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

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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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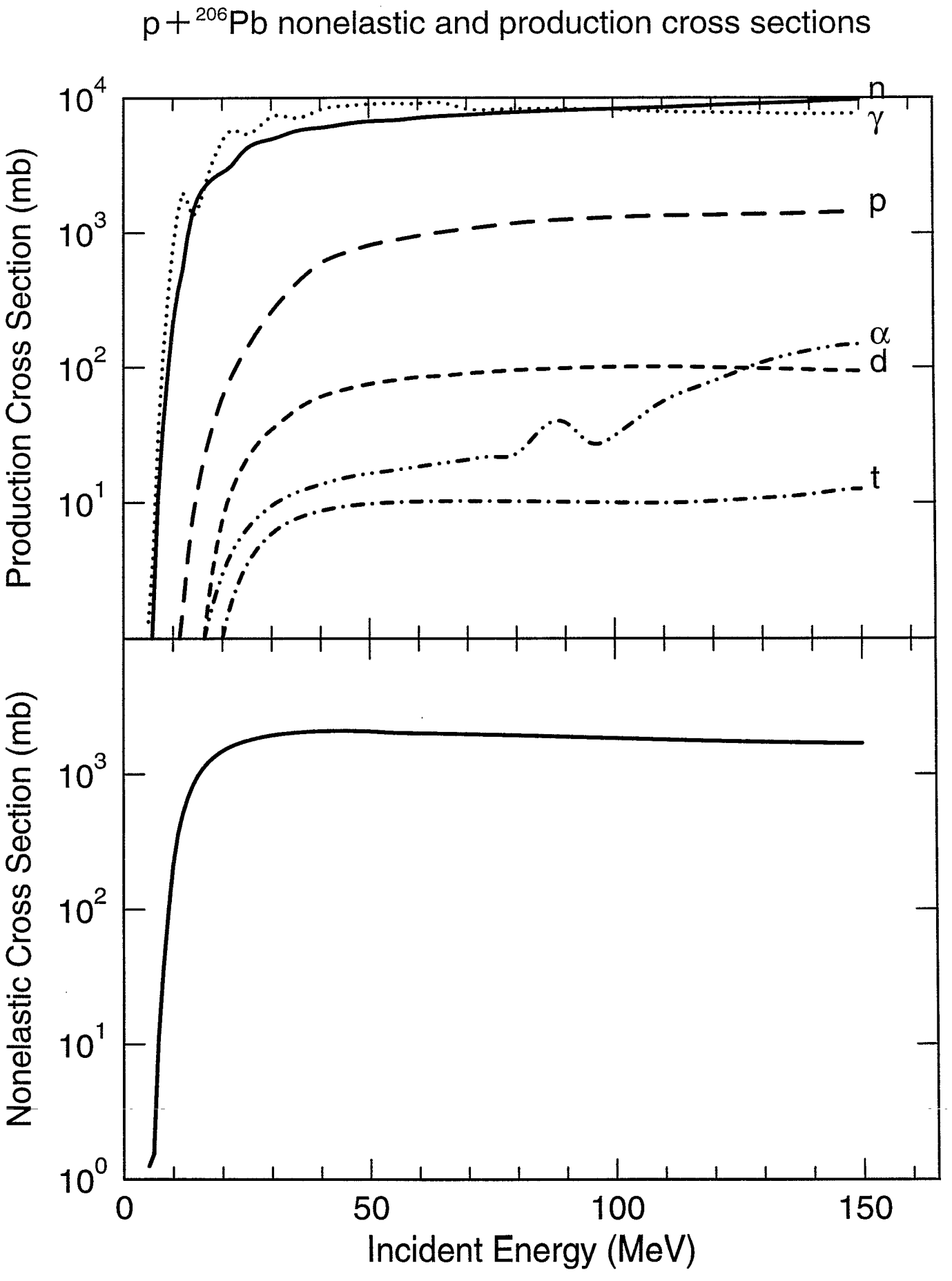
82206 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Nonelastic, elastic, and Production cross sections for A<5 ejectiles in barns:

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

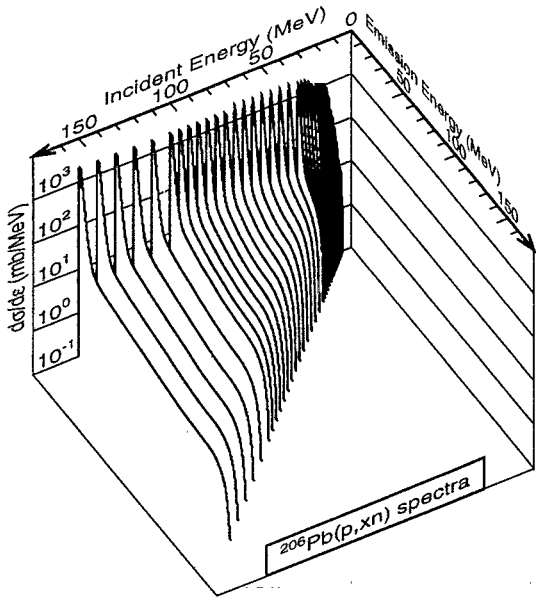
82206 = TARGET 1000Z+A (if A=0 then elemental)
1001 = PROJECTILE 1000Z+A
Aver. lab emission energies for A<5 ejectiles in MeV:

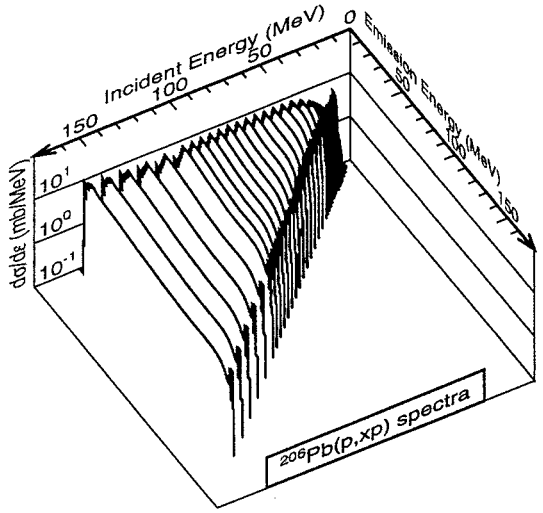
Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
4.000E+00	0.000E+00	3.191E+00	0.000E+00	0.000E+00	0.000E+00	1.043E+01	3.663E+00
5.000E+00	2.290E-01	4.142E+00	0.000E+00	0.000E+00	0.000E+00	1.086E+01	2.875E-01
6.000E+00	8.766E-01	4.937E+00	0.000E+00	0.000E+00	0.000E+00	1.168E+01	2.799E-01
7.000E+00	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

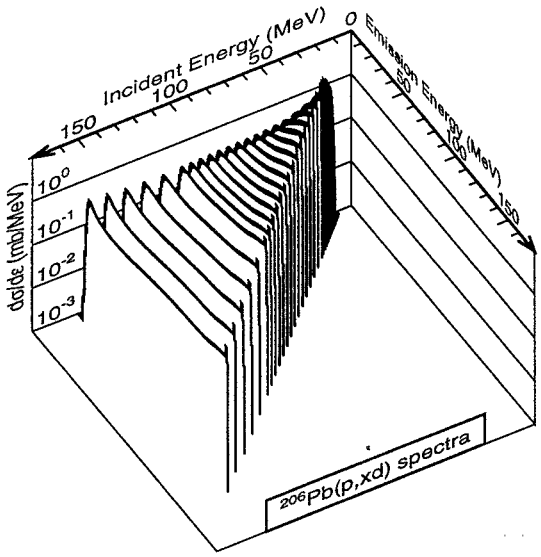
5.000E+01	3.504E+00	2.742E+01	3.179E+01	2.514E+01	0.000E+00	3.126E+01	1.143E+00
5.500E+01	3.791E+00	2.962E+01	3.494E+01	2.727E+01	0.000E+00	3.244E+01	1.148E+00
6.000E+01	4.037E+00	3.164E+01	3.804E+01	2.930E+01	0.000E+00	3.347E+01	1.141E+00
6.500E+01	4.297E+00	3.357E+01	4.077E+01	3.125E+01	0.000E+00	3.428E+01	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

