

EVALUATION OF p + 30Si 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 $n + Si_{28}$ and $p + Si_{28}$ 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 Becchetti-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 Becchetti-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 projectiles 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	6.656E-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)

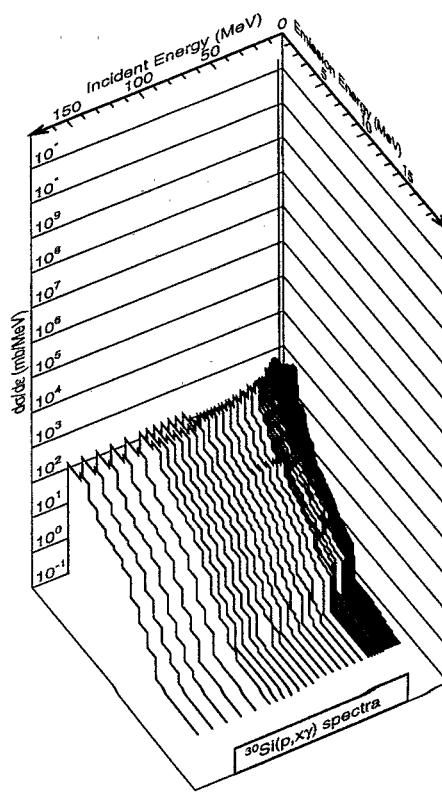
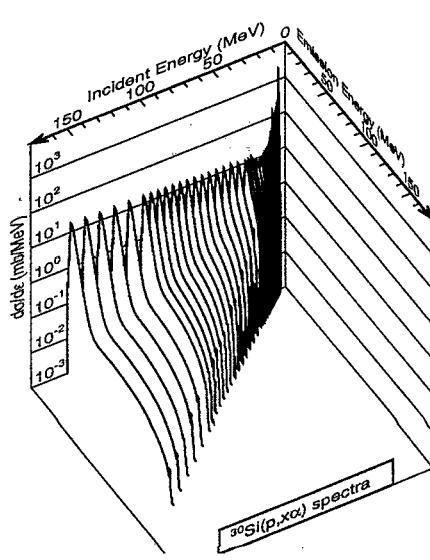
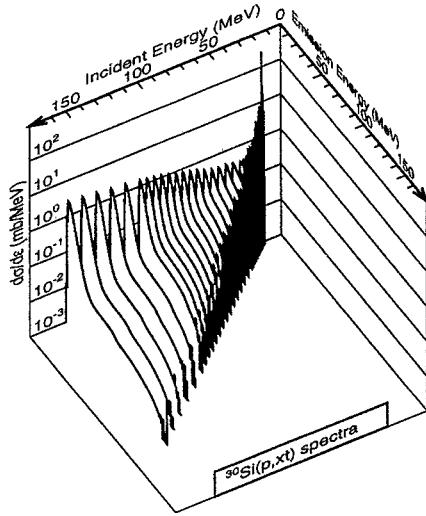
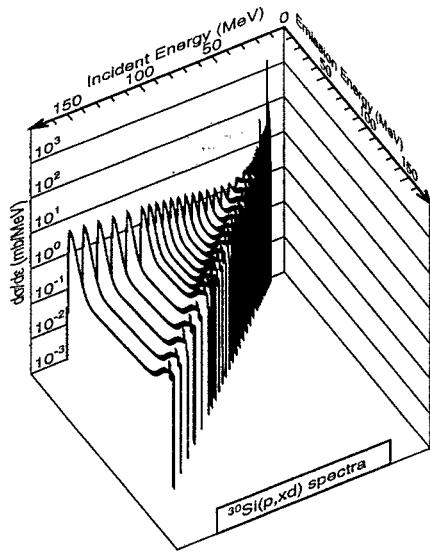
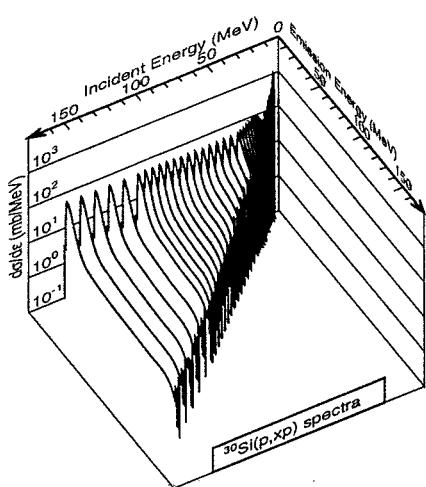
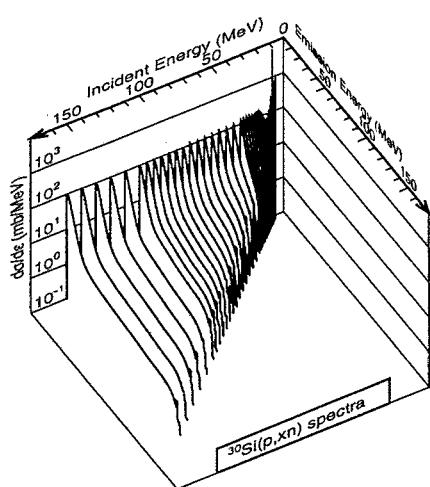
1001 = PROJECTILE 1000Z+A

