EVALUATION OF p + 14N CROSS SECTIONS FOR THE ENERGY RANGE 1 to 150 MeV

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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 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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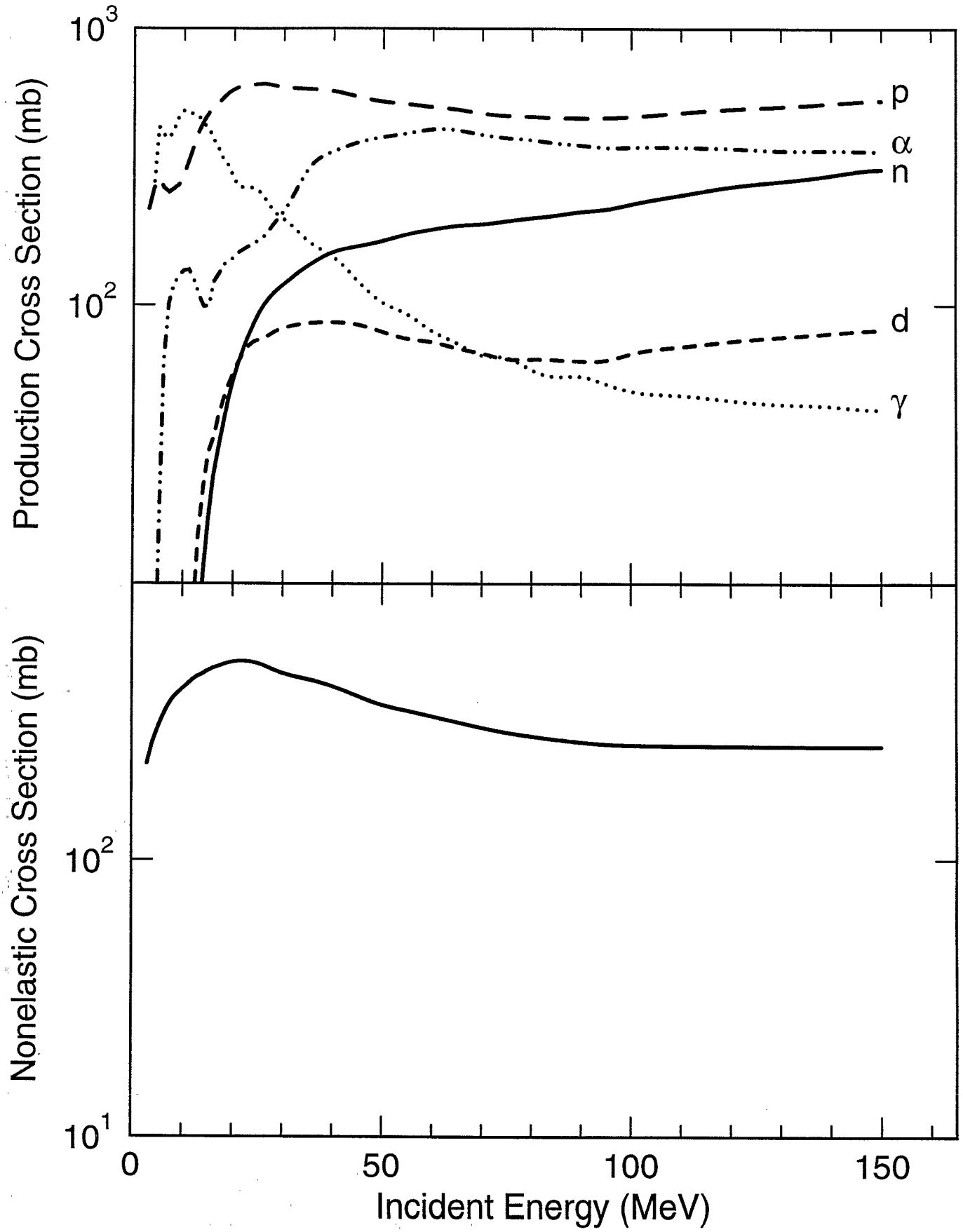
7014 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