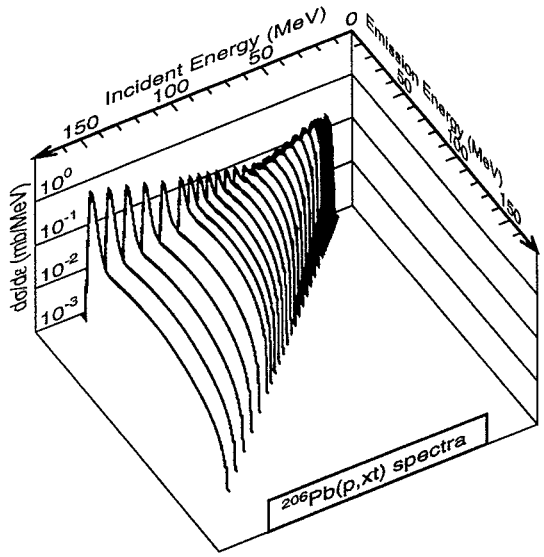

p + 206Pb nonelastic and production cross sections
Production Cross Section (mb)
Nonelastic Cross Section (mb)
Incident Energy (MeV)
n
γ
p
α
d
t
10^4
10^3
10^2
10^1
10^0
0
50
100
150

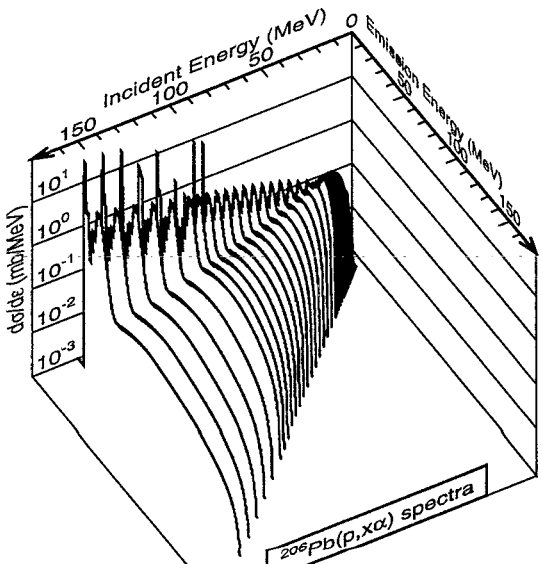
p + ^{206}Pb angle-integrated emission spectra

