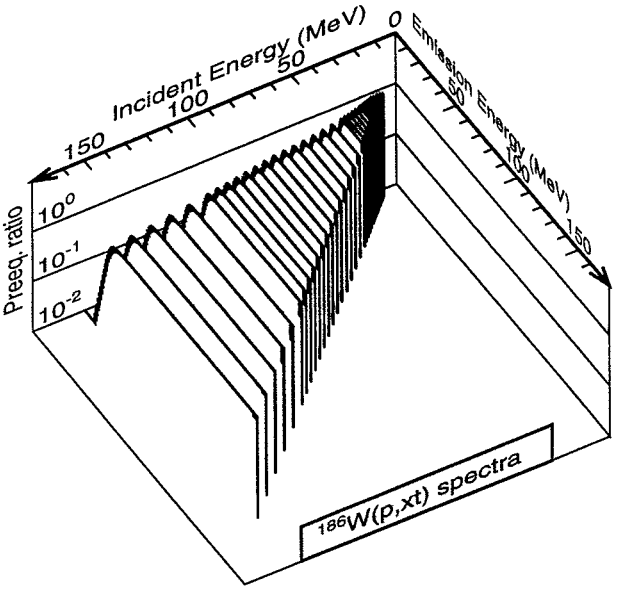


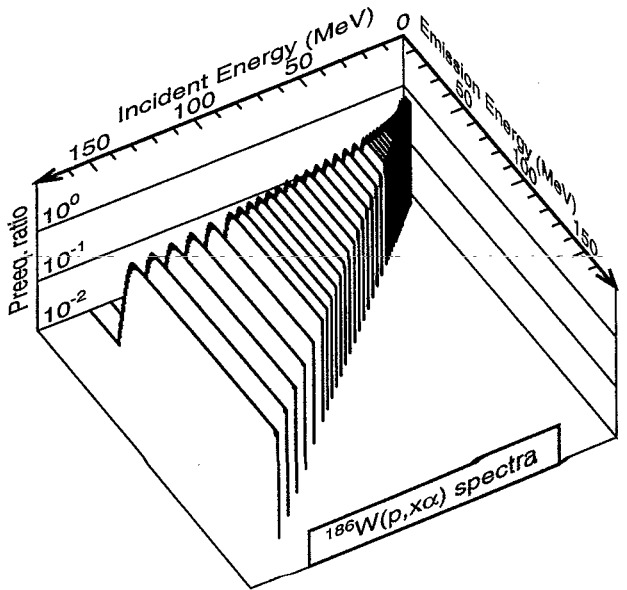
p + ^{186}W Kalbach preequilibrium ratios

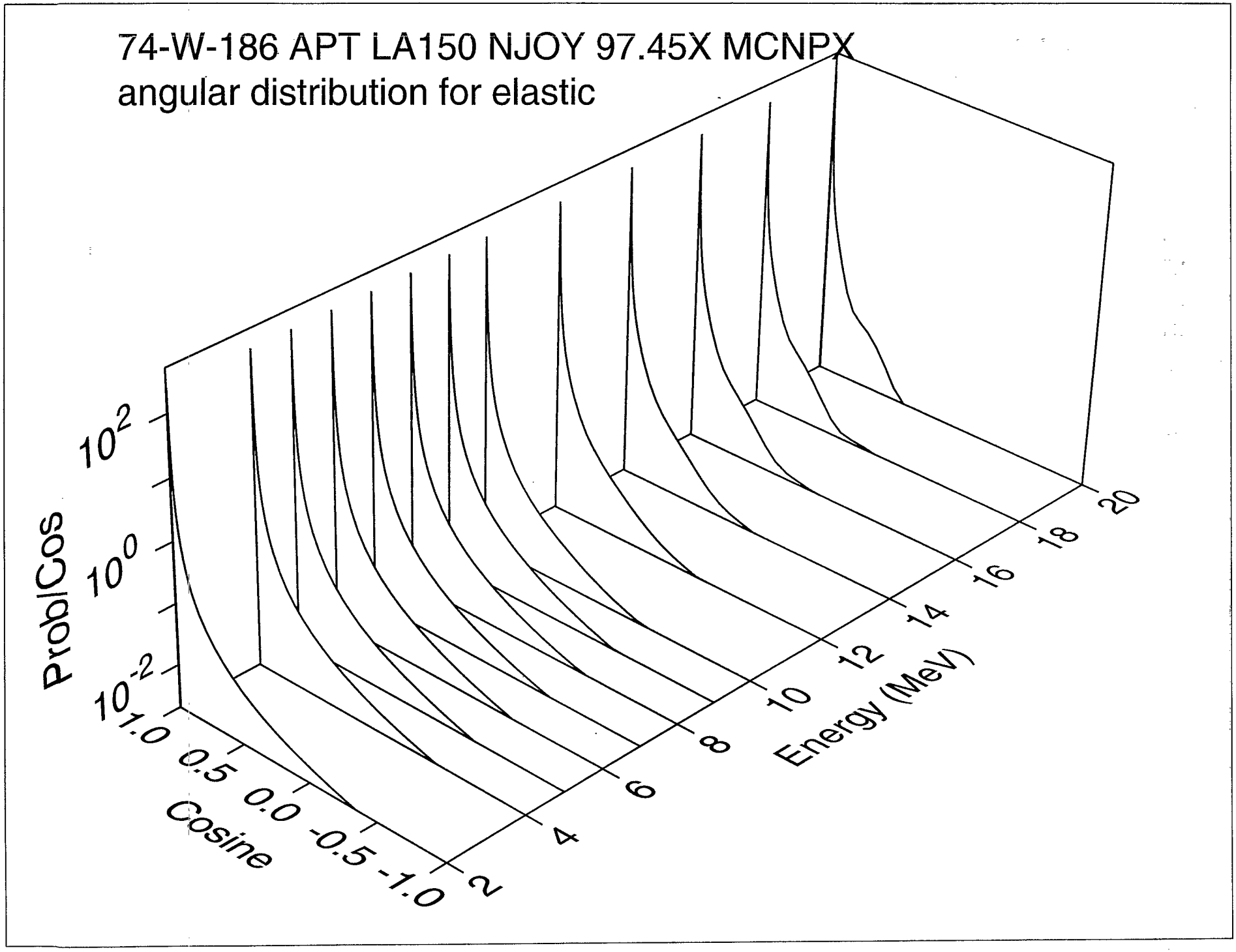


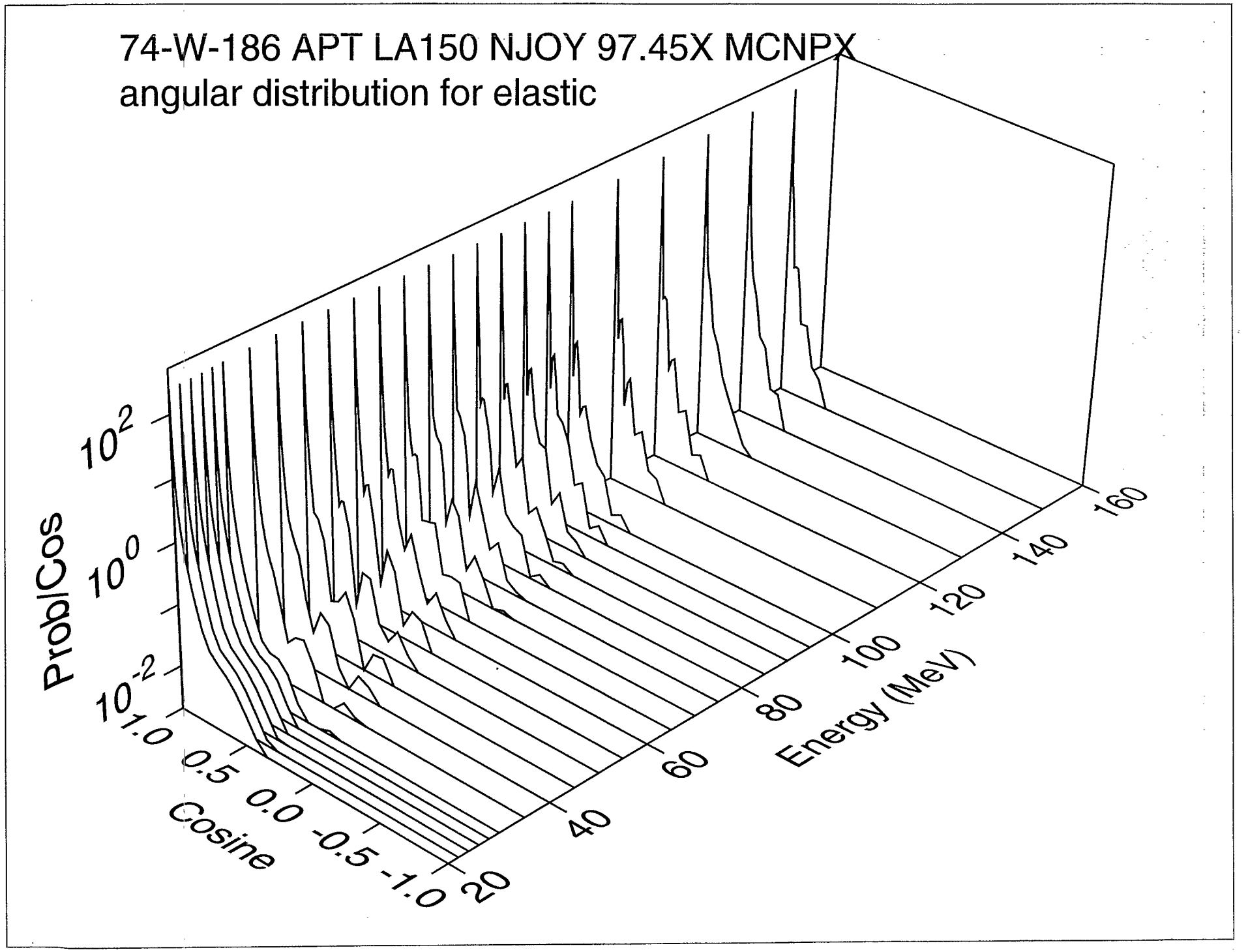


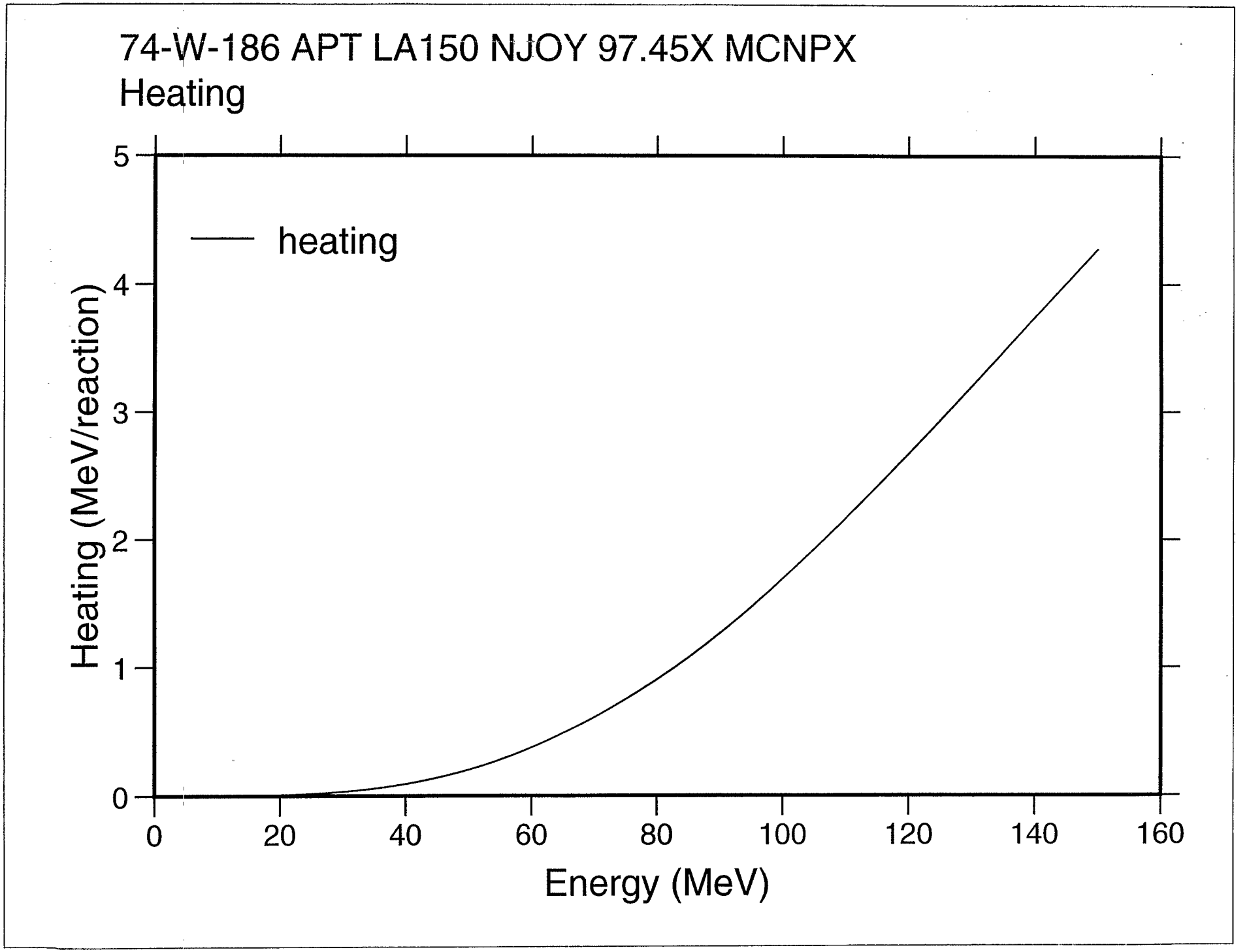







74-W-186 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
10^{-2}
1.0
0.5
0.0
-0.5
-1.0
Cosine
2
4
6
8
10
12
14
16
18
20
Energy (MeV)


74-W-186 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
20
40
60
80
100
120
140
160


74-W-186 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
1
2
3
4
5
0
20
40
60
80
100
120
140
160

EVALUATION OF p + 206Pb CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

M. B. Chadwick, P. G. Young, and A. J. Koning

21 October 1996

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV.

The evaluation utilizes MF = 3 [MT=2 and MT=5] and MF=6 [MT=2 and MT=5] to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced with non-negligible cross sections (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data are:

MF=3	MT= 2	Integral of nuclear plus interference components of the elastic scattering cross section
	MT= 5	Sum of binary (n,n') and (n,x) reactions
MF=6	MT= 2	Elastic angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
	MT= 5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Pb and p + Pb208 reactions (Ch96a). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Coupled-channel and spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96b). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. Note that all other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation requires a modification of the original ENDF-6 format.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities

using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

MT=2 elastic scattering data in MF=3 and MF=6 are based on optical model calculations with the SCAT2 code (Be92). We have made use of the "nuclear-plus-interference" option in MF=6, which corresponds to LAW=5, LTP=12, and the appropriate integrated cross section is stored in MF=3. Note that because of the interference effect, the tabulations in both MF=6 and MF=3 can be negative at some energies and angles.

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of Continuum Angular Distributions. I. Systematics and Parameterization," Phys.Rev.C 23, 112 (1981).

