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

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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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REFERENCES

[Ar80]. E.D. Arthur and P.G. Young, 'Evaluation of Neutron Cross Sections to 40 MeV for 54,56Fe," Proc. Sym. on Neutron Cross Sections from 10 to 50 MeV, 12-14 May 1980, Brookhaven National Laboratory [Eds. M. R. Bhat and S. Pearlstein, BNL-NCS-51245, 1980] p. 731.

[Be69]. F.D. Becchetti, Jr., and G.W. Greenlees, Phys. Rev. 182, 1190 (1969).

[Be71]. F.D. Becchetti, Jr., and G.W. Greenlees in "Polarization Phenomena in Nuclear Reactions," (Ed: H.H. Barschall and W. Haeberli, The University of Wisconsin Press, 1971) p.682.

[Be92]. O. Bersillon, "SCAT2 - A Spherical Optical Model Code," in Proc. ICTP Workshop on Computation and Analysis of Nuclear Data Relevant to Nuclear Energy and Safety, 10 February-13 March, 1992, Trieste, Italy, to be published in World Scientific Press, and Progress Report of the Nuclear Physics Division, Bruyeres-le-Chatel 1977, CEA-N-2037, p.111 (1978).

[Be97]. S. Benck, I. Slypen, V. Corcalciuc, J. P. Meulders, M. B. Chadwick, P. G. Young, and A. J. Koning, to be submitted to Physical Review, 1997; S. Benck, Ph.D. thesis at Louvain-la-Neuve, Belgium (1997).

[Ch93]. M. B. Chadwick and P. G. Young, "Feshbach-Kerman-Koonin Analysis of 93Nb Reactions: P --> Q Transitions and Reduced Importance of Multistep Compound Emission," Phys. Rev. C 47, 2255 (1993).

[Ch96]. M. B. Chadwick, P. G. Young, R. E. MacFarlane, and A. J. Koning, "High-Energy Nuclear Data Libraries for Accelerator-Driven Technologies: Calculational Method for Heavy Recoils," Proc. of 2nd Int. Conf. on Accelerator Driven Transmutation Technology and Applications, Kalmar, Sweden, 3-7 June 1996.

[Ch97]. M. B. Chadwick and P. G. Young, "GNASH Calculations of n,p + 27Al and Benchmarking of Results" in APT PROGRESS REPORT: 1 January - 1 February 1997, internal Los Alamos National Laboratory memo T-2-97/MS-52, 6 Feb.1997 from R.E. MacFarlane to L. Waters.

[Co67]. J. L. Cook, H. Ferguson, and A. R. Musgrove, "Nuclear Level Densities in Intermediate and Heavy Nuclei," Aust.J.Phys. 20, 477 (1967).

[Fi93]. R. W. Finley, W. P. Abfalterer, G. Fink, E. Montei, T. Adami, P. W. Lisowski, G. L. Morgan, and R. C. Haight, Phys. Rev. C 47, 237 (1993).

[Ig75]. A. V. Ignatyuk, G. N. Smirenkin, and A. S. Tishin, "Phenomenological Description of the Energy Dependence of the Level Density Parameter," Sov. J. Nucl. Phys. 21, 255 (1975).

[Ka77]. C. Kalbach, "The Griffin Model, Complex Particles and Direct Nuclear Reactions," Z.Phys.A 283, 401 (1977).

[Ka85]. C. Kalbach, "PRECO-D2: Program for Calculating Preequilibrium and Direct Reaction Double Differential Cross Sections," Los Alamos National Laboratory report LA-10248-MS (1985).

[Ka88]. C. Kalbach, "Systematics of Continuum Angular 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).

[Ko90]. J. Kopecky and M. Uhl, "Test of Gamma-Ray Strength Functions in Nuclear Reaction Model Calculations," Phys.Rev.C 42, 1941 (1990).

[Le72]. O. F. Lemos, "Diffusion Elastique de Particules Alpha de 21 a 29.6 MeV sur des Noyaux de la Region Ti-Zn," Orsay report, Series A, No. 136 (1976).

[Ma88]. D.G. Madland, "Recent Results in the Development of a Global Medium-Energy Nucleon-Nucleus Optical-Model Potential," Proc. OECD/NEANDC Specialist's Mtg. on Preequilibrium Nuclear Reactions, Semmering, Austria, 10-12 Feb. 1988, NEANDC-245 'U' (1988).