Aver. lab emission energies for A<5 projectiles in MeV:

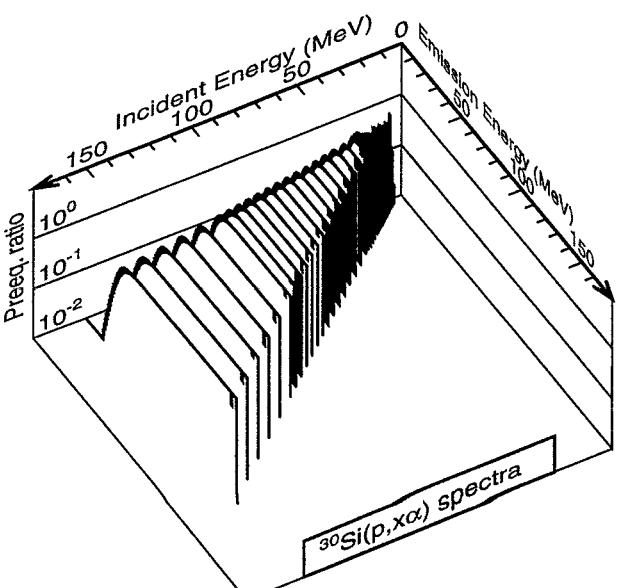
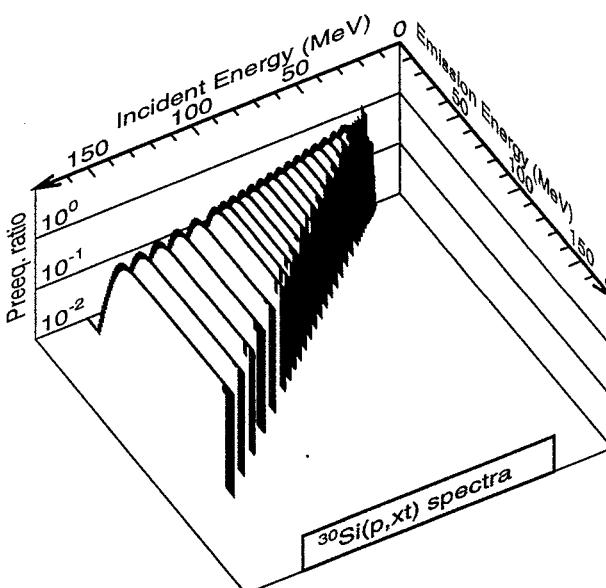
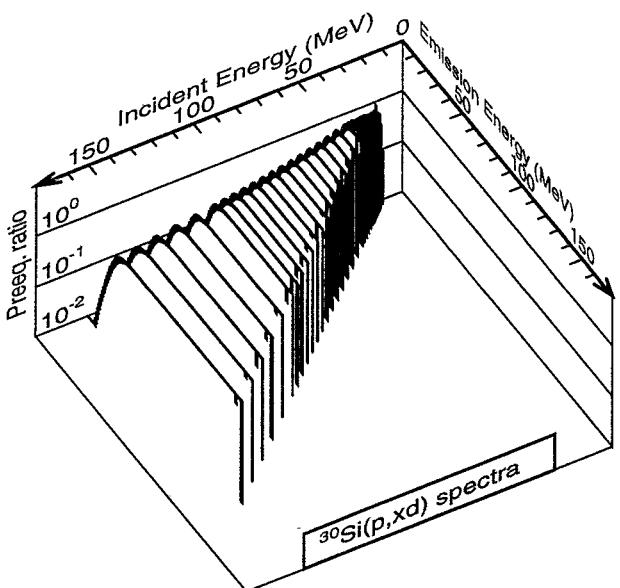
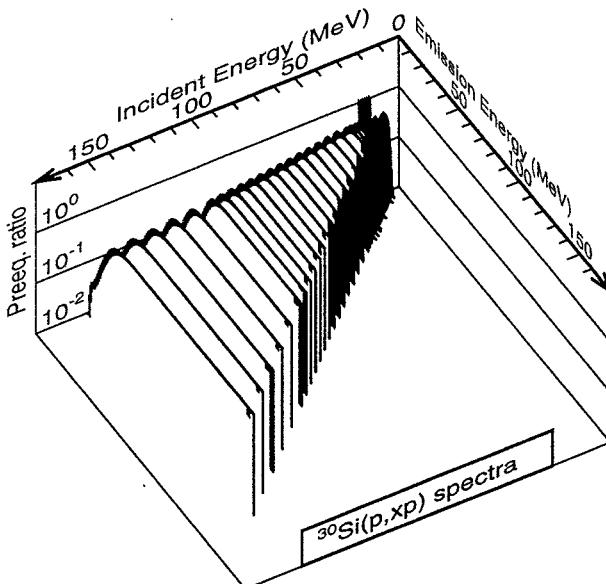
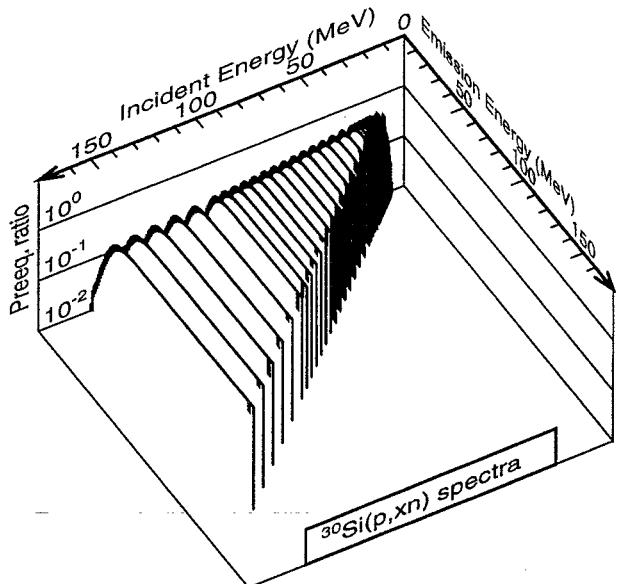
Energy	neutron	proton	deuteron	triton	helium3	alpha	gamma
3.000E+00	0.000E+00	3.176E-03	0.000E+00	0.000E+00	0.000E+00	1.270E-02	5.000E-12
4.000E+00	0.000E+00	1.698E+00	0.000E+00	0.000E+00	0.000E+00	1.268E+00	2.255E+00
5.000E+00	0.000E+00	2.341E+00	0.000E+00	0.000E+00	0.000E+00	2.109E+00	2.252E+00
6.000E+00	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