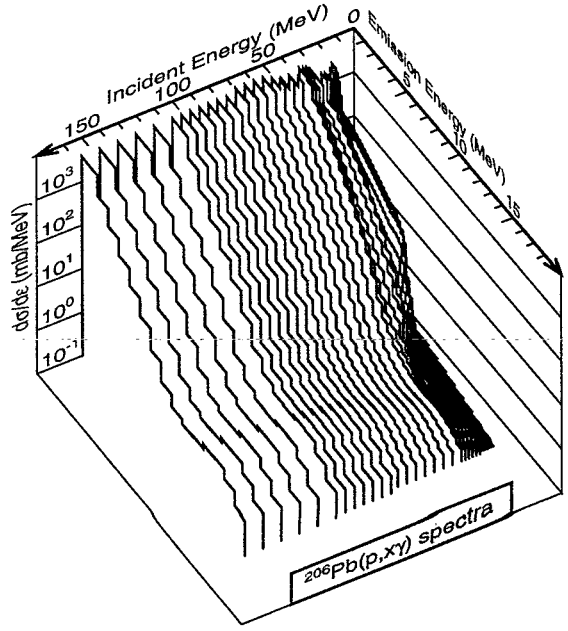




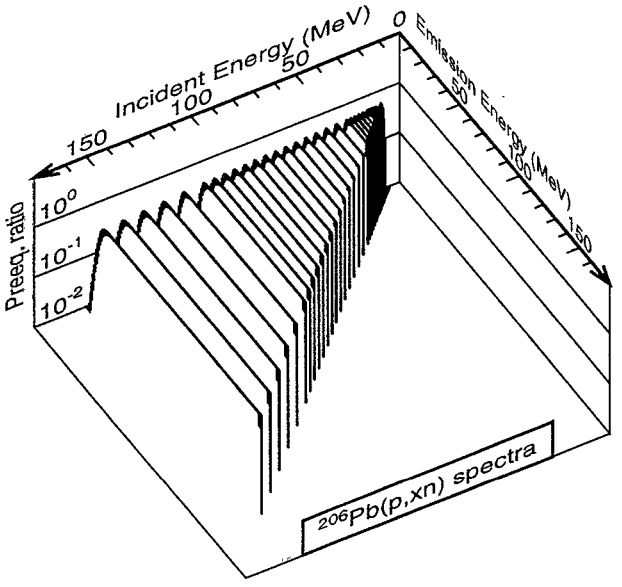


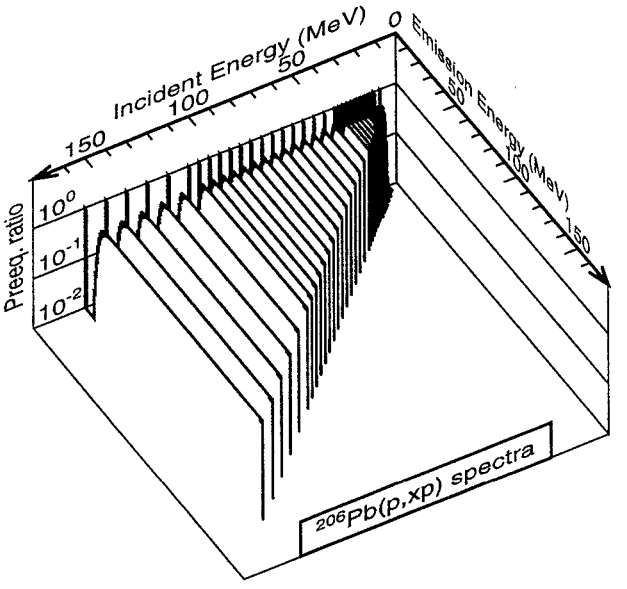