[Pe63]. C. M. Perey and F. G. Perey, Phys. Rev. 132, 755 (1963).

[Pe85]. J. S. Petler, M. S. Islam, and R. W. Finlay, "Microscopic Optical Model Analysis of Nucleon Scattering from Light Nuclei," Phys. Rev. C 32, 673 (1985).

[Vo94]. H. Vonach, A. Pavlik, M. B. Chadwick, R. C. Haight, R. O. Nelson, S. A. Wender, and P. G. Young, "207,208Pb(n,xng) Reactions for Neutron Energies up to 200 MeV," Phys. Rev. C 50, 1952 (1994).

[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).

[Yo94]. P. G. Young, "Evaluation of n + 27Al Cross Sections for the Energy Range 10-5 eV to 40 MeV," ENDF/B-VI Release 3 evaluation, Nov., 1994.

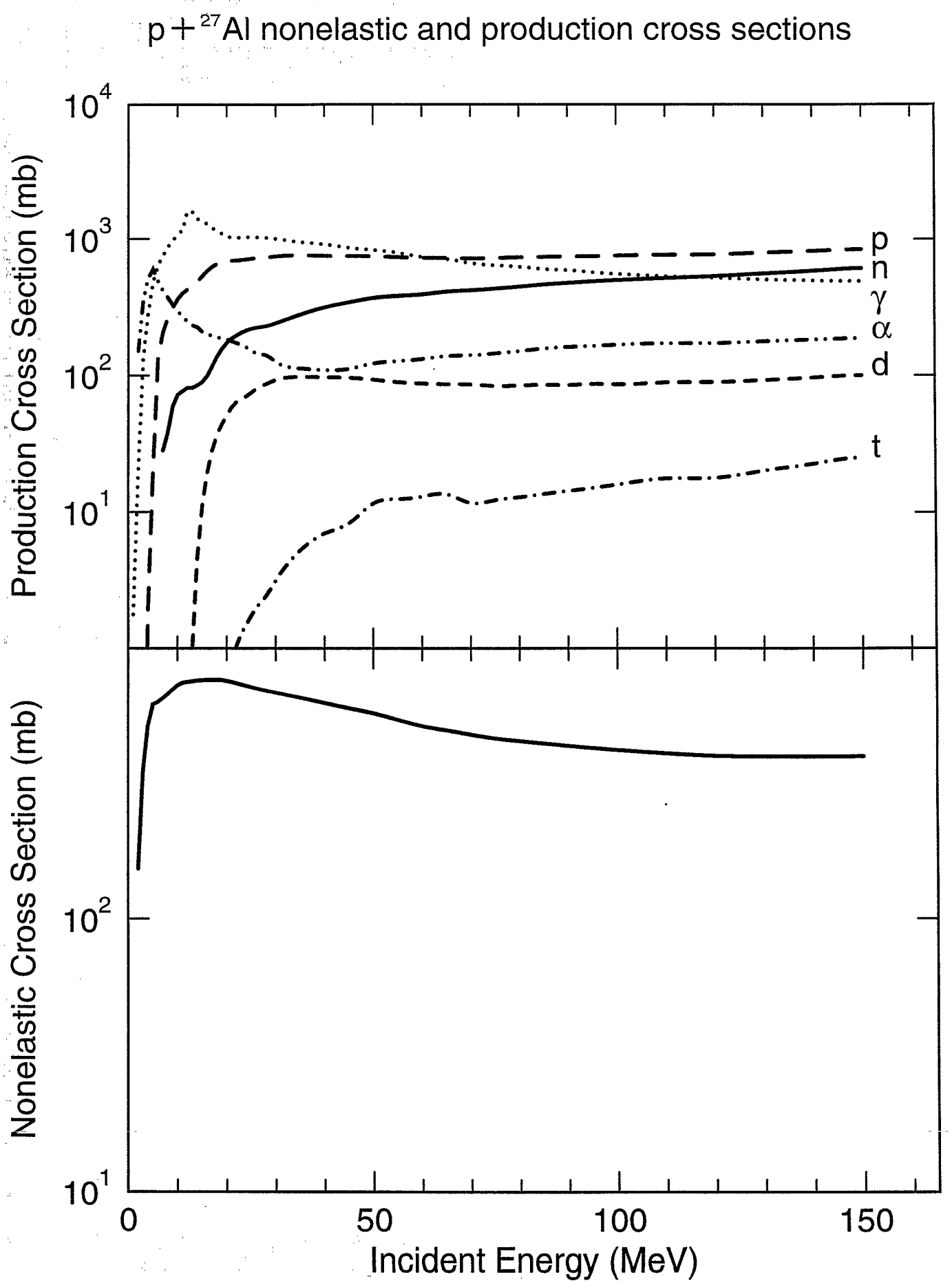
13027 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

