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REPRESENTATIVE RESULTS IN GRAPHICAL FORM FROM COMPUTER PRODUCTION RUNS OF THE LOW-ENERGY INTRANUCLEAR-CASCADE CALCULATION

Hugo W. Bertini, Barbara L. Bishop, and Miriam P. Guthrie

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ABSTRACT

This report contains an extensive set of graphs which are meant to illustrate the mass and energy dependence of results that were selected from the output of computer production runs of a low-energy intranuclear-cascade calculation. The nuclear reactions considered are those resulting from the interaction of neutrons and protons with energies from 50 to 400 MeV and π^+ and π^- with energies from 50 to 300 MeV with nuclei ranging from carbon to uranium. Plausibility arguments are given in an attempt to explain some of the results.

INTRODUCTION

The low-energy intranuclear-cascade calculation and its associated evaporation program, which are described elsewhere,[1] were used to generate an extensive set of data. Calculations were made on the nuclear interactions of protons, neutrons, π^+, and π^- with energies ranging from 25 to 400 MeV (25 to 300 MeV for pions) on nuclei with mass numbers from 12 to 238. A detailed description of the reactions that were calculated and the nature of the available data are given in ref. 2.* Although calculations were made at energies as low as 25 MeV, the data presented in this report begin at 50 MeV.

Samples of the available data which the authors felt would be generally useful and interesting were selected, and these data are

[1]Hugo W. Bertini, Phys. Rev. 131, 1801 (1963); Phys. Rev. 138, AB2 (1965); for greater detail, see Monte Carlo Calculations on Intranuclear Cascades, ORNL-3383 (April 23, 1963), and Effect of Error on Results of a Low-Energy Intranuclear Cascade Calculation, ORNL-3786 (June 1966).

[2]Hugo W. Bertini, Results from Low-Energy Intranuclear-Cascade Calculation, ORNL TM-1225 (September 10, 1965).

*These data can be obtained from the Oak Ridge Radiation Shielding Information Center where they are available on microfilm or on magnetic tape in a form that is suitable for listing on an IBM printer.

presented here in graphical form. Their mass and energy dependence are thereby readily ascertained. A user could, of course, determine these dependences for himself but he would be swamped with data from the computer, and it is a tedious task to sort out the particular pieces of information of interest, especially when dealing with data that have been put on microfilm.

This report, together with that of Alsmiller et al.,[3] provides an excellent summary of the computed data.

DESCRIPTION

The production of pions in any of the nuclear interactions was not taken into account because a large part of the energy range under consideration is below the effective production threshold. Therefore, the emitted particles for either incident protons or incident neutrons can only be protons and neutrons, whereas for incident charged pions* they can be protons, neutrons, π^+, π^0, and π^-.

The data pertaining to incident neutrons and emitted neutrons were given first preference. Some data pertaining to emitted protons for incident neutrons and to emitted protons and pions for incident protons or pions are also included.

To facilitate comparison, we attempted to keep the scales the same for the graphs that contain similar cross-section data. Tick marks were placed on the borders of each graph to aid in their reading. The calculated points were connected by straight lines merely to guide the eye. One should keep in mind that the calculation is a statistical one, and all of the results are expected to have statistical variations.

In the brief index that follows, the figure numbers in parentheses refer to graphs for incident pions. Those that are not in parentheses apply to incident nucleons. The parenthetical expressions in the titles

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[3] R. G. Alsmiller, Jr., M. Leimdorfer, and J. Barish, Analytical Representation of Nonelastic Cross Sections and Particle-Emission Spectra from Nucleon-Nucleus Collisions in the Energy Range 25 to 400 MeV, ORNL-4046 (April 1967).

*Pions can be emitted in a charged state different from that of the incident pion because charge-exchange reactions are included in the calculation.

refer to emitted particles when incident pions are used; otherwise, the titles apply to both incident nucleons and pions.

Figs. 1, 2 (42, 43)	Total Nonelastic Cross Sections.
Figs. 3-6 (44-47)	Average Number of Emitted Cascade Neutrons and Protons (Neutrons and Pions).
Figs. 7-10 (48-51)	Average Number of Evaporation Nucleons.
Figs. 11-14 (52-55)	Average Energy of Cascade and Evaporation Nucleons (Neutrons, Protons, and π^-)
Figs. 15-22 (56-63)	Differential Cross Sections for the Emission of Cascade Nucleons (Neutrons and π^-) into Various Angular Intervals.
Figs. 23-30 (64-71)	Average Energy of Cascade Nucleons (Neutrons and π^-) Emitted into Various Angular Intervals.
Fig. 31 (72)	Average Excitation Energy Following the Cascade Reaction.
Figs. 32-35 (73-76)	Excitation Energy Distributions Following the Cascade Reaction for Aluminum and Lead Targets.
Figs. 36-41 (77-82)	Radiochemical Cross Sections vs Mass Number for Aluminum, Copper, and Lead Targets.

COMMENTS

It is not readily apparent why some of the data have the values or the dependences that are illustrated. In this section plausibility arguments are given to explain some of these results.

The first result that we should discuss is illustrated in Fig. 1. Here the total nonelastic cross section for 400-MeV neutrons is slightly greater than that for 200-MeV neutrons over the bulk of the mass range. The higher mass nuclei have an excess of neutrons; therefore, for incident neutrons the free-particle n-n cross section has a greater effect on the nuclear nonelastic cross section than the n-p cross section does. The free-particle n-n (or p-p) cross section is higher at 430 MeV than it is at 230 MeV,* whereas the reverse is true for the n-p cross section, so

*The free-particle cross sections are evaluated at 430 and 230 MeV to include the effect of the attractive nuclear potential - about 30 MeV. The p-p cross section starts to increase rapidly at about 400 MeV.

the net effect is a slight increase in the total nuclear nonelastic cross section. The reverse of this is expected for incident protons, illustrated in Fig. 2.

The next result which requires an explanation is the factor-of-two difference in the number of cascade neutrons emitted compared to the number of cascade protons for incident neutrons. These data are illustrated in Figs. 3 and 4. If the free-particle cross sections were equal and if the neutron and proton densities inside the nucleus were the same, then the probability of an incident neutron interacting with a neutron or proton on the first collision would be the same. After the first collision, there would be two neutrons in the second generation if the first interaction were with a neutron. There would be one neutron and one proton if the interaction were with a proton. Under these circumstances, the average number of neutrons in the second generation is three times higher than the number of protons. This ratio is reduced in subsequent generations, but the particles escape before many generations can develop. Differences in cross sections and in the numbers of neutrons and protons inside the nucleus complicate the argument, but the main effect is apparent in the results. In Figs. 5 and 6 the same type of data is illustrated for incident protons, but the effect is manifest only in the light elements where the number of neutrons and protons in the nucleus is the same. The neutron excess in the heavier nuclei apparently wipes out the effect completely.

In Fig. 8 there is a peculiar discontinuity in the number of evaporation protons for a copper target (A = 65). This comes from our use of the A = 65, Z = 29 isotope as our target, which is slightly to the right of the valley of stability, indicating a degree of proton deficiency. Our evaporation program is apparently quite sensitive to this in the midrange mass region, for when we use the A = 63 isotope the number of evaporation protons is increased to the point where the discontinuities are eliminated.

A steep drop to zero at the end of the mass range for the average energy of evaporation protons using 50-MeV incident protons is illustrated in Fig. 14. There were no evaporation protons emitted for the A = 238 case. The average number of evaporation protons is very small for the

A = 183 and A = 207 cases (see Fig. 8), but not zero, so a reasonable average energy is obtained for these targets.

In Fig. 32, illustrating the excitation energy distribution for 50-MeV neutrons on lead, the value of the distribution is zero for the energy interval between 48 and 54 MeV and a peak between 54 and 60 MeV is exhibited. The peak should actually be a spike at 57 MeV because it represents the excitation energy when a 50-MeV neutron with a 7-MeV binding energy* is absorbed without subsequent cascade particle emission. One has the maximum possible excitation energy when this occurs. The next highest possible excitation energy is given by the situation where the incident particle is absorbed and one nucleon is emitted with the smallest possible kinetic energy, i.e., the cutoff energy for the cascade calculation. The excitation energy is then the incident energy minus the cutoff energy (6.7 MeV for lead and 1.6 MeV for aluminum). Therefore, there cannot be an excitation energy between 48 and 54 MeV for the case of the lead target.

Figures 40 and 41 illustrate peaks in the mass distribution of the radiochemical cross sections for 50- and 100-MeV neutrons and protons on lead. These result from the rather high probability of absorption of the incident particle with the subsequent emission of particles (mostly neutrons) by evaporation only.

The pion-nucleon resonance at 200-MeV accounts for the fact that the total nonelastic cross sections for 150-MeV pions are larger than those with either 50- or 300-MeV incident energy. The curves are illustrated in Figs. 42 and 43.

The factor-of-two difference in the cascade neutron multiplicities between the π^- and π^+ interactions (Figs. 44 and 45) is due to the large difference in the π^-+n and π^++n cross sections in this energy region. One assumes that

$$\sigma(\pi^-+n) = \sigma(\pi^++p)$$

*The nucleons are assumed to have a 7-MeV binding energy in all the nuclei.

and

$$\sigma(\pi^{+}+n) = \sigma(\pi^{-}+p)$$

from charge symmetry.

Pion absorption accounts for the high average cascade-neutron energy, particularly for 50-MeV incident π^{-}, illustrated in Fig. 52. When a pion is absorbed, its kinetic energy plus its rest mass energy ($\sim$ 140 MeV) is given up to the nucleons in the nucleus.

Absorption is also a contributing factor in the rather high magnitudes of the average evaporation neutron energies from the light elements, illustrated in Fig. 54, which result from the increased average excitation energy caused by absorption. The mass dependence of the average evaporation neutron energy for incident pions is the same as that for incident nucleons (Fig. 13), as would be expected.

As shown in Figs. 81 and 82, there are many peaks in the cross sections, but the prominent one at mass number 190 for 50-MeV π^{-} and π^{+} on lead is caused by the rather high probability of absorption without emission of cascade nucleons. The others result from complicated relationships between all of the quantities associated with the cascade-evaporation process, and no attempt at an explanation will be made.

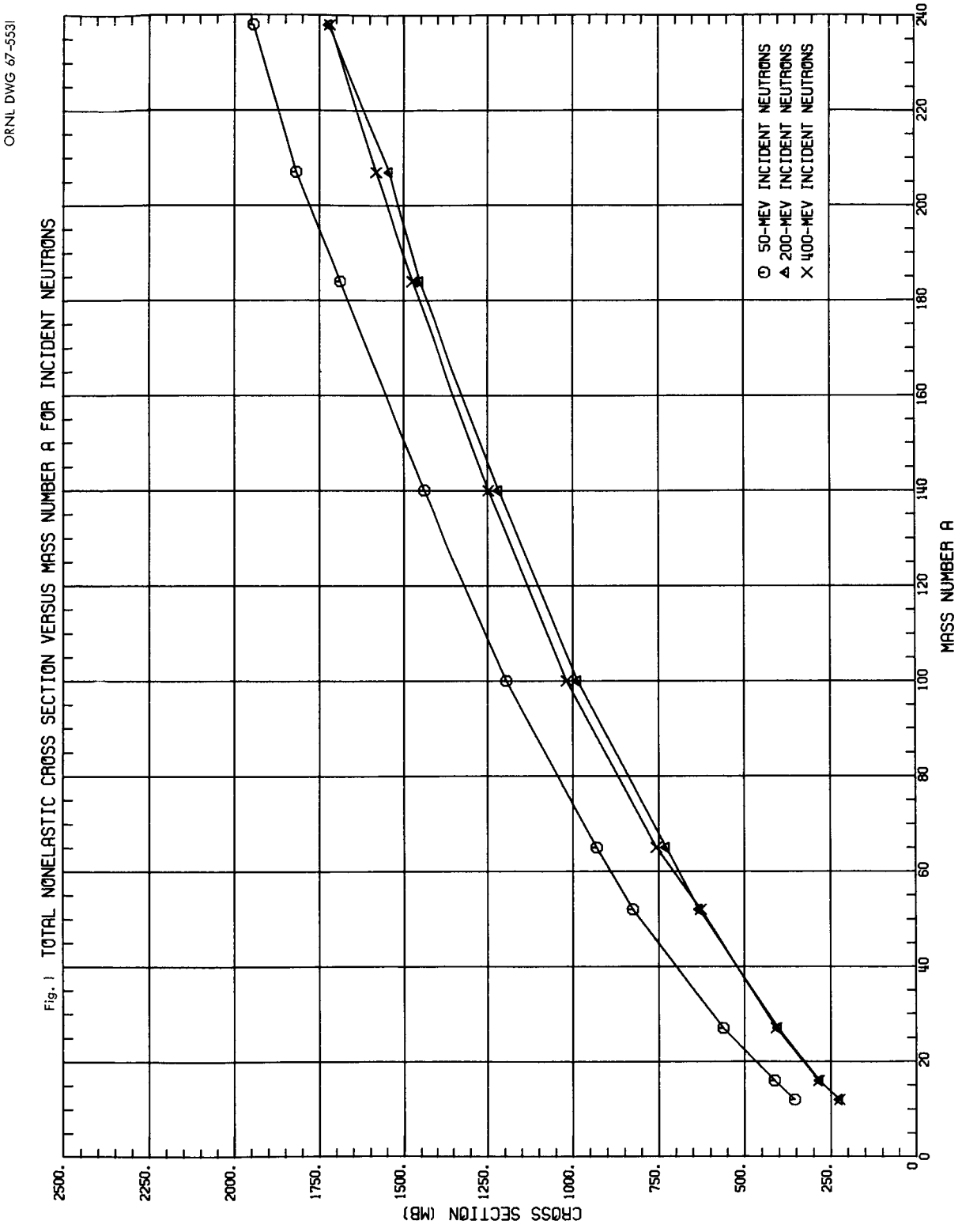

ORNL DWG 67-5531
TOTAL NONELASTIC CROSS SECTION VERSUS MASS NUMBER A FOR INCIDENT NEUTRONS
CROSS SECTION (MB)
MASS NUMBER A
50-MEV INCIDENT NEUTRONS
200-MEV INCIDENT NEUTRONS
400-MEV INCIDENT NEUTRONS
2500.
2250.
2000.
1750.
1500.
1250.
1000.
750.
500.
250.
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 1

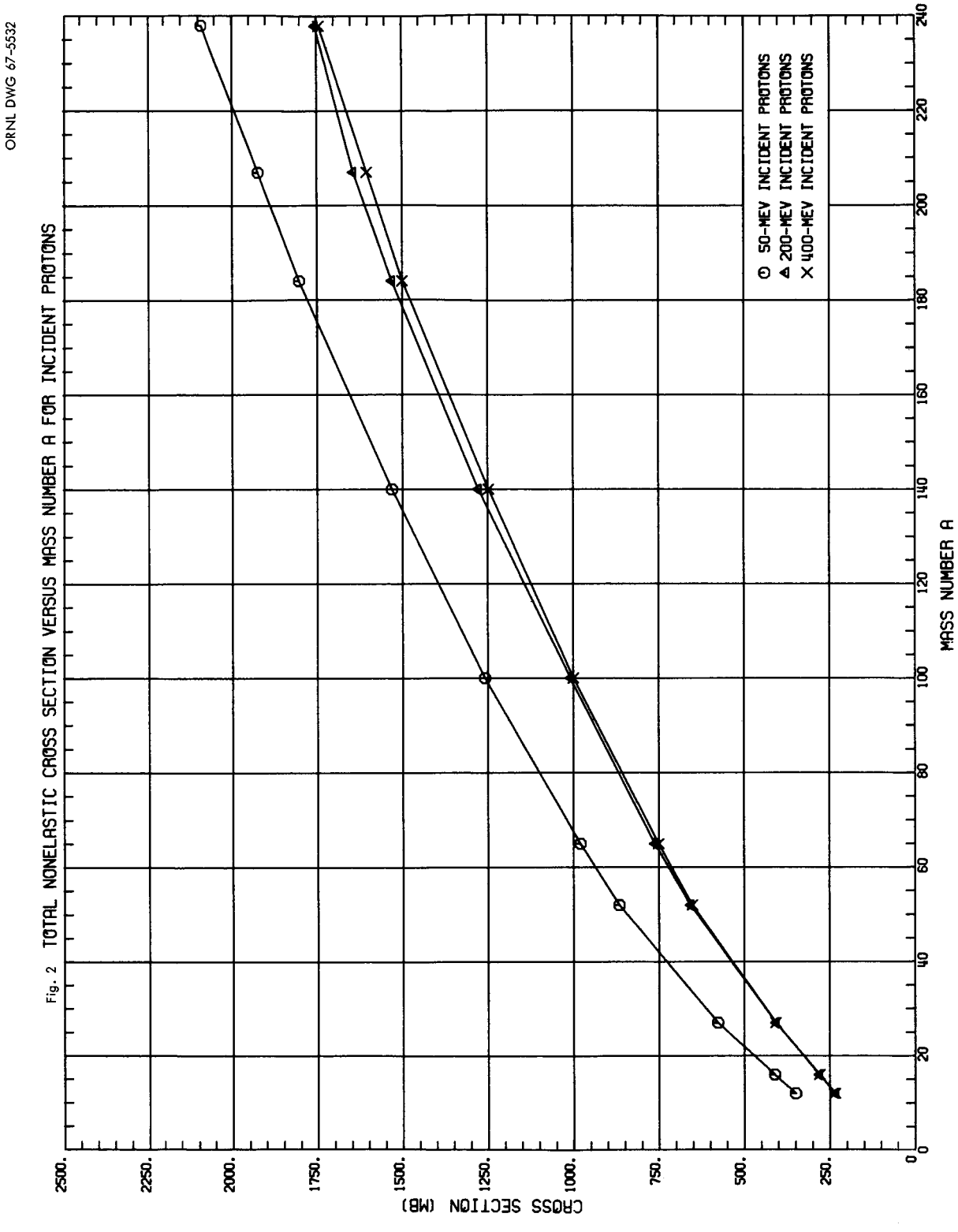

ORNL DWG 67-5532
TOTAL NONELASTIC CROSS SECTION VERSUS MASS NUMBER A FOR INCIDENT PROTONS
CROSS SECTION (MB)
MASS NUMBER A
50-MEV INCIDENT PROTONS
200-MEV INCIDENT PROTONS
400-MEV INCIDENT PROTONS
2500.
2250.
2000.
1750.
1500.
1250.
1000.
750.
500.
250.
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 2

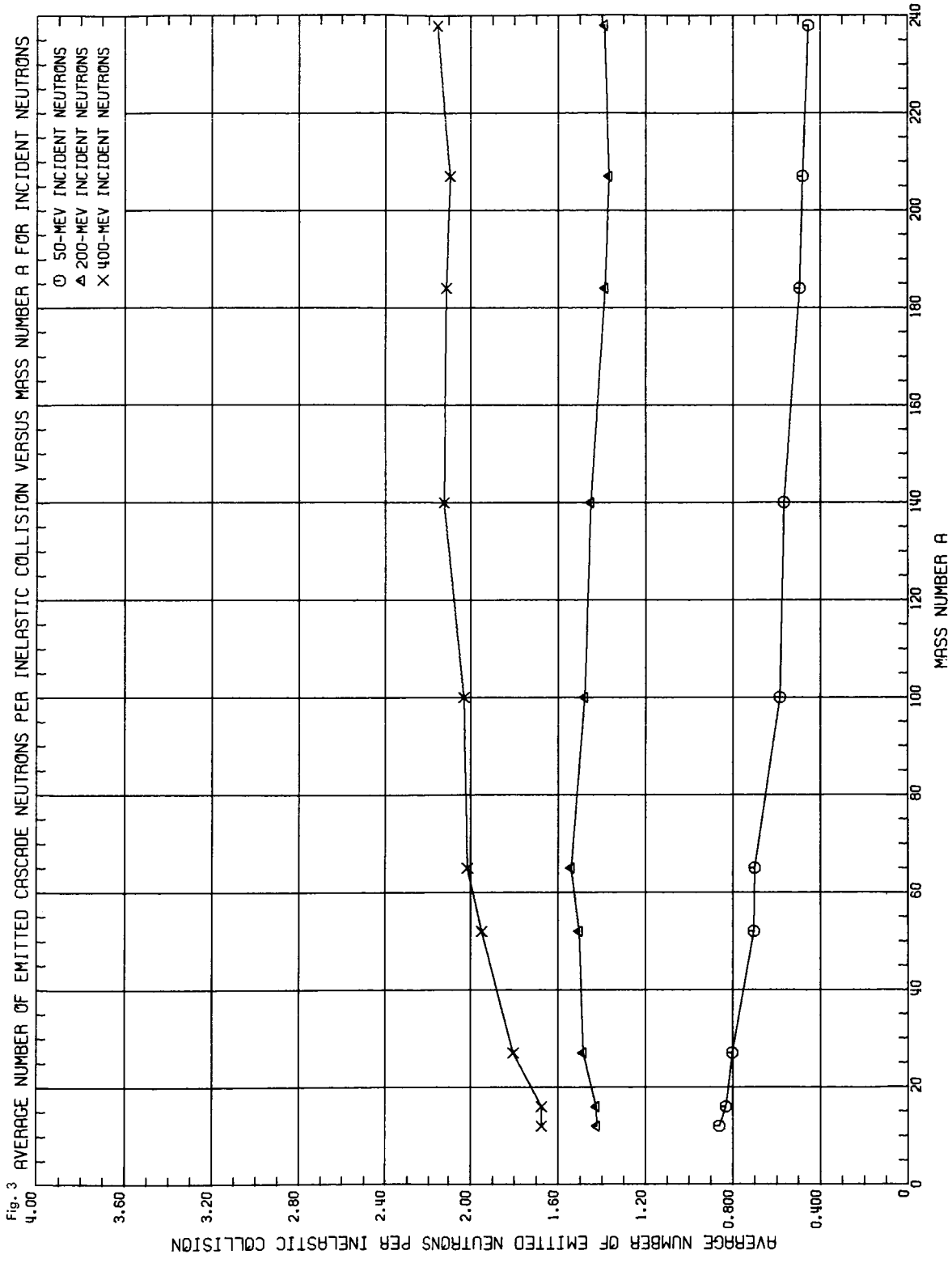

ORNL DWG 67-5533
AVERAGE NUMBER OF EMITTED CASCADE NEUTRONS PER INELASTIC COLLISION VERSUS MASS NUMBER A FOR INCIDENT NEUTRONS
50-MEV INCIDENT NEUTRONS
200-MEV INCIDENT NEUTRONS
400-MEV INCIDENT NEUTRONS
AVERAGE NUMBER OF EMITTED NEUTRONS PER INELASTIC COLLISION
MASS NUMBER A
4.00
3.60
3.20
2.80
2.40
2.00
1.60
1.20
0.800
0.400
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 3