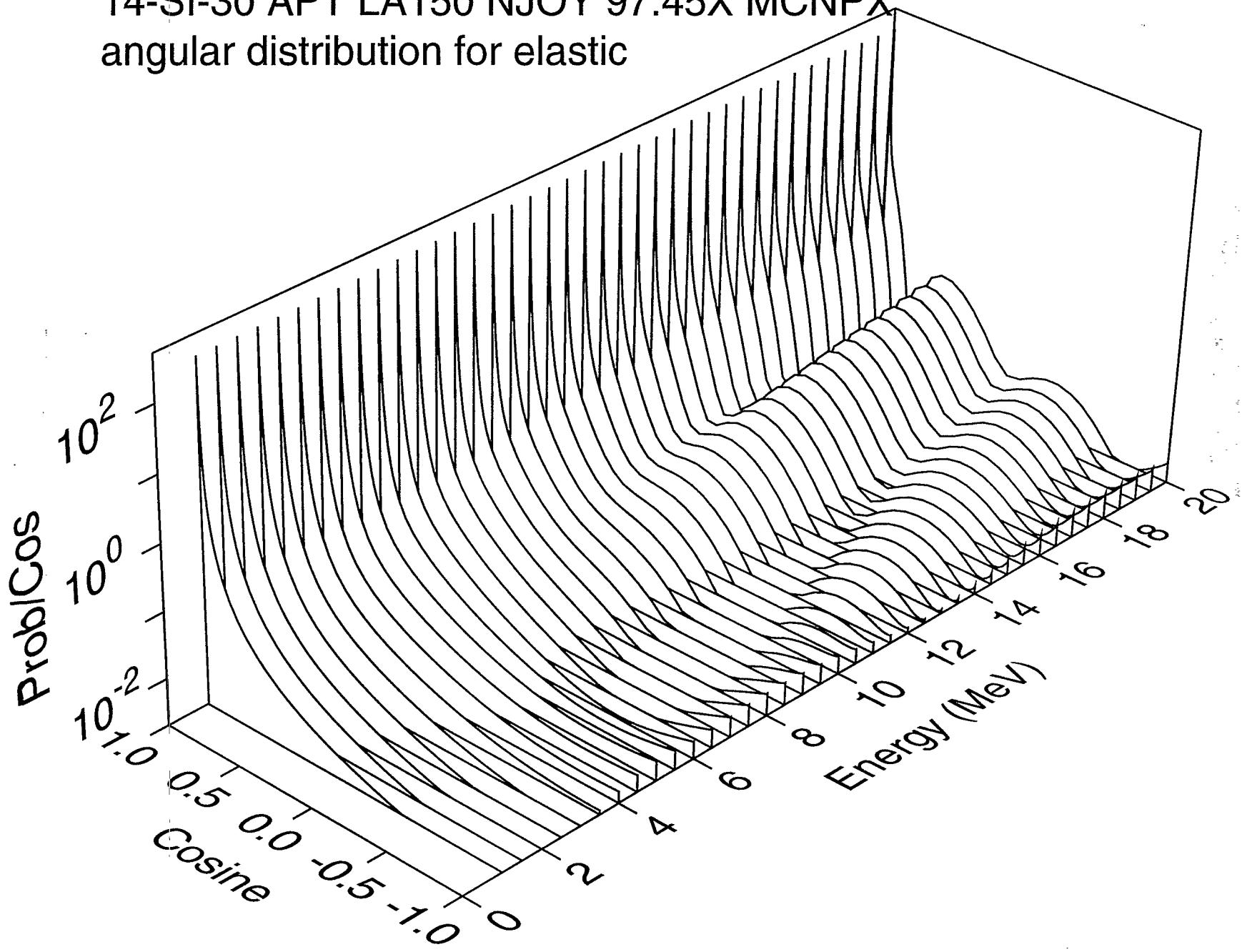
$p + {}^{30}\text{Si}$ angle-integrated emission spectra