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

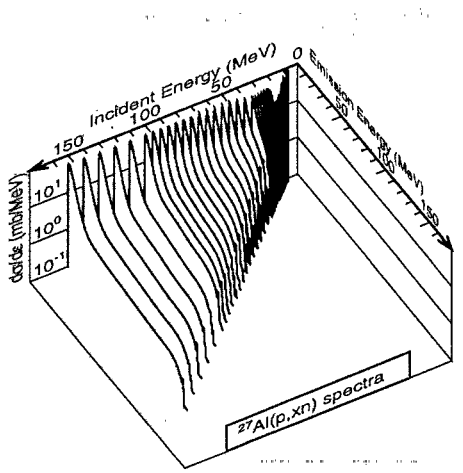
13027 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

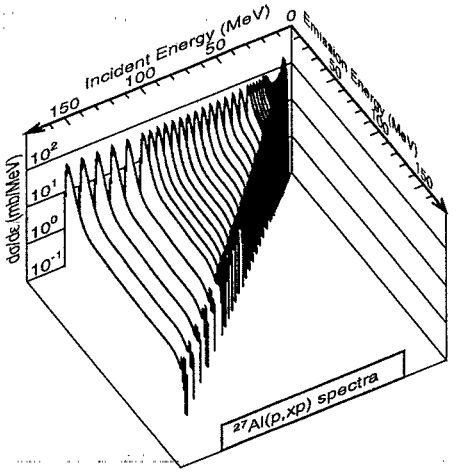
Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
1.000E+00	0.000E+00	1.297E-03	0.000E+00	0.000E+00	0.000E+00	5.188E-03	5.000E-12
2.000E+00	0.000E+00	9.775E-01	0.000E+00	0.000E+00	0.000E+00	2.942E+00	1.762E+00
3.000E+00	0.000E+00	1.135E+00	0.000E+00	0.000E+00	0.000E+00	3.479E+00	1.314E+00
4.000E+00	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

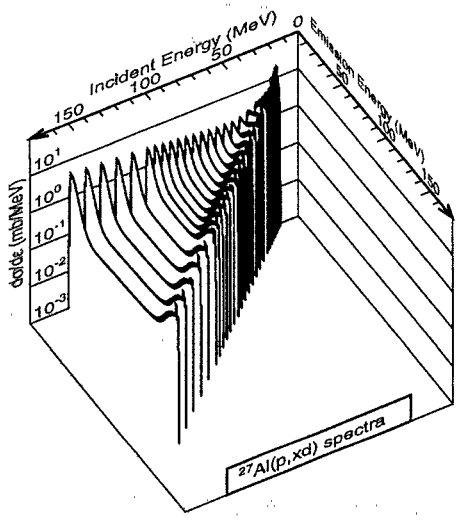
2.600E+01	4.930E+00	8.950E+00	9.168E+00	5.078E+00	0.000E+00	7.700E+00	2.301E+00
2.800E+01	5.504E+00	9.496E+00	1.033E+01	5.760E+00	0.000E+00	7.974E+00	2.277E+00
3.000E+01	5.932E+00	1.004E+01	1.152E+01	6.338E+00	0.000E+00	8.336E+00	2.253E+00
3.500E+01	6.933E+00	1.118E+01	1.451E+01	7.664E+00	0.000E+00	8.721E+00	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