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

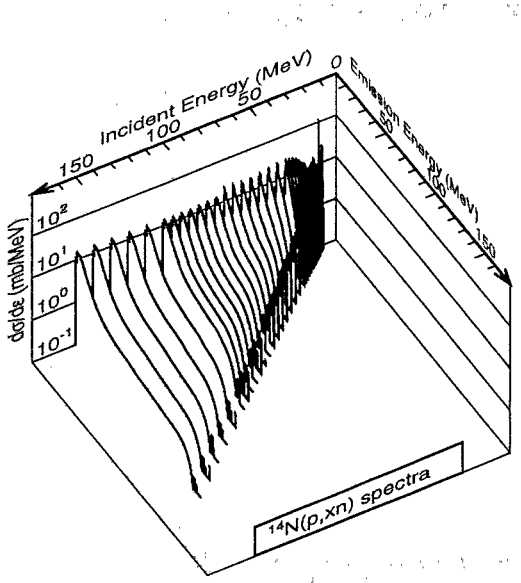
7014 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

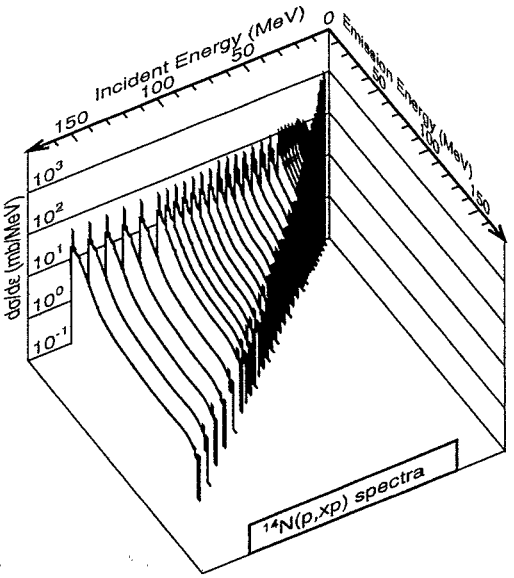
Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
3.000E+00	0.000E+00	4.949E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.250E+00
4.000E+00	0.000E+00	1.452E+00	0.000E+00	0.000E+00	0.000E+00	6.426E-01	2.250E+00
5.000E+00	0.000E+00	1.367E+00	0.000E+00	0.000E+00	0.000E+00	1.411E+00	2.099E+00
6.000E+00	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

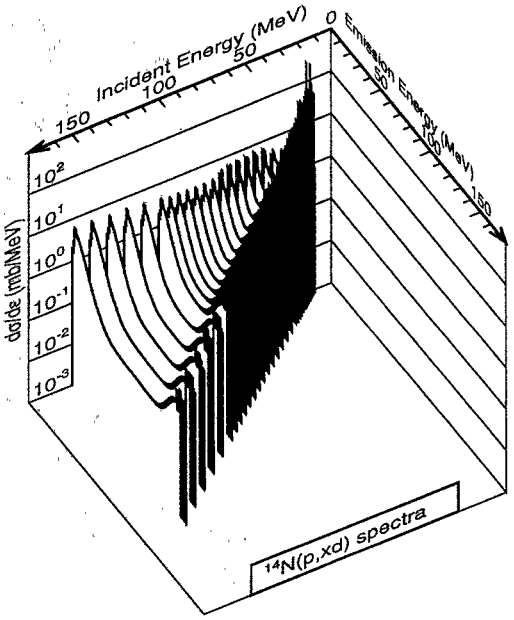
4.000E+01	7.051E+00	1.109E+01	1.444E+01	0.000E+00	0.000E+00	4.375E+00	3.111E+00
4.500E+01	8.135E+00	1.217E+01	1.676E+01	0.000E+00	0.000E+00	4.428E+00	3.153E+00
5.000E+01	9.188E+00	1.319E+01	1.909E+01	0.000E+00	0.000E+00	4.543E+00	3.243E+00
5.500E+01	1.031E+01	1.436E+01	2.108E+01	0.000E+00	0.000E+00	4.724E+00	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