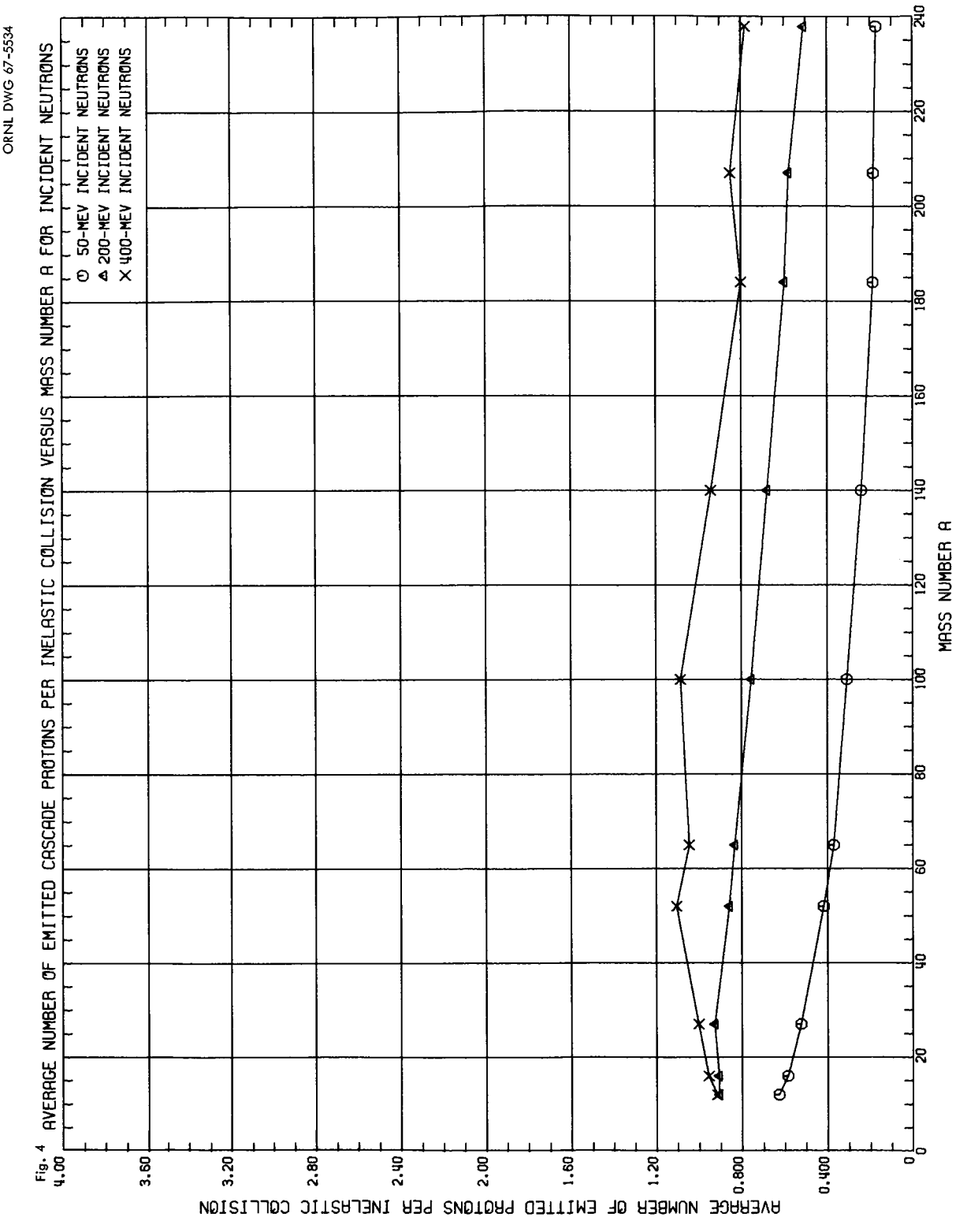
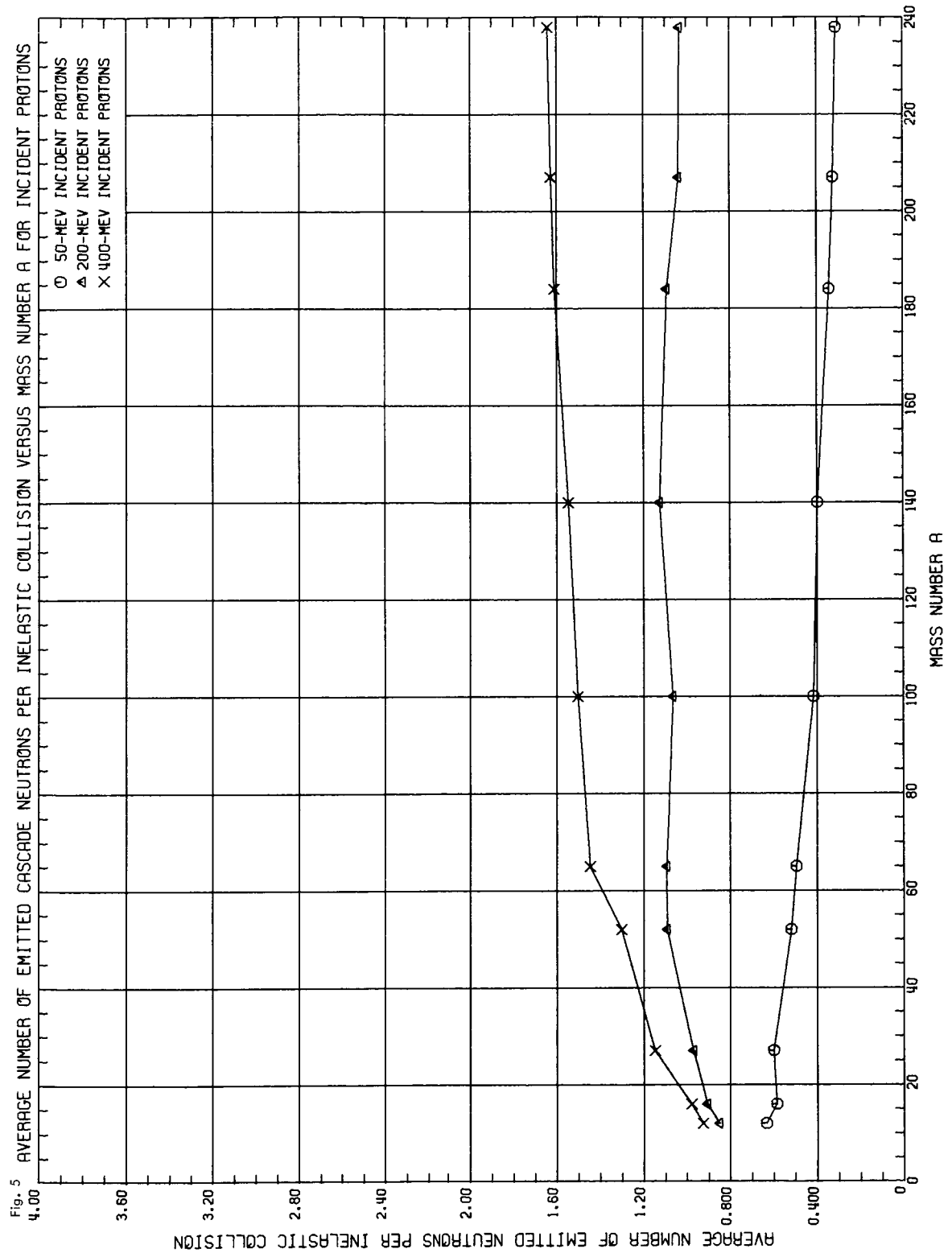

ORNL DWG 67-5534
AVERAGE NUMBER OF EMITTED CASCADE PROTONS PER INELASTIC COLLISION VERSUS MASS NUMBER A FOR INCIDENT NEUTRONS
50-MEV INCIDENT NEUTRONS
200-MEV INCIDENT NEUTRONS
400-MEV INCIDENT NEUTRONS
AVERAGE NUMBER OF EMITTED PROTONS PER INELASTIC COLLISION
MASS NUMBER A
4.00
3.60
3.20
2.80
2.40
2.00
1.60
1.20
0.800
0.400
0
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 4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AVERAGE NUMBER OF EMITTED CASCADE NEUTRONS PER INELASTIC COLLISION VERSUS MASS NUMBER A FOR INCIDENT PROTONS
50-MEV INCIDENT PROTONS
200-MEV INCIDENT PROTONS
400-MEV INCIDENT PROTONS
AVERAGE NUMBER OF EMITTED NEUTRONS PER INELASTIC COLLISION
MASS NUMBER A
4.00
3.60
3.20
2.80
2.40
2.00
1.60
1.20
0.800
0.400
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 5

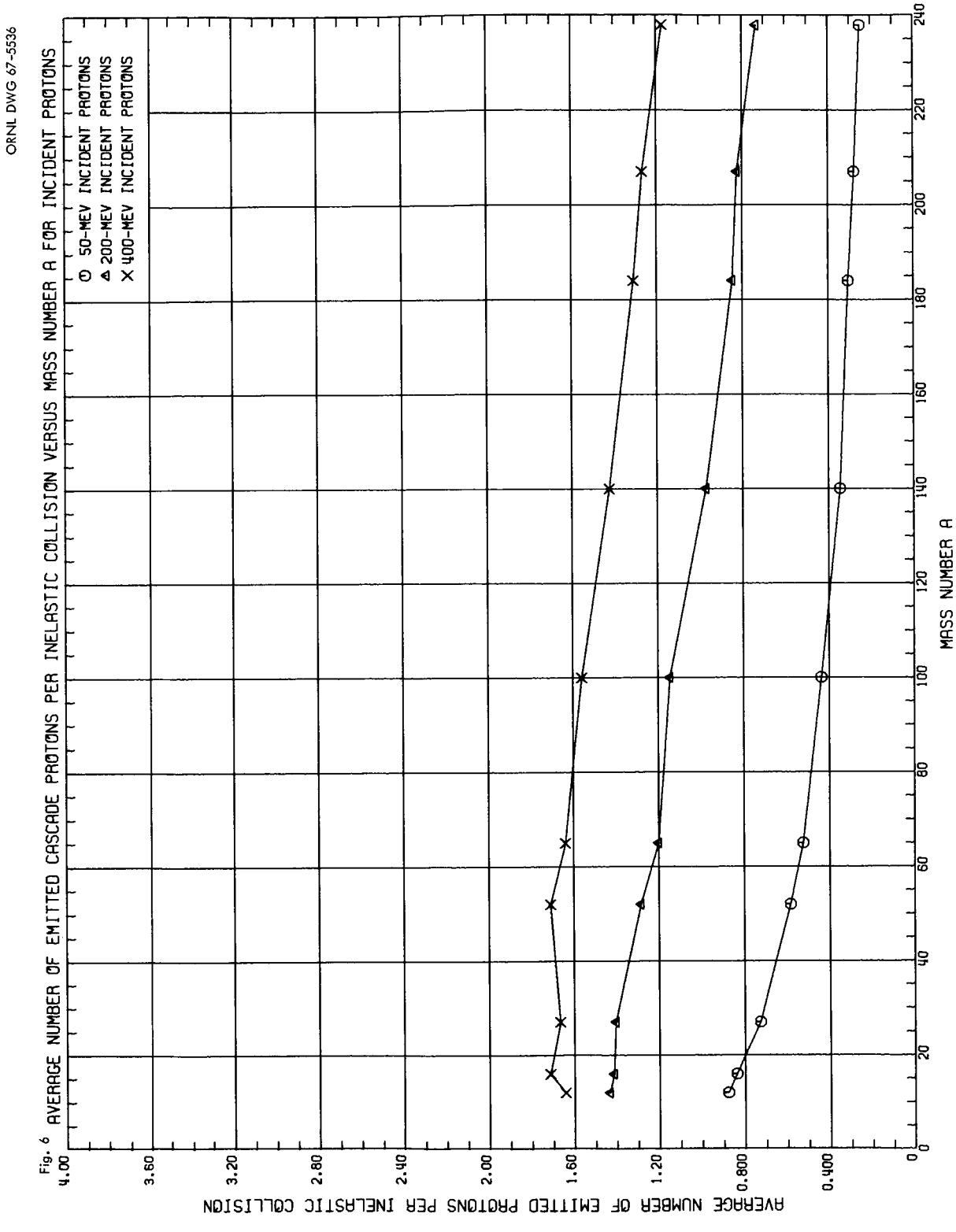

ORNL DWG 67-5536
AVERAGE NUMBER OF EMITTED CASCADE PROTONS PER INELASTIC COLLISION VERSUS MASS NUMBER A FOR INCIDENT PROTONS
50-MEV INCIDENT PROTONS
200-MEV INCIDENT PROTONS
400-MEV INCIDENT PROTONS
AVERAGE NUMBER OF EMITTED PROTONS PER INELASTIC COLLISION
MASS NUMBER A
0
20
40
60
80
100
120
140
160
180
200
220
240
0.400
0.800
1.20
1.60
2.00
2.40
2.80
3.20
3.60
4.00

Fig. 6

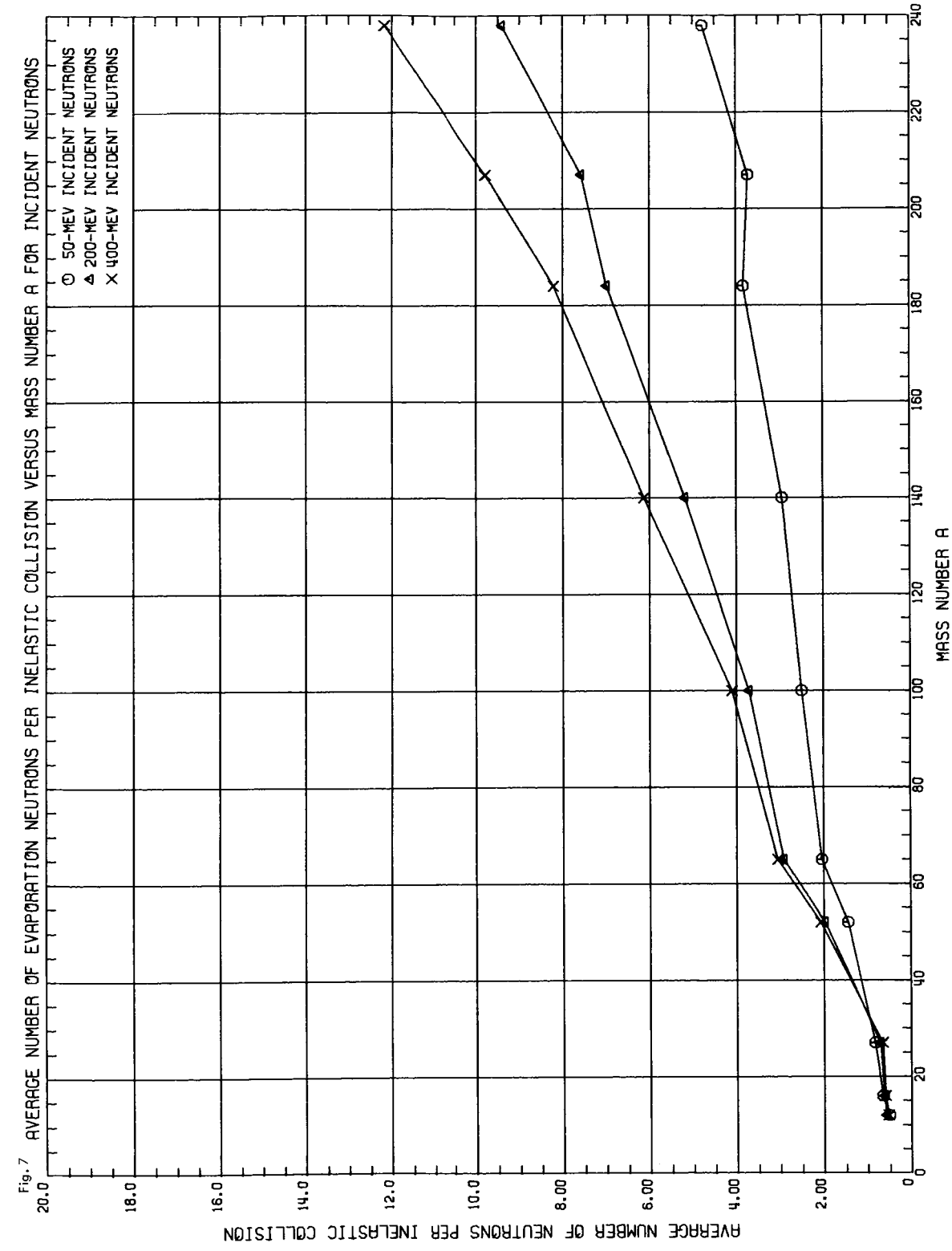

ORNL DWG 67-5537
AVERAGE NUMBER OF EVAPORATION NEUTRONS PER INELASTIC COLLISION VERSUS MASS NUMBER A FOR INCIDENT NEUTRONS
○ 50-MEV INCIDENT NEUTRONS
△ 200-MEV INCIDENT NEUTRONS
× 400-MEV INCIDENT NEUTRONS
AVERAGE NUMBER OF NEUTRONS PER INELASTIC COLLISION
MASS NUMBER A
0
2.00
4.00
6.00
8.00
10.0
12.0
14.0
16.0
18.0
20.0
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 7