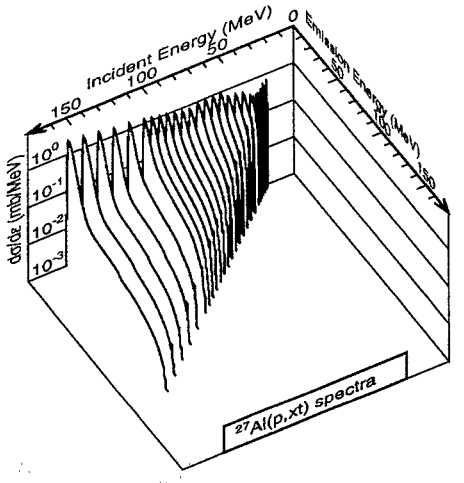

p + 27Al nonelastic and production cross sections
Production Cross Section (mb)
10^4
10^3
10^2
10^1
p
n
γ
α
d
t
Nonelastic Cross Section (mb)
10^2
10^1
0
50
100
150
Incident Energy (MeV)

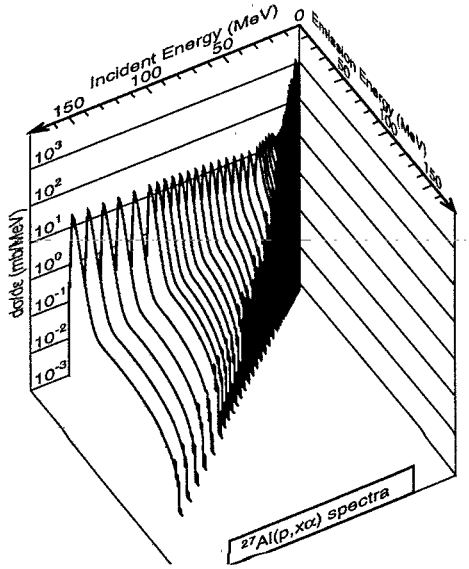
p + ^{27}Al angle-integrated emission spectra