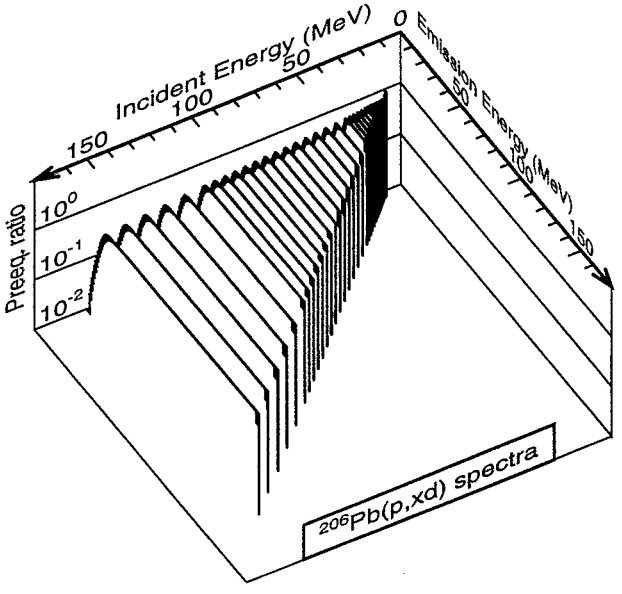


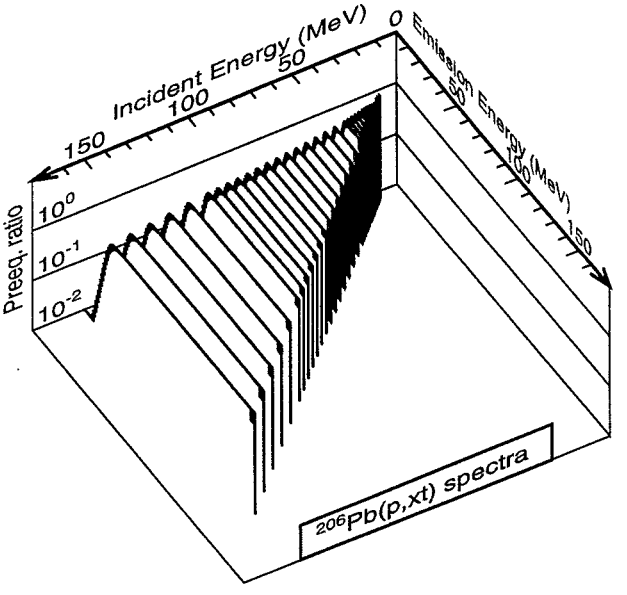


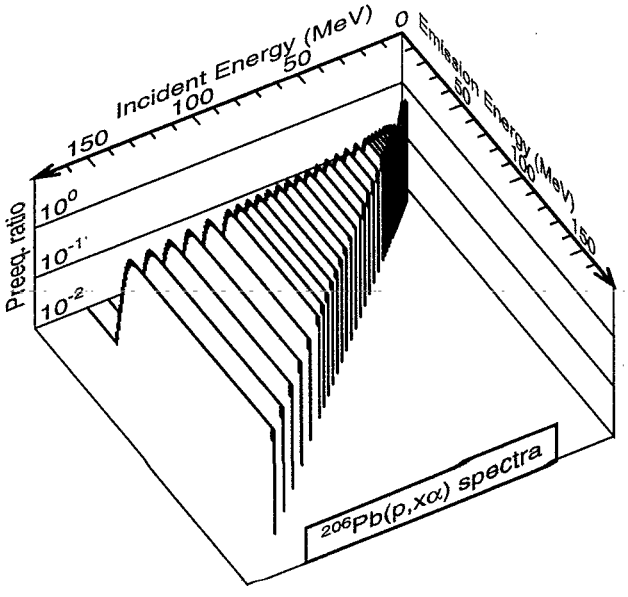
p + ^{206}Pb Kalbach preequilibrium ratios