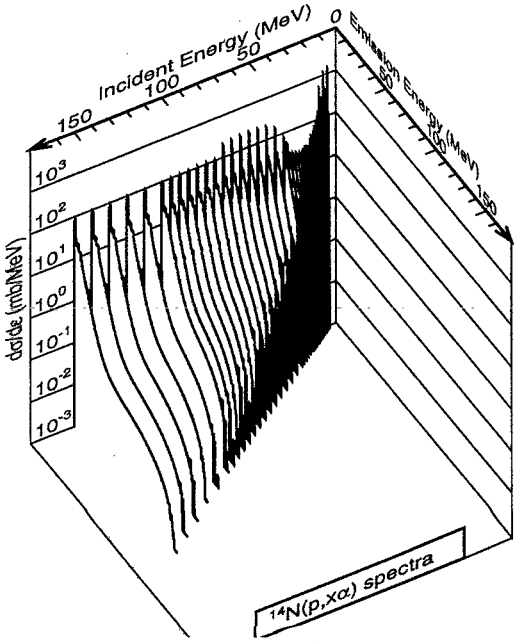

p + 14N nonelastic and production cross sections
Production Cross Section (mb)
10^3
10^2
p
α
n
d
γ
Nonelastic Cross Section (mb)
10^2
10^1
0
50
100
150
Incident Energy (MeV)

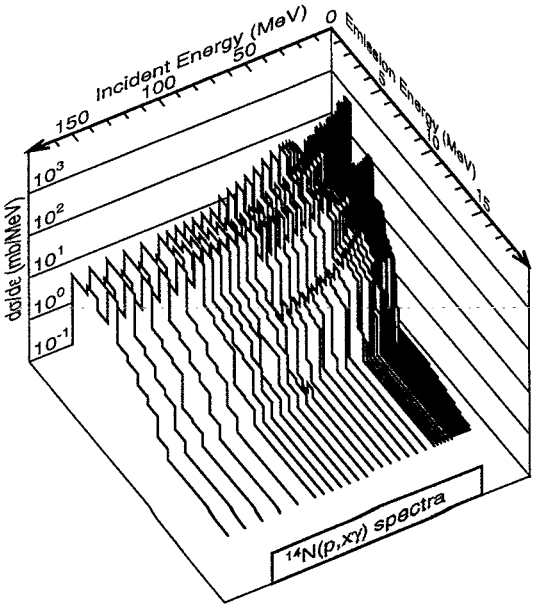
p + ^{14}N angle-integrated emission spectra