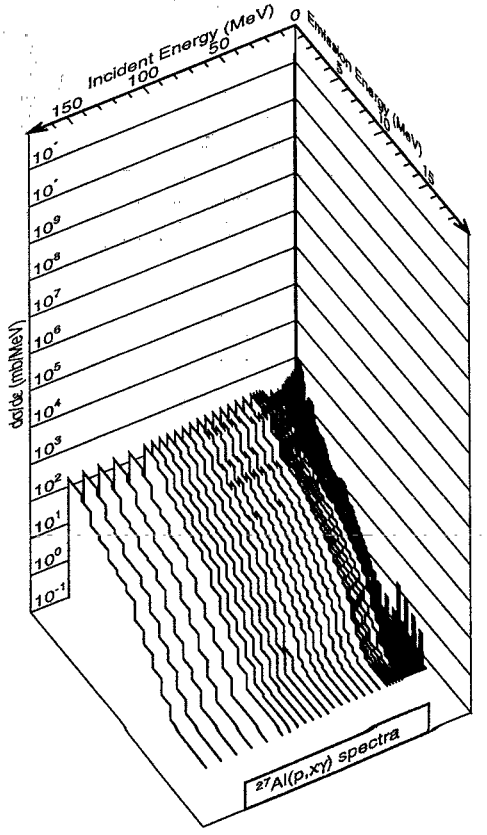




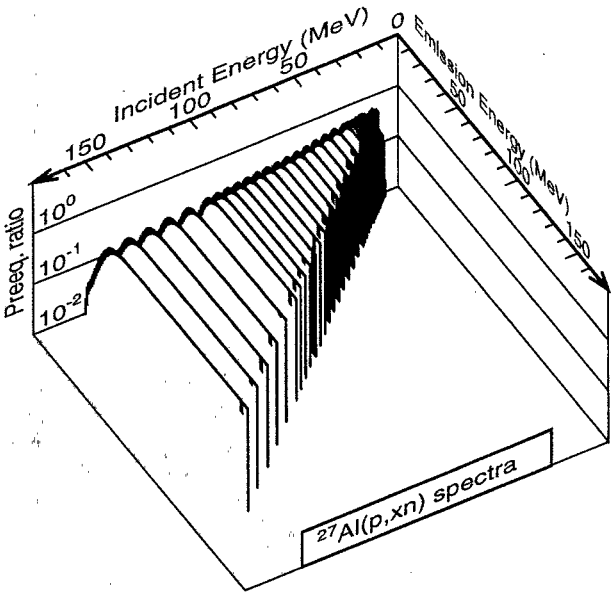


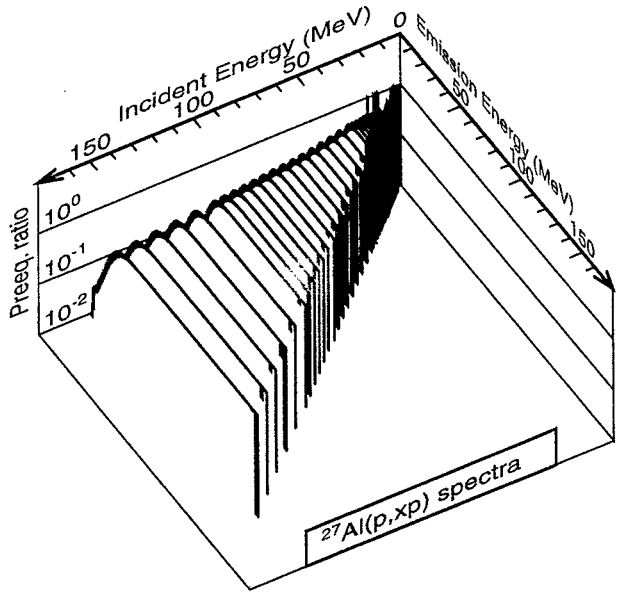