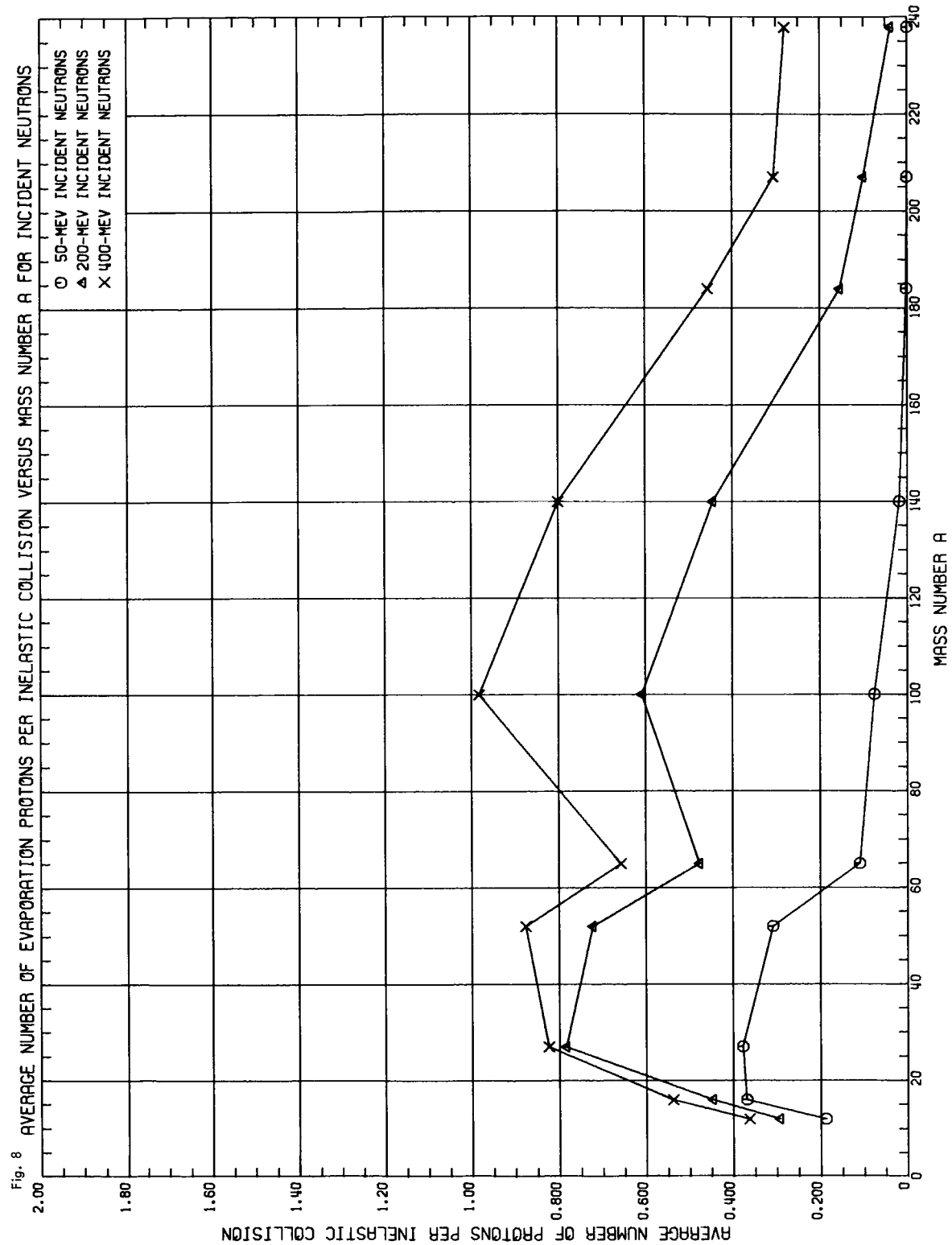
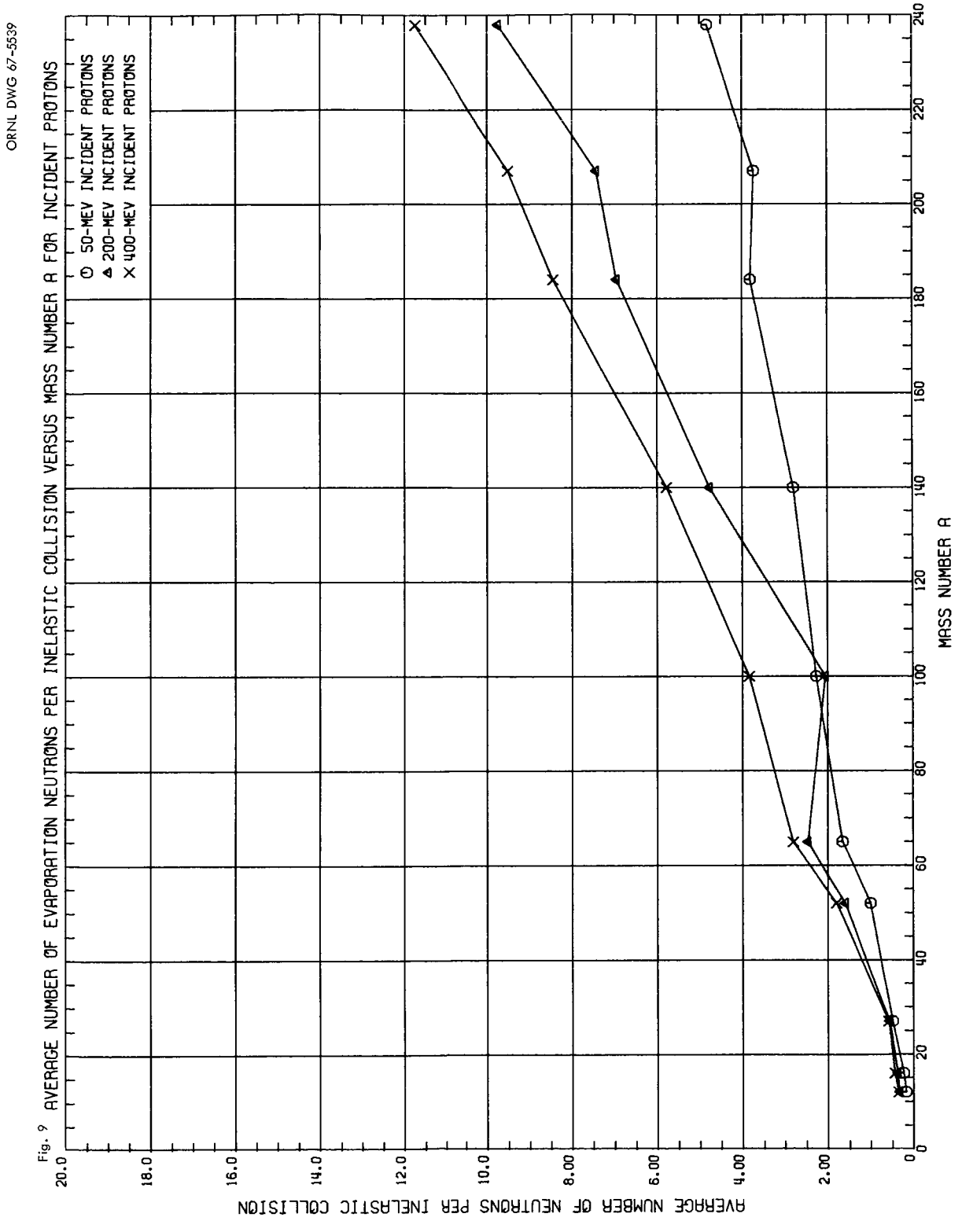

ORNL DWG 67-5538
AVERAGE NUMBER OF EVAPORATION PROTONS PER INELASTIC COLLISION VERSUS MASS NUMBER A FOR INCIDENT NEUTRONS
○ 50-MEV INCIDENT NEUTRONS
△ 200-MEV INCIDENT NEUTRONS
× 400-MEV INCIDENT NEUTRONS
AVERAGE NUMBER OF PROTONS PER INELASTIC COLLISION
MASS NUMBER A
0
0.200
0.400
0.600
0.800
1.00
1.20
1.40
1.60
1.80
2.00
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 8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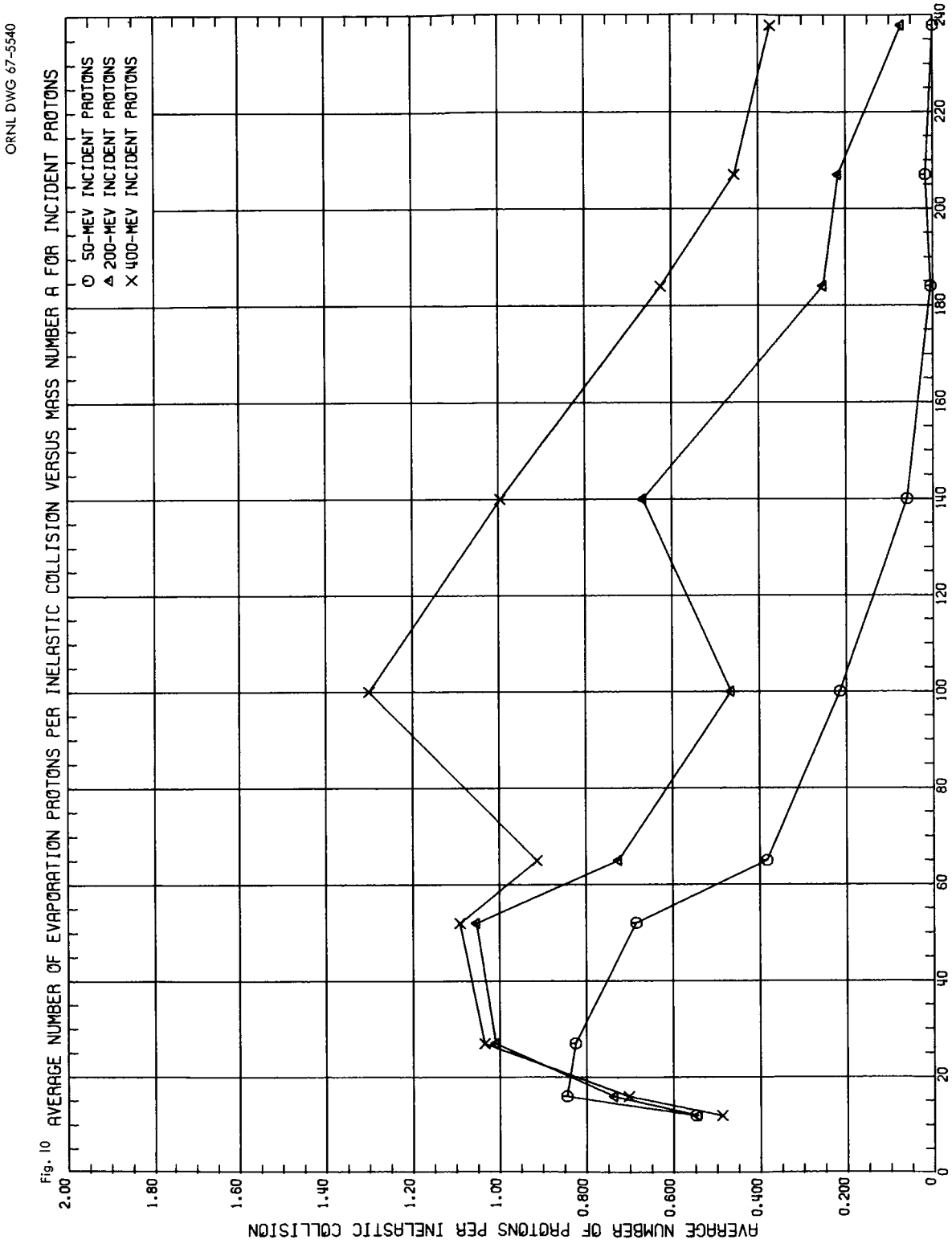
AVERAGE NUMBER OF EVAPORATION NEUTRONS PER INELASTIC COLLISION VERSUS MASS NUMBER A FOR INCIDENT PROTONS
○ 50-MEV INCIDENT PROTONS
△ 200-MEV INCIDENT PROTONS
× 400-MEV INCIDENT PROTONS
AVERAGE NUMBER OF NEUTRONS PER INELASTIC COLLISION
MASS NUMBER A
0
2.00
4.00
6.00
8.00
10.0
12.0
14.0
16.0
18.0
20.0
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 9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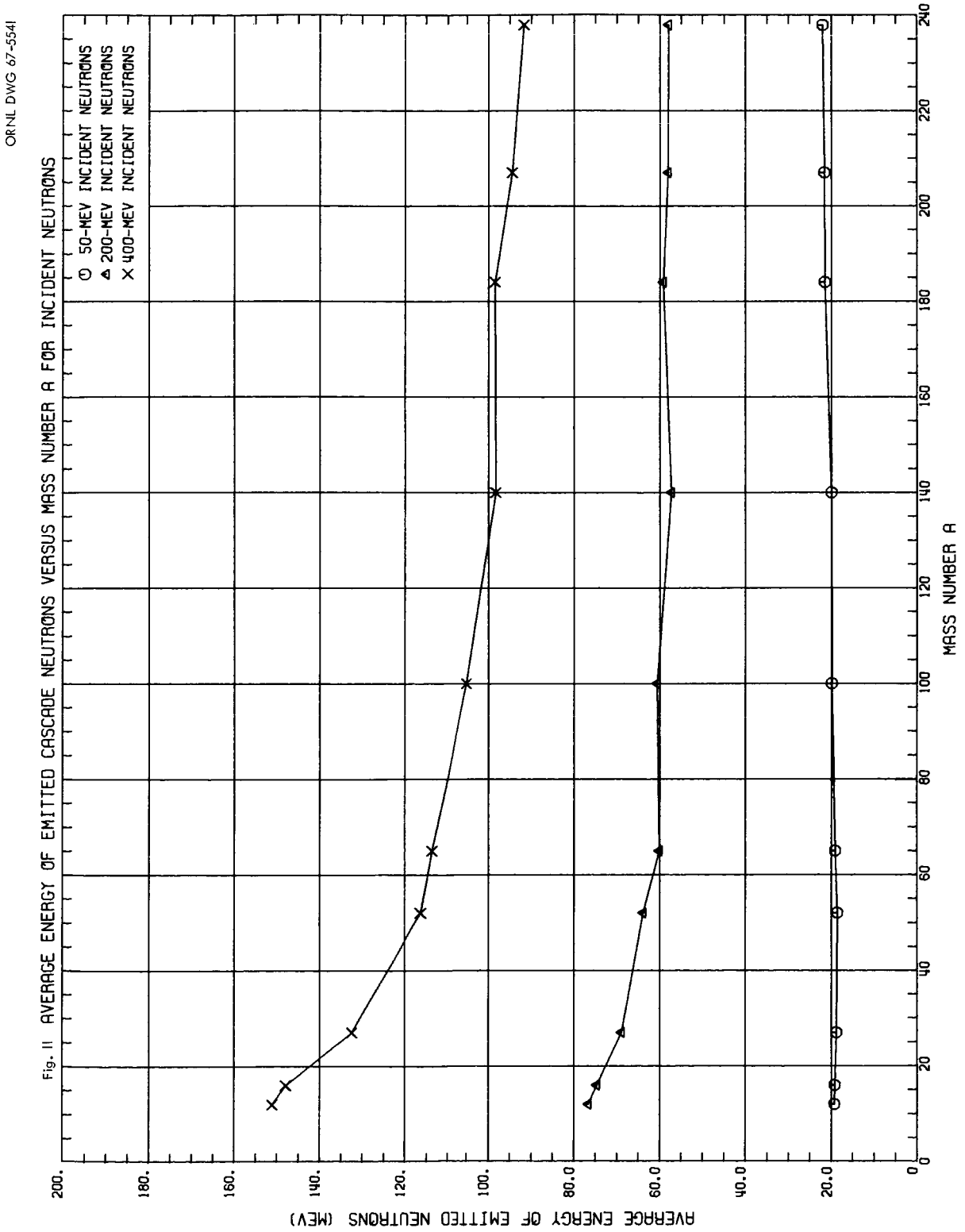
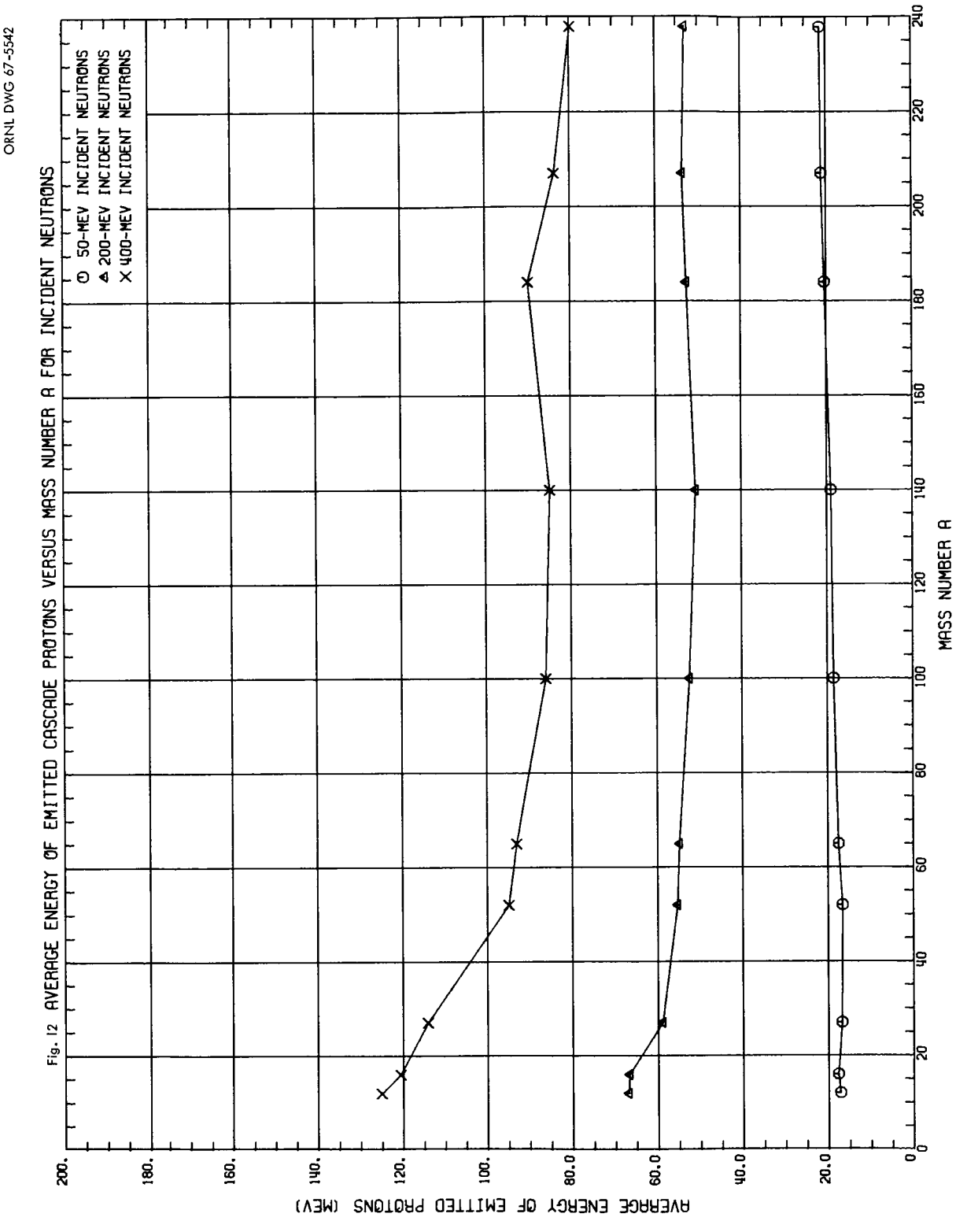
AVERAGE NUMBER OF EVAPORATION PROTONS PER INELASTIC COLLISION VERSUS MASS NUMBER A FOR INCIDENT PROTONS
○ 50-MEV INCIDENT PROTONS
△ 200-MEV INCIDENT PROTONS
× 400-MEV INCIDENT PROTONS
AVERAGE NUMBER OF PROTONS PER INELASTIC COLLISION
MASS NUMBER A
0
0.200
0.400
0.600
0.800
1.00
1.20
1.40
1.60
1.80
2.00
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 10


ORNL DWG 67-5541
Fig. 11 AVERAGE ENERGY OF EMITTED CASCADE NEUTRONS VERSUS MASS NUMBER A FOR INCIDENT NEUTRONS
50-MEV INCIDENT NEUTRONS
200-MEV INCIDENT NEUTRONS
400-MEV INCIDENT NEUTRONS
AVERAGE ENERGY OF EMITTED NEUTRONS (MEV)
MASS NUMBER A
200.
180.
160.
140.
120.
100.
80.0
60.0
40.0
20.0
0
20
40
60
80
100
120
140
160
180
200
220
240


ORNL DWG 67-5542
Fig. 12 AVERAGE ENERGY OF EMITTED CASCADE PROTONS VERSUS MASS NUMBER A FOR INCIDENT NEUTRONS
50-MEV INCIDENT NEUTRONS
200-MEV INCIDENT NEUTRONS
400-MEV INCIDENT NEUTRONS
AVERAGE ENERGY OF EMITTED PROTONS (MEV)
MASS NUMBER A
200.
180.
160.
140.
120.
100.
80.0
60.0
40.0
20.0
0
20
40
60
80
100
120
140
160
180
200
220
240