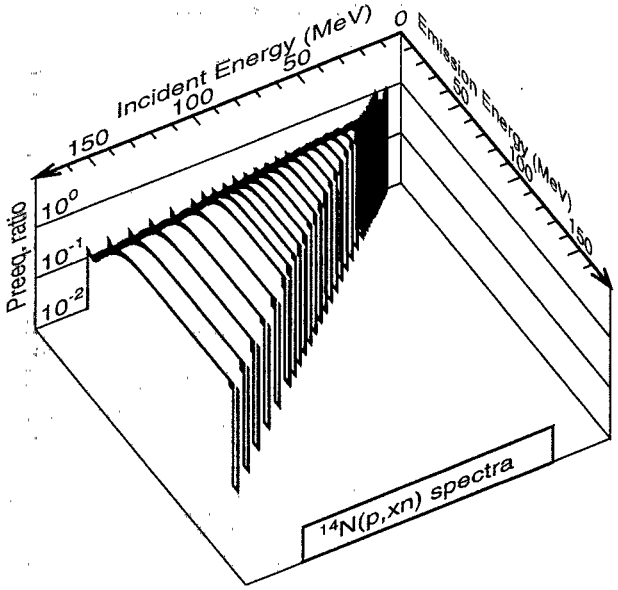


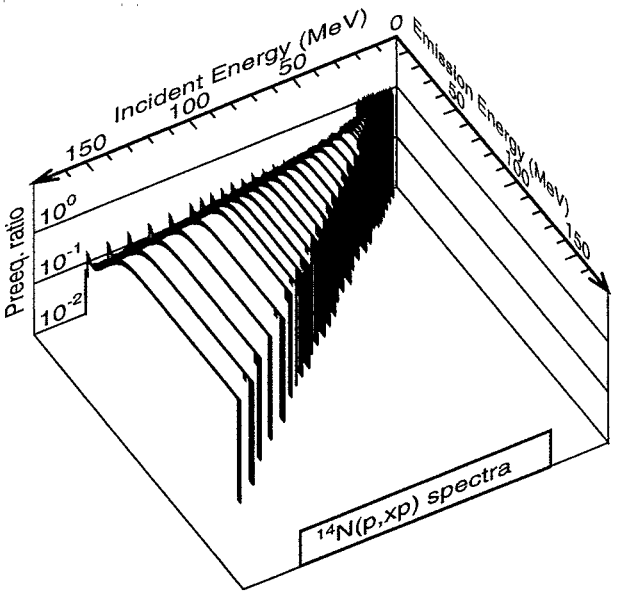


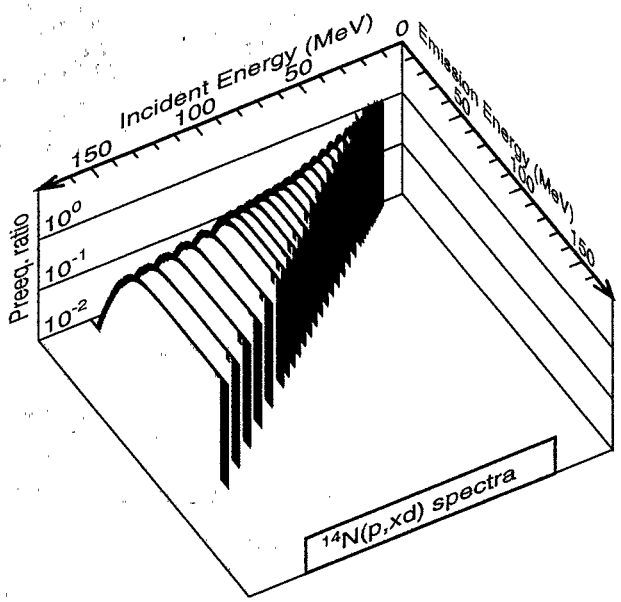