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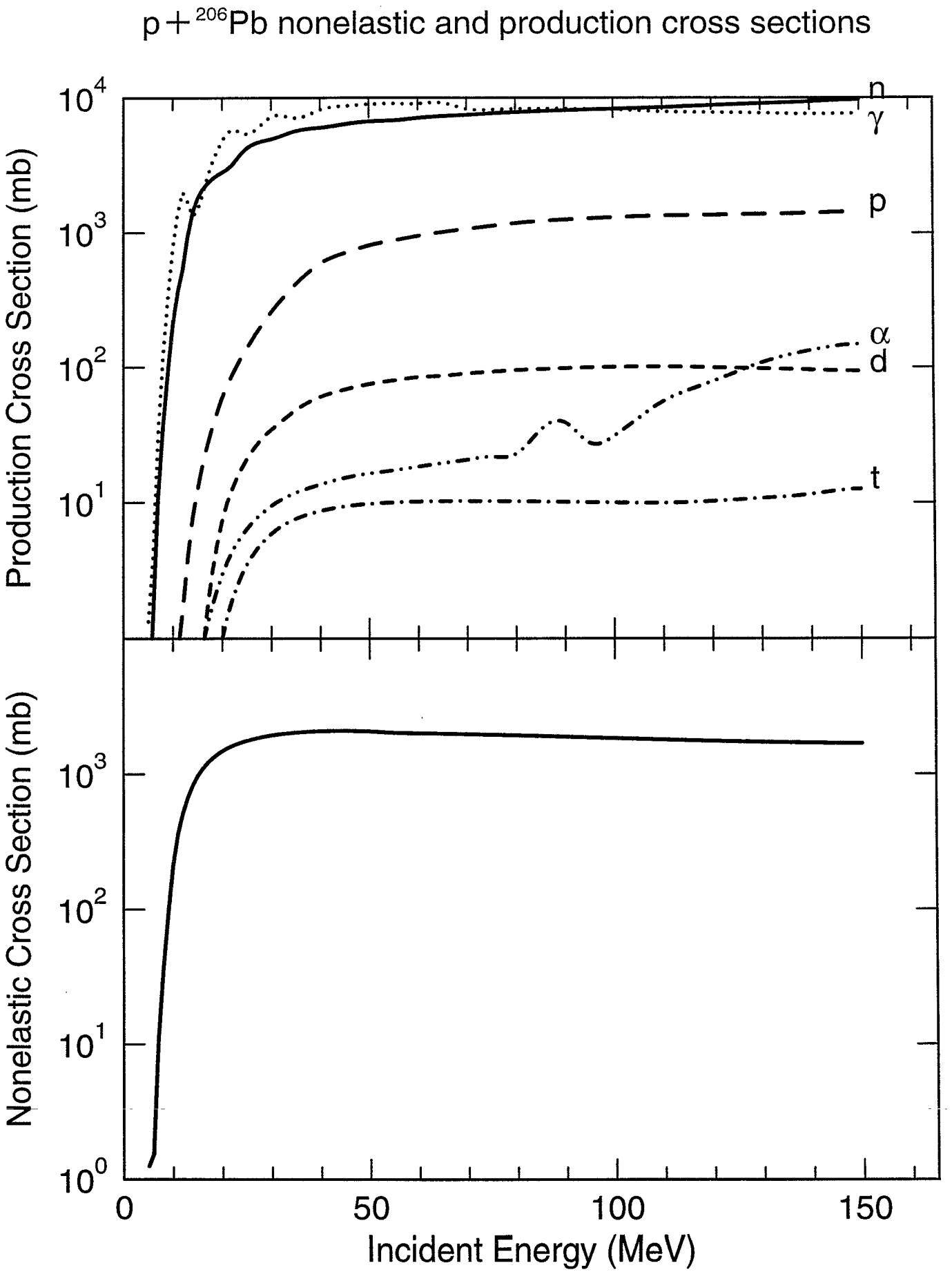
82206 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
4.000E+00	1.000E-20	0.000E+00	0.000E+00	1.000E-20	0.000E+00	0.000E+00	0.000E+00	1.000E-20	1.000E-20
5.000E+00	5.125E-04	0.000E+00	4.884E-04	2.694E-07	0.000E+00	0.000E+00	0.000E+00	5.386E-08	9.740E-04
6.000E+00	1.524E-03	0.000E+00	1.517E-03	8.666E-07	0.000E+00	0.000E+00	0.000E+00	7.129E-08	3.935E-03
7.000E+00	1.104E-02	0.000E+00	1.100E-02	6.818E-06	0.000E+00	0.000E+00	0.000E+00	5.111E-07	3.150E-02
8.000E+00	3.672E-02	0.000E+00	3.657E-02	3.801E-05	1.931E-08	0.000E+00	0.000E+00	3.315E-06	1.191E-01
9.000E+00	9.410E-02	0.000E+00	9.366E-02	1.525E-04	1.588E-08	0.000E+00	0.000E+00	1.479E-05	3.260E-01
1.000E+01	2.107E-01	0.000E+00	2.097E-01	4.003E-04	1.657E-08	2.555E-08	0.000E+00	4.752E-05	7.697E-01
1.100E+01	3.644E-01	0.000E+00	3.626E-01	8.180E-04	2.750E-07	3.426E-08	0.000E+00	9.547E-05	1.397E+00
1.200E+01	5.192E-01	0.000E+00	5.360E-01	1.634E-03	1.065E-06	1.084E-07	0.000E+00	1.735E-04	1.998E+00
1.300E+01	6.749E-01	0.000E+00	9.313E-01	3.880E-03	6.967E-06	3.803E-07	0.000E+00	2.879E-04	1.706E+00
1.400E+01	8.304E-01	0.000E+00	1.402E+00	7.703E-03	4.707E-05	1.997E-06	0.000E+00	4.182E-04	1.332E+00
1.500E+01	9.732E-01	0.000E+00	1.786E+00	1.247E-02	2.295E-04	1.096E-05	0.000E+00	6.084E-04	1.455E+00
1.600E+01	1.097E+00	0.000E+00	2.073E+00	1.882E-02	7.243E-04	4.771E-05	0.000E+00	8.890E-04	1.889E+00
1.700E+01	1.211E+00	0.000E+00	2.305E+00	2.663E-02	1.652E-03	1.442E-04	0.000E+00	1.271E-03	2.541E+00
1.800E+01	1.312E+00	0.000E+00	2.496E+00	3.591E-02	3.090E-03	3.254E-04	0.000E+00	1.748E-03	3.268E+00
1.900E+01	1.403E+00	0.000E+00	2.658E+00	4.670E-02	4.968E-03	6.004E-04	0.000E+00	2.308E-03	4.024E+00
2.000E+01	1.485E+00	0.000E+00	2.793E+00	5.988E-02	7.356E-03	9.943E-04	0.000E+00	2.942E-03	4.764E+00
2.200E+01	1.619E+00	0.000E+00	3.151E+00	8.747E-02	1.252E-02	1.911E-03	0.000E+00	4.357E-03	5.819E+00
2.400E+01	1.724E+00	0.000E+00	3.889E+00	1.201E-01	1.807E-02	2.943E-03	0.000E+00	5.722E-03	5.460E+00
2.600E+01	1.809E+00	0.000E+00	4.450E+00	1.586E-01	2.379E-02	3.991E-03	0.000E+00	7.046E-03	5.514E+00
2.800E+01	1.881E+00	0.000E+00	4.738E+00	2.049E-01	2.961E-02	4.990E-03	0.000E+00	8.306E-03	6.308E+00
3.000E+01	1.939E+00	0.000E+00	4.918E+00	2.581E-01	3.455E-02	5.901E-03	0.000E+00	9.462E-03	7.219E+00
3.500E+01	2.033E+00	0.000E+00	5.677E+00	4.173E-01	4.837E-02	7.616E-03	0.000E+00	1.189E-02	7.054E+00
4.000E+01	2.081E+00	0.000E+00	6.004E+00	5.937E-01	6.064E-02	8.707E-03	0.000E+00	1.367E-02	8.138E+00
4.500E+01	2.091E+00	0.000E+00	6.361E+00	7.113E-01	6.885E-02	9.385E-03	0.000E+00	1.528E-02	8.686E+00
5.000E+01	2.071E+00	0.000E+00	6.666E+00	8.082E-01	7.523E-02	9.796E-03	0.000E+00	1.647E-02	8.949E+00
5.500E+01	2.023E+00	0.000E+00	6.789E+00	8.809E-01	8.008E-02	1.002E-02	0.000E+00	1.741E-02	9.072E+00
6.000E+01	2.008E+00	0.000E+00	7.071E+00	9.528E-01	8.453E-02	1.017E-02	0.000E+00	1.852E-02	9.054E+00
6.500E+01	1.991E+00	0.000E+00	7.298E+00	1.018E+00	8.651E-02	1.023E-02	0.000E+00	1.965E-02	9.185E+00
7.000E+01	1.973E+00	0.000E+00	7.457E+00	1.075E+00	9.005E-02	1.025E-02	0.000E+00	2.077E-02	8.251E+00
7.500E+01	1.954E+00	0.000E+00	7.653E+00	1.130E+00	9.276E-02	1.022E-02	0.000E+00	2.182E-02	8.141E+00
8.000E+01	1.934E+00	0.000E+00	7.806E+00	1.185E+00	9.521E-02	1.020E-02	0.000E+00	2.290E-02	8.250E+00
8.500E+01	1.911E+00	0.000E+00	7.945E+00	1.227E+00	9.676E-02	1.016E-02	0.000E+00	3.444E-02	8.291E+00
9.000E+01	1.888E+00	0.000E+00	8.064E+00	1.259E+00	9.838E-02	1.010E-02	0.000E+00	3.931E-02	8.277E+00
9.500E+01	1.865E+00	0.000E+00	8.175E+00	1.285E+00	9.968E-02	1.005E-02	0.000E+00	2.773E-02	8.256E+00
1.000E+02	1.842E+00	0.000E+00	8.278E+00	1.309E+00	1.006E-01	9.990E-03	0.000E+00	3.101E-02	8.176E+00
1.100E+02	1.798E+00	0.000E+00	8.496E+00	1.345E+00	1.011E-01	9.942E-03	0.000E+00	5.582E-02	7.885E+00
1.200E+02	1.759E+00	0.000E+00	8.809E+00	1.363E+00	9.962E-02	1.025E-02	0.000E+00	7.820E-02	7.775E+00
1.300E+02	1.728E+00	0.000E+00	9.103E+00	1.383E+00	9.780E-02	1.081E-02	0.000E+00	1.079E-01	7.689E+00
1.400E+02	1.704E+00	0.000E+00	9.399E+00	1.407E+00	9.583E-02	1.161E-02	0.000E+00	1.337E-01	7.583E+00
1.500E+02	1.688E+00	0.000E+00	9.705E+00	1.439E+00	9.381E-02	1.266E-02	0.000E+00	1.487E-01	7.637E+00

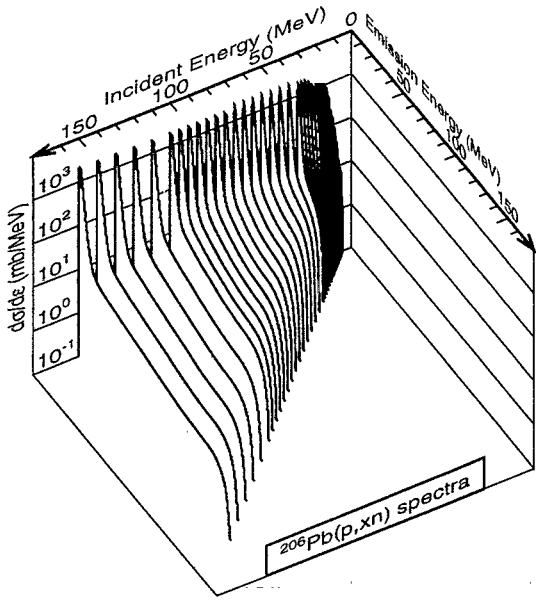
82206 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

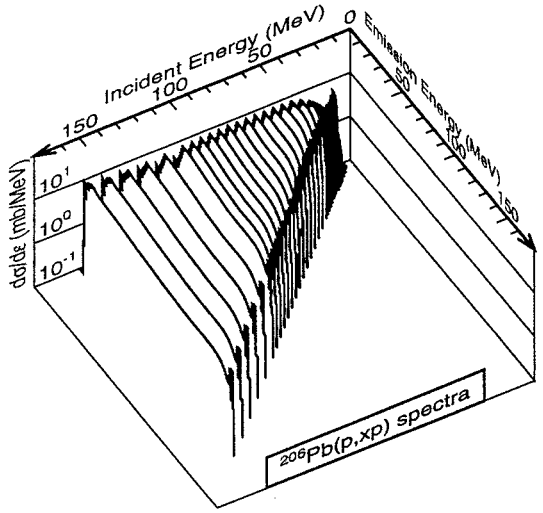
Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
4.000E+00	0.000E+00	3.191E+00	0.000E+00	0.000E+00	0.000E+00	1.043E+01	3.663E+00
5.000E+00	2.290E-01	4.142E+00	0.000E+00	0.000E+00	0.000E+00	1.086E+01	2.875E-01
6.000E+00	8.766E-01	4.937E+00	0.000E+00	0.000E+00	0.000E+00	1.168E+01	2.799E-01
7.000E+00	1.370E+00	5.533E+00	0.000E+00	0.000E+00	0.000E+00	1.239E+01	4.253E-01
8.000E+00	1.588E+00	6.514E+00	1.990E+00	0.000E+00	0.000E+00	1.325E+01	6.135E-01
9.000E+00	1.630E+00	7.342E+00	2.984E+00	0.000E+00	0.000E+00	1.402E+01	8.482E-01
1.000E+01	1.670E+00	8.038E+00	3.974E+00	3.468E+00	0.000E+00	1.454E+01	1.065E+00
1.100E+01	1.640E+00	8.604E+00	4.737E+00	4.448E+00	0.000E+00	1.500E+01	1.282E+00
1.200E+01	1.561E+00	8.978E+00	5.402E+00	5.003E+00	0.000E+00	1.545E+01	1.468E+00
1.300E+01	1.302E+00	9.035E+00	6.506E+00	5.461E+00	0.000E+00	1.609E+01	1.536E+00
1.400E+01	1.268E+00	9.869E+00	7.456E+00	6.558E+00	0.000E+00	1.707E+01	1.393E+00
1.500E+01	1.366E+00	1.081E+01	8.356E+00	7.492E+00	0.000E+00	1.789E+01	1.166E+00
1.600E+01	1.493E+00	1.156E+01	9.169E+00	8.322E+00	0.000E+00	1.858E+01	1.138E+00
1.700E+01	1.598E+00	1.224E+01	9.954E+00	9.019E+00	0.000E+00	1.921E+01	1.207E+00
1.800E+01	1.685E+00	1.286E+01	1.073E+01	9.684E+00	0.000E+00	1.978E+01	1.310E+00
1.900E+01	1.753E+00	1.346E+01	1.148E+01	1.033E+01	0.000E+00	2.031E+01	1.417E+00
2.000E+01	1.811E+00	1.411E+01	1.224E+01	1.094E+01	0.000E+00	2.080E+01	1.558E+00
2.200E+01	1.886E+00	1.482E+01	1.365E+01	1.210E+01	0.000E+00	2.157E+01	1.622E+00
2.400E+01	1.887E+00	1.576E+01	1.502E+01	1.318E+01	0.000E+00	2.249E+01	1.350E+00
2.600E+01	1.974E+00	1.665E+01	1.631E+01	1.421E+01	0.000E+00	2.336E+01	1.144E+00
2.800E+01	2.101E+00	1.752E+01	1.763E+01	1.522E+01	0.000E+00	2.416E+01	1.181E+00
3.000E+01	2.244E+00	1.839E+01	1.881E+01	1.621E+01	0.000E+00	2.493E+01	1.286E+00
3.500E+01	2.521E+00	2.059E+01	2.204E+01	1.852E+01	0.000E+00	2.673E+01	1.298E+00
4.000E+01	2.936E+00	2.291E+01	2.530E+01	2.075E+01	0.000E+00	2.847E+01	1.261E+00
4.500E+01	3.230E+00	2.517E+01	2.858E+01	2.296E+01	0.000E+00	2.986E+01	1.238E+00

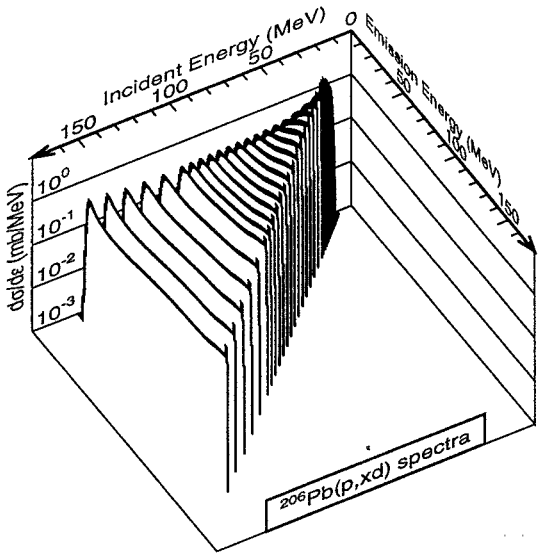
5.000E+01	3.504E+00	2.742E+01	3.179E+01	2.514E+01	0.000E+00	3.126E+01	1.143E+00
5.500E+01	3.791E+00	2.962E+01	3.494E+01	2.727E+01	0.000E+00	3.244E+01	1.148E+00
6.000E+01	4.037E+00	3.164E+01	3.804E+01	2.930E+01	0.000E+00	3.347E+01	1.141E+00
6.500E+01	4.297E+00	3.357E+01	4.077E+01	3.125E+01	0.000E+00	3.428E+01	1.148E+00
7.000E+01	4.573E+00	3.550E+01	4.383E+01	3.306E+01	0.000E+00	3.494E+01	1.264E+00
7.500E+01	4.817E+00	3.728E+01	4.683E+01	3.480E+01	0.000E+00	3.542E+01	1.267E+00
8.000E+01	5.065E+00	3.890E+01	4.981E+01	3.646E+01	0.000E+00	3.569E+01	1.266E+00
8.500E+01	5.301E+00	4.072E+01	5.268E+01	3.799E+01	0.000E+00	2.675E+01	1.264E+00
9.000E+01	5.533E+00	4.267E+01	5.564E+01	3.941E+01	0.000E+00	2.503E+01	1.272E+00
9.500E+01	5.757E+00	4.468E+01	5.857E+01	4.069E+01	0.000E+00	3.418E+01	1.271E+00
1.000E+02	5.975E+00	4.661E+01	6.146E+01	4.182E+01	0.000E+00	3.221E+01	1.267E+00
1.100E+02	6.375E+00	5.038E+01	6.707E+01	4.328E+01	0.000E+00	2.199E+01	1.283E+00
1.200E+02	6.673E+00	5.398E+01	7.232E+01	4.272E+01	0.000E+00	1.913E+01	1.289E+00
1.300E+02	6.978E+00	5.751E+01	7.720E+01	4.117E+01	0.000E+00	1.659E+01	1.291E+00
1.400E+02	7.285E+00	6.093E+01	8.179E+01	3.898E+01	0.000E+00	1.568E+01	1.281E+00
1.500E+02	7.595E+00	6.418E+01	8.602E+01	3.648E+01	0.000E+00	1.584E+01	1.282E+00