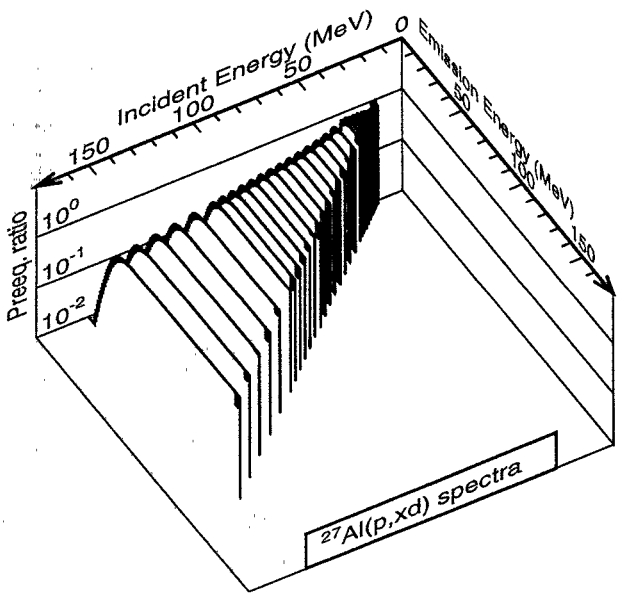


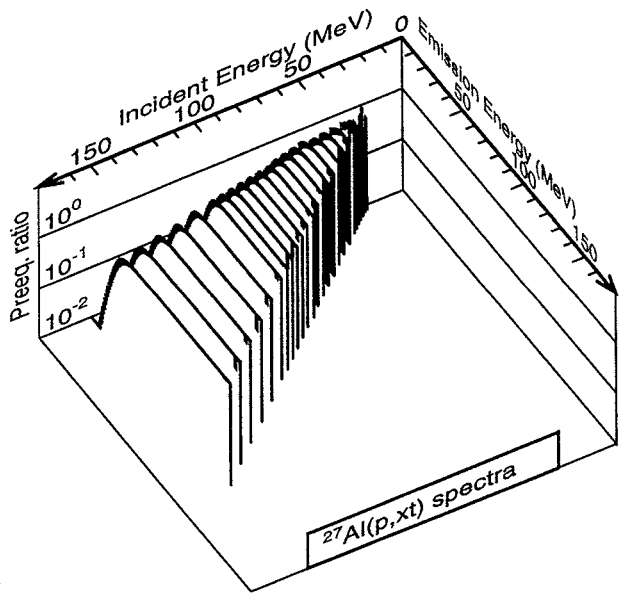


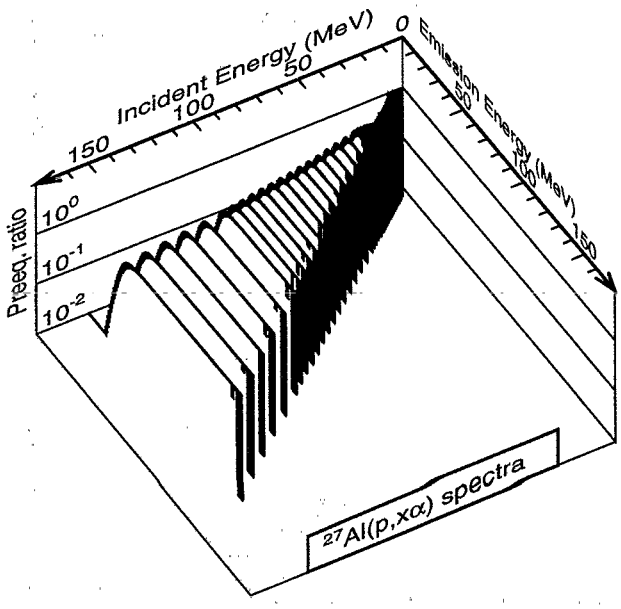
p + ^{27}Al Kalbach preequilibrium ratios