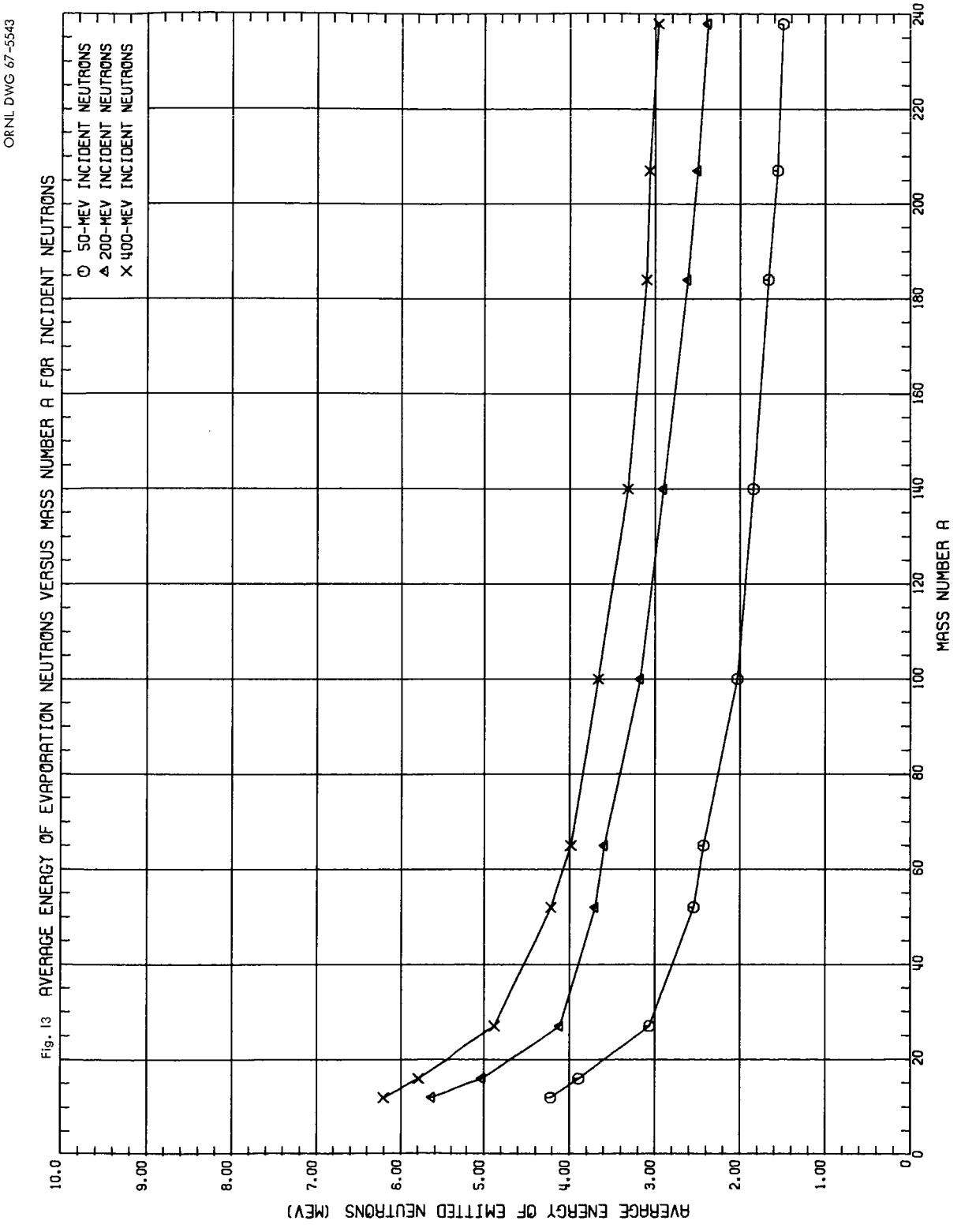


Fig. 13 AVERAGE ENERGY OF EVAPORATION NEUTRONS VERSUS MASS NUMBER A FOR INCIDENT NEUTRONS

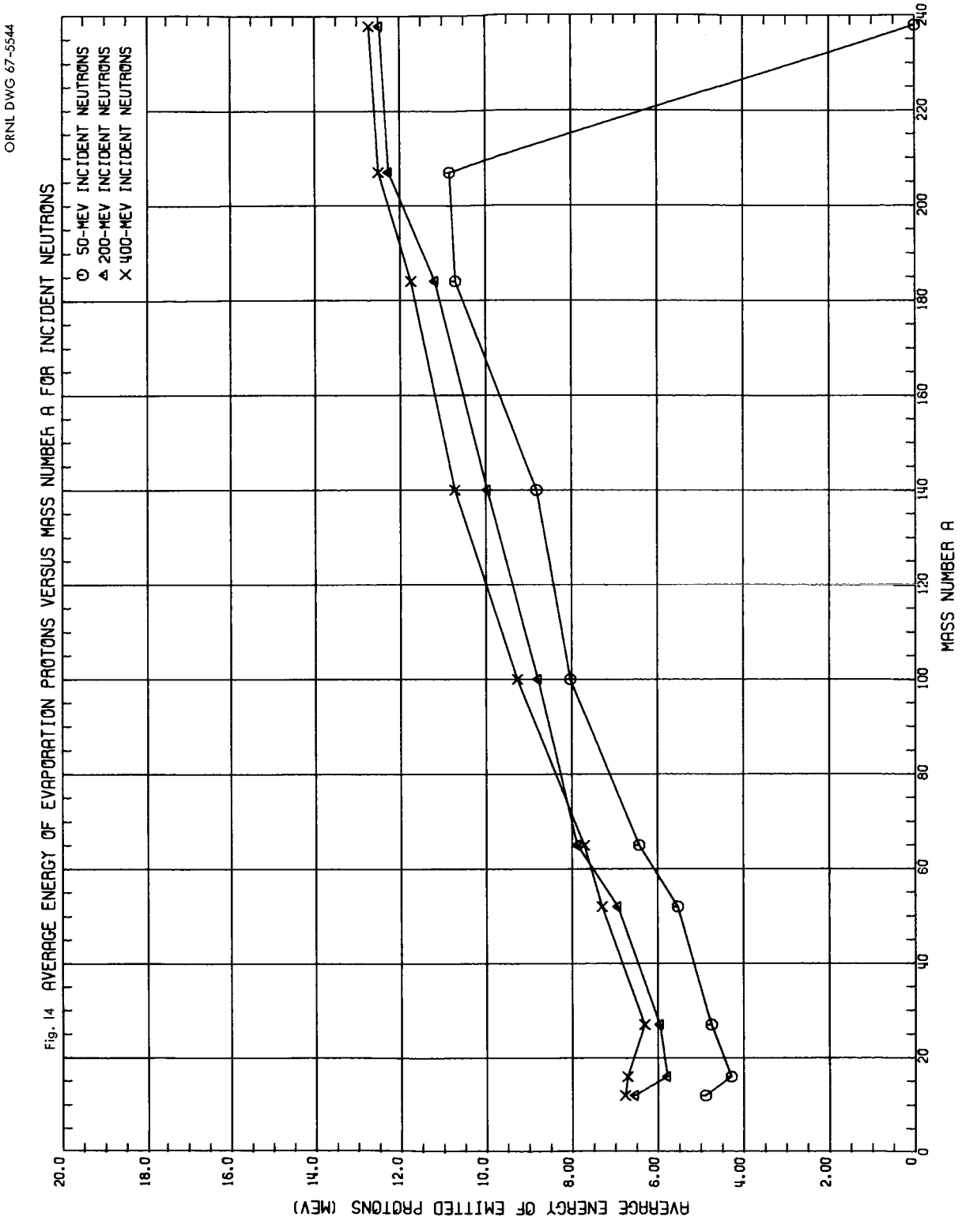


Fig. 14 AVERAGE ENERGY OF EVAPORATION PROTONS VERSUS MASS NUMBER A FOR INCIDENT NEUTRONS

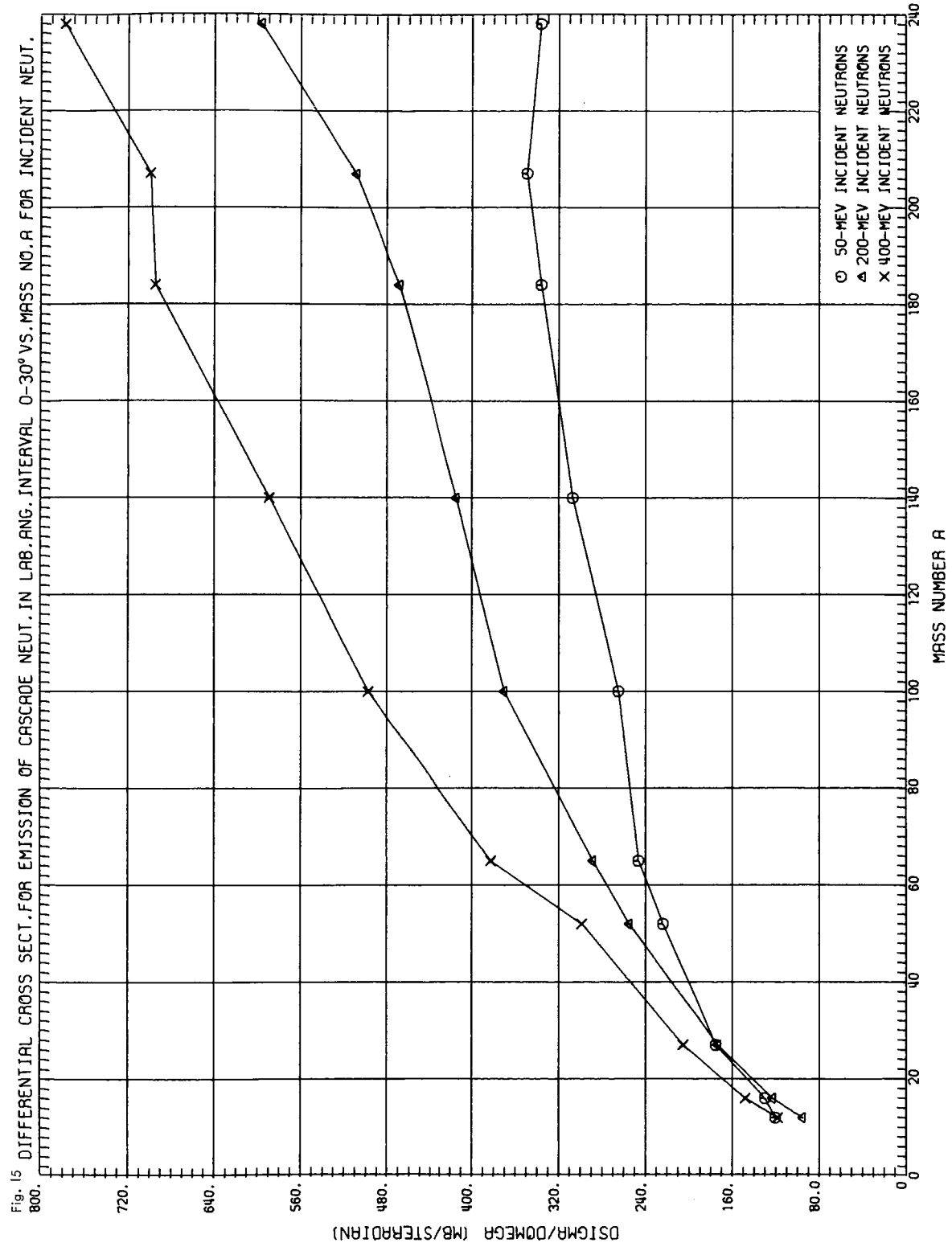

ORNL DWG 67-5545
DIFFERENTIAL CROSS SECT. FOR EMISSION OF CASCADE NEUT. IN LAB. ANG. INTERVAL 0-30° VS. MASS NO. A FOR INCIDENT NEUT.
DSIGMA/DOMEGA (MB/STERADIAN)
MASS NUMBER A
50-MEV INCIDENT NEUTRONS
200-MEV INCIDENT NEUTRONS
400-MEV INCIDENT NEUTRONS
800.
720.
640.
560.
480.
400.
320.
240.
160.
80.0
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 15

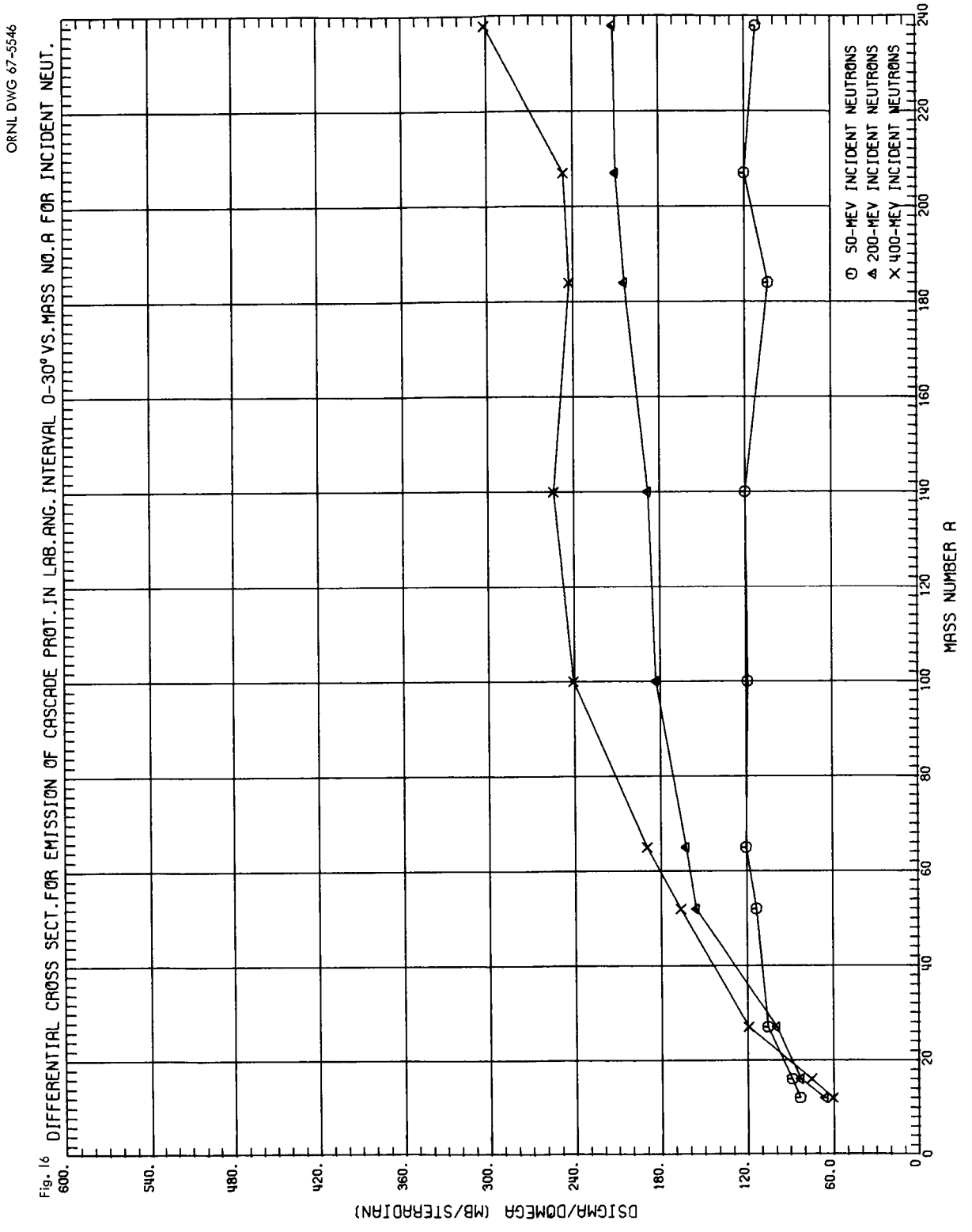

ORNL DWG 67-5546
DIFFERENTIAL CROSS SECT. FOR EMISSION OF CASCADE PROT. IN LAB. ANG. INTERVAL 0-30° VS. MASS NO. A FOR INCIDENT NEUT.
DSIGMA/DOMEGA (MB/STERADIAN)
MASS NUMBER A
50-MEV INCIDENT NEUTRONS
200-MEV INCIDENT NEUTRONS
400-MEV INCIDENT NEUTRONS
600.
540.
480.
420.
360.
300.
240.
180.
120.
60.0
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 16

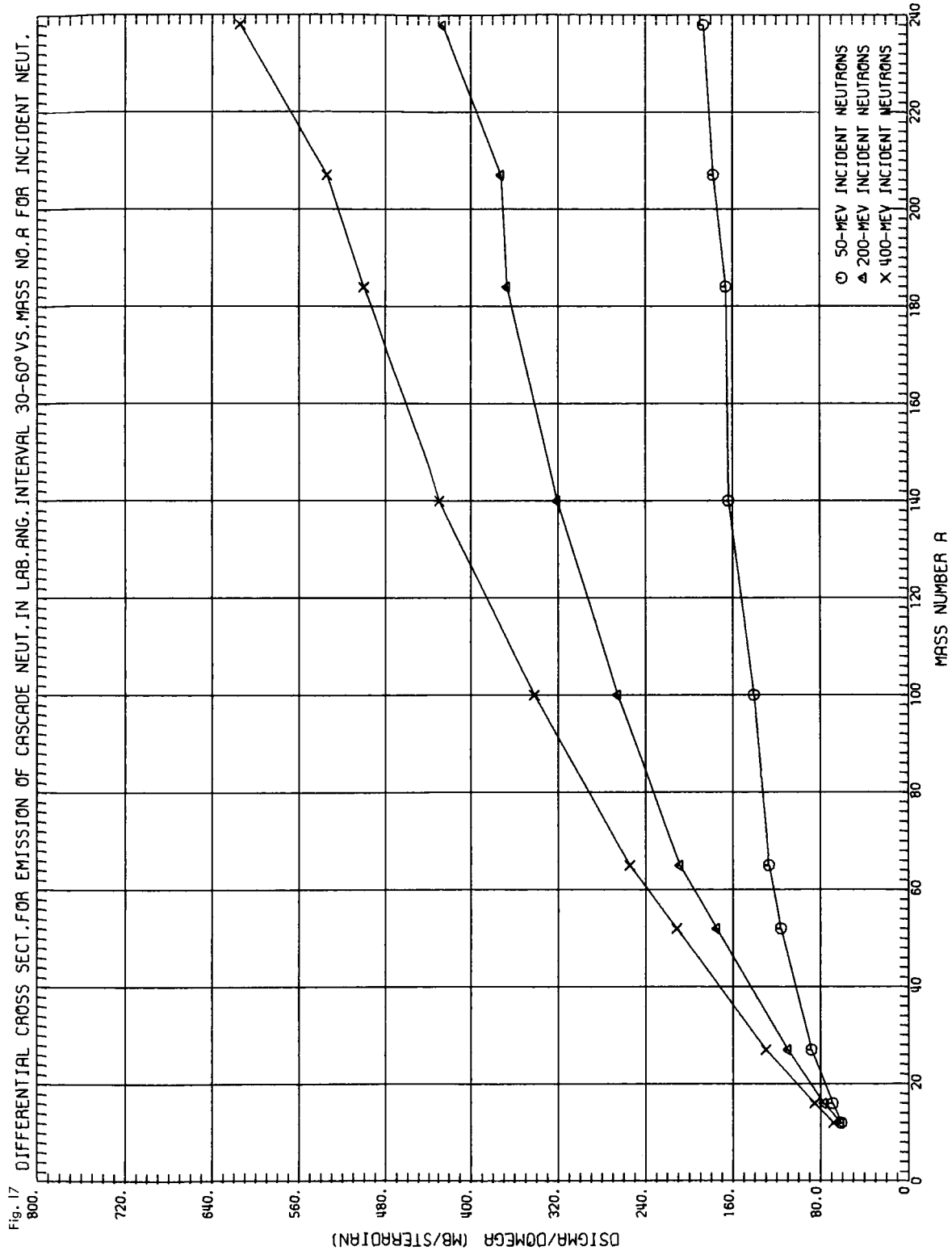

ORNL DWG 67-5547
DIFFERENTIAL CROSS SECT.FOR EMISSION OF CASCADE NEUT.IN LAB.ANG.INTERVAL 30-60° VS.MASS NO.A FOR INCIDENT NEUT.
DSIGMA/DOMEGA (MB/STERADIAN)
MASS NUMBER A
50-MEV INCIDENT NEUTRONS
200-MEV INCIDENT NEUTRONS
400-MEV INCIDENT NEUTRONS
800.
720.
640.
560.
480.
400.
320.
240.
160.
80.0
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 17

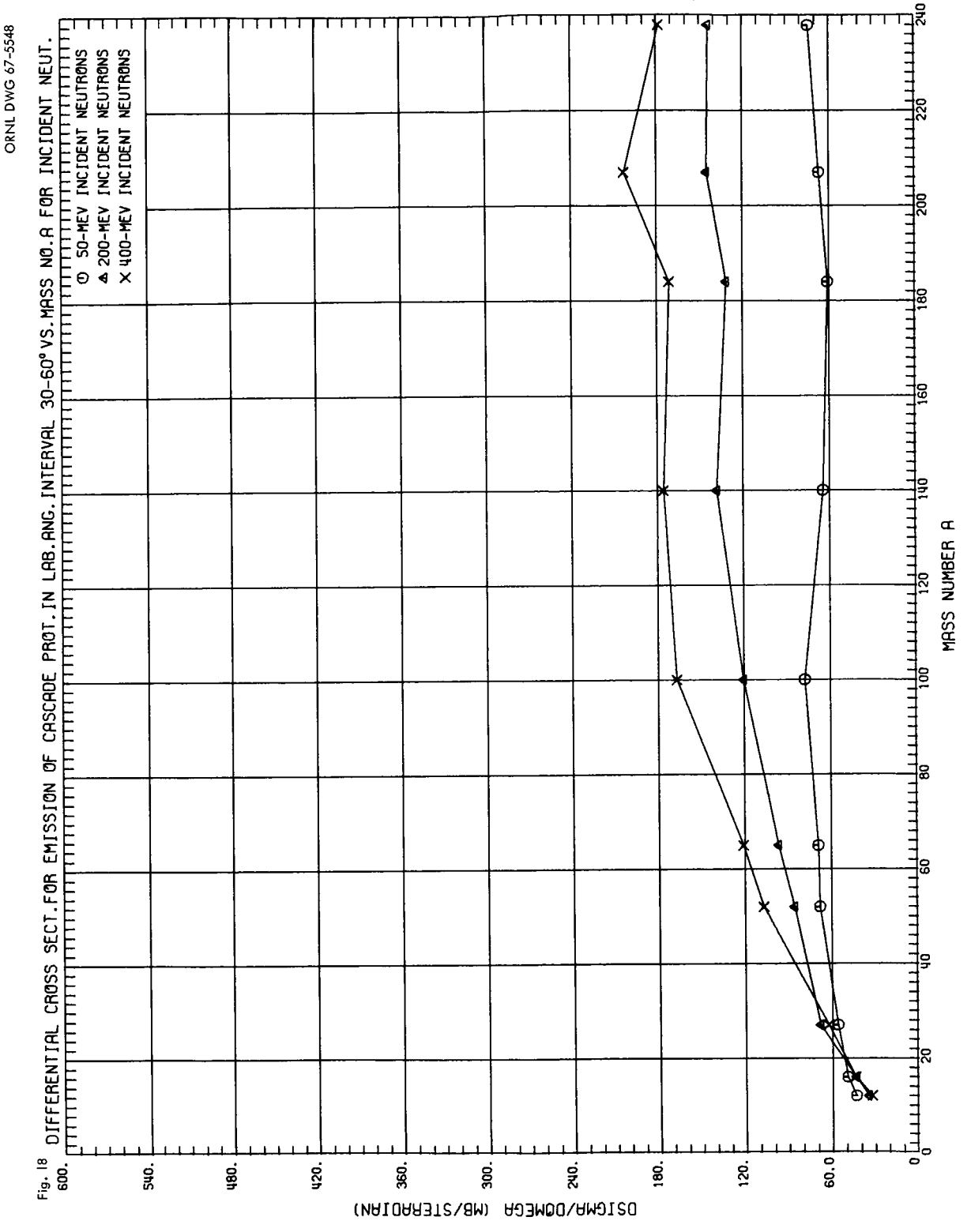

ORNL DWG 67-5548
DIFFERENTIAL CROSS SECT.FOR EMISSION OF CASCADE PROT.IN LAB.ANG.INTERVAL 30-60°VS.MASS NO.A FOR INCIDENT NEUT.
○ 50-MEV INCIDENT NEUTRONS
△ 200-MEV INCIDENT NEUTRONS
× 400-MEV INCIDENT NEUTRONS
DSIGMA/DOMEGA (MB/STERADIAN)
600.
540.
480.
420.
360.
300.
240.
180.
120.
60.0
0
0
20
40
60
80
100
120
140
160
180
200
220
240
MASS NUMBER A