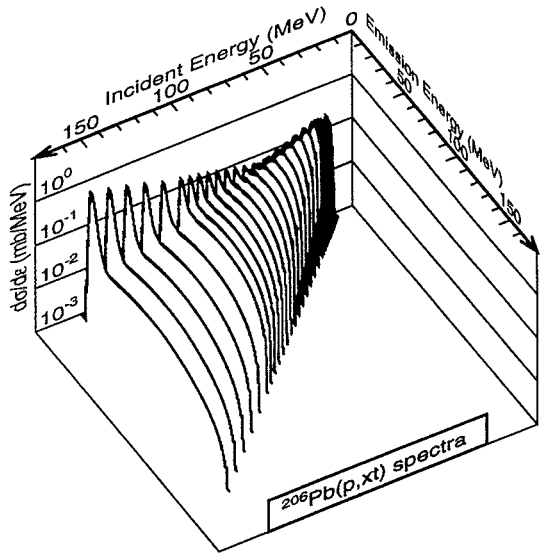

p + 206Pb nonelastic and production cross sections
Production Cross Section (mb)
Nonelastic Cross Section (mb)
Incident Energy (MeV)
n
γ
p
α
d
t
10^4
10^3
10^2
10^1
10^0
0
50
100
150

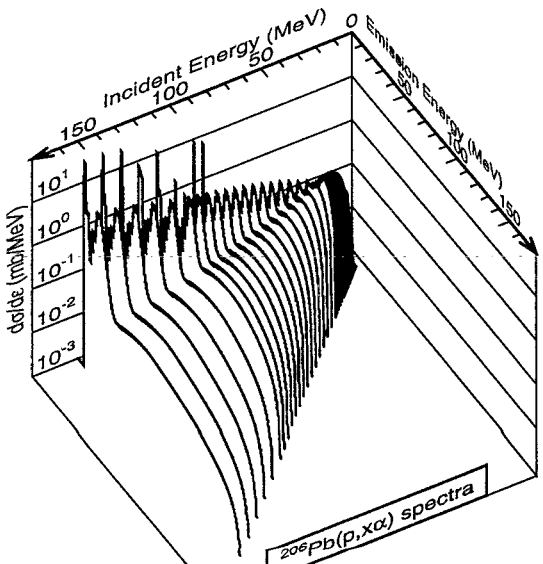
p + ^{206}Pb angle-integrated emission spectra

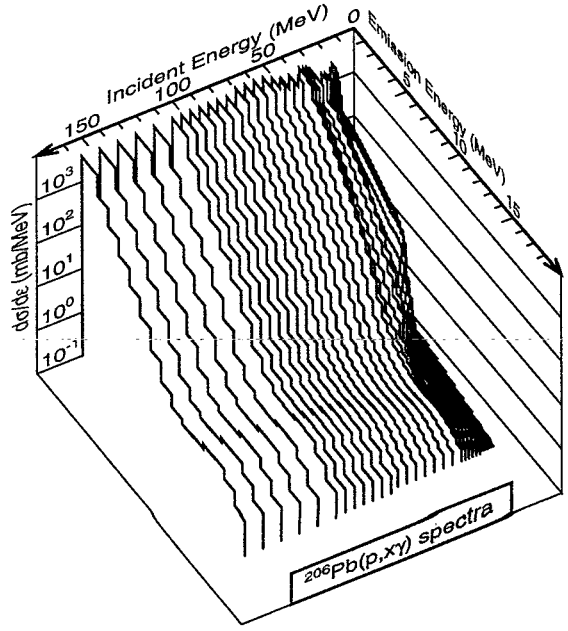




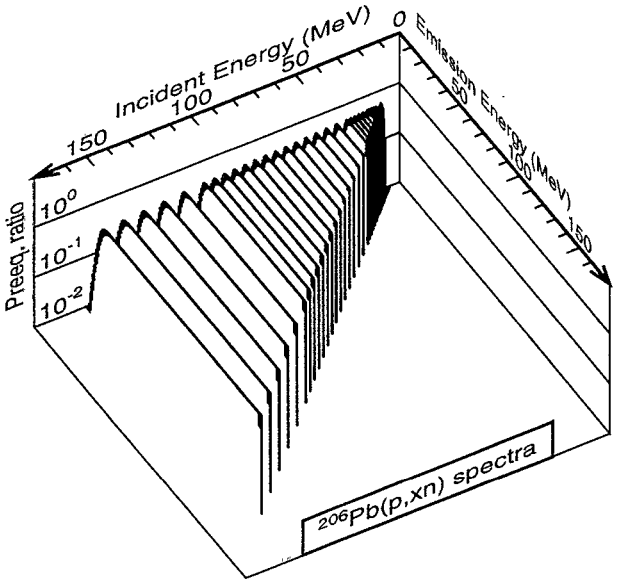


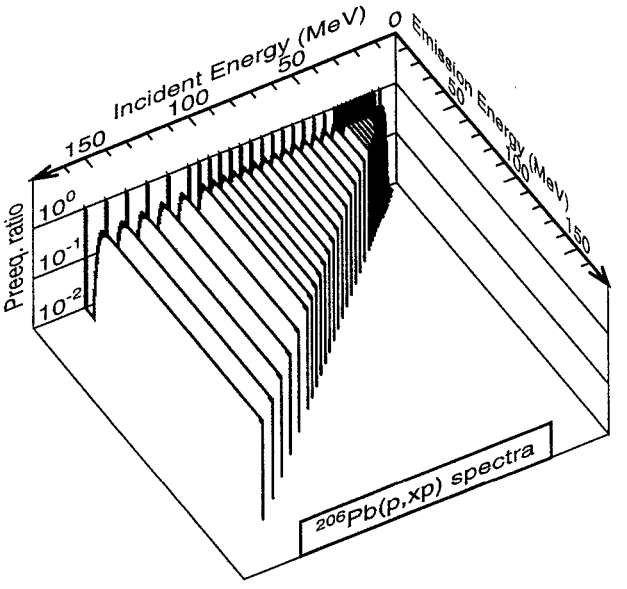


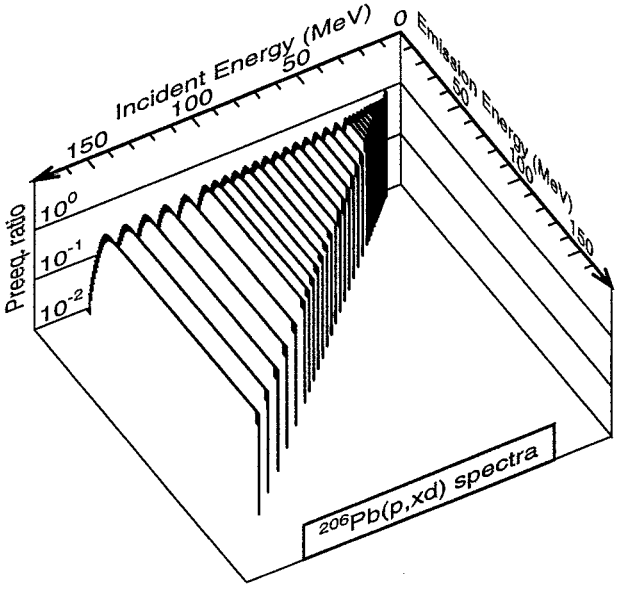


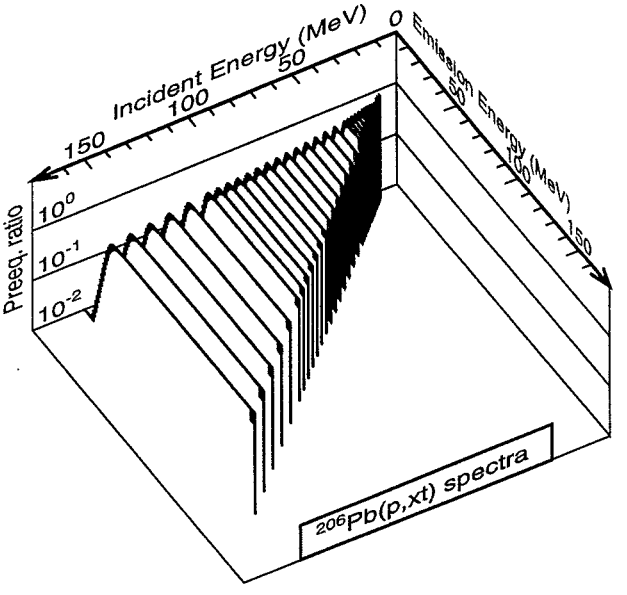


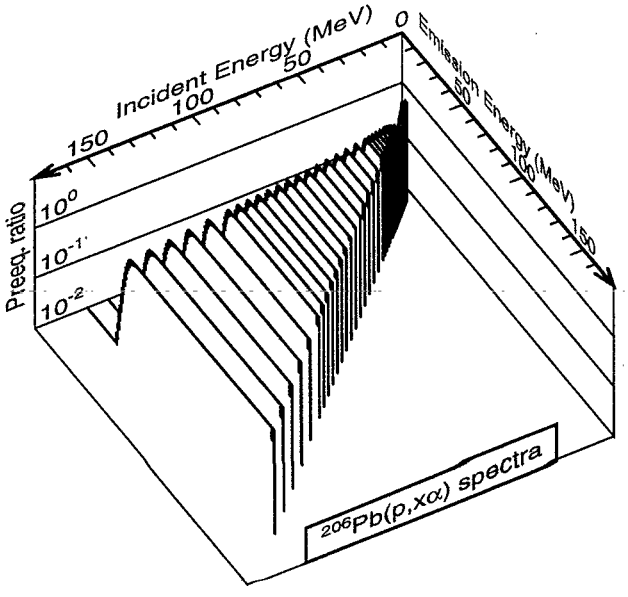
p + ^{206}Pb Kalbach preequilibrium ratios