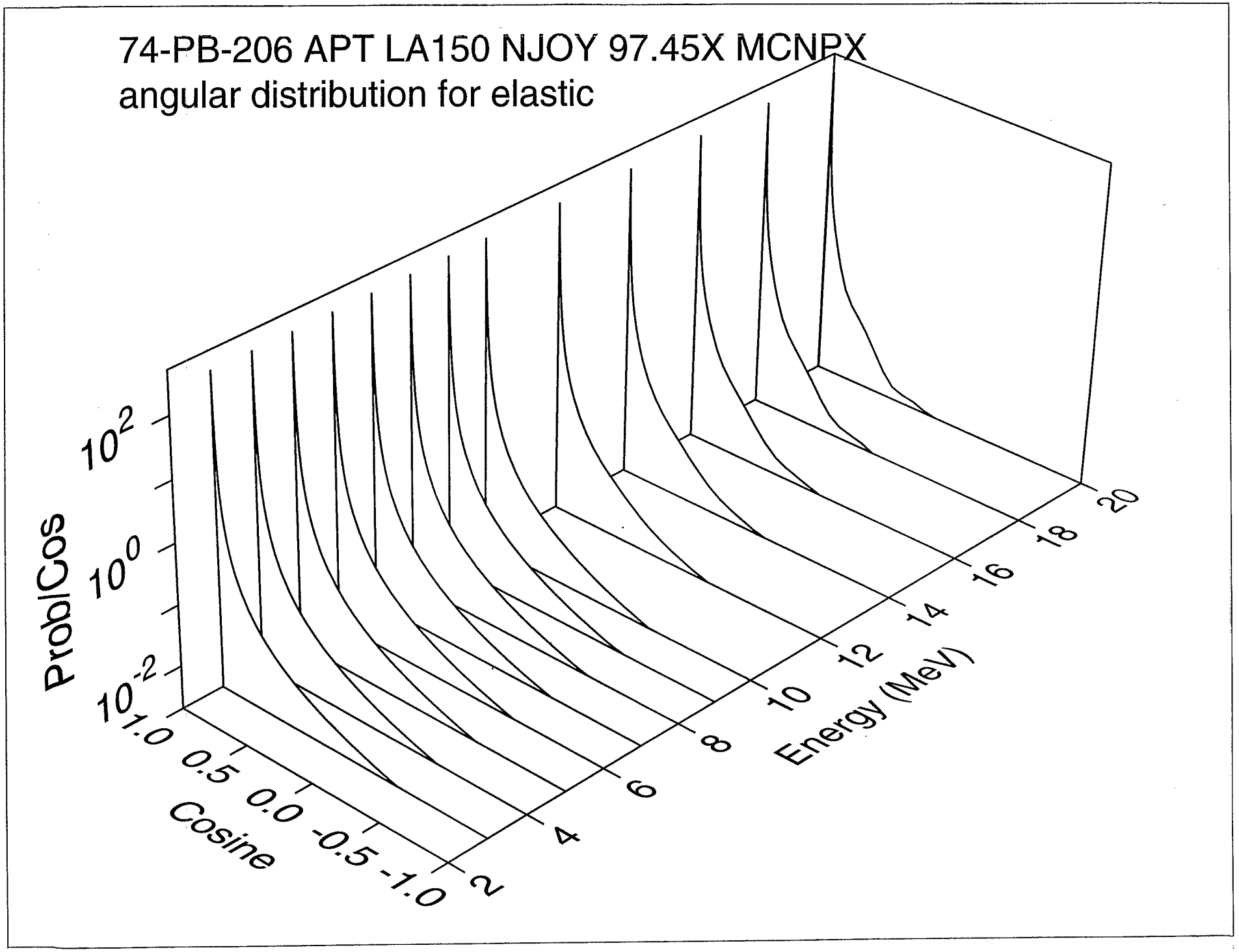


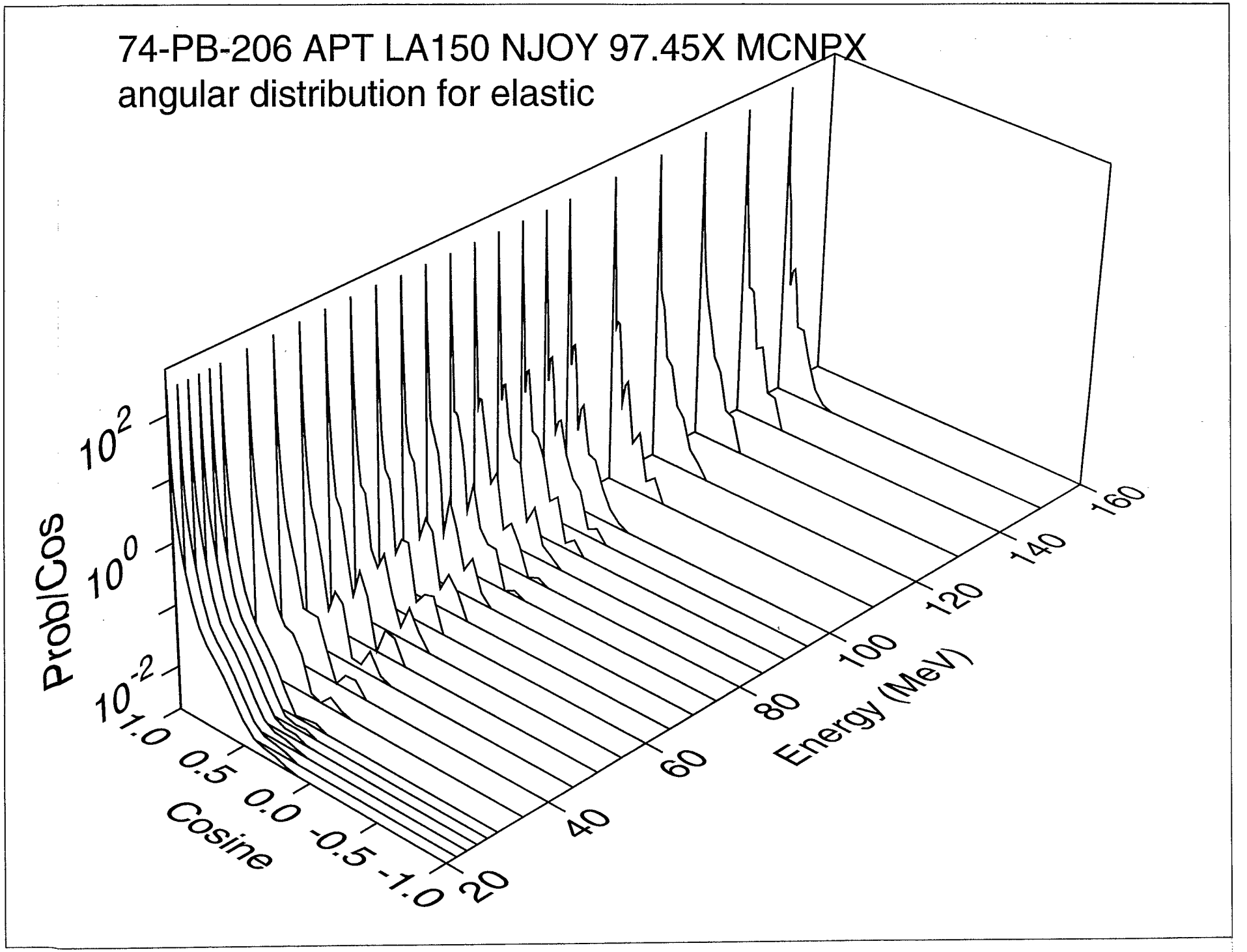


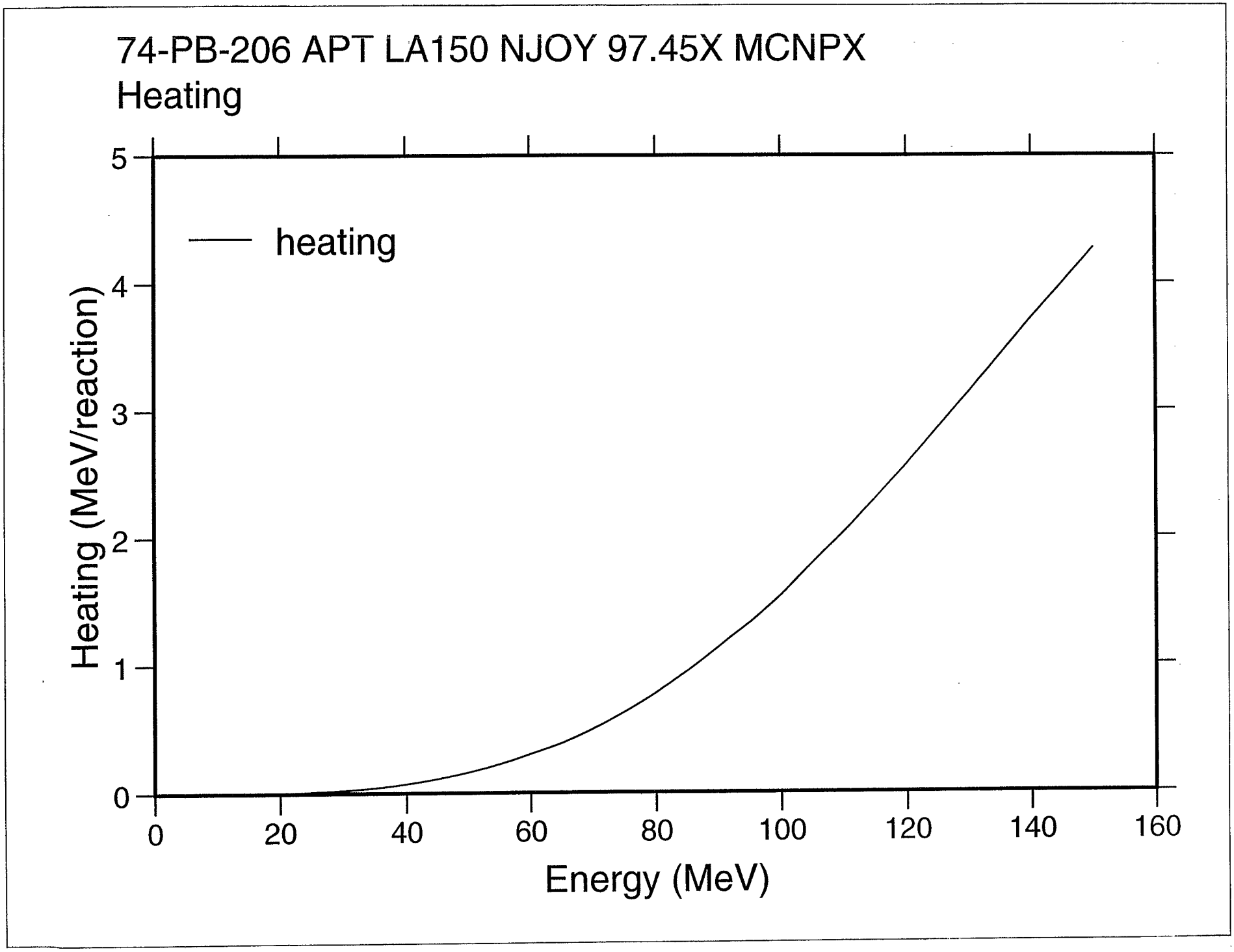







74-PB-206 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic
ProblCos
10^2
10^0
10^{-2}
Cosine
1.0
0.5
0.0
-0.5
-1.0
Energy (MeV)
2
4
6
8
10
12
14
16
18
20


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