Fig. 18

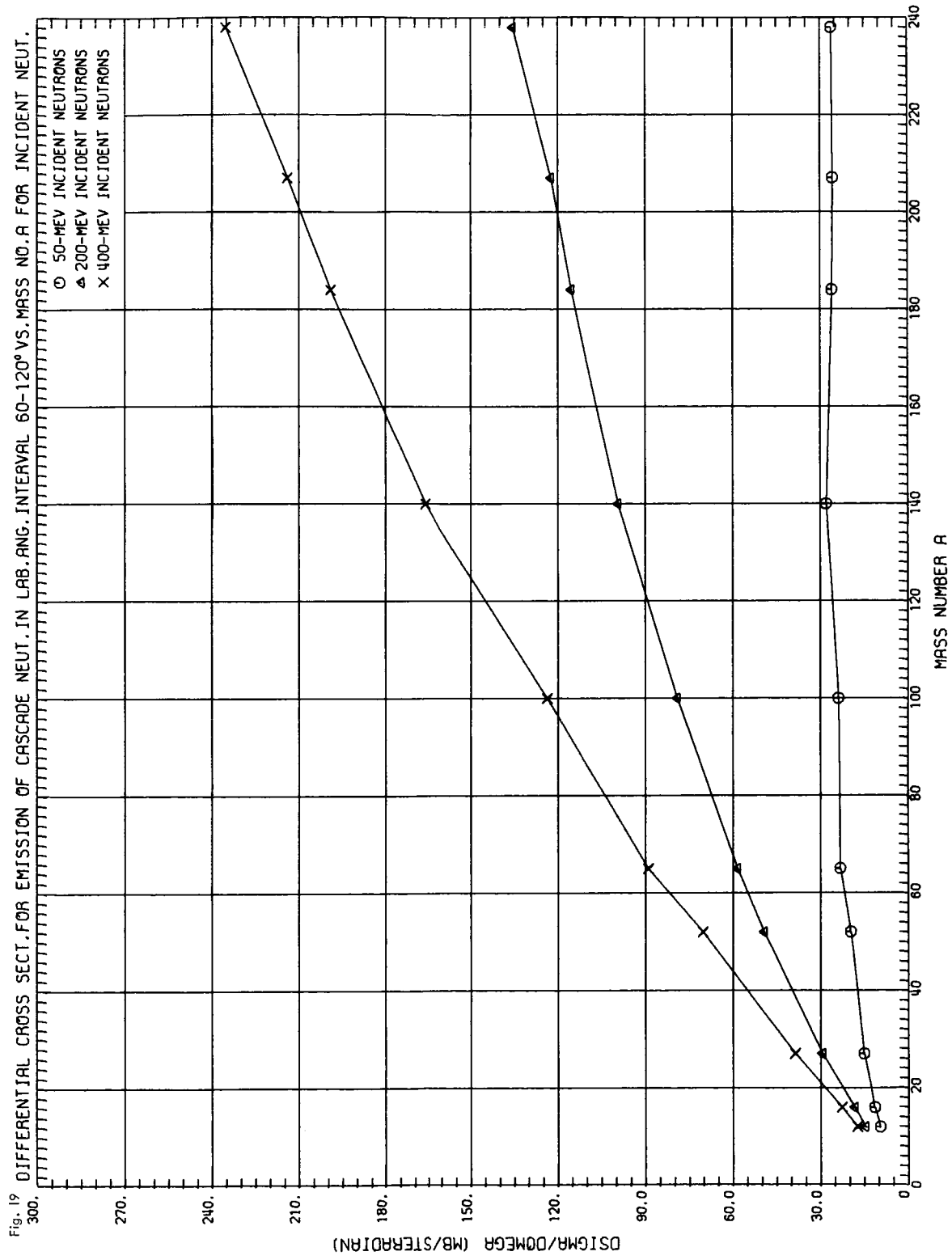

ORNL DWG 67-5549
DIFFERENTIAL CROSS SECT.FOR EMISSION OF CASCADE NEUT.IN LAB.ANG.INTERVAL 60-120° VS.MASS NO.A FOR INCIDENT NEUT.
○ 50-MEV INCIDENT NEUTRONS
△ 200-MEV INCIDENT NEUTRONS
× 400-MEV INCIDENT NEUTRONS
DSIGMA/DOMEGA (MB/STERADIAN)
MASS NUMBER A
300.
270.
240.
210.
180.
150.
120.
90.0
60.0
30.0
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 19

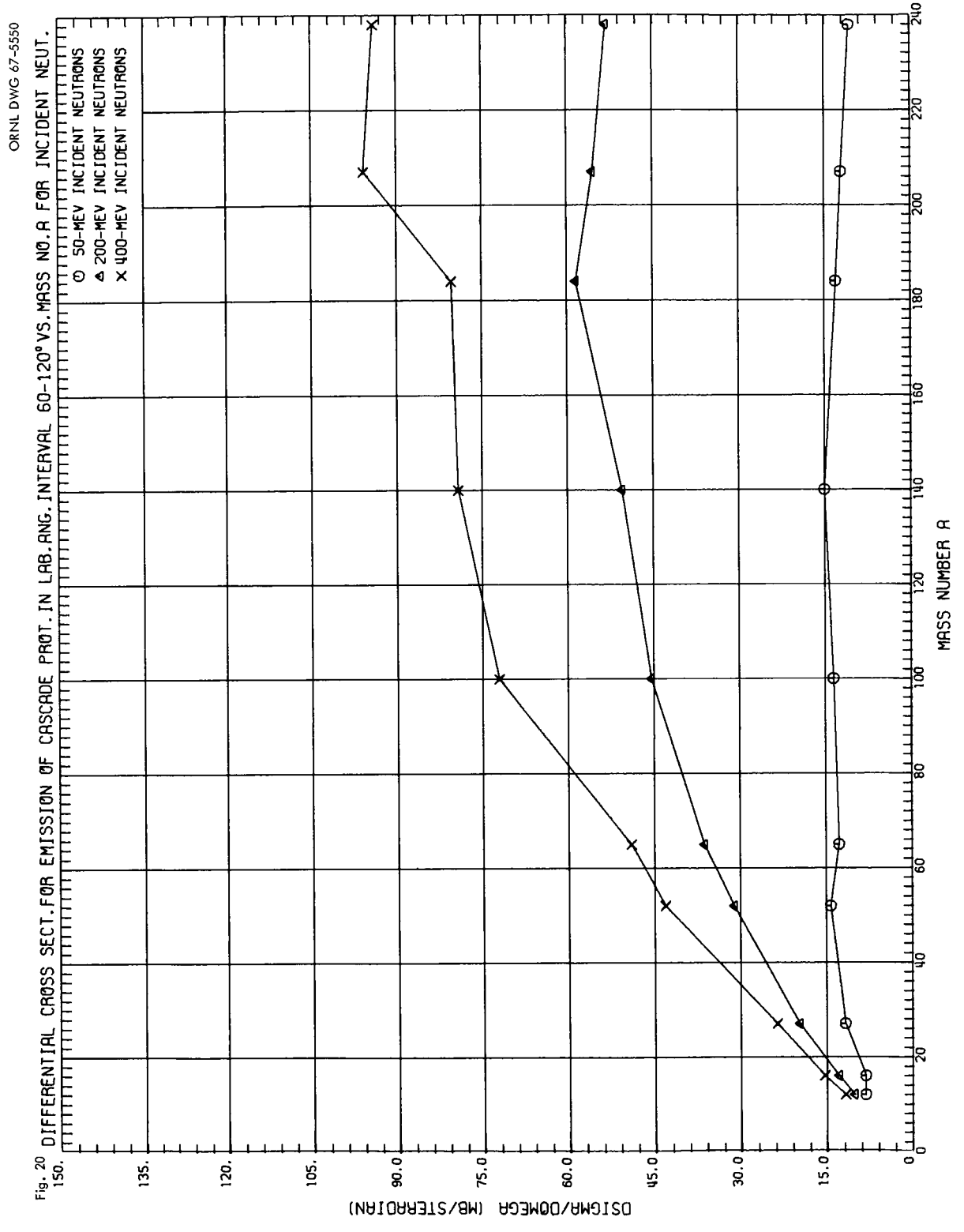

ORNL DWG 67-5550
DIFFERENTIAL CROSS SECT.FOR EMISSION OF CASCADE PROT.IN LAB.ANG.INTERVAL 60-120° VS.MASS NO.A FOR INCIDENT NEUT.
50-MEV INCIDENT NEUTRONS
200-MEV INCIDENT NEUTRONS
400-MEV INCIDENT NEUTRONS
DSIGMA/DOMEGA (MB/STERADIAN)
MASS NUMBER A
150.
135.
120.
105.
90.0
75.0
60.0
45.0
30.0
15.0
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 20

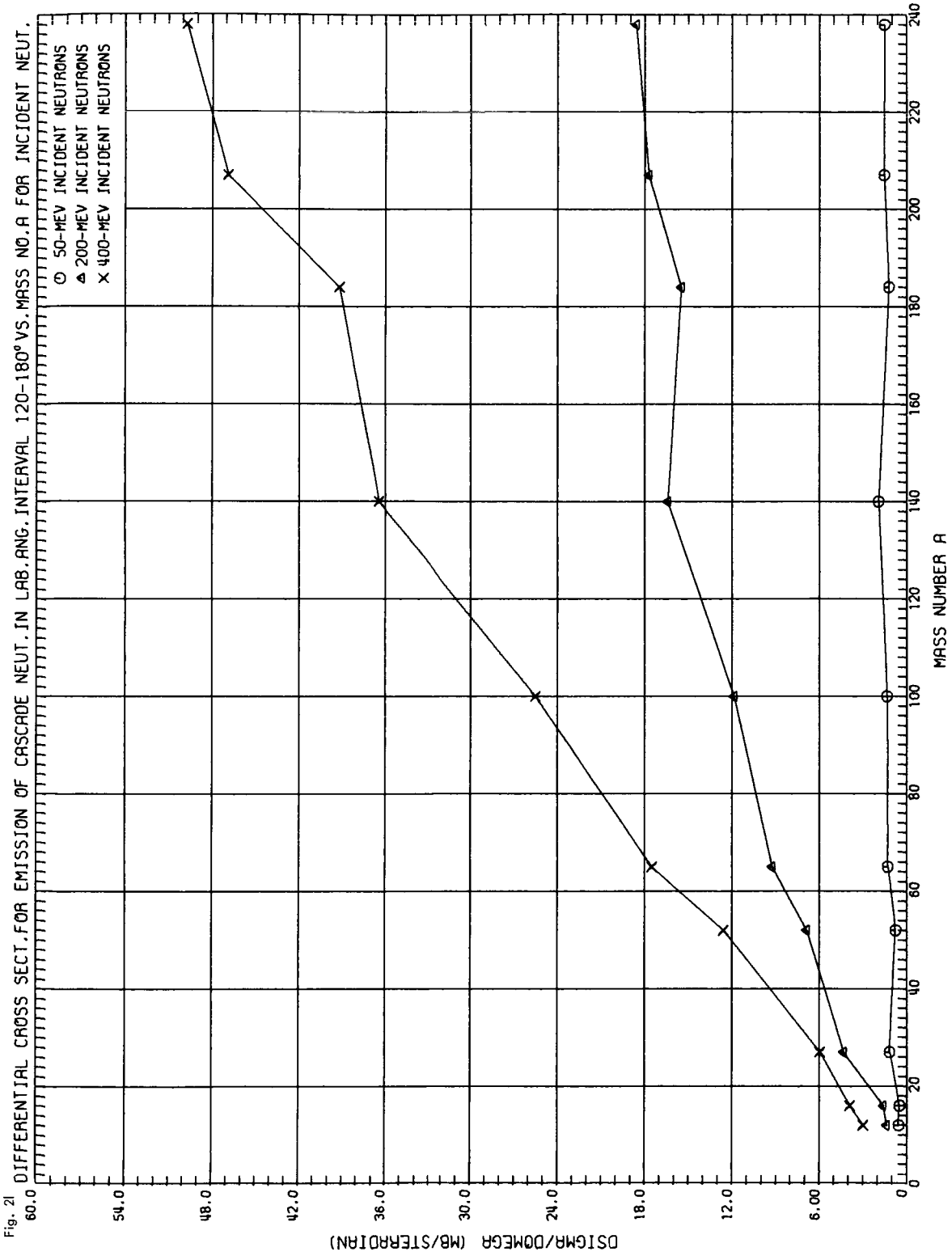

ORNL DWG 67-5551
DIFFERENTIAL CROSS SECT.FOR EMISSION OF CASCADE NEUT.IN LAB.ANG.INTERVAL 120-180° VS.MASS NO.A FOR INCIDENT NEUT.
⊙ 50-MEV INCIDENT NEUTRONS
▲ 200-MEV INCIDENT NEUTRONS
× 400-MEV INCIDENT NEUTRONS
DSIGMA/DOMEGA (MB/STERADIAN)
MASS NUMBER A
60.0
54.0
48.0
42.0
36.0
30.0
24.0
18.0
12.0
6.00
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 21

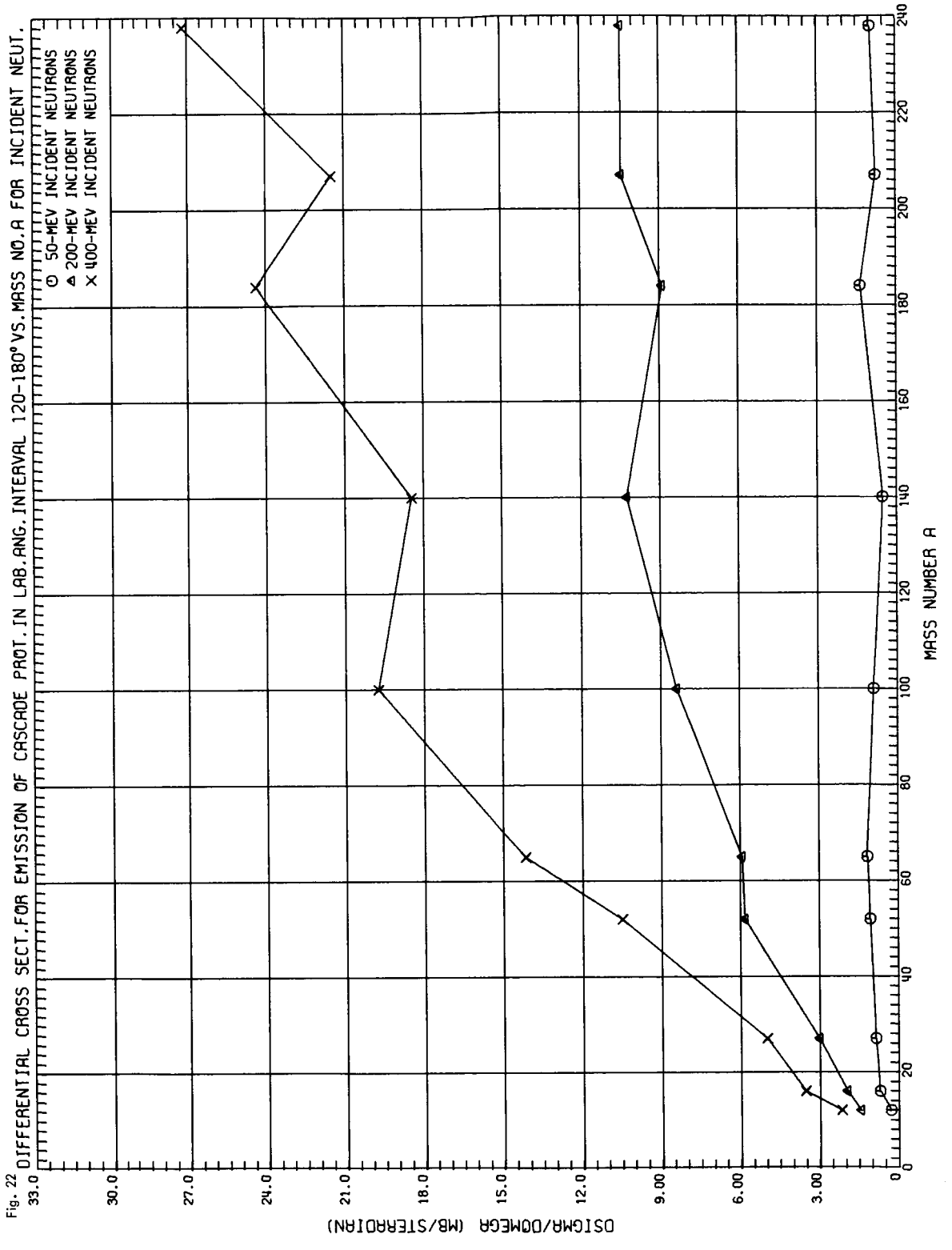

ORNL DWG 67-5552
DIFFERENTIAL CROSS SECT. FOR EMISSION OF CASCADE PROT. IN LAB. ANG. INTERVAL 120-180° VS. MASS NO. A FOR INCIDENT NEUT.
○ 50-MEV INCIDENT NEUTRONS
△ 200-MEV INCIDENT NEUTRONS
× 400-MEV INCIDENT NEUTRONS
DSIGMA/DOMEGA (MB/STERADIAN)
MASS NUMBER A
33.0
30.0
27.0
24.0
21.0
18.0
15.0
12.0
9.00
6.00
3.00
0
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 22

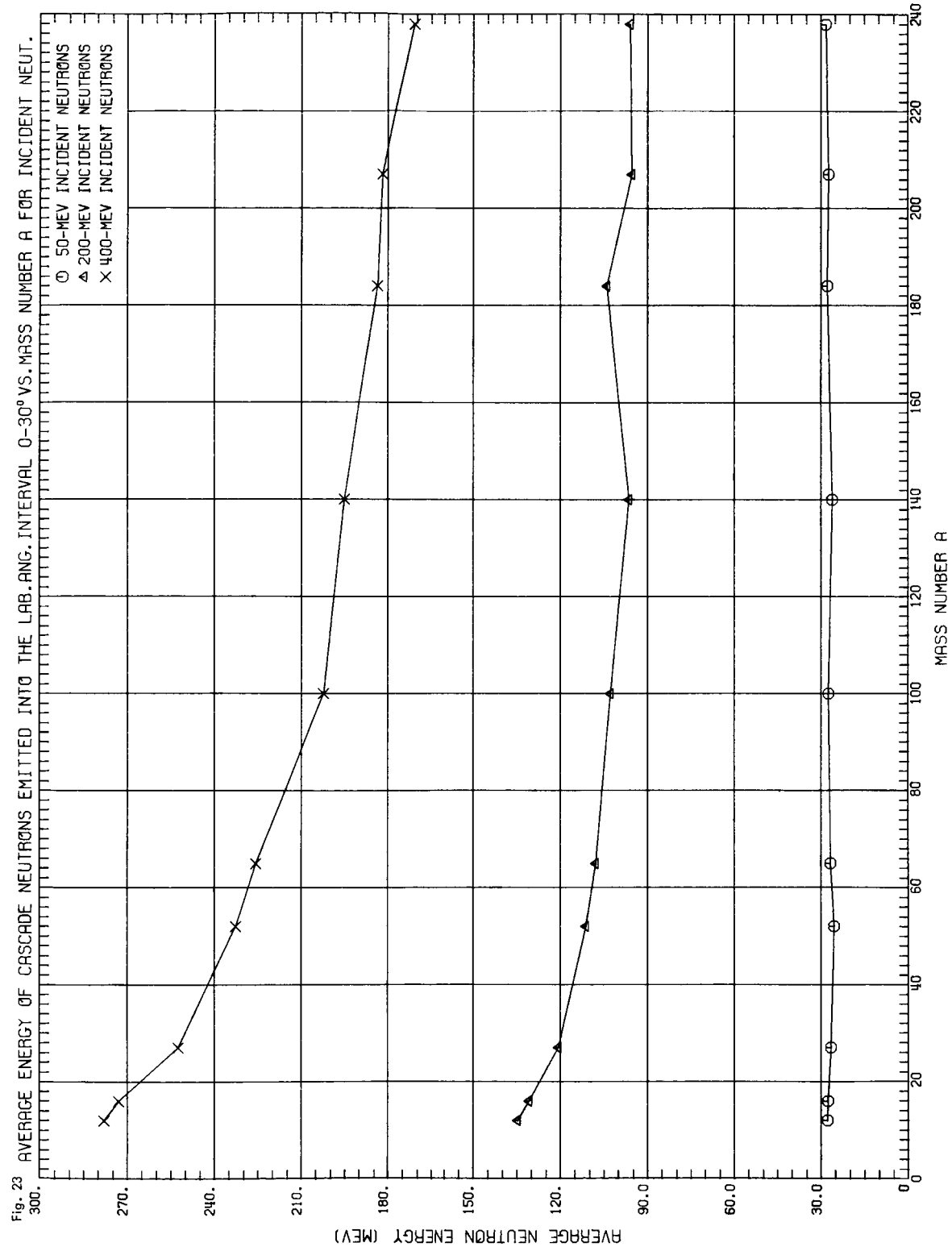

ORNL DWG 67-5553
AVERAGE ENERGY OF CASCADE NEUTRONS EMITTED INTO THE LAB. ANG. INTERVAL 0-30° VS. MASS NUMBER A FOR INCIDENT NEUT.
○ 50-MEV INCIDENT NEUTRONS
△ 200-MEV INCIDENT NEUTRONS
× 400-MEV INCIDENT NEUTRONS
AVERAGE NEUTRON ENERGY (MEV)
300.
270.
240.
210.
180.
150.
120.
90.0
60.0
30.0
0
0
20
40
60
80
100
120
140
160
180
200
220
240
MASS NUMBER A