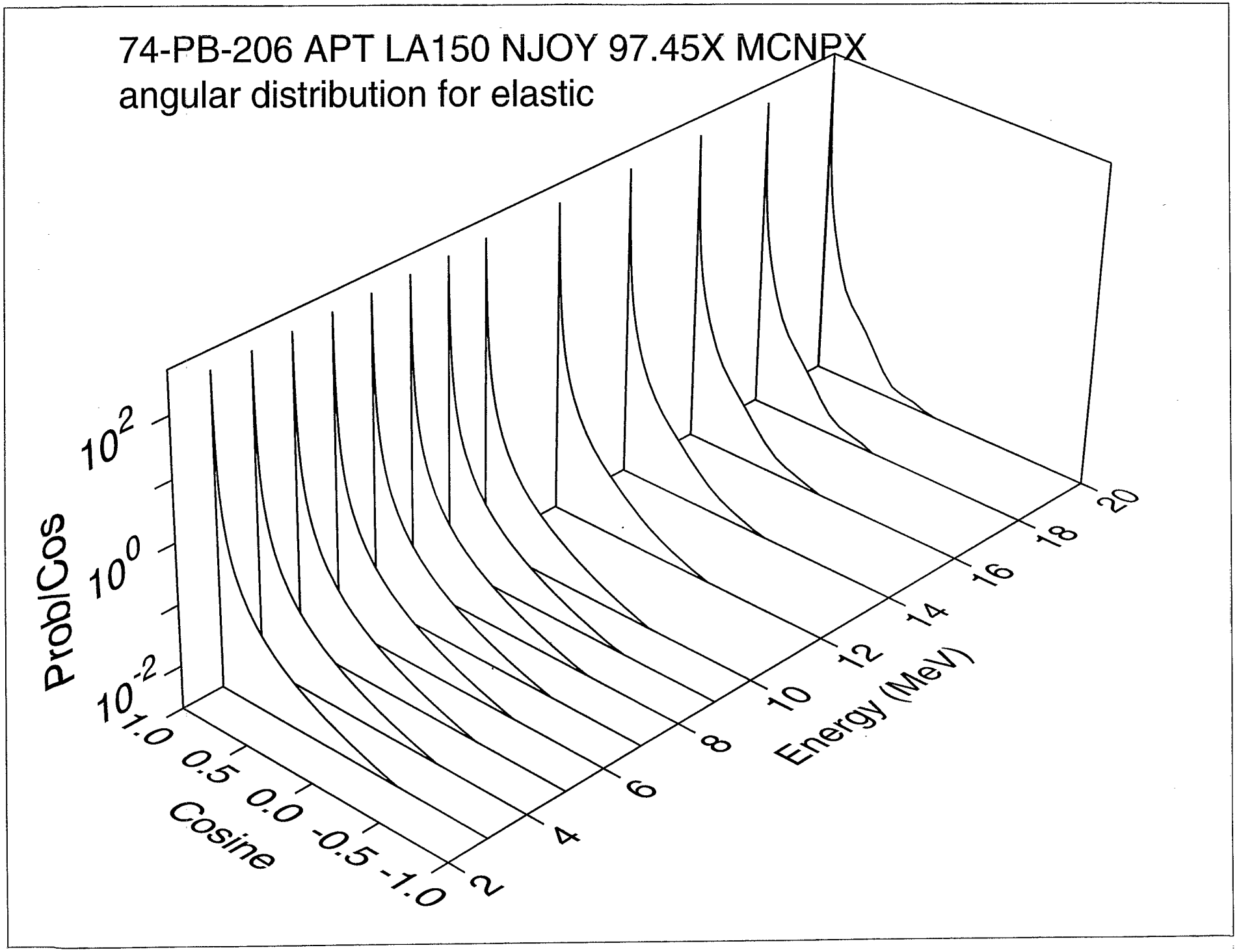


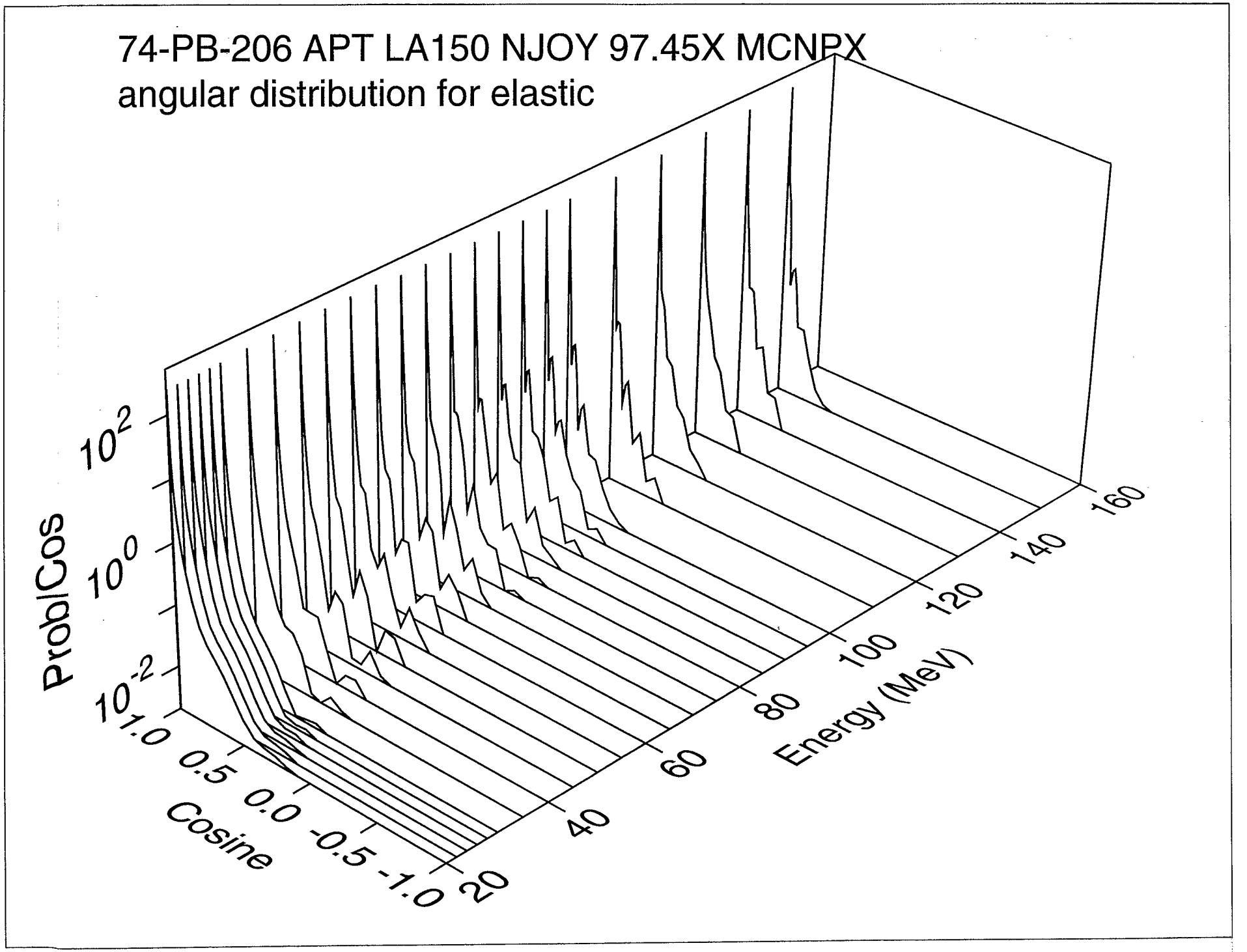


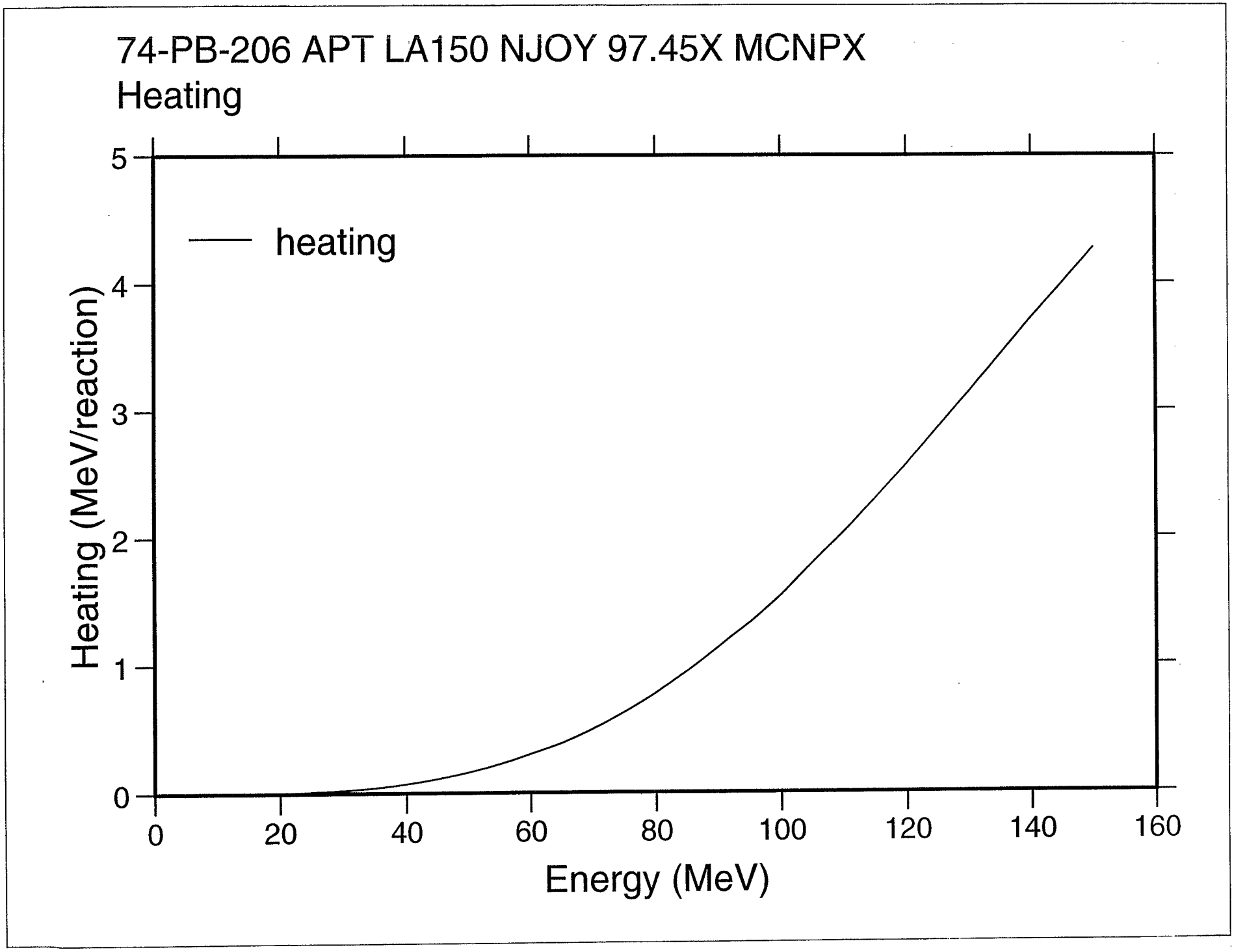







74-PB-206 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
ProblCos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
2
4
6
8
10
12
14
16
18
20


74-PB-206 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
10^{-2}
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


74-PB-206 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
1
2
3
4
5
0
20
40
60
80
100
120
140
160

EVALUATION OF p + 207Pb CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

M. B. Chadwick, P. G. Young, and A. J. Koning

21 October 1996

This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV.

The evaluation utilizes MF = 3 [MT=2 and MT=5] and MF=6 [MT=2 and MT=5] to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced with non-negligible cross sections (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data are:

MF=3	MT= 2	Integral of nuclear plus interference components of the elastic scattering cross section
	MT= 5	Sum of binary (n,n') and (n,x) reactions
MF=6	MT= 2	Elastic angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
	MT= 5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Pb and p + Pb208 reactions (Ch96a). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Coupled-channel and spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96b). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. Note that all other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation requires a modification of the original ENDF-6 format.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities

using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

MT=2 elastic scattering data in MF=3 and MF=6 are based on optical model calculations with the SCAT2 code (Be92). We have made use of the "nuclear-plus-interference" option in MF=6, which corresponds to LAW=5, LTP=12, and the appropriate integrated cross section is stored in MF=3. Note that because of the interference effect, the tabulations in both MF=6 and MF=3 can be negative at some energies and angles.

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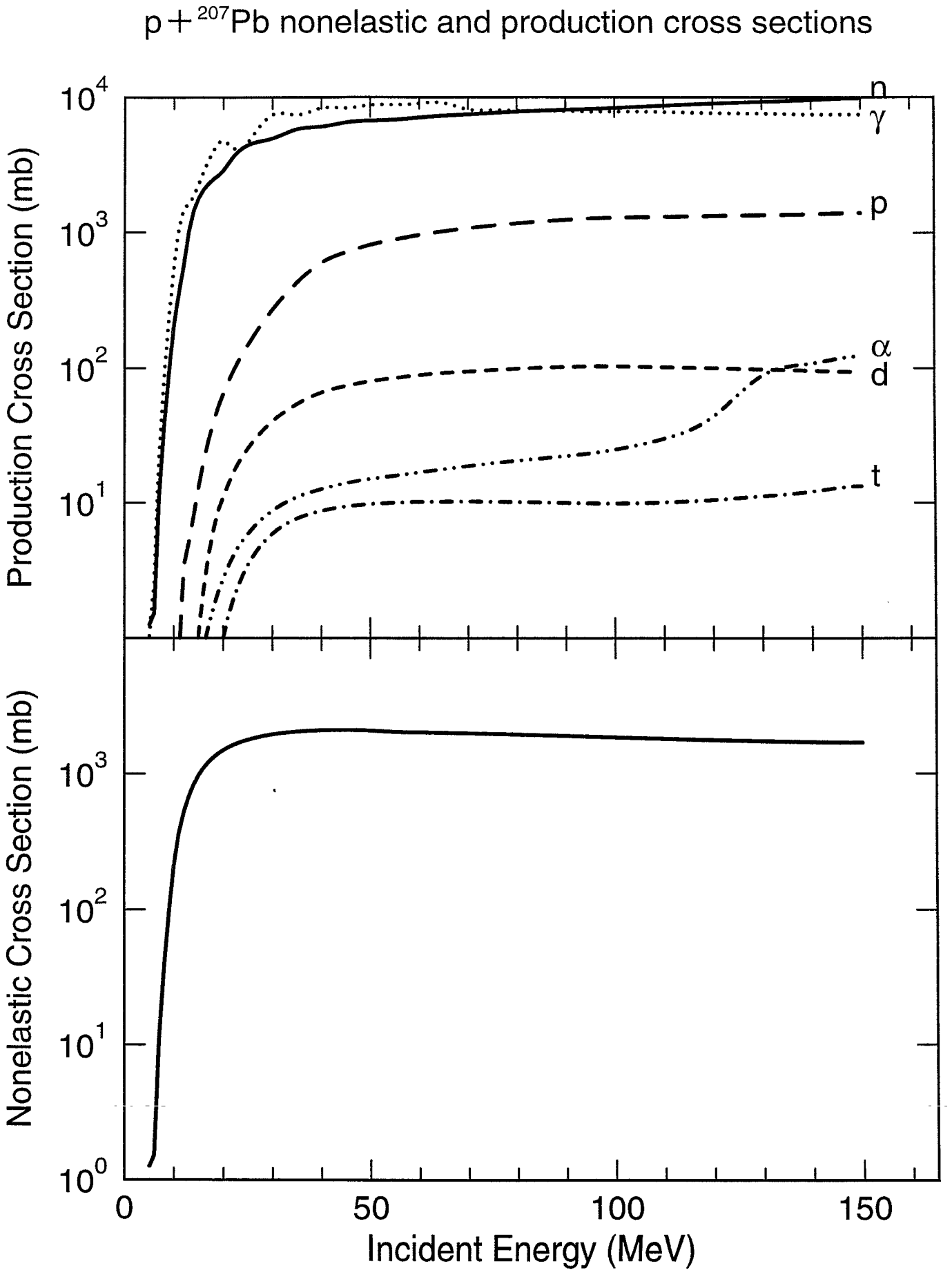
82207 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
4.000E+00	1.000E-20	0.000E+00	1.000E-20	1.000E-20	0.000E+00	0.000E+00	0.000E+00	1.000E-20	1.000E-20
5.000E+00	5.166E-04	0.000E+00	5.149E-04	6.437E-08	0.000E+00	0.000E+00	0.000E+00	1.344E-08	5.635E-04
6.000E+00	1.524E-03	0.000E+00	1.522E-03	3.739E-07	0.000E+00	0.000E+00	0.000E+00	4.905E-08	2.552E-03
7.000E+00	1.104E-02	0.000E+00	1.103E-02	2.076E-06	7.138E-15	0.000E+00	0.000E+00	5.045E-07	2.180E-02
8.000E+00	3.672E-02	0.000E+00	3.666E-02	1.855E-05	1.443E-11	0.000E+00	0.000E+00	3.009E-06	8.462E-02
9.000E+00	9.411E-02	0.000E+00	9.391E-02	6.931E-05	1.478E-08	0.000E+00	0.000E+00	1.660E-05	2.390E-01
1.000E+01	2.107E-01	0.000E+00	2.102E-01	2.053E-04	4.621E-07	2.303E-08	0.000E+00	4.894E-05	5.773E-01
1.100E+01	3.644E-01	0.000E+00	3.633E-01	6.638E-04	1.704E-06	5.244E-08	0.000E+00	1.177E-04	1.071E+00
1.200E+01	5.192E-01	0.000E+00	5.825E-01	3.402E-03	1.456E-05	2.049E-07	0.000E+00	2.696E-04	1.495E+00
1.300E+01	6.749E-01	0.000E+00	1.016E+00	5.026E-03	8.751E-05	5.043E-07	0.000E+00	3.634E-04	1.630E+00
1.400E+01	8.304E-01	0.000E+00	1.450E+00	7.924E-03	3.838E-04	2.482E-06	0.000E+00	4.571E-04	1.867E+00
1.500E+01	9.732E-01	0.000E+00	1.804E+00	1.297E-02	1.066E-03	1.251E-05	0.000E+00	6.108E-04	2.282E+00
1.600E+01	1.097E+00	0.000E+00	2.073E+00	2.008E-02	2.241E-03	5.044E-05	0.000E+00	8.544E-04	2.817E+00
1.700E+01	1.211E+00	0.000E+00	2.294E+00	2.903E-02	3.996E-03	1.489E-04	0.000E+00	1.210E-03	3.411E+00
1.800E+01	1.312E+00	0.000E+00	2.478E+00	3.960E-02	6.193E-03	3.279E-04	0.000E+00	1.662E-03	4.020E+00
1.900E+01	1.403E+00	0.000E+00	2.639E+00	5.161E-02	8.760E-03	6.021E-04	0.000E+00	2.190E-03	4.625E+00
2.000E+01	1.485E+00	0.000E+00	2.871E+00	6.449E-02	1.092E-02	9.906E-04	0.000E+00	2.758E-03	4.784E+00
2.200E+01	1.619E+00	0.000E+00	3.604E+00	9.459E-02	1.672E-02	1.900E-03	0.000E+00	4.015E-03	4.191E+00
2.400E+01	1.724E+00	0.000E+00	4.226E+00	1.291E-01	2.248E-02	2.934E-03	0.000E+00	5.272E-03	4.211E+00
2.600E+01	1.809E+00	0.000E+00	4.572E+00	1.690E-01	2.849E-02	3.989E-03	0.000E+00	6.487E-03	5.199E+00
2.800E+01	1.881E+00	0.000E+00	4.763E+00	2.164E-01	3.451E-02	4.995E-03	0.000E+00	7.652E-03	6.481E+00
3.000E+01	1.939E+00	0.000E+00	4.960E+00	2.708E-01	4.046E-02	5.917E-03	0.000E+00	8.760E-03	7.424E+00
3.500E+01	2.033E+00	0.000E+00	5.807E+00	4.297E-01	5.426E-02	7.648E-03	0.000E+00	1.102E-02	7.379E+00
4.000E+01	2.081E+00	0.000E+00	6.066E+00	6.036E-01	6.625E-02	8.742E-03	0.000E+00	1.265E-02	8.278E+00
4.500E+01	2.091E+00	0.000E+00	6.507E+00	7.190E-01	7.411E-02	9.419E-03	0.000E+00	1.406E-02	8.275E+00
5.000E+01	2.071E+00	0.000E+00	6.708E+00	8.169E-01	8.034E-02	9.821E-03	0.000E+00	1.517E-02	8.735E+00
5.500E+01	2.023E+00	0.000E+00	6.826E+00	8.918E-01	8.487E-02	1.004E-02	0.000E+00	1.601E-02	8.770E+00
6.000E+01	2.008E+00	0.000E+00	7.083E+00	9.631E-01	8.906E-02	1.017E-02	0.000E+00	1.697E-02	9.006E+00
6.500E+01	1.991E+00	0.000E+00	7.305E+00	1.025E+00	9.248E-02	1.020E-02	0.000E+00	1.792E-02	9.078E+00
7.000E+01	1.973E+00	0.000E+00	7.450E+00	1.081E+00	9.471E-02	1.023E-02	0.000E+00	1.893E-02	8.086E+00
7.500E+01	1.954E+00	0.000E+00	7.632E+00	1.131E+00	9.715E-02	1.018E-02	0.000E+00	1.989E-02	7.986E+00
8.000E+01	1.934E+00	0.000E+00	7.790E+00	1.176E+00	9.935E-02	1.014E-02	0.000E+00	2.076E-02	7.921E+00
8.500E+01	1.911E+00	0.000E+00	7.924E+00	1.215E+00	1.011E-01	1.008E-02	0.000E+00	2.160E-02	7.896E+00
9.000E+01	1.888E+00	0.000E+00	8.044E+00	1.251E+00	1.024E-01	1.000E-02	0.000E+00	2.252E-02	7.875E+00
9.500E+01	1.865E+00	0.000E+00	8.149E+00	1.282E+00	1.034E-01	9.930E-03	0.000E+00	2.353E-02	7.792E+00
1.000E+02	1.842E+00	0.000E+00	8.294E+00	1.299E+00	1.036E-01	9.903E-03	0.000E+00	2.509E-02	7.789E+00
1.100E+02	1.798E+00	0.000E+00	8.641E+00	1.317E+00	1.017E-01	1.008E-02	0.000E+00	3.019E-02	7.740E+00
1.200E+02	1.759E+00	0.000E+00	8.954E+00	1.334E+00	1.002E-01	1.051E-02	0.000E+00	4.389E-02	7.573E+00
1.300E+02	1.728E+00	0.000E+00	9.250E+00	1.353E+00	9.801E-02	1.119E-02	0.000E+00	8.831E-02	7.530E+00
1.400E+02	1.704E+00	0.000E+00	9.544E+00	1.376E+00	9.589E-02	1.212E-02	0.000E+00	1.086E-01	7.420E+00
1.500E+02	1.688E+00	0.000E+00	9.846E+00	1.404E+00	9.383E-02	1.329E-02	0.000E+00	1.223E-01	7.433E+00

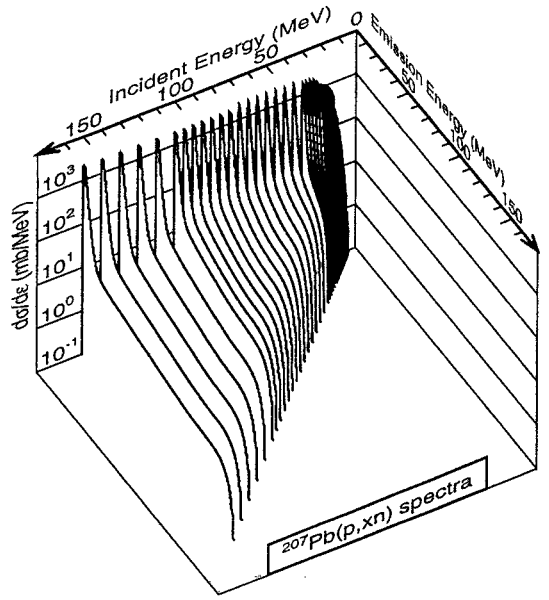
82207 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