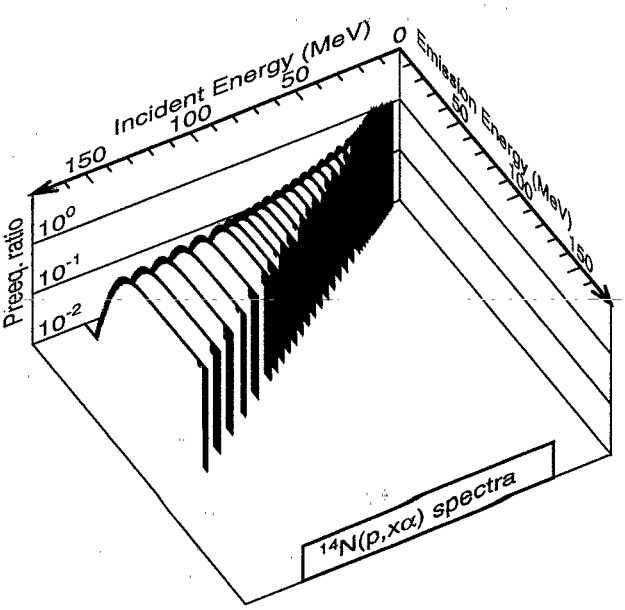


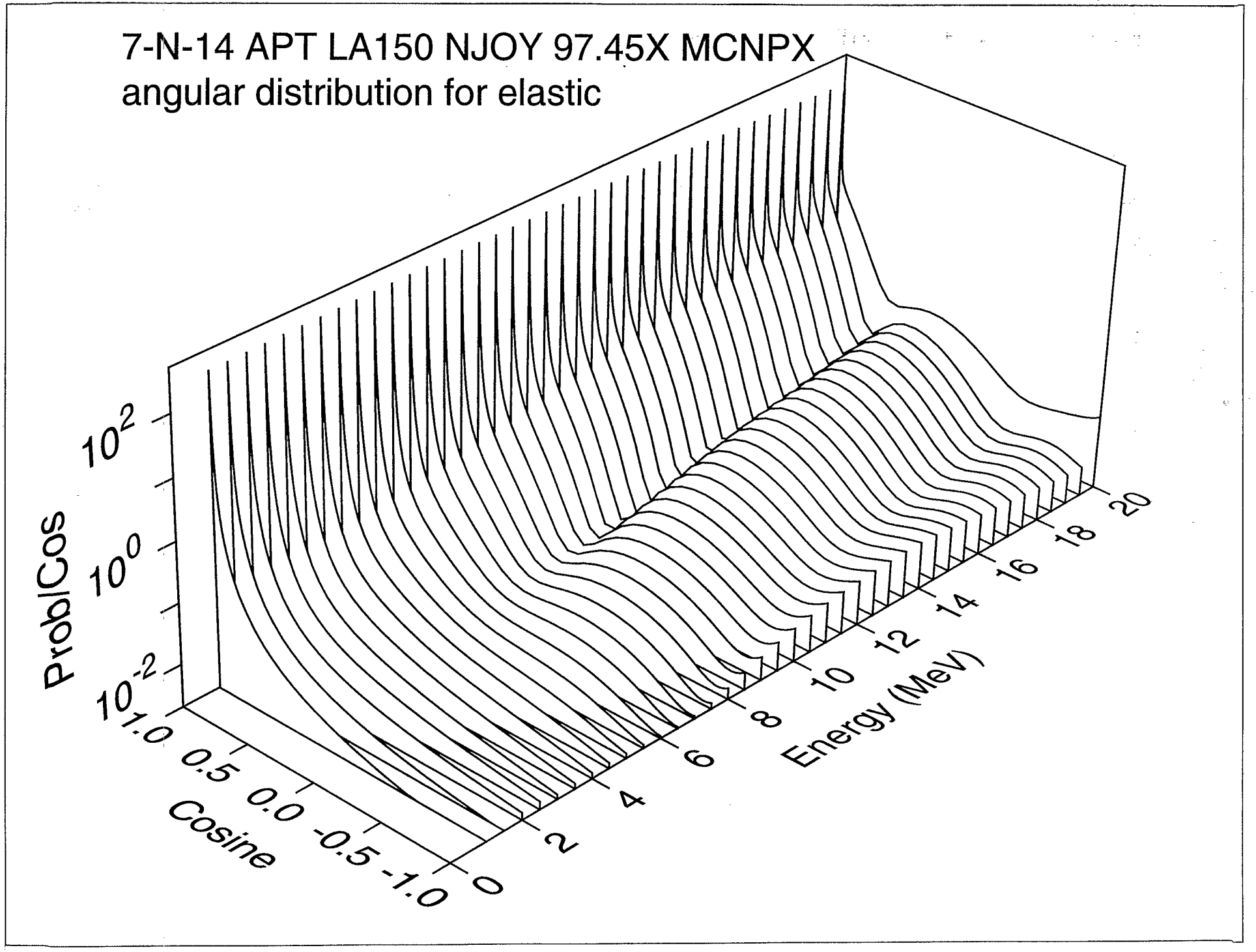
p + ^{14}N Kalbach preequilibrium ratios