Fig. 23

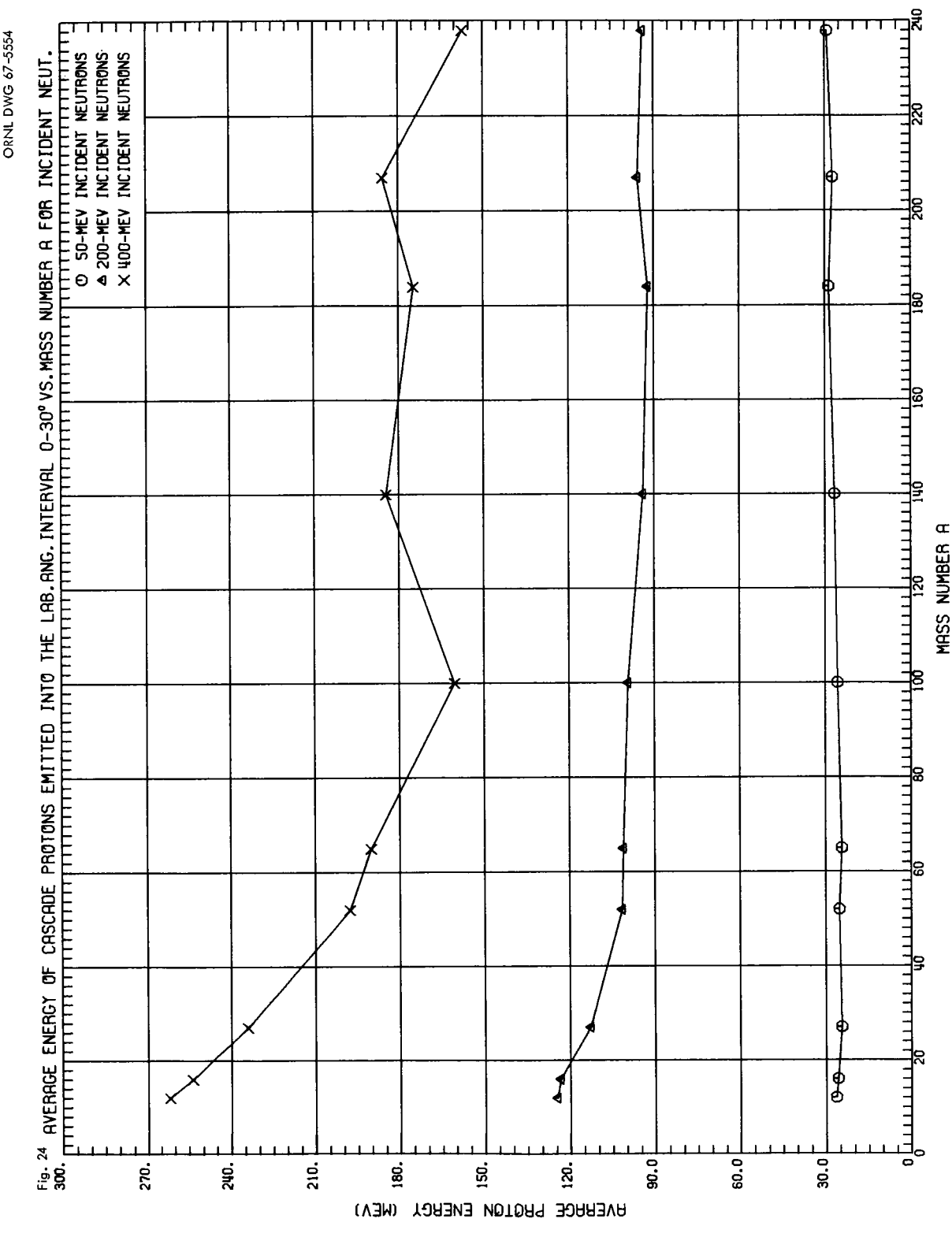

ORNL DWG 67-5554
AVERAGE ENERGY OF CASCADE PROTONS EMITTED INTO THE LAB. ANG. INTERVAL 0-30° VS. MASS NUMBER A FOR INCIDENT NEUT.
○ 50-MEV INCIDENT NEUTRONS
△ 200-MEV INCIDENT NEUTRONS
× 400-MEV INCIDENT NEUTRONS
AVERAGE PROTON ENERGY (MEV)
300.
270.
240.
210.
180.
150.
120.
90.0
60.0
30.0
0
0
20
40
60
80
100
120
140
160
180
200
220
240
MASS NUMBER A

Fig. 24

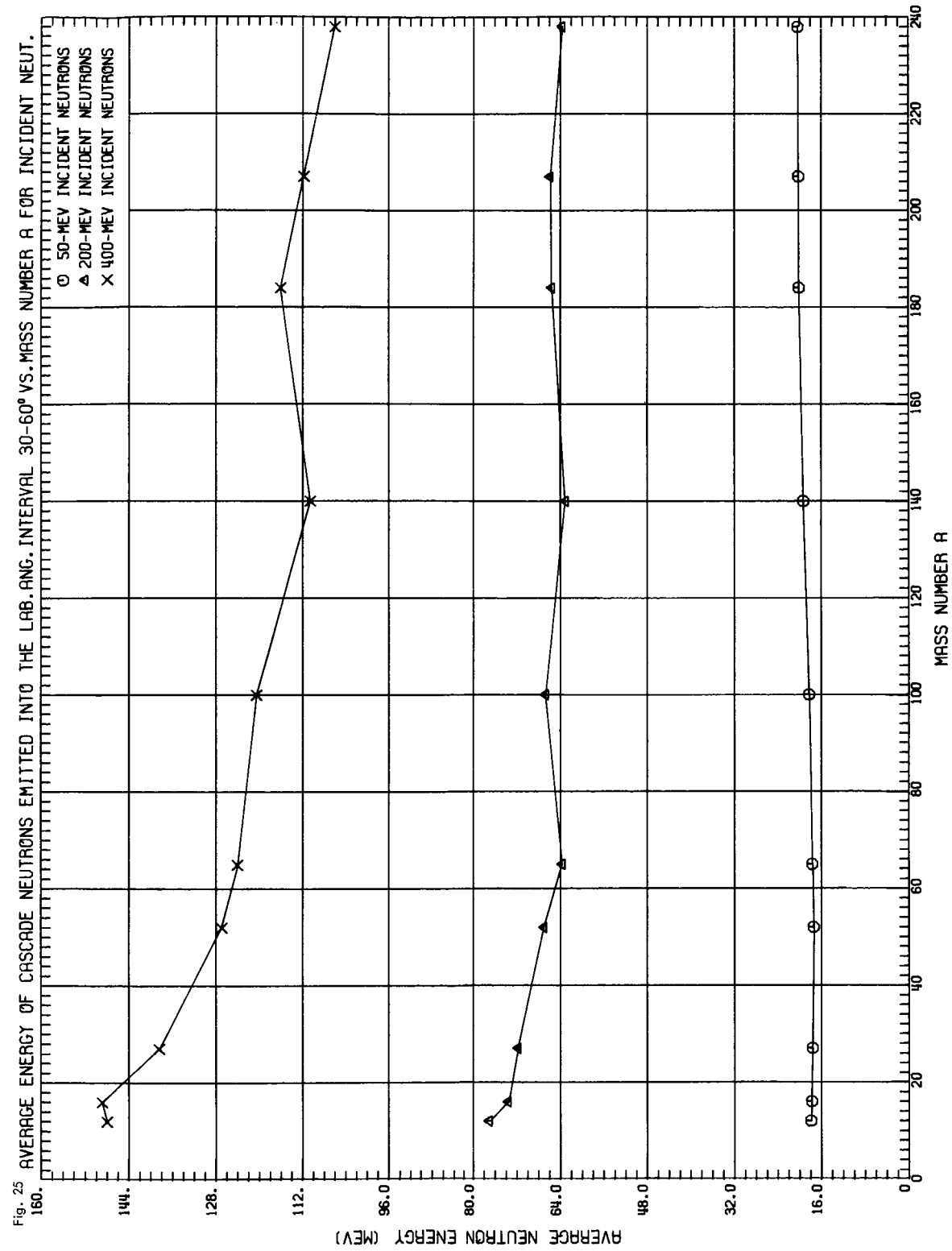

ORNL DWG 67-5555
AVERAGE ENERGY OF CASCADE NEUTRONS EMITTED INTO THE LAB. ANG. INTERVAL 30-60° VS. MASS NUMBER A FOR INCIDENT NEUT.
50-MEV INCIDENT NEUTRONS
200-MEV INCIDENT NEUTRONS
400-MEV INCIDENT NEUTRONS
AVERAGE NEUTRON ENERGY (MEV)
MASS NUMBER A
160.
144.
128.
112.
96.0
80.0
64.0
48.0
32.0
16.0
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 25

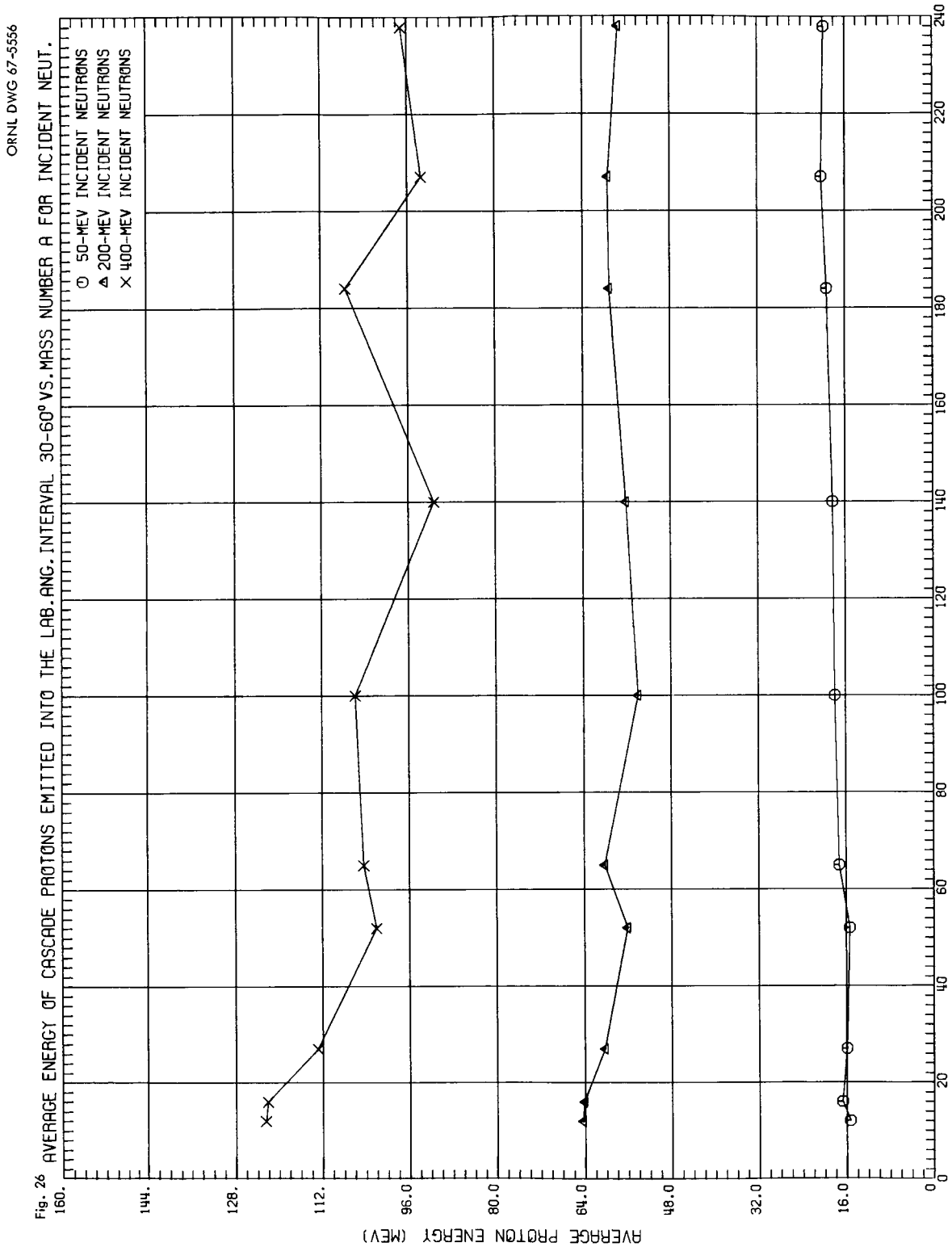

ORNL DWG 67-5556
AVERAGE ENERGY OF CASCADE PROTONS EMITTED INTO THE LAB. ANG. INTERVAL 30-60° VS. MASS NUMBER A FOR INCIDENT NEUT.
50-MEV INCIDENT NEUTRONS
200-MEV INCIDENT NEUTRONS
400-MEV INCIDENT NEUTRONS
AVERAGE PROTON ENERGY (MEV)
MASS NUMBER A
160.
144.
128.
112.
96.0
80.0
64.0
48.0
32.0
16.0
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 26

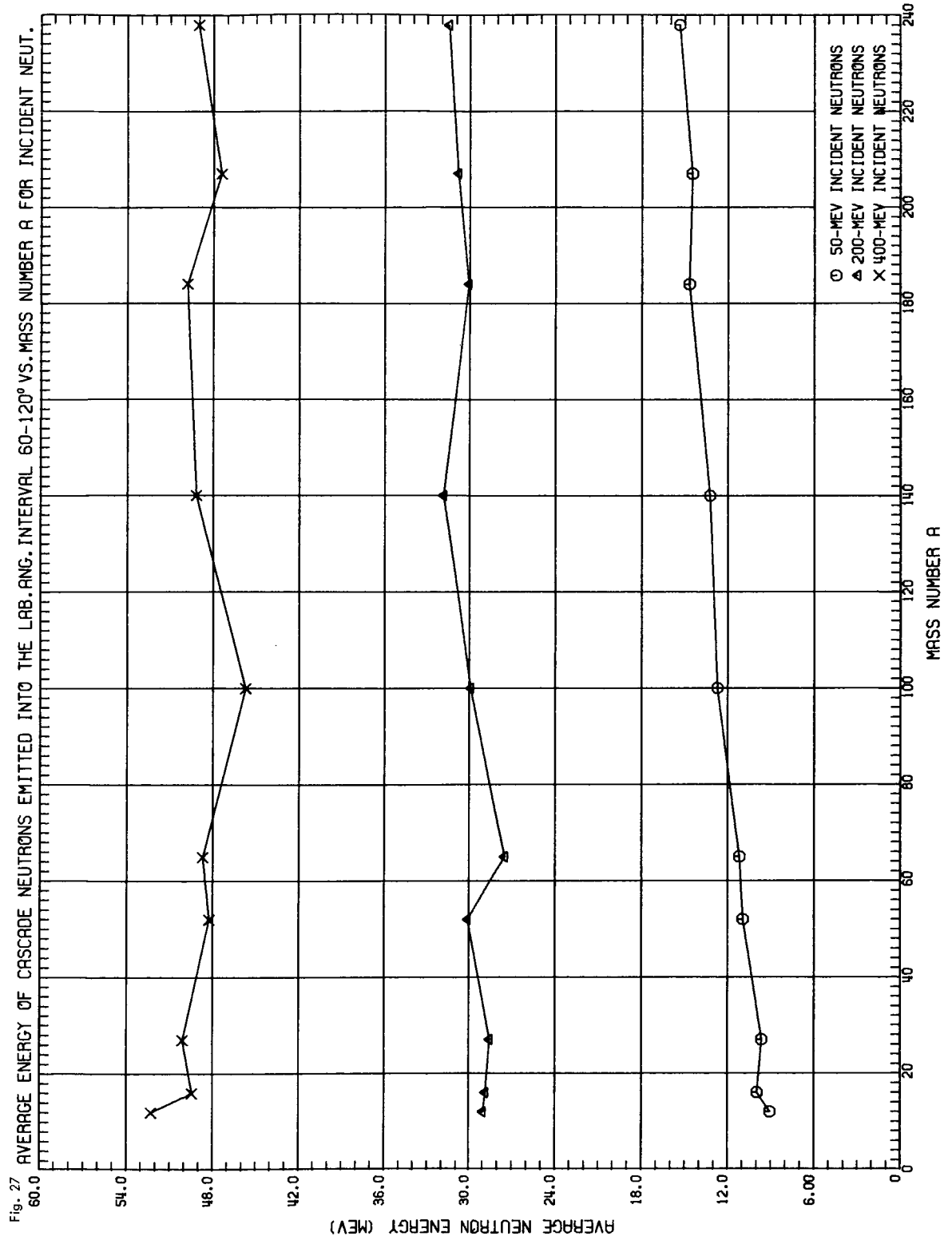

ORNL DWG 67-5557
AVERAGE ENERGY OF CASCADE NEUTRONS EMITTED INTO THE LAB. ANG. INTERVAL 60-120° VS. MASS NUMBER A FOR INCIDENT NEUT.
AVERAGE NEUTRON ENERGY (MEV)
MASS NUMBER A
50-MEV INCIDENT NEUTRONS
200-MEV INCIDENT NEUTRONS
400-MEV INCIDENT NEUTRONS
60.0
54.0
48.0
42.0
36.0
30.0
24.0
18.0
12.0
6.00
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 27

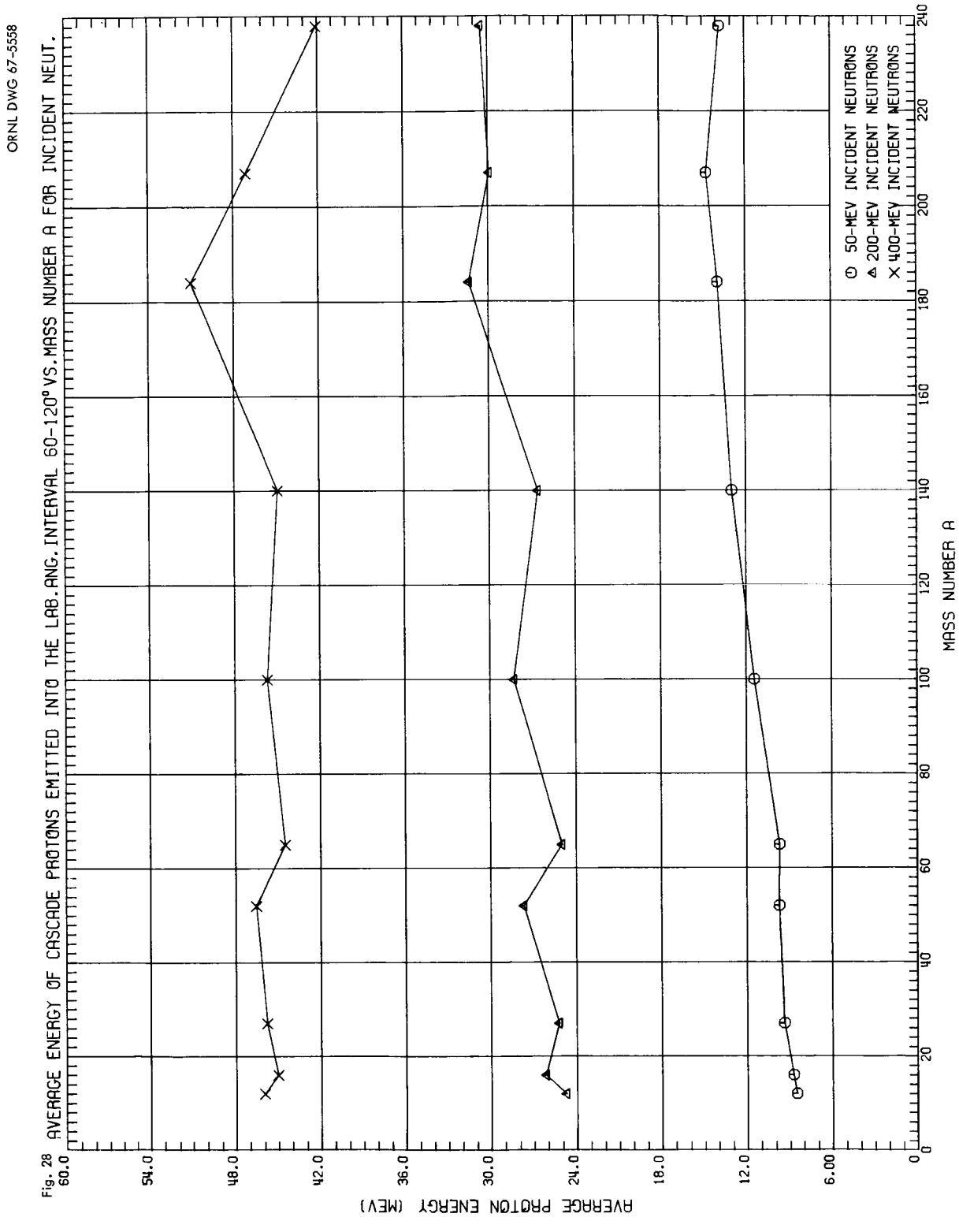

ORNL DWG 67-5558
AVERAGE ENERGY OF CASCADE PROTONS EMITTED INTO THE LAB. ANG. INTERVAL 60-120° VS. MASS NUMBER A FOR INCIDENT NEUT.
AVERAGE PROTON ENERGY (MEV)
MASS NUMBER A
50-MEV INCIDENT NEUTRONS
200-MEV INCIDENT NEUTRONS
400-MEV INCIDENT NEUTRONS
60.0
54.0
48.0
42.0
36.0
30.0
24.0
18.0
12.0
6.00
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 28