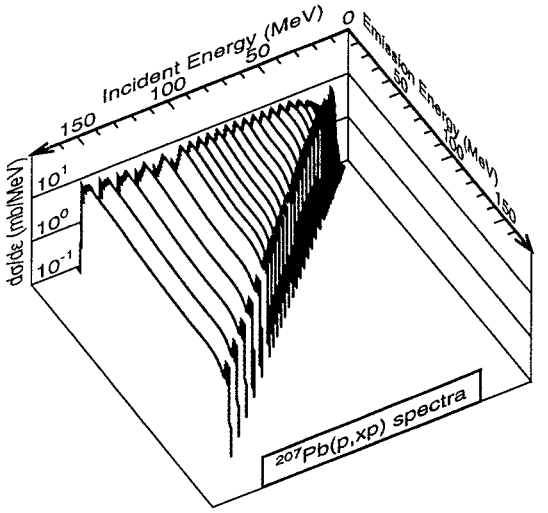
Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
4.000E+00	6.817E-01	3.415E+00	0.000E+00	0.000E+00	0.000E+00	9.851E+00	2.374E+00
5.000E+00	9.290E-01	4.434E+00	0.000E+00	0.000E+00	0.000E+00	1.074E+01	8.460E-01
6.000E+00	1.231E+00	5.240E+00	0.000E+00	0.000E+00	0.000E+00	1.157E+01	9.547E-01
7.000E+00	1.559E+00	6.145E+00	5.033E-02	0.000E+00	0.000E+00	1.260E+01	1.143E+00
8.000E+00	1.753E+00	6.866E+00	3.462E+00	0.000E+00	0.000E+00	1.344E+01	1.329E+00
9.000E+00	1.872E+00	7.493E+00	4.454E+00	0.000E+00	0.000E+00	1.434E+01	1.551E+00
1.000E+01	1.903E+00	7.947E+00	5.082E+00	3.468E+00	0.000E+00	1.467E+01	1.775E+00
1.100E+01	1.845E+00	7.610E+00	5.744E+00	4.413E+00	0.000E+00	1.458E+01	2.009E+00
1.200E+01	1.626E+00	6.176E+00	6.872E+00	5.022E+00	0.000E+00	1.469E+01	2.044E+00
1.300E+01	1.384E+00	7.659E+00	7.788E+00	5.561E+00	0.000E+00	1.600E+01	1.468E+00
1.400E+01	1.476E+00	9.454E+00	8.657E+00	6.637E+00	0.000E+00	1.714E+01	9.201E-01
1.500E+01	1.615E+00	1.060E+01	9.434E+00	7.516E+00	0.000E+00	1.793E+01	7.286E-01
1.600E+01	1.724E+00	1.142E+01	1.019E+01	8.328E+00	0.000E+00	1.853E+01	7.901E-01
1.700E+01	1.809E+00	1.213E+01	1.093E+01	9.025E+00	0.000E+00	1.906E+01	9.463E-01
1.800E+01	1.875E+00	1.280E+01	1.166E+01	9.698E+00	0.000E+00	1.957E+01	1.120E+00
1.900E+01	1.925E+00	1.343E+01	1.238E+01	1.034E+01	0.000E+00	2.009E+01	1.282E+00
2.000E+01	1.911E+00	1.402E+01	1.297E+01	1.100E+01	0.000E+00	2.065E+01	1.465E+00
2.200E+01	1.847E+00	1.510E+01	1.436E+01	1.212E+01	0.000E+00	2.166E+01	1.437E+00
2.400E+01	1.920E+00	1.607E+01	1.568E+01	1.318E+01	0.000E+00	2.263E+01	1.226E+00
2.600E+01	2.068E+00	1.698E+01	1.700E+01	1.421E+01	0.000E+00	2.352E+01	1.173E+00
2.800E+01	2.232E+00	1.783E+01	1.829E+01	1.521E+01	0.000E+00	2.432E+01	1.253E+00
3.000E+01	2.374E+00	1.868E+01	1.958E+01	1.620E+01	0.000E+00	2.505E+01	1.309E+00
3.500E+01	2.645E+00	2.087E+01	2.277E+01	1.851E+01	0.000E+00	2.692E+01	1.131E+00
4.000E+01	3.081E+00	2.320E+01	2.599E+01	2.075E+01	0.000E+00	2.876E+01	1.198E+00
4.500E+01	3.350E+00	2.555E+01	2.923E+01	2.298E+01	0.000E+00	3.031E+01	1.162E+00

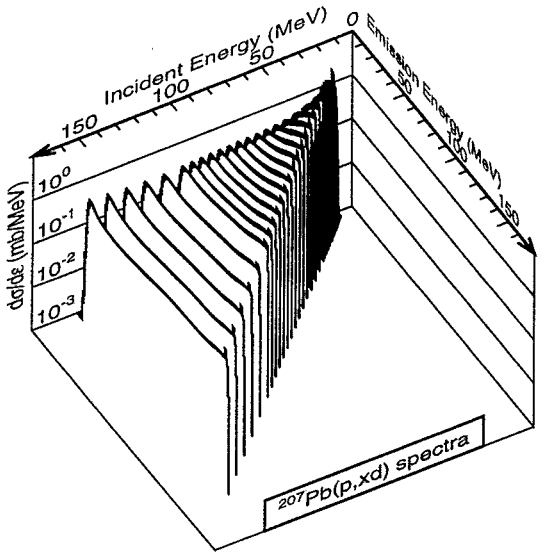
5.000E+01	3.657E+00	2.788E+01	3.242E+01	2.518E+01	0.000E+00	3.171E+01	1.161E+00
5.500E+01	3.933E+00	3.017E+01	3.554E+01	2.734E+01	0.000E+00	3.299E+01	1.150E+00
6.000E+01	4.183E+00	3.227E+01	3.860E+01	2.941E+01	0.000E+00	3.412E+01	1.112E+00
6.500E+01	4.435E+00	3.428E+01	4.162E+01	3.140E+01	0.000E+00	3.504E+01	1.113E+00
7.000E+01	4.713E+00	3.628E+01	4.446E+01	3.331E+01	0.000E+00	3.572E+01	1.211E+00
7.500E+01	4.960E+00	3.824E+01	4.745E+01	3.510E+01	0.000E+00	3.622E+01	1.231E+00
8.000E+01	5.199E+00	4.019E+01	5.043E+01	3.682E+01	0.000E+00	3.663E+01	1.233E+00
8.500E+01	5.432E+00	4.209E+01	5.340E+01	3.842E+01	0.000E+00	3.688E+01	1.234E+00
9.000E+01	5.659E+00	4.394E+01	5.635E+01	3.990E+01	0.000E+00	3.691E+01	1.236E+00
9.500E+01	5.883E+00	4.583E+01	5.927E+01	4.126E+01	0.000E+00	3.675E+01	1.239E+00
1.000E+02	6.061E+00	4.775E+01	6.214E+01	4.216E+01	0.000E+00	3.606E+01	1.236E+00
1.100E+02	6.348E+00	5.158E+01	6.743E+01	4.254E+01	0.000E+00	3.341E+01	1.247E+00
1.200E+02	6.639E+00	5.534E+01	7.270E+01	4.172E+01	0.000E+00	2.707E+01	1.246E+00
1.300E+02	6.938E+00	5.899E+01	7.752E+01	4.000E+01	0.000E+00	1.791E+01	1.245E+00
1.400E+02	7.242E+00	6.252E+01	8.212E+01	3.774E+01	0.000E+00	1.692E+01	1.253E+00
1.500E+02	7.551E+00	6.598E+01	8.644E+01	3.525E+01	0.000E+00	1.703E+01	1.264E+00

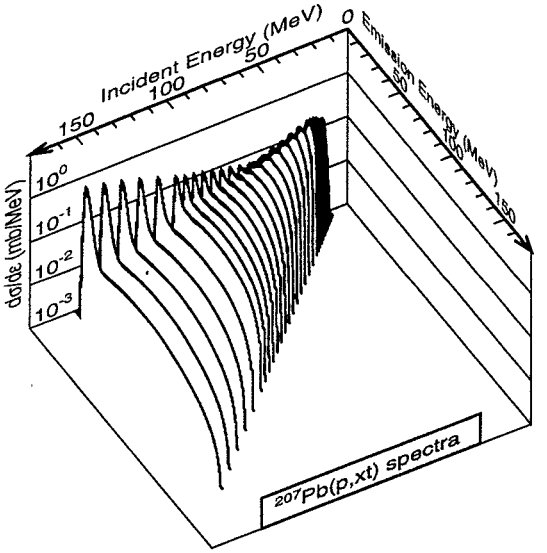

p + 207Pb nonelastic and production cross sections
Production Cross Section (mb)
Nonelastic Cross Section (mb)
Incident Energy (MeV)
n
γ
p
α
d
t
10^4
10^3
10^2
10^1
10^0
0
50
100
150

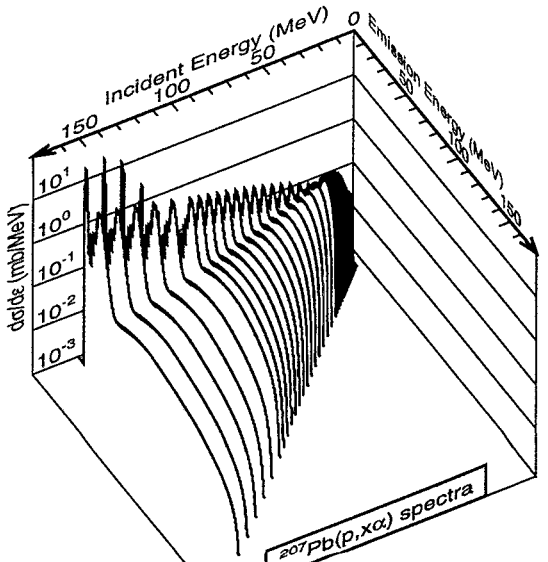
p + ^{207}Pb angle-integrated emission spectra

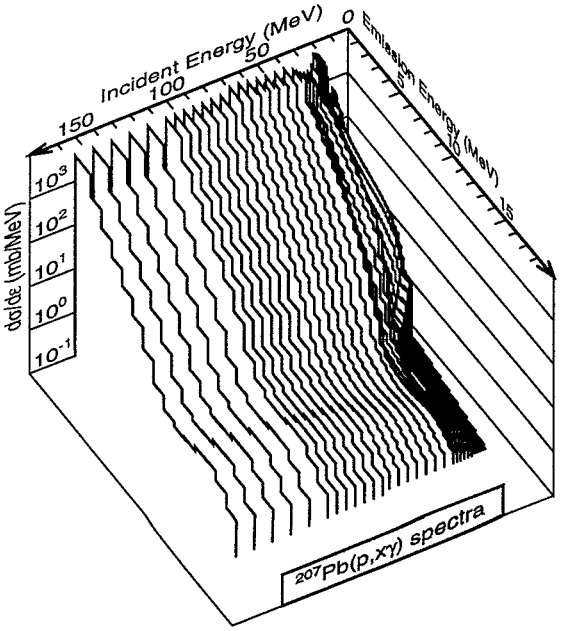




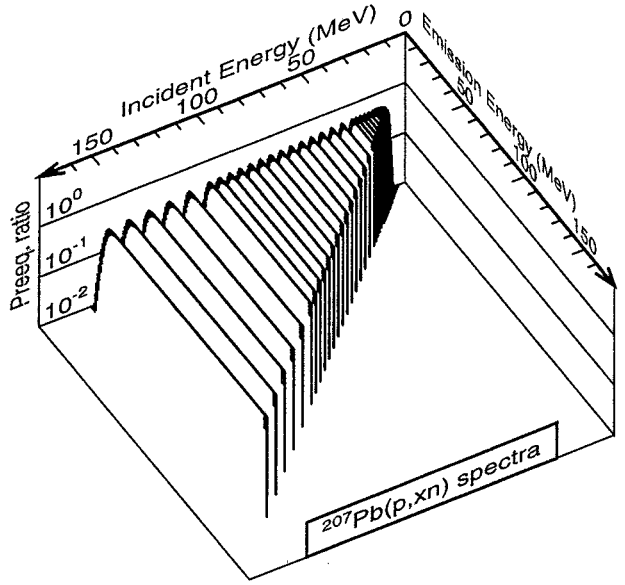


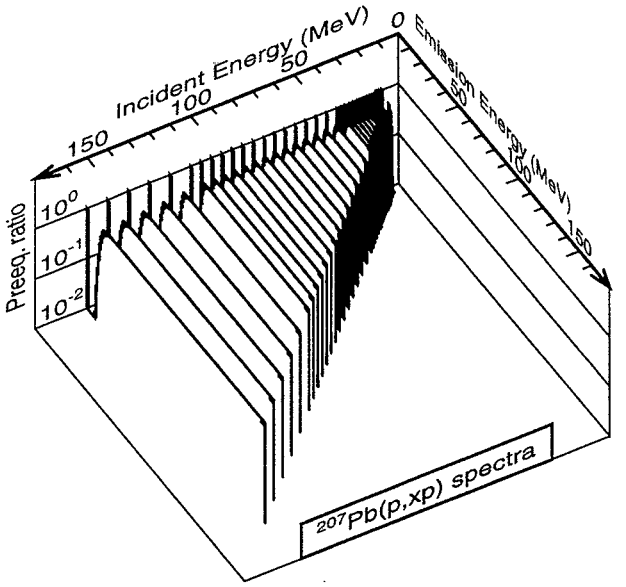


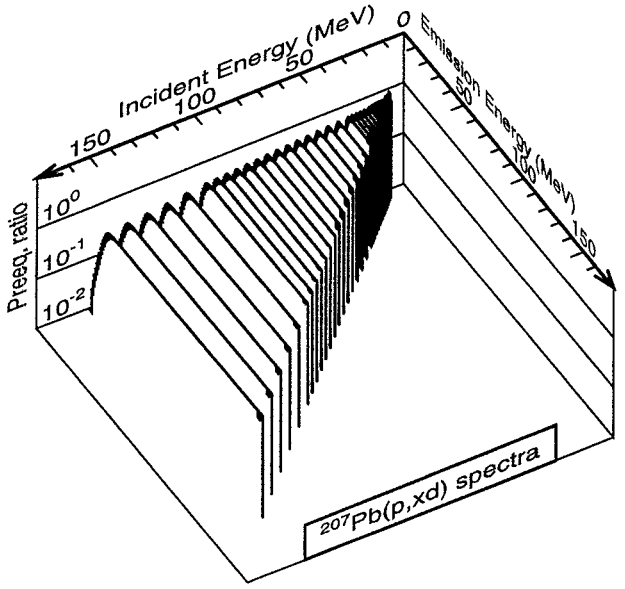


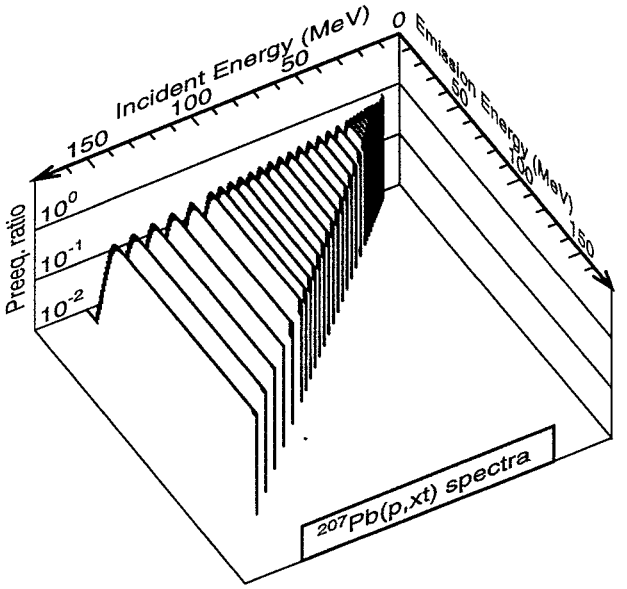


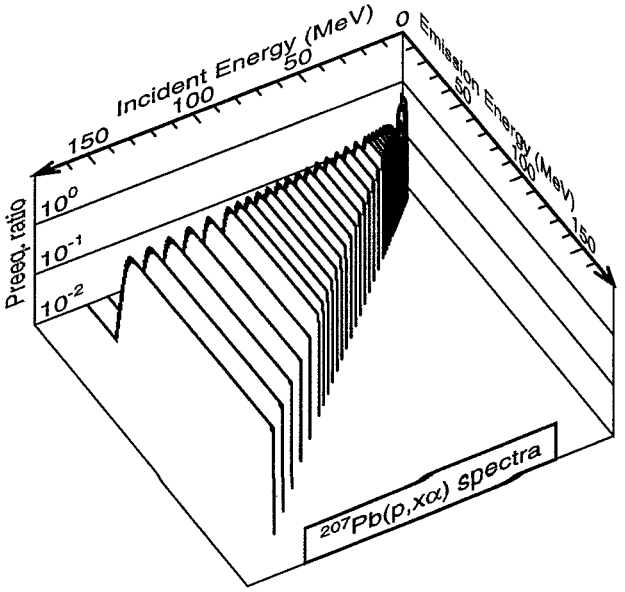
p + ^{207}Pb Kalbach preequilibrium ratios