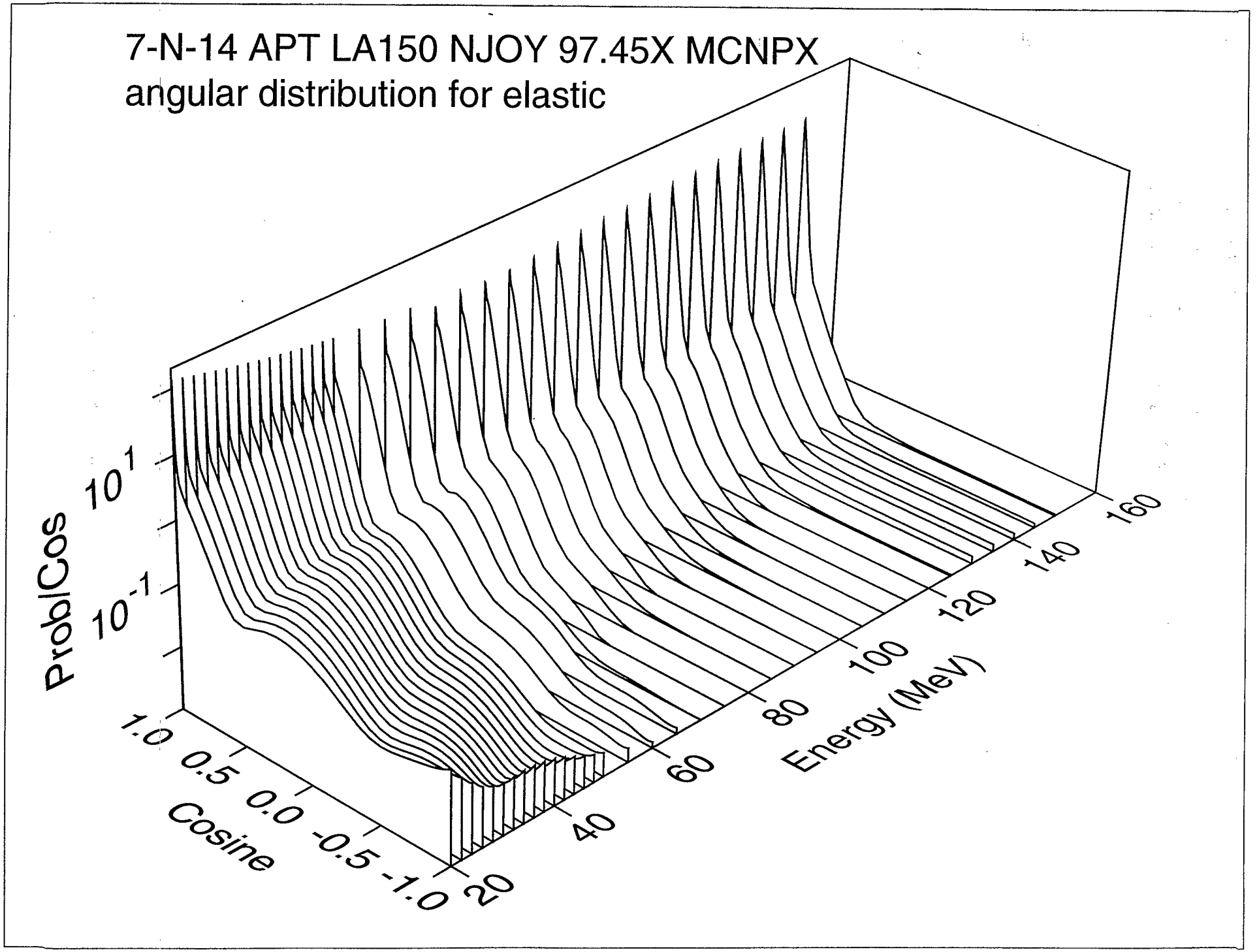


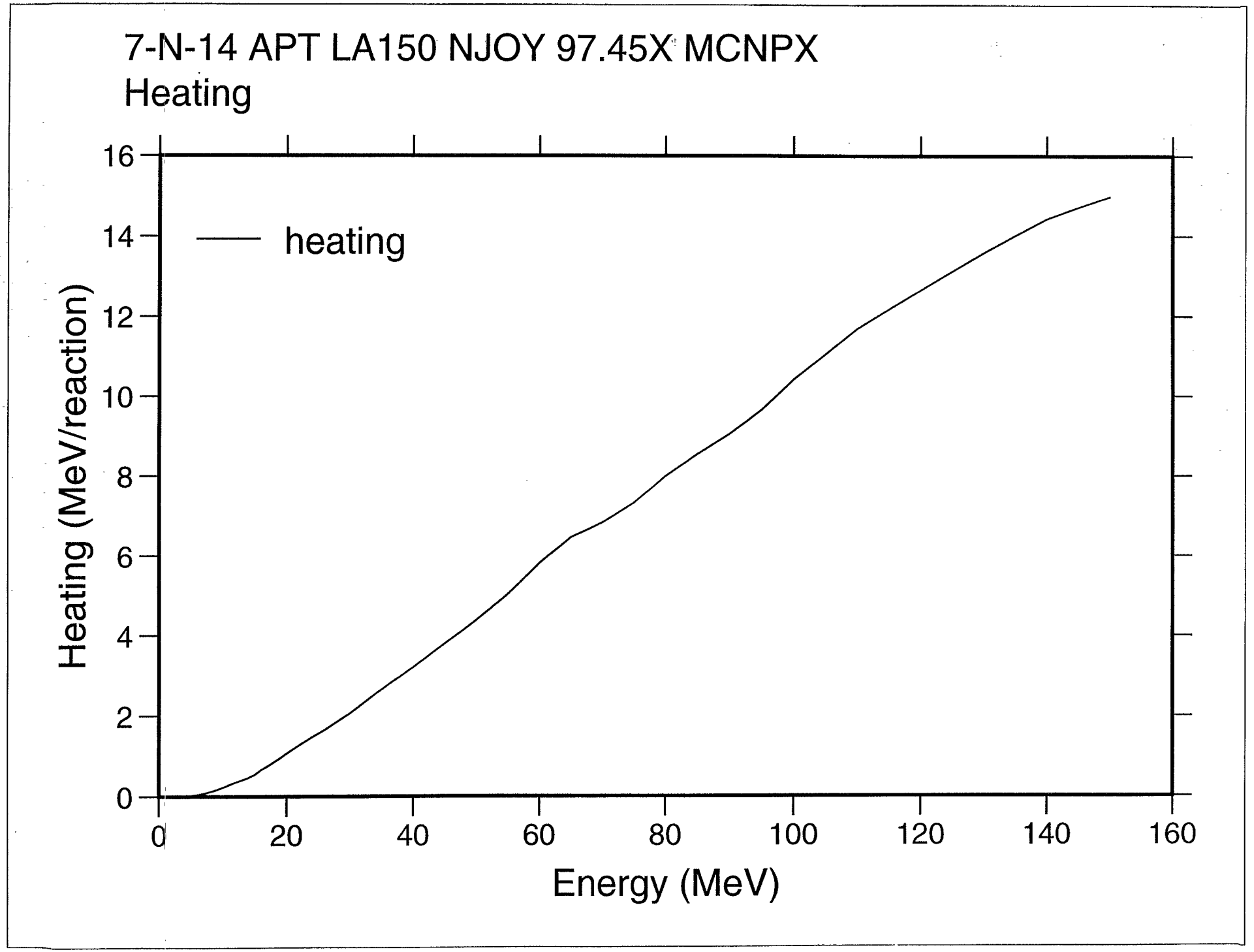







7-N-14 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
Prob/Cos
10^2
10^0
10^{-2}
1.0
0.5
0.0
-0.5
-1.0
Cosine
0
2
4
6
8
10
12
14
16
18
20
Energy (MeV)


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