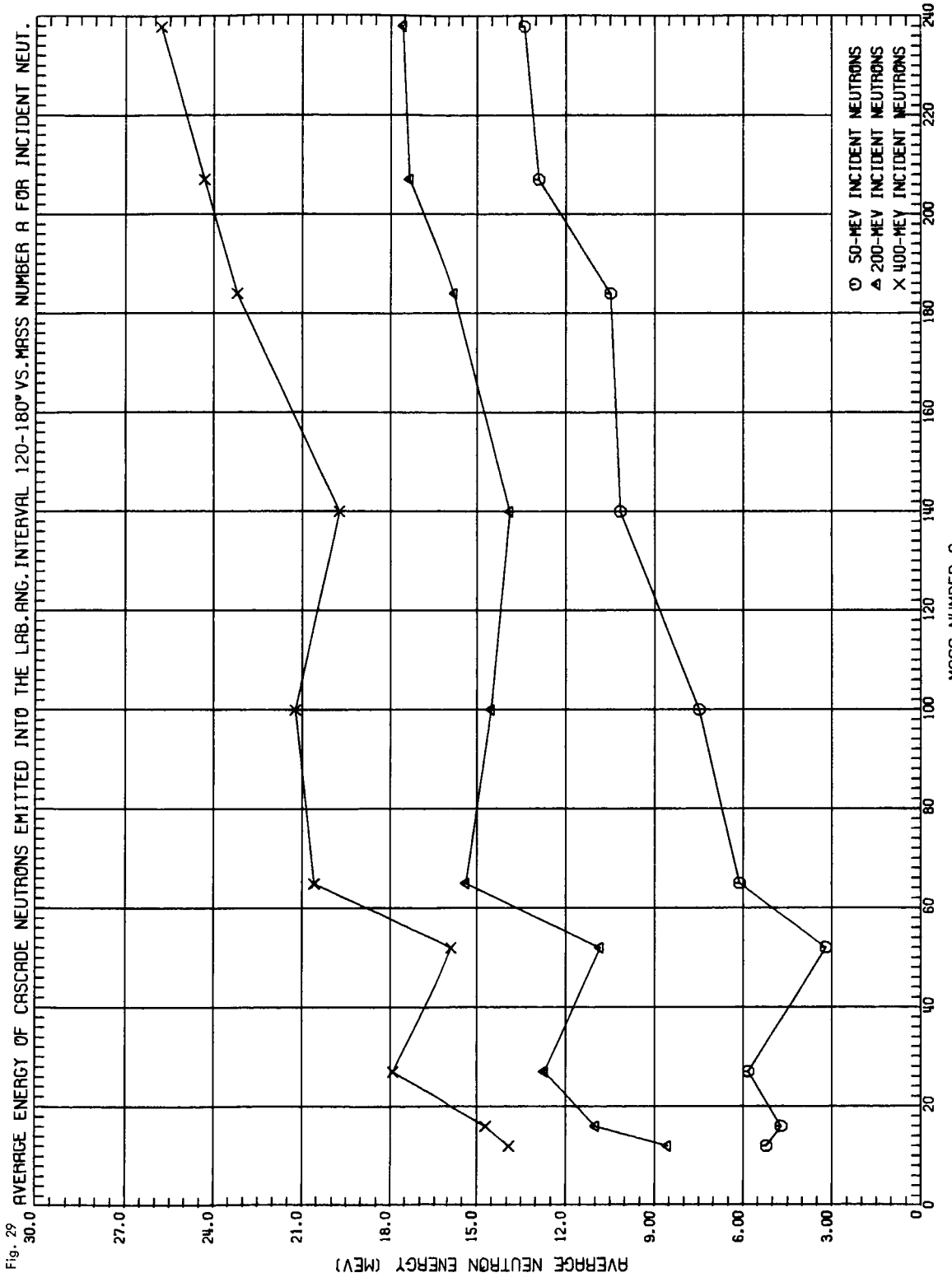

ORNL DWG 67-5559
AVERAGE ENERGY OF CASCADE NEUTRONS EMITTED INTO THE LAB. ANG. INTERVAL 120-180° VS. MASS NUMBER A FOR INCIDENT NEUT.
AVERAGE NEUTRON ENERGY (MEV)
MASS NUMBER A
50-MEV INCIDENT NEUTRONS
200-MEV INCIDENT NEUTRONS
400-MEV INCIDENT NEUTRONS
30.0
27.0
24.0
21.0
18.0
15.0
12.0
9.00
6.00
3.00
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 29

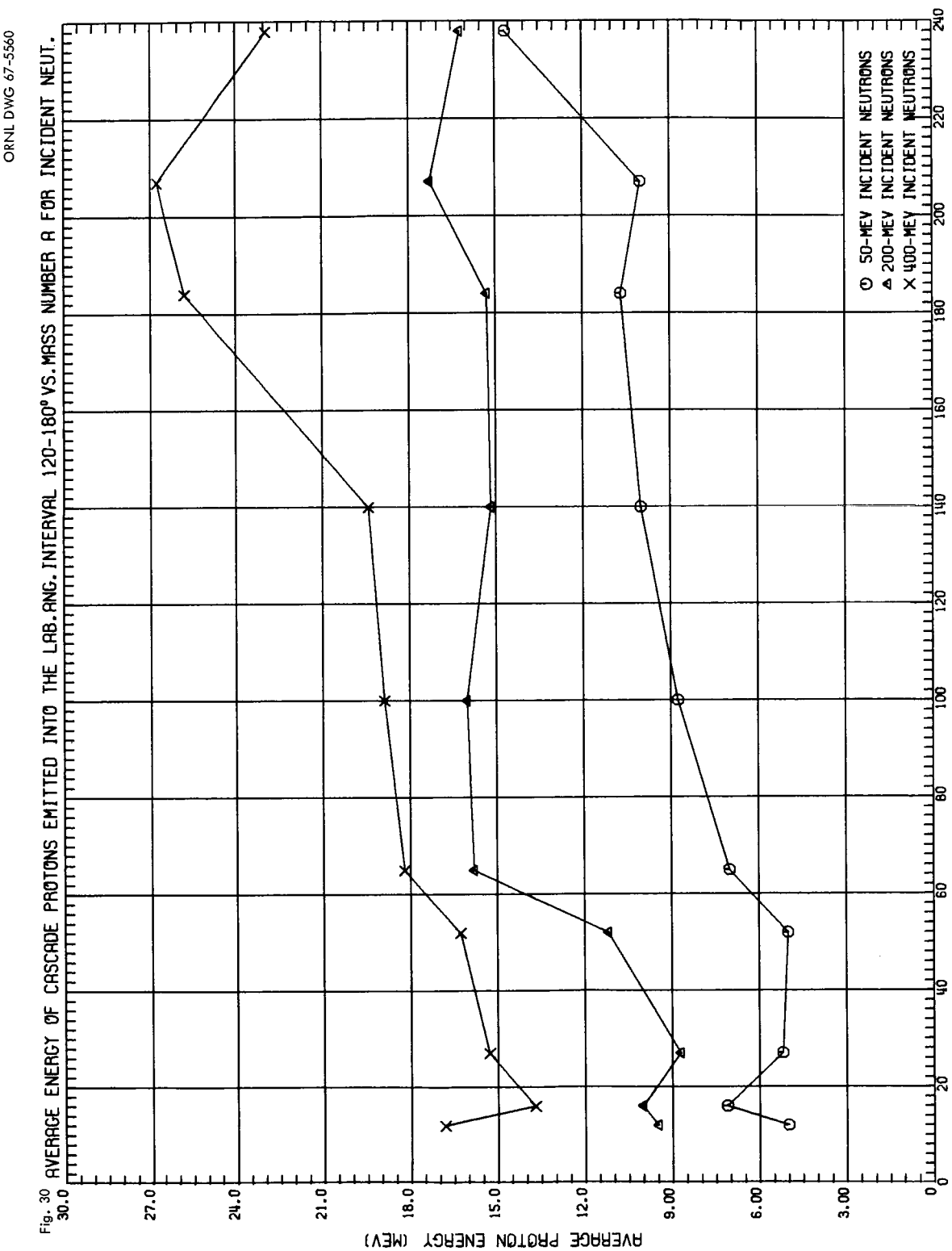

ORNL DWG 67-5560
AVERAGE ENERGY OF CASCADE PROTONS EMITTED INTO THE LAB. ANG. INTERVAL 120-180° VS. MASS NUMBER A FOR INCIDENT NEUT.
AVERAGE PROTON ENERGY (MEV)
MASS NUMBER A
50-MEV INCIDENT NEUTRONS
200-MEV INCIDENT NEUTRONS
400-MEV INCIDENT NEUTRONS
30.0
27.0
24.0
21.0
18.0
15.0
12.0
9.00
6.00
3.00
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 30

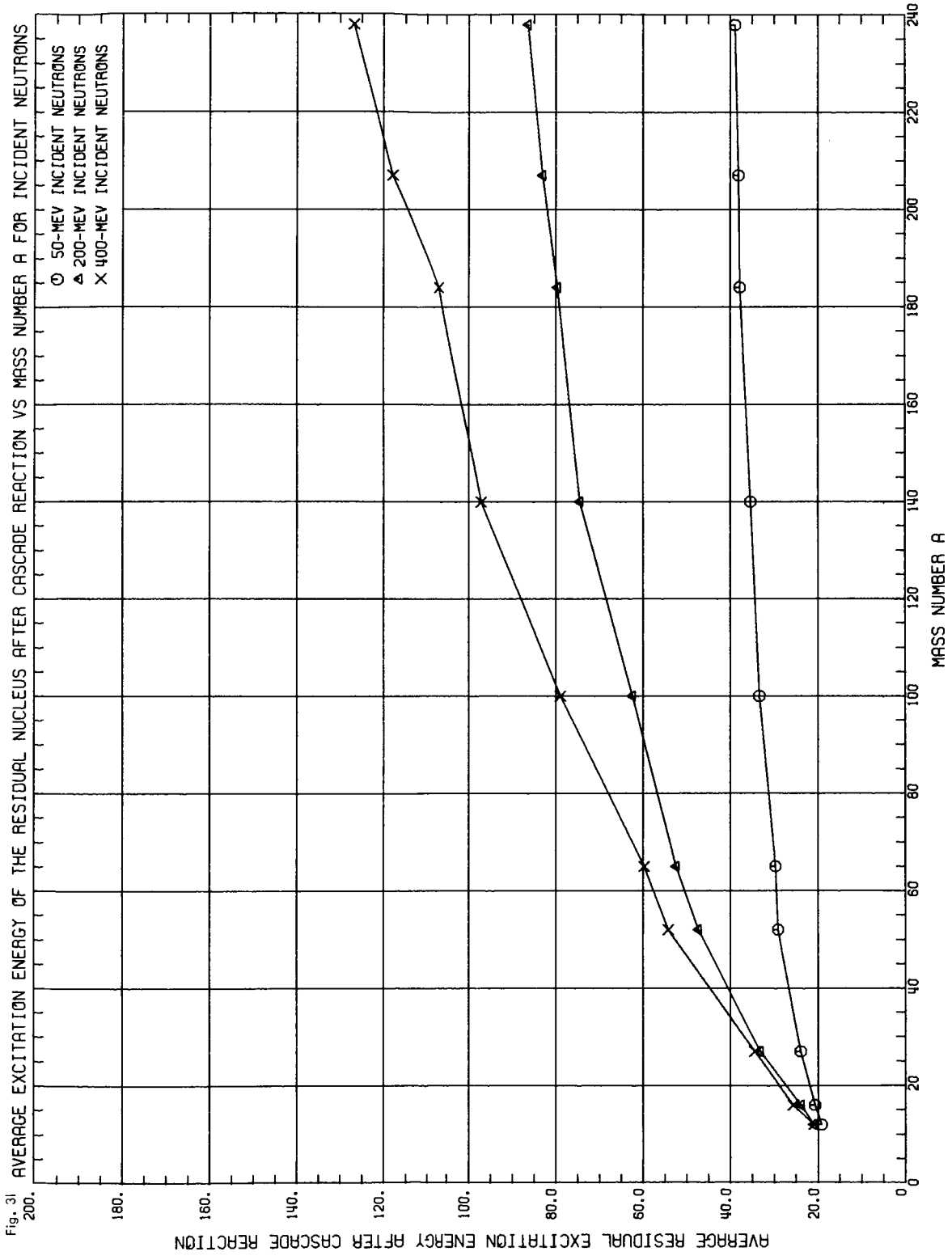

ORNL DWG 67-5561
AVERAGE EXCITATION ENERGY OF THE RESIDUAL NUCLEUS AFTER CASCADE REACTION VS MASS NUMBER A FOR INCIDENT NEUTRONS
50-MEV INCIDENT NEUTRONS
200-MEV INCIDENT NEUTRONS
400-MEV INCIDENT NEUTRONS
AVERAGE RESIDUAL EXCITATION ENERGY AFTER CASCADE REACTION
MASS NUMBER A
0
20.0
40.0
60.0
80.0
100.
120.
140.
160.
180.
200.
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 31

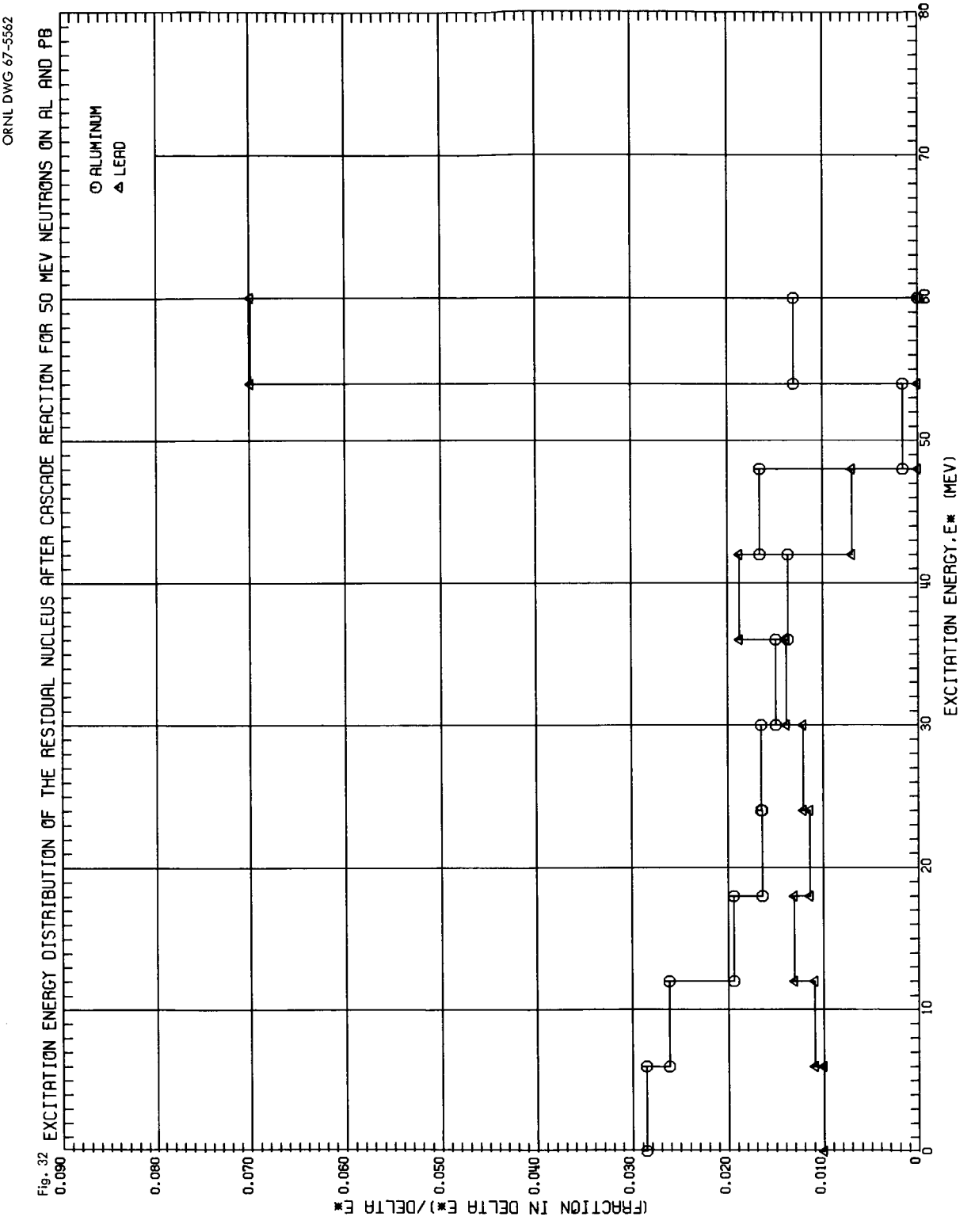

ORNL DWG 67-5562
EXCITATION ENERGY DISTRIBUTION OF THE RESIDUAL NUCLEUS AFTER CASCADE REACTION FOR 50 MEV NEUTRONS ON AL AND PB
ALUMINUM
LEAD
(FRACTION IN DELTA E*)/DELTA E*
EXCITATION ENERGY, E* (MEV)
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0
10
20
30
40
50
60
70
80

Fig. 32

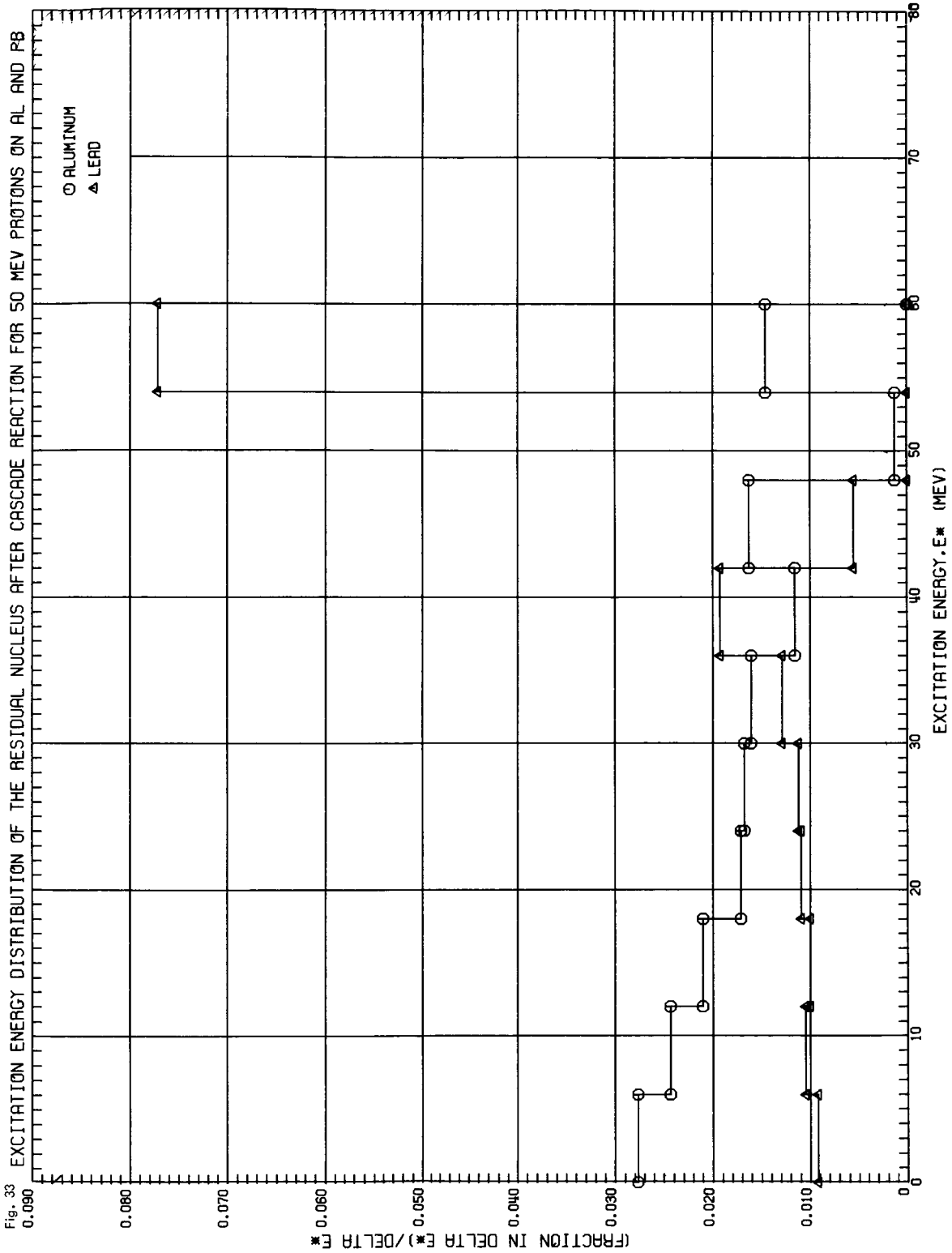

ORNL DWG 67-5563
EXCITATION ENERGY DISTRIBUTION OF THE RESIDUAL NUCLEUS AFTER CASCADE REACTION FOR 50 MEV PROTONS ON AL AND PB
ALUMINUM
LEAD
(FRACTION IN DELTA E*)/DELTA E*
EXCITATION ENERGY, E* (MEV)
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0
10
20
30
40
50
60
70
80