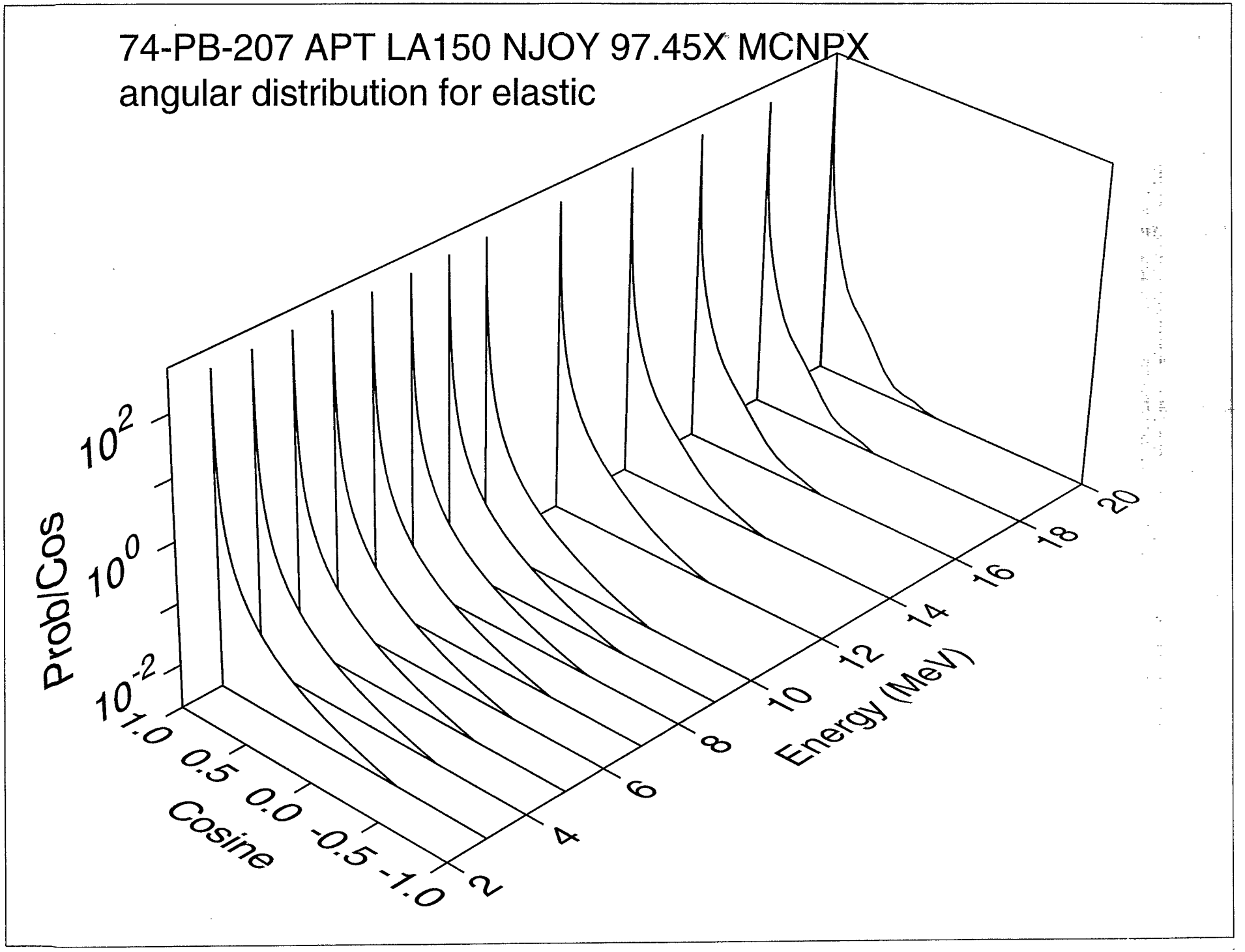


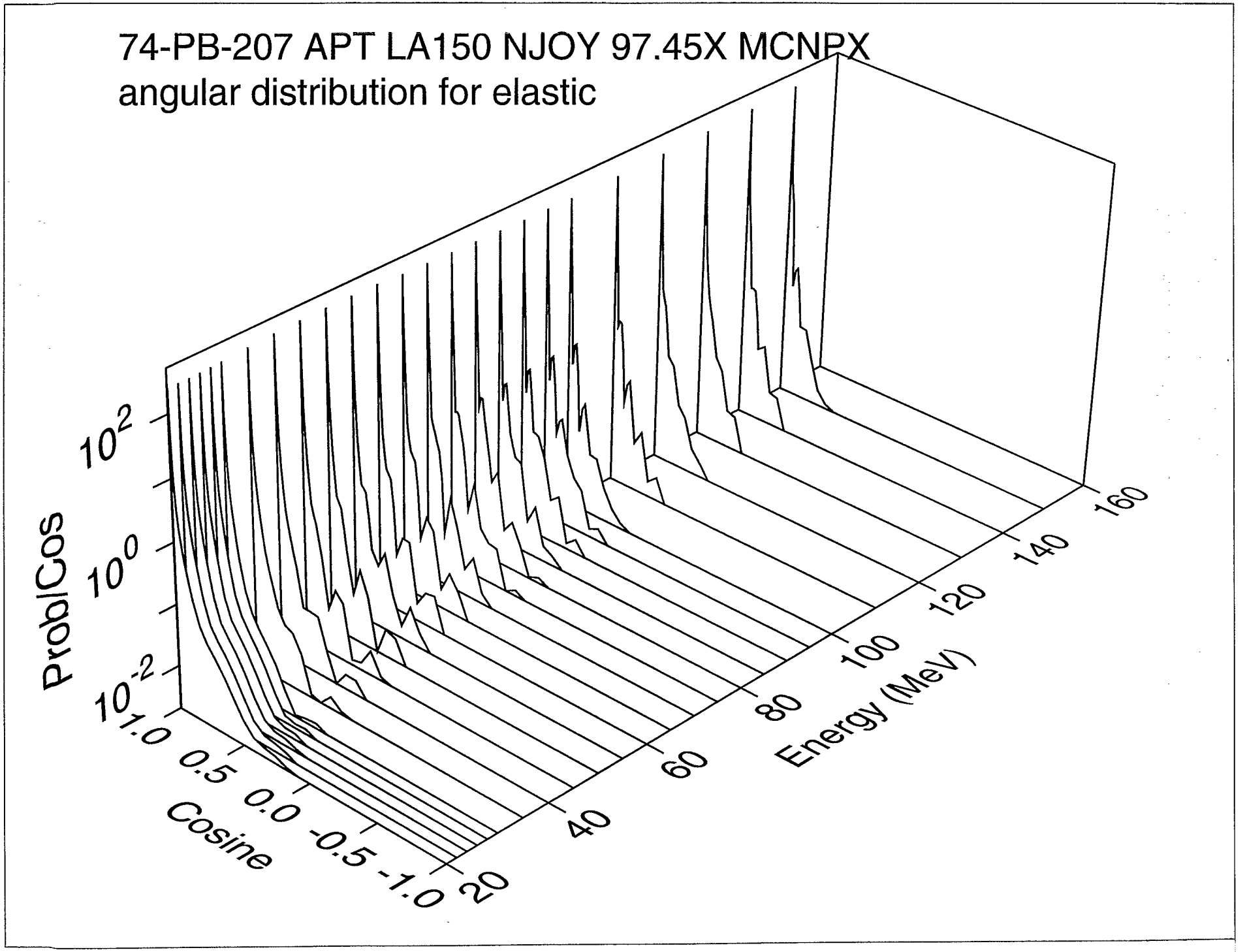


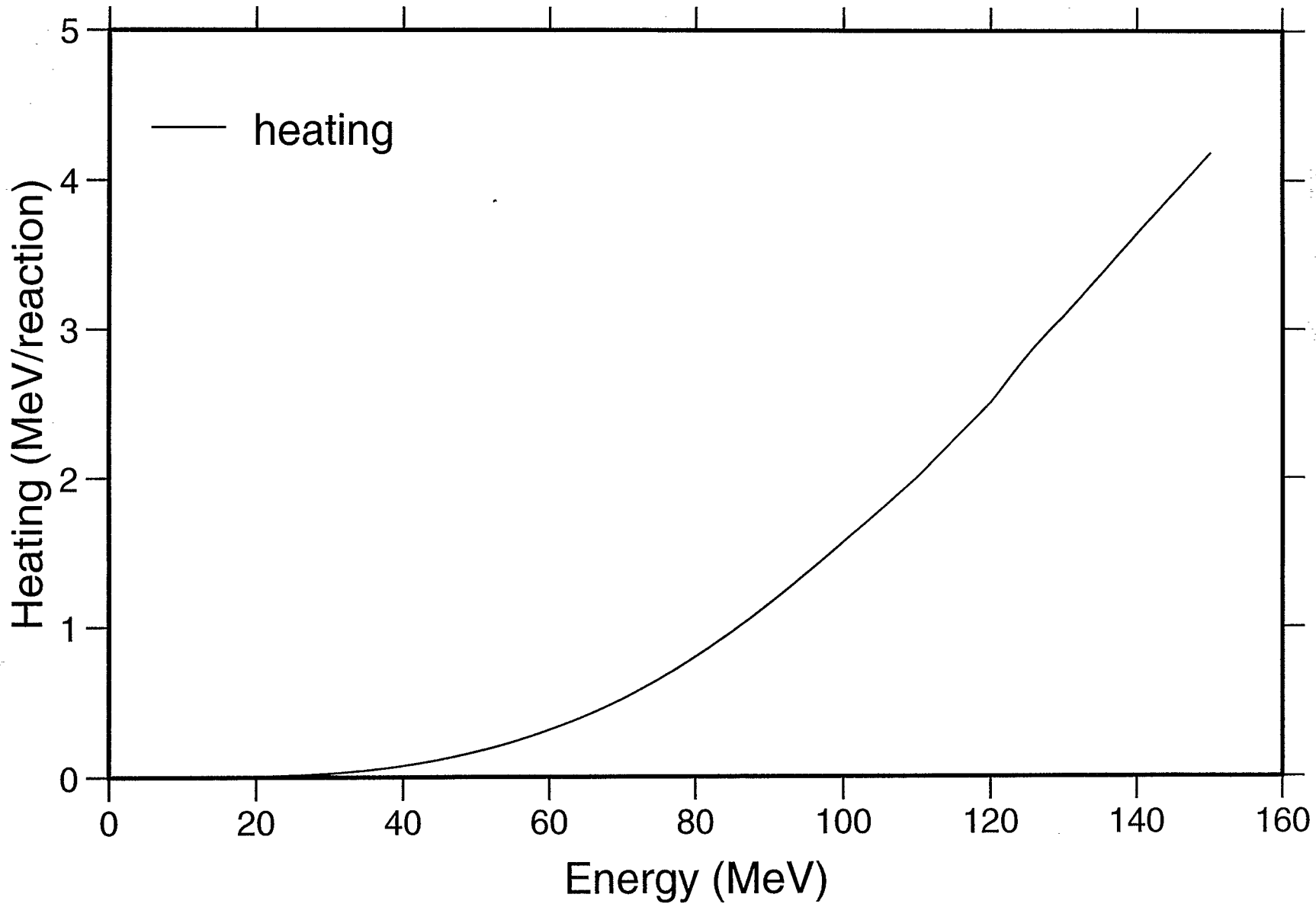







74-PB-207 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
ProbCos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
2
4
6
8
10
12
14
16
18
20


74-PB-207 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
ProblCos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
20
40
60
80
100
120
140
160


74-PB-207 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
1
2
3
4
5
0
20
40
60
80
100
120
140
160

EVALUATION OF p + 208Pb CROSS SECTIONS FOR THE ENERGY RANGE 1.0E-11 to 150 MeV

M. B. Chadwick, P. G. Young, and A. J. Koning

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This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV.

The evaluation utilizes MF = 3 [MT=2 and MT=5] and MF=6 [MT=2 and MT=5] to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced with non-negligible cross sections (A>5) in the reaction chains. To summarize, the ENDF sections with non-zero data are:

MF=3	MT= 2	Integral of nuclear plus interference components of the elastic scattering cross section
	MT= 5	Sum of binary (n,n') and (n,x) reactions
MF=6	MT= 2	Elastic angular distributions given as ratios of the differential nuclear-plus-interference to the integrated value.
	MT= 5	Production cross sections and energy-angle distributions for emission neutrons, protons, deuterons, and alphas; and angle-integrated spectra for gamma rays and residual nuclei that are stable against particle emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Pb and p + Pb208 reactions (Ch96a). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Coupled-channel and spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of all recoil nuclei in the GNASH calculations (Ch96b). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. Note that all other data in MT=5,MF=6 are given in the center-of-mass system. This method of representation requires a modification of the original ENDF-6 format.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities

using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

MT=2 elastic scattering data in MF=3 and MF=6 are based on optical model calculations with the SCAT2 code (Be92). We have made use of the "nuclear-plus-interference" option in MF=6, which corresponds to LAW=5, LTP=12, and the appropriate integrated cross section is stored in MF=3. Note that because of the interference effect, the tabulations in both MF=6 and MF=3 can be negative at some energies and angles.