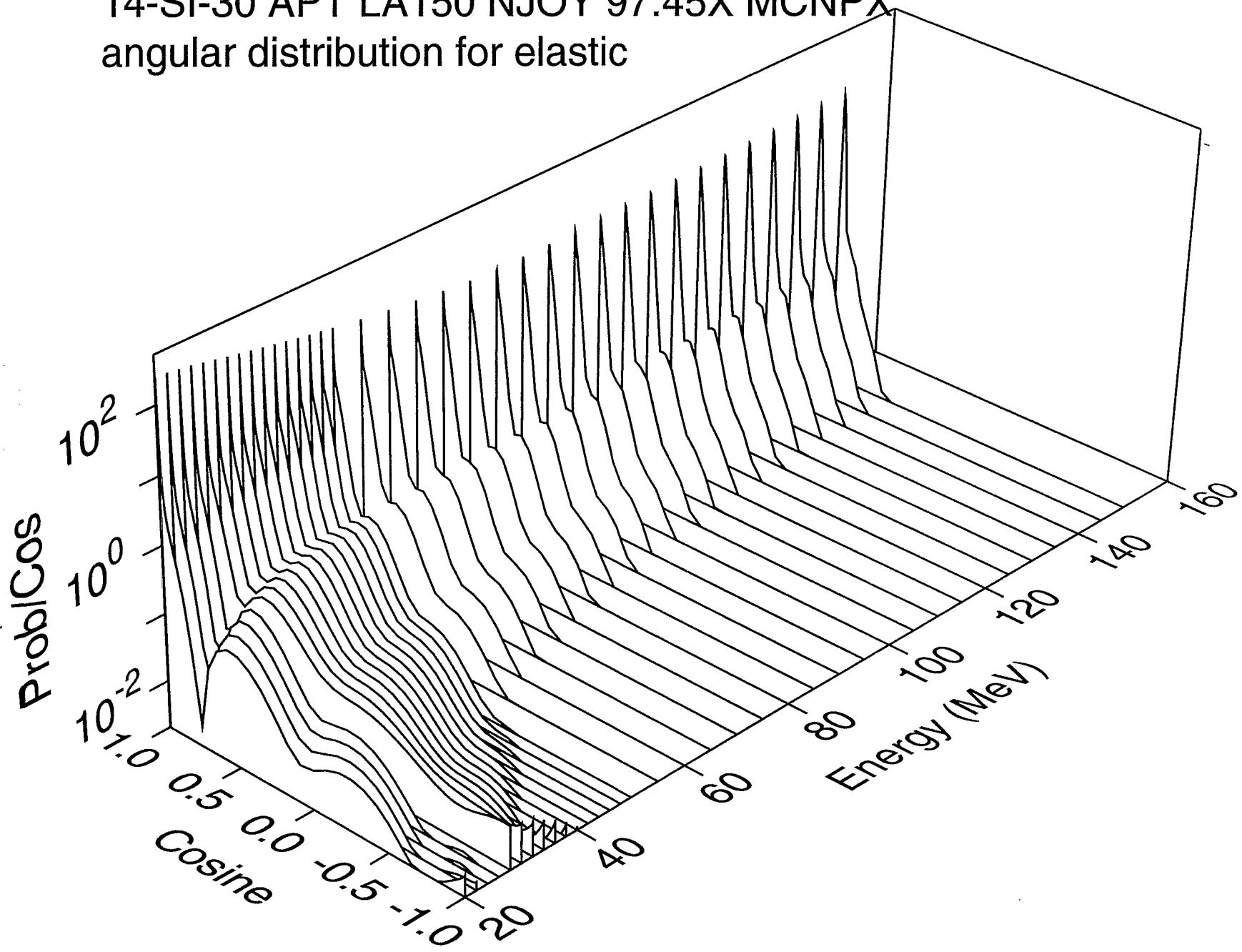
$p + {}^{30}\text{Si}$ Kalbach preequilibrium ratios



14-SI-30 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic



14-SI-30 APT LA150 NJOY 97.45X MCNPX
angular distribution for elastic



14-SI-30 APT LA150 NJOY 97.45X MCNPX

Heating