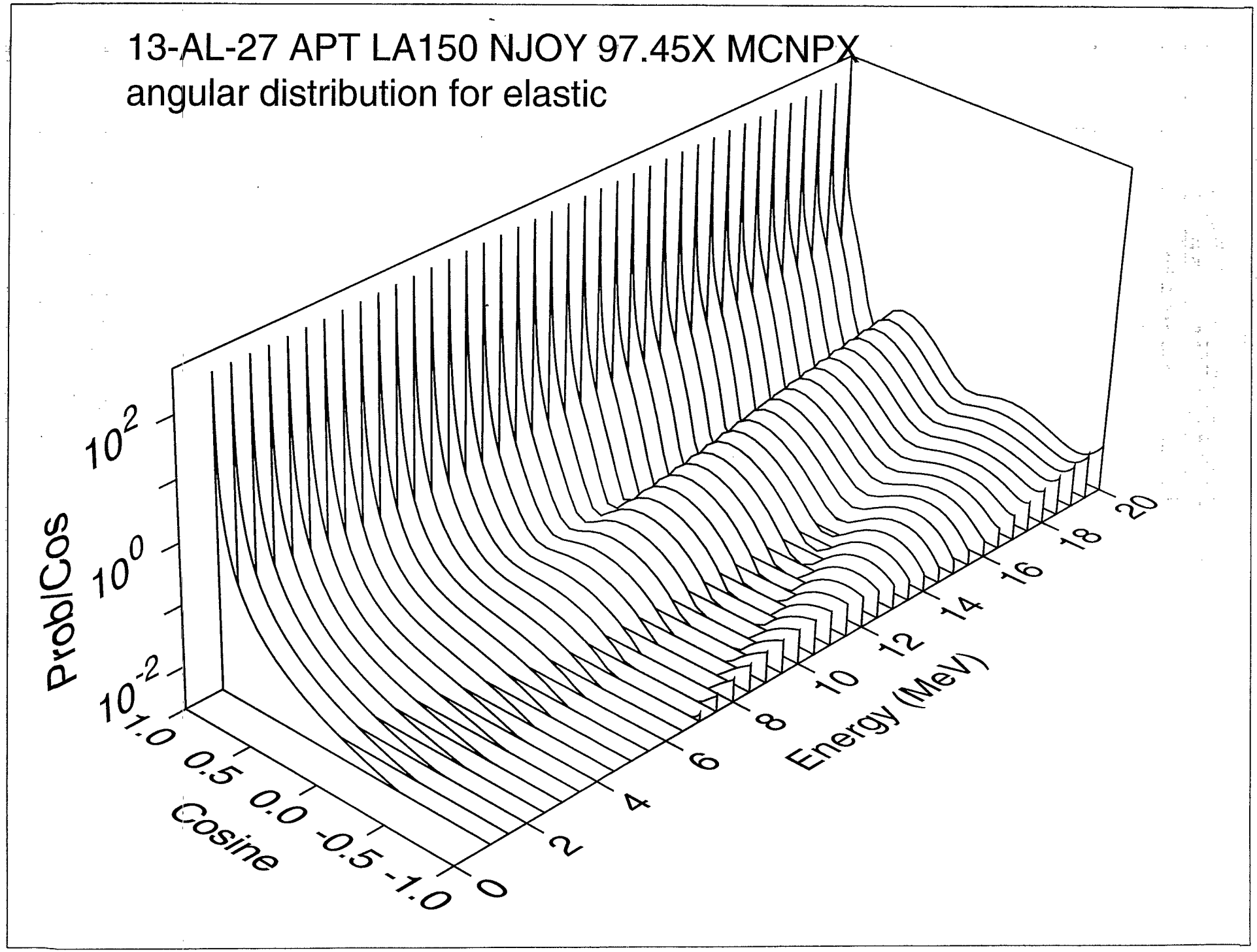


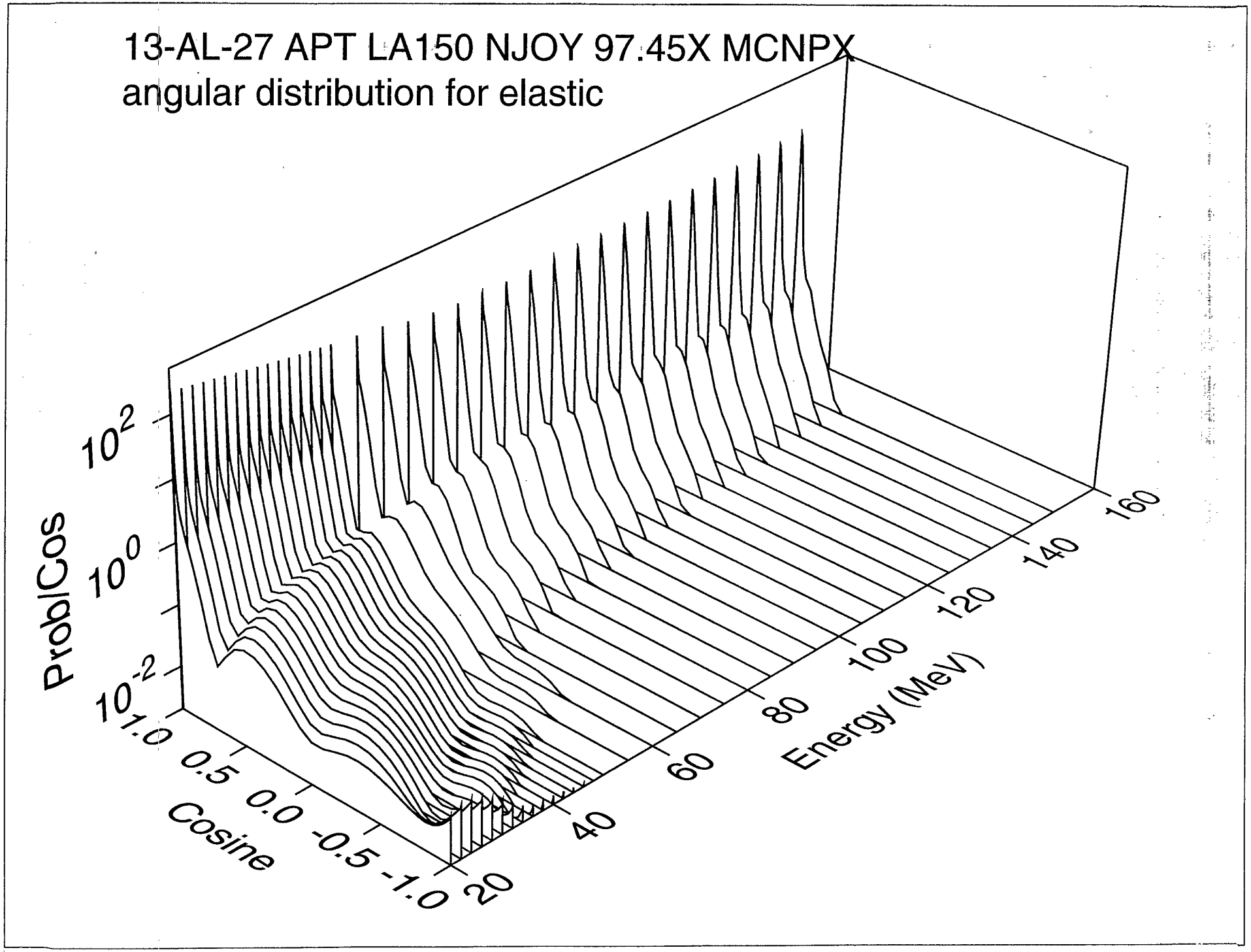


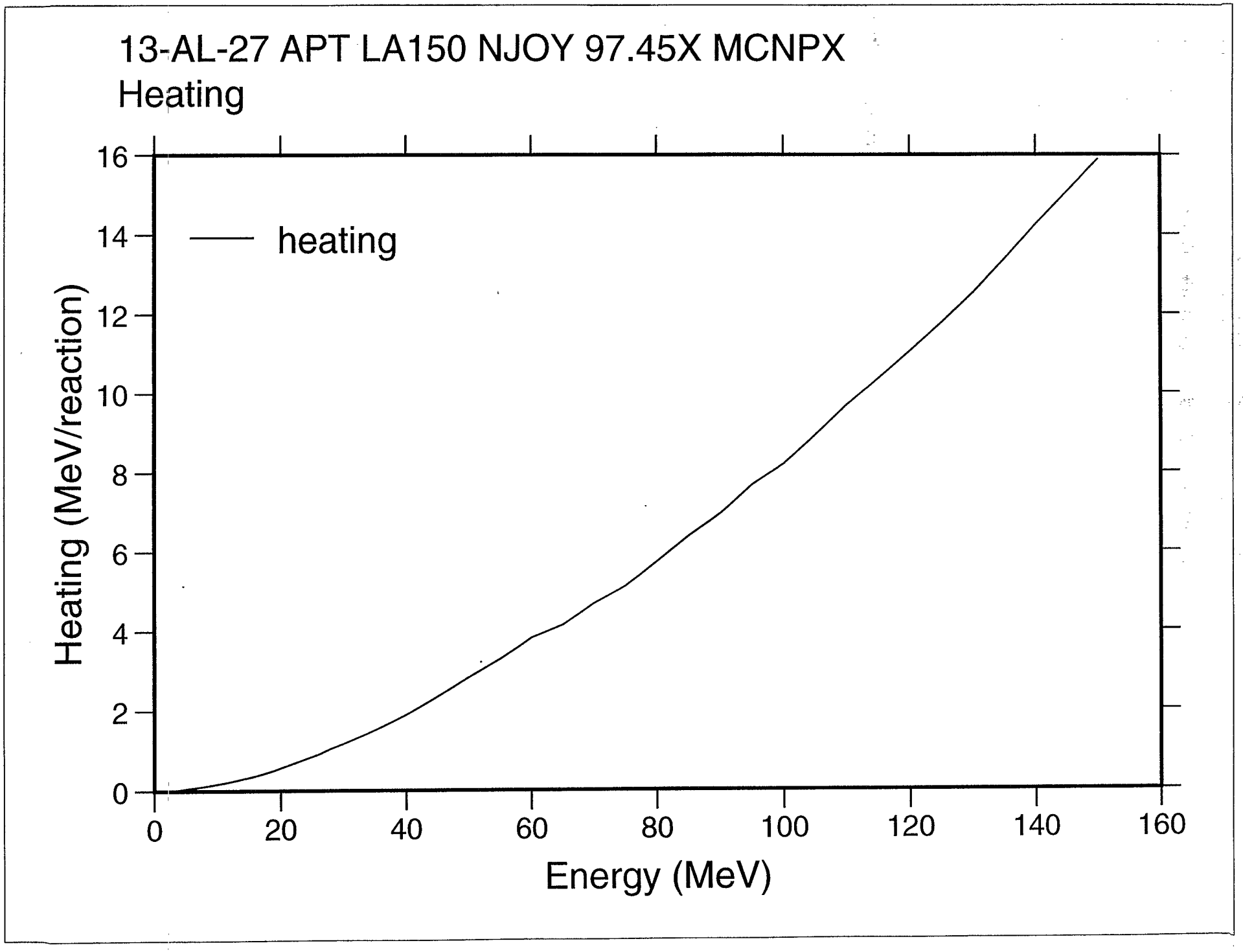







13-AL-27 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
ProblCos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
0
2
4
6
8
10
12
14
16
18
20


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