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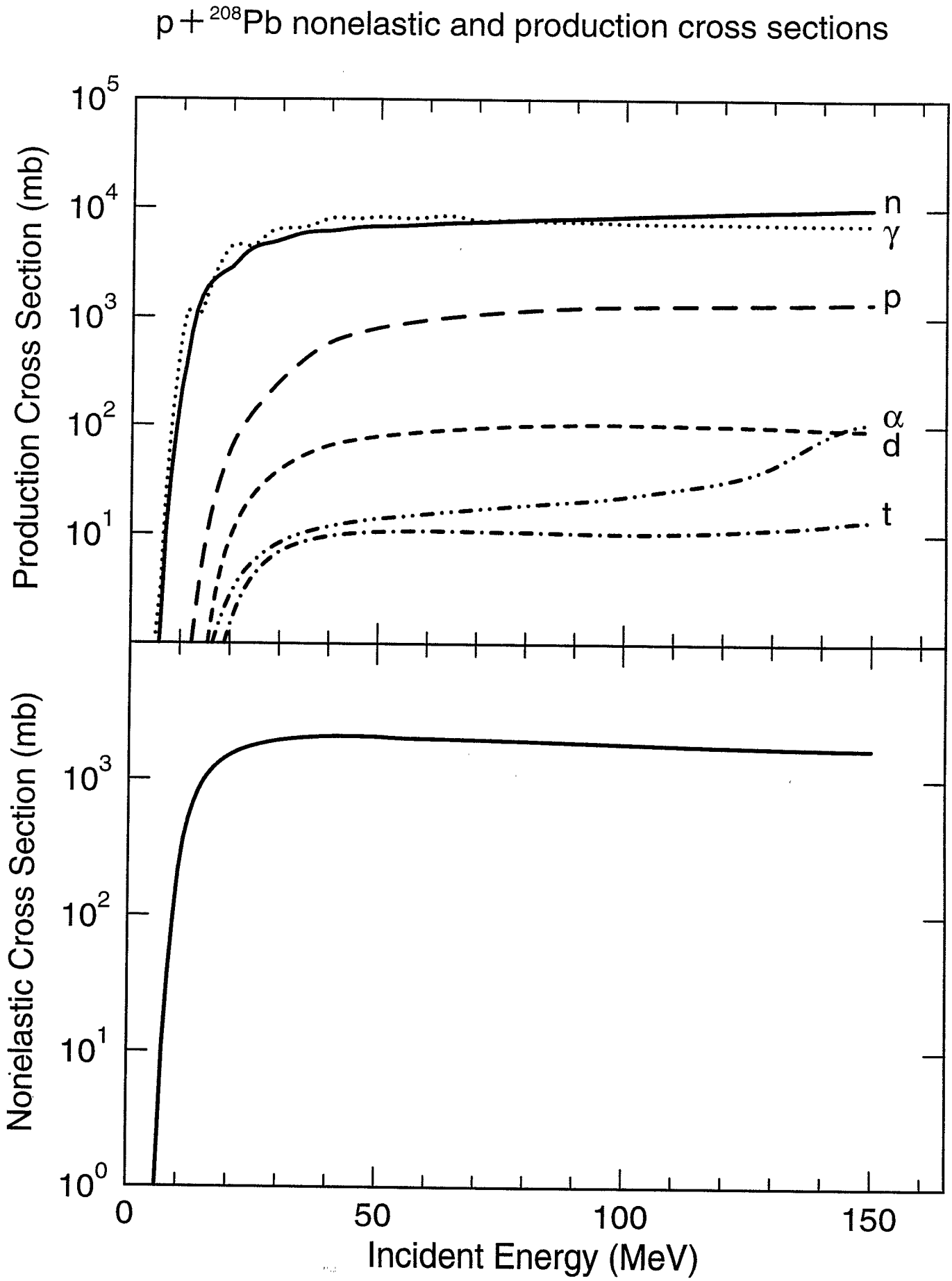
82208 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
4.000E+00	1.000E-20	0.000E+00	1.000E-20	1.000E-20	0.000E+00	0.000E+00	0.000E+00	1.000E-20	1.000E-20
5.000E+00	5.166E-04	0.000E+00	5.158E-04	2.465E-12	0.000E+00	0.000E+00	0.000E+00	1.284E-08	8.949E-04
6.000E+00	1.524E-03	0.000E+00	1.523E-03	3.953E-10	0.000E+00	0.000E+00	0.000E+00	5.591E-08	3.351E-03
7.000E+00	1.104E-02	0.000E+00	1.103E-02	6.529E-08	0.000E+00	0.000E+00	0.000E+00	3.641E-07	2.642E-02
8.000E+00	3.672E-02	0.000E+00	3.669E-02	9.051E-07	9.421E-09	0.000E+00	0.000E+00	2.424E-06	1.006E-01
9.000E+00	9.410E-02	0.000E+00	9.399E-02	9.304E-06	7.514E-09	1.246E-08	0.000E+00	1.059E-05	2.771E-01
1.000E+01	2.107E-01	0.000E+00	2.104E-01	4.407E-05	1.457E-07	2.011E-08	0.000E+00	3.351E-05	6.537E-01
1.100E+01	3.644E-01	0.000E+00	3.760E-01	2.313E-04	9.218E-07	1.321E-07	0.000E+00	8.482E-05	1.145E+00
1.200E+01	5.192E-01	0.000E+00	7.088E-01	7.670E-04	4.212E-06	4.759E-07	0.000E+00	1.690E-04	1.112E+00
1.300E+01	6.749E-01	0.000E+00	1.134E+00	1.934E-03	3.271E-05	1.912E-06	0.000E+00	2.676E-04	9.686E-01
1.400E+01	8.304E-01	0.000E+00	1.524E+00	4.448E-03	1.717E-04	9.843E-06	0.000E+00	3.901E-04	1.137E+00
1.500E+01	9.732E-01	0.000E+00	1.846E+00	8.542E-03	6.048E-04	4.289E-05	0.000E+00	5.675E-04	1.549E+00
1.600E+01	1.097E+00	0.000E+00	2.101E+00	1.464E-02	1.440E-03	1.367E-04	0.000E+00	8.297E-04	2.101E+00
1.700E+01	1.211E+00	0.000E+00	2.317E+00	2.279E-02	2.814E-03	3.281E-04	0.000E+00	1.197E-03	2.724E+00
1.800E+01	1.312E+00	0.000E+00	2.499E+00	3.278E-02	4.656E-03	6.381E-04	0.000E+00	1.659E-03	3.367E+00
1.900E+01	1.403E+00	0.000E+00	2.657E+00	4.446E-02	6.899E-03	1.052E-03	0.000E+00	2.207E-03	4.014E+00
2.000E+01	1.485E+00	0.000E+00	2.833E+00	6.005E-02	9.353E-03	1.496E-03	0.000E+00	2.799E-03	4.509E+00
2.200E+01	1.619E+00	0.000E+00	3.550E+00	9.015E-02	1.497E-02	2.607E-03	0.000E+00	4.058E-03	4.528E+00
2.400E+01	1.724E+00	0.000E+00	4.216E+00	1.237E-01	2.105E-02	3.780E-03	0.000E+00	5.235E-03	4.450E+00
2.600E+01	1.809E+00	0.000E+00	4.585E+00	1.589E-01	2.708E-02	4.933E-03	0.000E+00	6.365E-03	5.156E+00
2.800E+01	1.881E+00	0.000E+00	4.795E+00	2.049E-01	3.310E-02	5.990E-03	0.000E+00	7.430E-03	6.100E+00
3.000E+01	1.939E+00	0.000E+00	5.094E+00	2.572E-01	3.906E-02	6.927E-03	0.000E+00	8.409E-03	6.464E+00
3.500E+01	2.033E+00	0.000E+00	5.945E+00	4.120E-01	5.298E-02	8.600E-03	0.000E+00	1.035E-02	6.711E+00
4.000E+01	2.081E+00	0.000E+00	6.172E+00	5.836E-01	6.510E-02	9.616E-03	0.000E+00	1.182E-02	8.066E+00
4.500E+01	2.091E+00	0.000E+00	6.634E+00	7.003E-01	7.304E-02	1.021E-02	0.000E+00	1.301E-02	7.999E+00
5.000E+01	2.071E+00	0.000E+00	6.820E+00	8.005E-01	7.918E-02	1.053E-02	0.000E+00	1.394E-02	8.283E+00
5.500E+01	2.023E+00	0.000E+00	6.946E+00	8.774E-01	8.379E-02	1.067E-02	0.000E+00	1.462E-02	8.082E+00
6.000E+01	2.008E+00	0.000E+00	7.168E+00	9.512E-01	8.805E-02	1.074E-02	0.000E+00	1.545E-02	8.286E+00
6.500E+01	1.991E+00	0.000E+00	7.388E+00	1.014E+00	9.153E-02	1.072E-02	0.000E+00	1.625E-02	8.489E+00
7.000E+01	1.973E+00	0.000E+00	7.511E+00	1.070E+00	9.478E-02	1.064E-02	0.000E+00	1.704E-02	7.724E+00
7.500E+01	1.954E+00	0.000E+00	7.689E+00	1.120E+00	9.761E-02	1.056E-02	0.000E+00	1.781E-02	7.829E+00
8.000E+01	1.934E+00	0.000E+00	7.870E+00	1.162E+00	1.000E-01	1.051E-02	0.000E+00	1.860E-02	7.763E+00
8.500E+01	1.911E+00	0.000E+00	8.008E+00	1.200E+00	1.013E-01	1.042E-02	0.000E+00	1.937E-02	7.637E+00
9.000E+01	1.888E+00	0.000E+00	8.127E+00	1.233E+00	1.026E-01	1.032E-02	0.000E+00	2.012E-02	7.605E+00
9.500E+01	1.865E+00	0.000E+00	8.254E+00	1.259E+00	1.034E-01	1.023E-02	0.000E+00	2.103E-02	7.525E+00
1.000E+02	1.842E+00	0.000E+00	8.440E+00	1.271E+00	1.031E-01	1.020E-02	0.000E+00	2.244E-02	7.398E+00
1.100E+02	1.798E+00	0.000E+00	8.784E+00	1.291E+00	1.019E-01	1.033E-02	0.000E+00	2.613E-02	7.317E+00
1.200E+02	1.759E+00	0.000E+00	9.098E+00	1.307E+00	1.002E-01	1.072E-02	0.000E+00	3.101E-02	7.304E+00
1.300E+02	1.728E+00	0.000E+00	9.395E+00	1.324E+00	9.810E-02	1.139E-02	0.000E+00	4.311E-02	7.221E+00
1.400E+02	1.704E+00	0.000E+00	9.694E+00	1.347E+00	9.461E-02	1.231E-02	0.000E+00	7.809E-02	7.193E+00
1.500E+02	1.688E+00	0.000E+00	1.000E+01	1.373E+00	9.256E-02	1.349E-02	0.000E+00	1.069E-01	7.175E+00

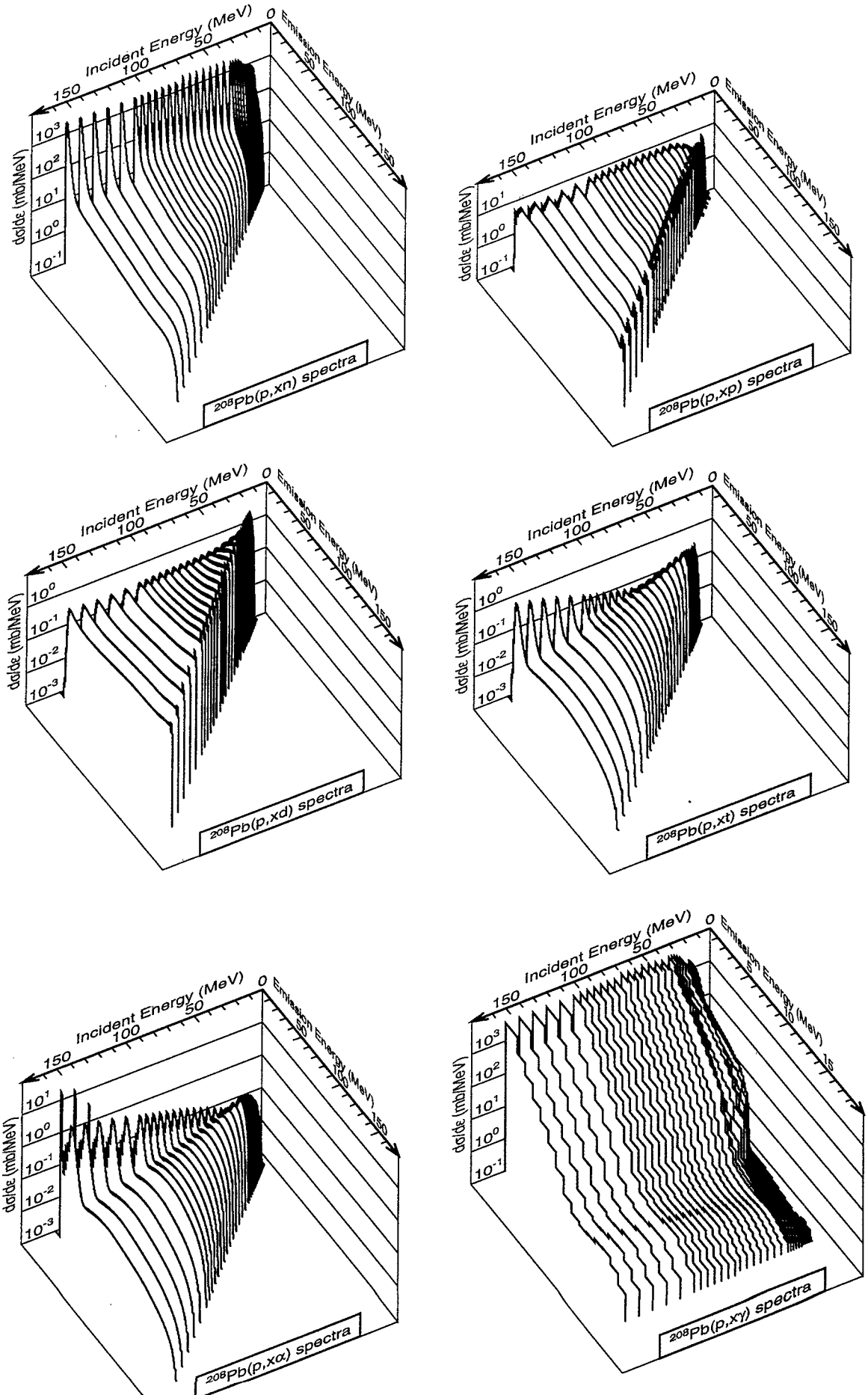
82208 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
4.000E+00	1.867E-01	5.009E-02	0.000E+00	0.000E+00	0.000E+00	1.031E+01	1.219E+00
5.000E+00	7.598E-01	2.241E+00	0.000E+00	0.000E+00	0.000E+00	1.074E+01	3.665E-01
6.000E+00	1.227E+00	3.237E+00	0.000E+00	0.000E+00	0.000E+00	1.169E+01	5.171E-01
7.000E+00	1.624E+00	4.227E+00	0.000E+00	0.000E+00	0.000E+00	1.264E+01	7.246E-01
8.000E+00	1.831E+00	5.060E+00	2.735E+00	0.000E+00	0.000E+00	1.373E+01	9.227E-01
9.000E+00	1.984E+00	5.607E+00	3.727E+00	3.220E+00	0.000E+00	1.453E+01	1.131E+00
1.000E+01	2.059E+00	6.437E+00	4.594E+00	4.201E+00	0.000E+00	1.479E+01	1.373E+00
1.100E+01	1.940E+00	7.225E+00	5.312E+00	4.856E+00	0.000E+00	1.520E+01	1.616E+00
1.200E+01	1.563E+00	7.818E+00	6.312E+00	5.247E+00	0.000E+00	1.608E+01	1.707E+00
1.300E+01	1.456E+00	8.812E+00	7.308E+00	6.285E+00	0.000E+00	1.708E+01	1.509E+00
1.400E+01	1.529E+00	9.760E+00	8.224E+00	7.270E+00	0.000E+00	1.786E+01	1.228E+00
1.500E+01	1.651E+00	1.056E+01	9.073E+00	8.102E+00	0.000E+00	1.849E+01	1.169E+00
1.600E+01	1.778E+00	1.123E+01	9.857E+00	8.813E+00	0.000E+00	1.906E+01	1.242E+00
1.700E+01	1.882E+00	1.188E+01	1.063E+01	9.456E+00	0.000E+00	1.957E+01	1.339E+00
1.800E+01	1.969E+00	1.252E+01	1.131E+01	1.009E+01	0.000E+00	2.004E+01	1.459E+00
1.900E+01	2.031E+00	1.313E+01	1.203E+01	1.073E+01	0.000E+00	2.048E+01	1.591E+00
2.000E+01	2.046E+00	1.375E+01	1.264E+01	1.134E+01	0.000E+00	2.086E+01	1.639E+00
2.200E+01	1.943E+00	1.487E+01	1.404E+01	1.247E+01	0.000E+00	2.185E+01	1.428E+00
2.400E+01	2.004E+00	1.596E+01	1.540E+01	1.354E+01	0.000E+00	2.289E+01	1.115E+00
2.600E+01	2.144E+00	1.682E+01	1.673E+01	1.457E+01	0.000E+00	2.382E+01	1.093E+00
2.800E+01	2.290E+00	1.771E+01	1.803E+01	1.557E+01	0.000E+00	2.466E+01	1.225E+00
3.000E+01	2.384E+00	1.856E+01	1.932E+01	1.657E+01	0.000E+00	2.548E+01	1.296E+00
3.500E+01	2.654E+00	2.077E+01	2.252E+01	1.887E+01	0.000E+00	2.756E+01	1.147E+00
4.000E+01	3.101E+00	2.309E+01	2.575E+01	2.112E+01	0.000E+00	2.944E+01	1.203E+00
4.500E+01	3.357E+00	2.546E+01	2.896E+01	2.336E+01	0.000E+00	3.113E+01	1.145E+00

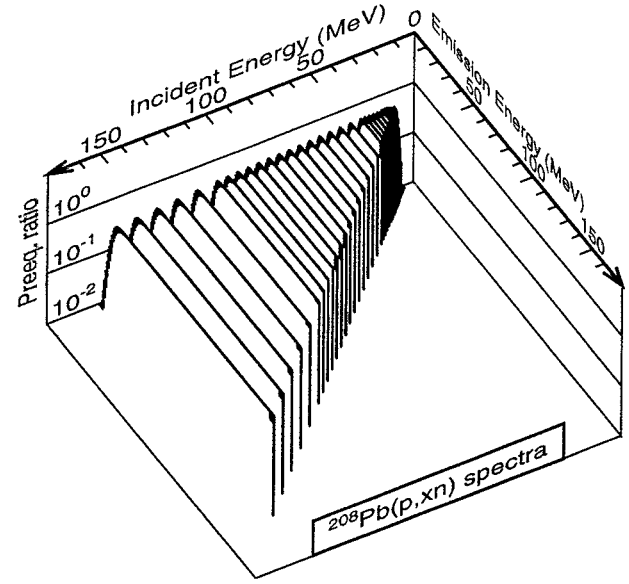
5.000E+01	3.662E+00	2.786E+01	3.213E+01	2.557E+01	0.000E+00	3.268E+01	1.147E+00
5.500E+01	3.927E+00	3.024E+01	3.525E+01	2.775E+01	0.000E+00	3.410E+01	1.156E+00
6.000E+01	4.188E+00	3.242E+01	3.830E+01	2.984E+01	0.000E+00	3.530E+01	1.149E+00
6.500E+01	4.436E+00	3.447E+01	4.132E+01	3.185E+01	0.000E+00	3.632E+01	1.136E+00
7.000E+01	4.714E+00	3.663E+01	4.441E+01	3.373E+01	0.000E+00	3.711E+01	1.262E+00
7.500E+01	4.957E+00	3.862E+01	4.750E+01	3.554E+01	0.000E+00	3.772E+01	1.260E+00
8.000E+01	5.192E+00	4.046E+01	5.048E+01	3.727E+01	0.000E+00	3.817E+01	1.254E+00
8.500E+01	5.418E+00	4.245E+01	5.334E+01	3.889E+01	0.000E+00	3.838E+01	1.253E+00
9.000E+01	5.641E+00	4.443E+01	5.630E+01	4.039E+01	0.000E+00	3.846E+01	1.257E+00
9.500E+01	5.845E+00	4.641E+01	5.924E+01	4.168E+01	0.000E+00	3.825E+01	1.262E+00
1.000E+02	5.988E+00	4.836E+01	6.210E+01	4.238E+01	0.000E+00	3.746E+01	1.270E+00
1.100E+02	6.273E+00	5.217E+01	6.769E+01	4.280E+01	0.000E+00	3.544E+01	1.280E+00
1.200E+02	6.563E+00	5.603E+01	7.299E+01	4.203E+01	0.000E+00	3.315E+01	1.269E+00
1.300E+02	6.860E+00	5.982E+01	7.796E+01	4.031E+01	0.000E+00	2.765E+01	1.270E+00
1.400E+02	7.167E+00	6.348E+01	8.196E+01	3.802E+01	0.000E+00	1.935E+01	1.272E+00
1.500E+02	7.474E+00	6.705E+01	8.636E+01	3.549E+01	0.000E+00	1.697E+01	1.274E+00

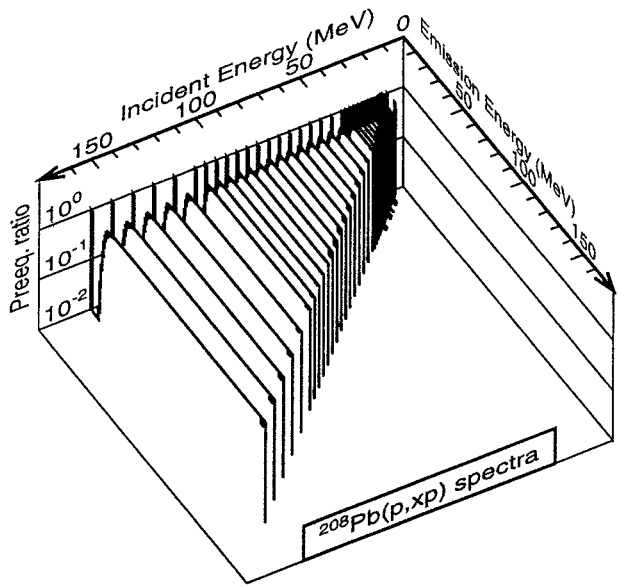

p + 208Pb nonelastic and production cross sections
Production Cross Section (mb)
10^5
10^4
10^3
10^2
10^1
n
γ
p
α
d
t
Nonelastic Cross Section (mb)
10^3
10^2
10^1
10^0
0
50
100
150
Incident Energy (MeV)

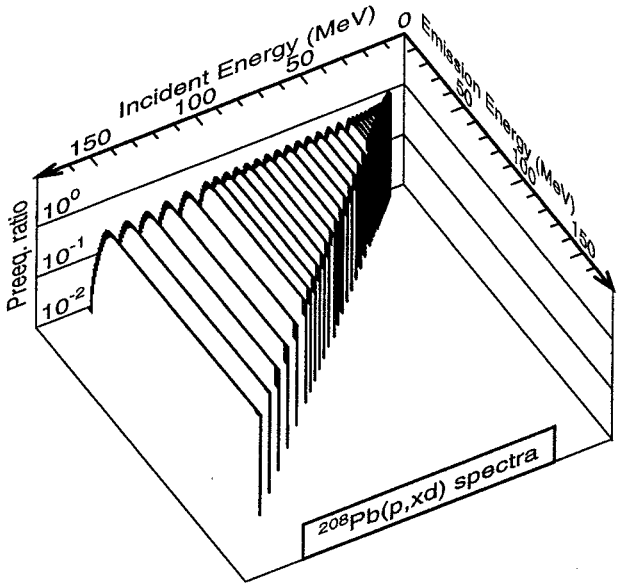
p + ^{208}Pb angle-integrated emission spectra

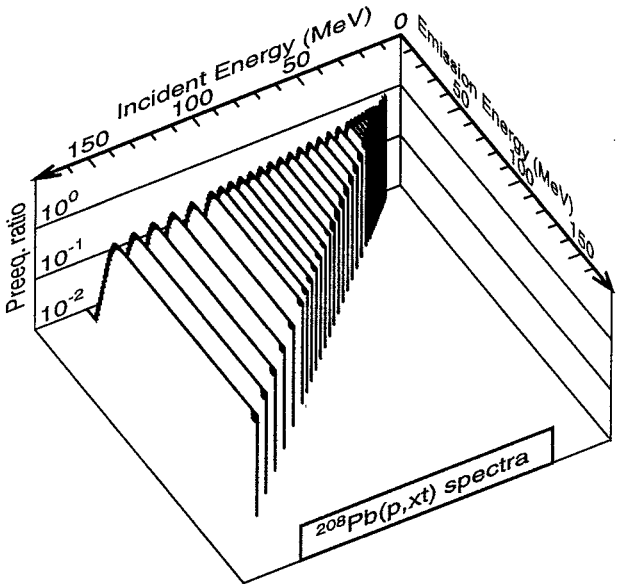


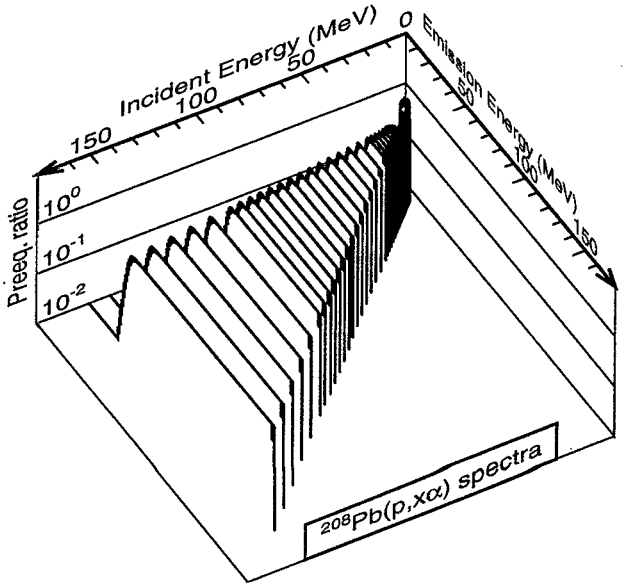
p + ^{208}Pb Kalbach preequilibrium ratios

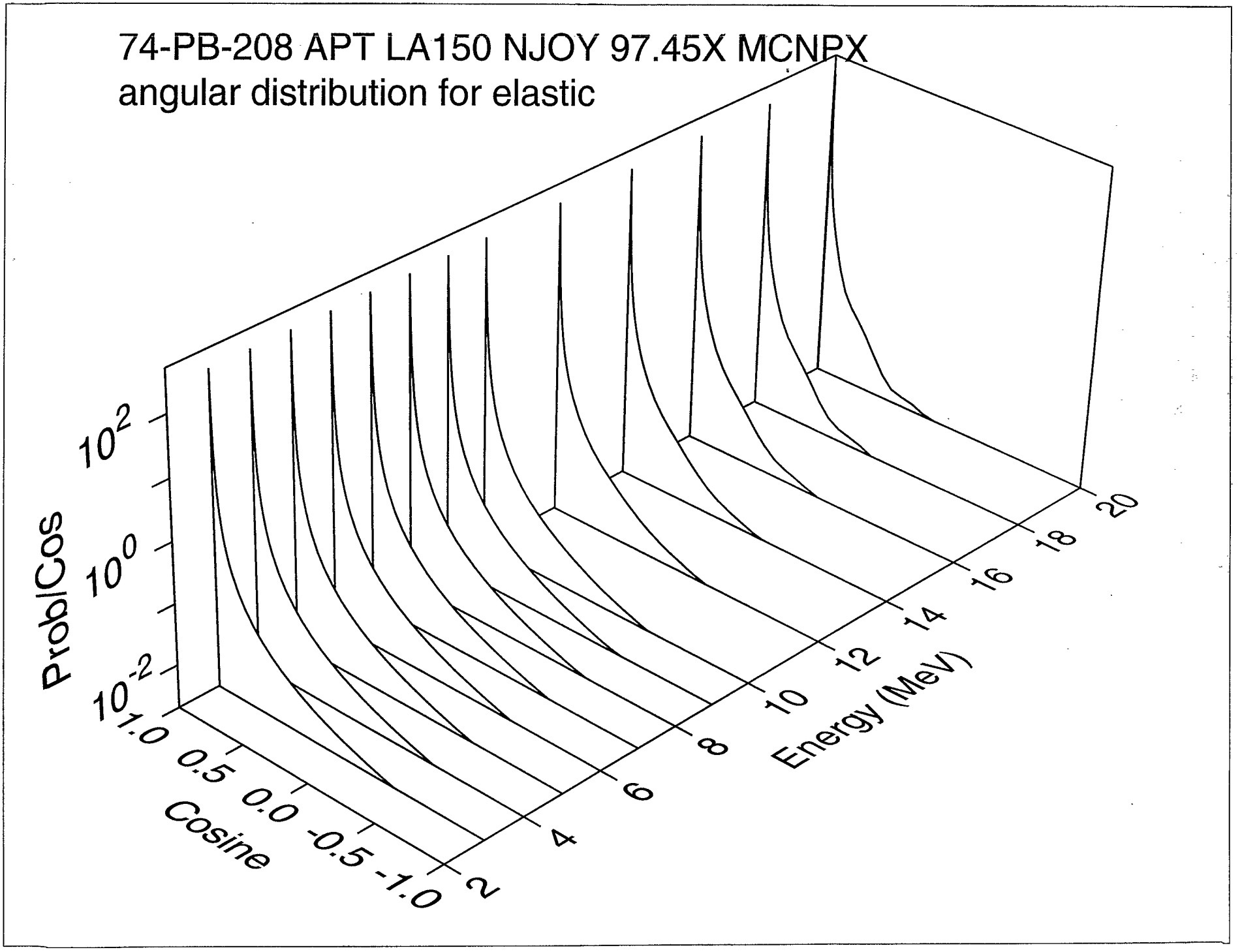


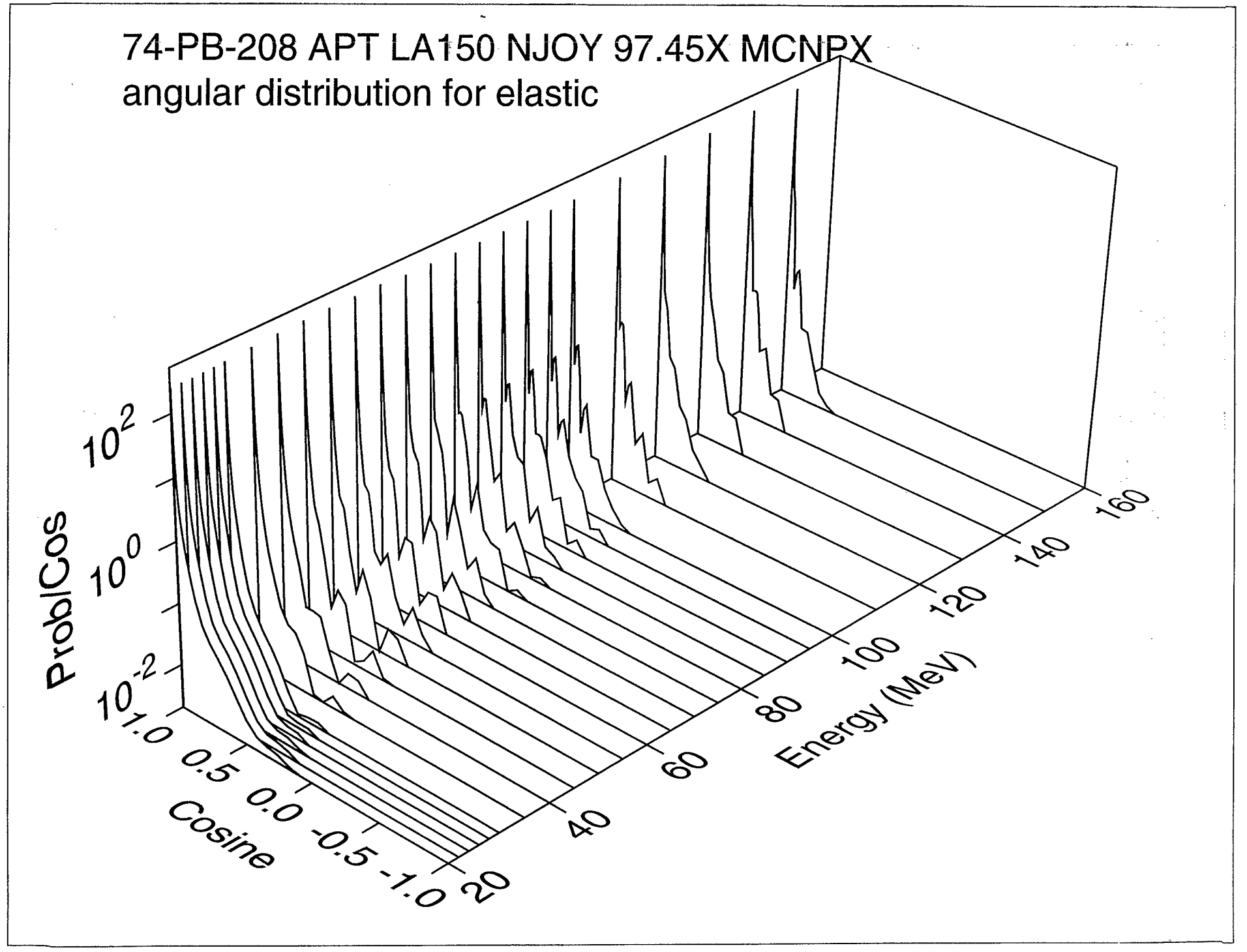


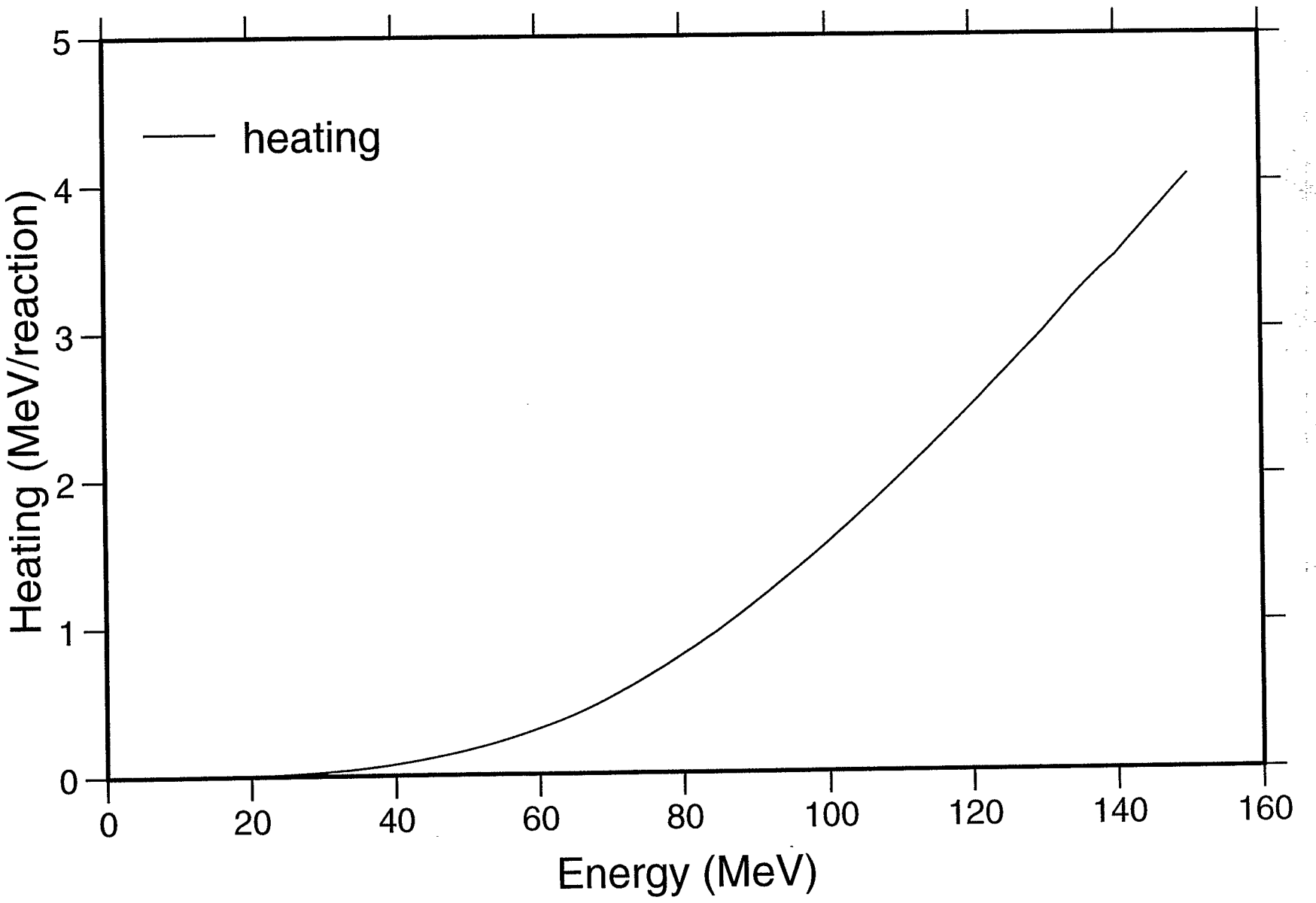







74-PB-208 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
ProbCos
10^{2}
10^{0}
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
2
4
6
8
10
12
14
16
18
20


74-PB-208 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
ProblCos
10^2
10^0
10^{-2}
1.0
0.5
0.0
-0.5
-1.0
Cosine
20
40
60
80
100
120
140
160
Energy (MeV)


74-PB-208 APT LA150 NJOY 97.45X MCNPX
Heating
heating
Heating (MeV/reaction)
Energy (MeV)
0
1
2
3
4
5
0
20
40
60
80
100
120
140
160