Fig. 33

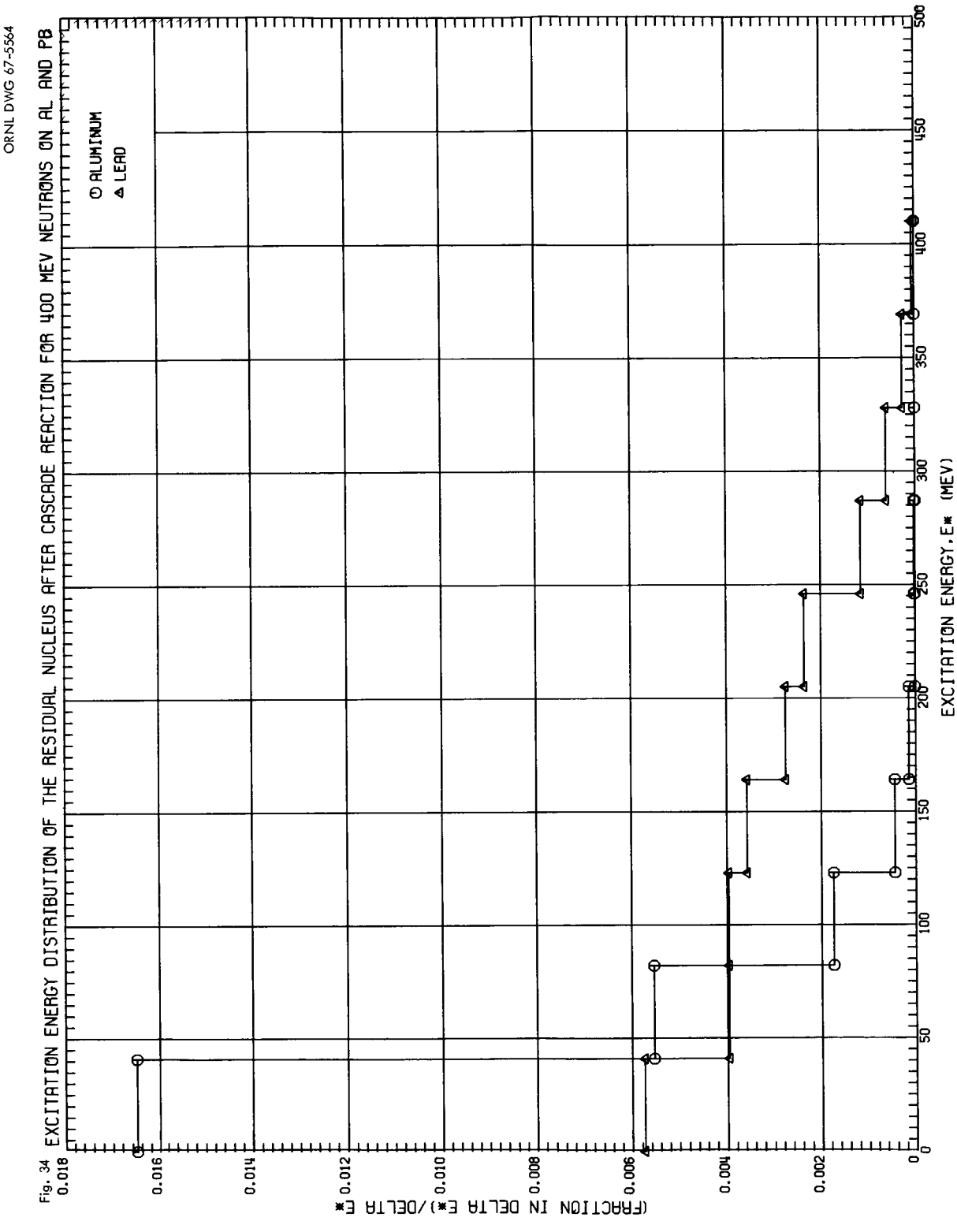

ORNL DWG 67-5564
EXCITATION ENERGY DISTRIBUTION OF THE RESIDUAL NUCLEUS AFTER CASCADE REACTION FOR 400 MEV NEUTRONS ON AL AND PB
ALUMINUM
LEAD
(FRACTION IN DELTA E*)/DELTA E*
EXCITATION ENERGY, E* (MEV)
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0
50
100
150
200
250
300
350
400
450
500

Fig. 34

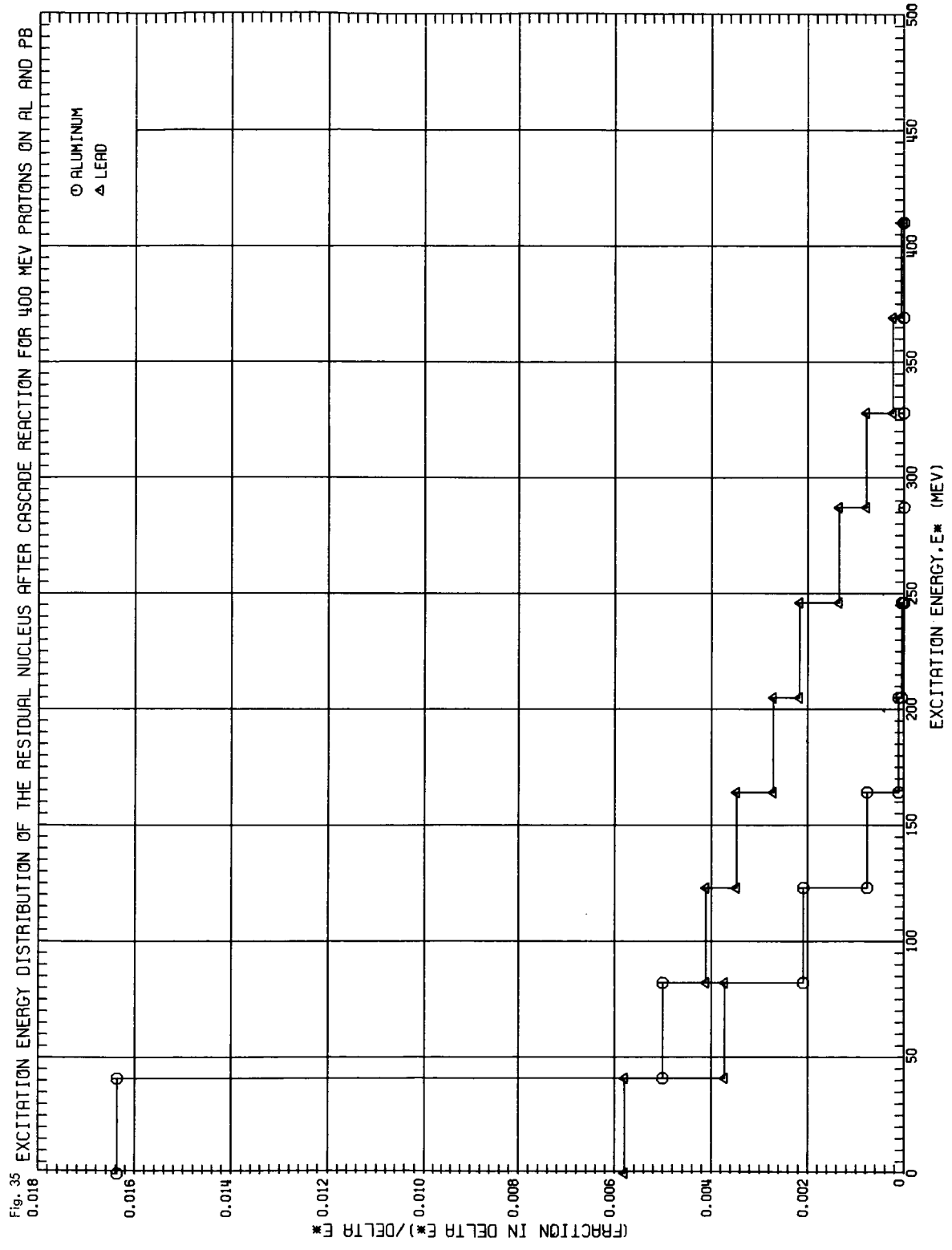

ORNL DWG 67-5565
EXCITATION ENERGY DISTRIBUTION OF THE RESIDUAL NUCLEUS AFTER CASCADE REACTION FOR 400 MEV PROTONS ON AL AND PB
ALUMINUM
LEAD
(FRACTION IN DELTA E*)/DELTA E*
EXCITATION ENERGY, E* (MEV)
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0
50
100
150
200
250
300
350
400
450
500

Fig. 35

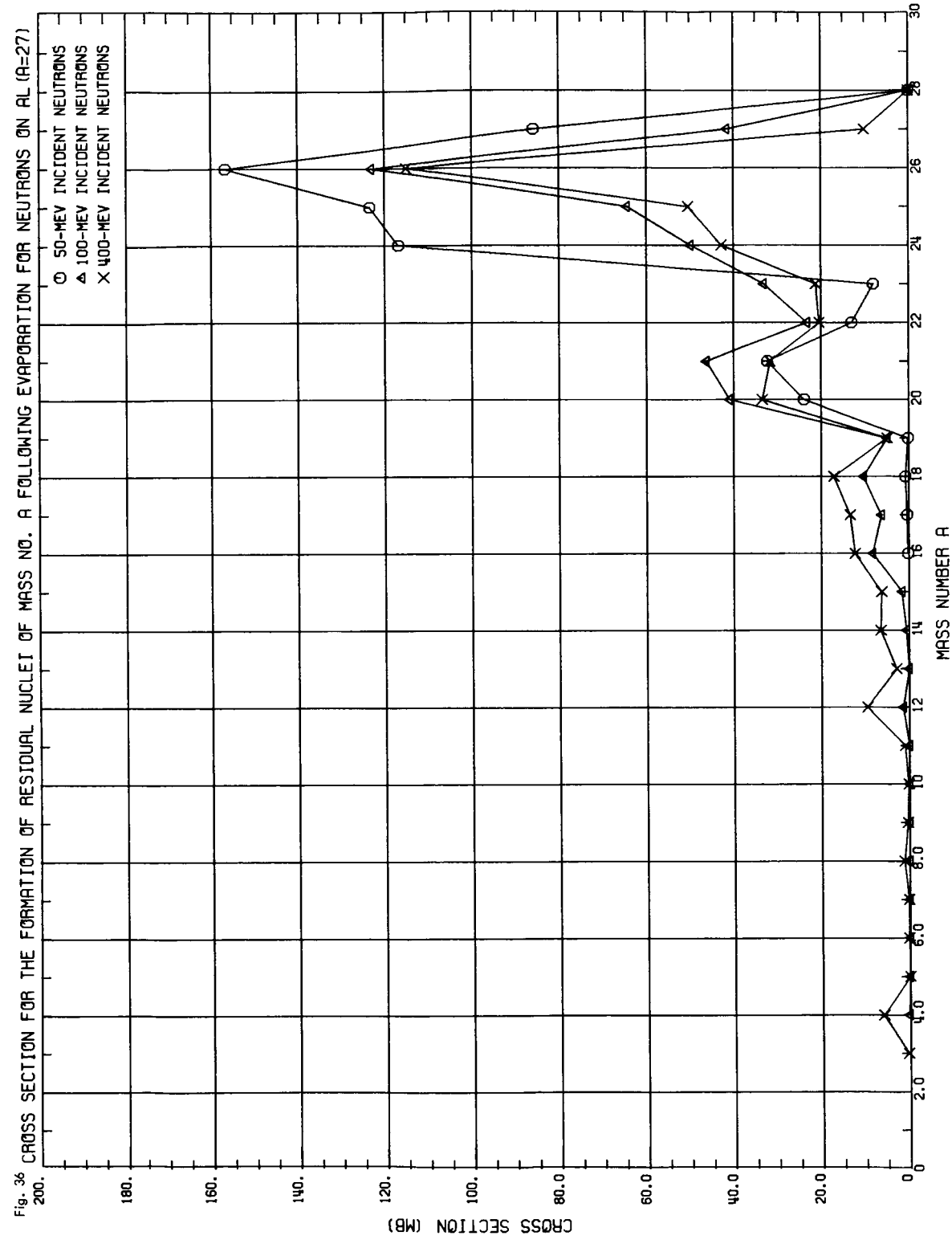

ORNL DWG 67-5566
CROSS SECTION FOR THE FORMATION OF RESIDUAL NUCLEI OF MASS NO. A FOLLOWING EVAPORATION FOR NEUTRONS ON AL (A=27)
50-MEV INCIDENT NEUTRONS
100-MEV INCIDENT NEUTRONS
400-MEV INCIDENT NEUTRONS
CROSS SECTION (MB)
MASS NUMBER A
200.
180.
160.
140.
120.
100.
80.0
60.0
40.0
20.0
0
2.0
4.0
6.0
8.0
10
12
14
16
18
20
22
24
26
28
30

Fig. 36

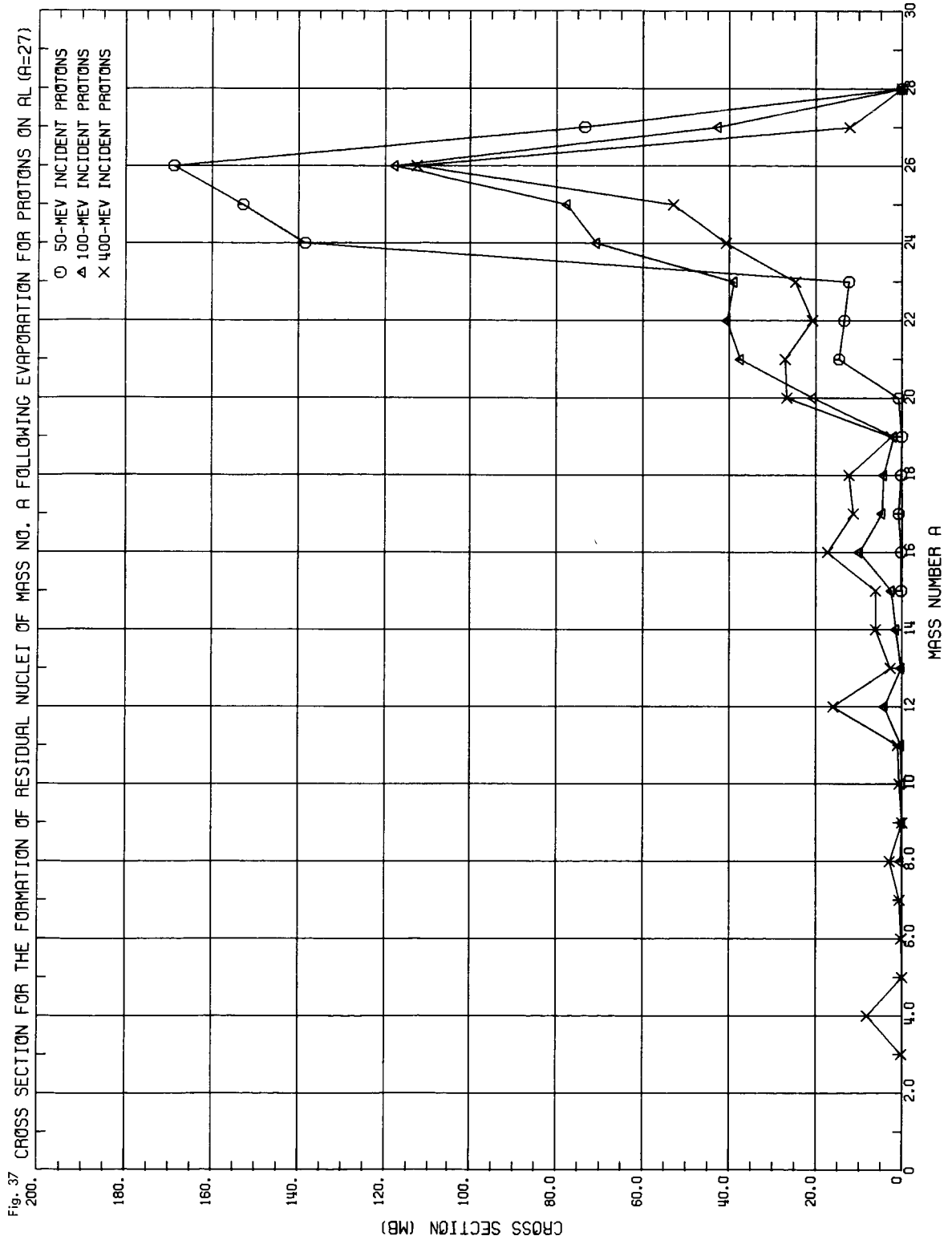

ORNL DWG 67-5567
CROSS SECTION FOR THE FORMATION OF RESIDUAL NUCLEI OF MASS NO. A FOLLOWING EVAPORATION FOR PROTONS ON AL (A=27)
50-MEV INCIDENT PROTONS
100-MEV INCIDENT PROTONS
400-MEV INCIDENT PROTONS
CROSS SECTION (MB)
MASS NUMBER A
200.
180.
160.
140.
120.
100.
80.0
60.0
40.0
20.0
0
2.0
4.0
6.0
8.0
10
12
14
16
18
20
22
24
26
28
30

Fig. 37

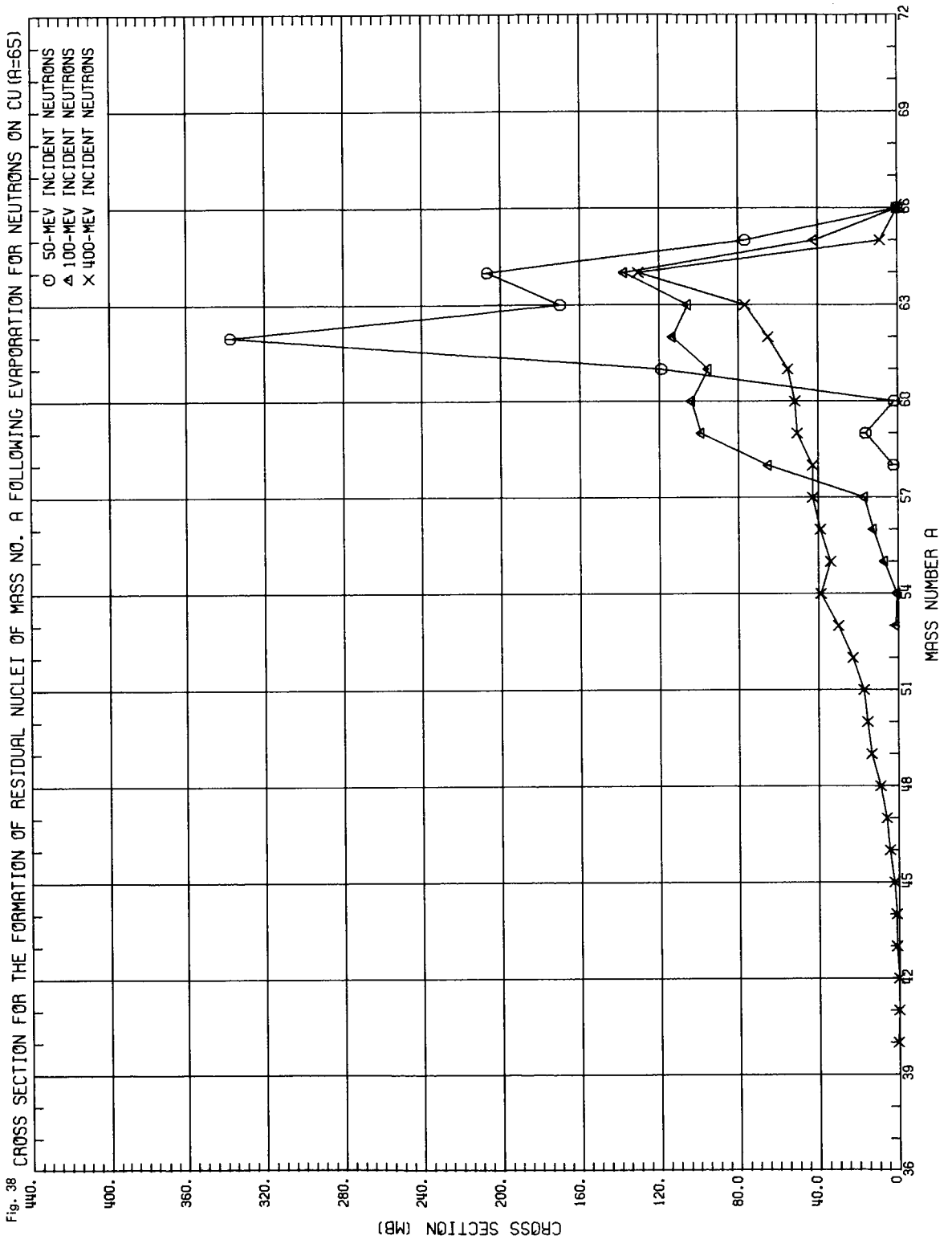

ORNL DWG 67-5568
CROSS SECTION FOR THE FORMATION OF RESIDUAL NUCLEI OF MASS NO. A FOLLOWING EVAPORATION FOR NEUTRONS ON CU (A=65)
○ 50-MEV INCIDENT NEUTRONS
△ 100-MEV INCIDENT NEUTRONS
× 400-MEV INCIDENT NEUTRONS
CROSS SECTION (MB)
440.
400.
360.
320.
280.
240.
200.
160.
120.
80.0
40.0
0
36
39
42
45
48
51
54
57
60
63
66
69
72
MASS NUMBER A

Fig. 38

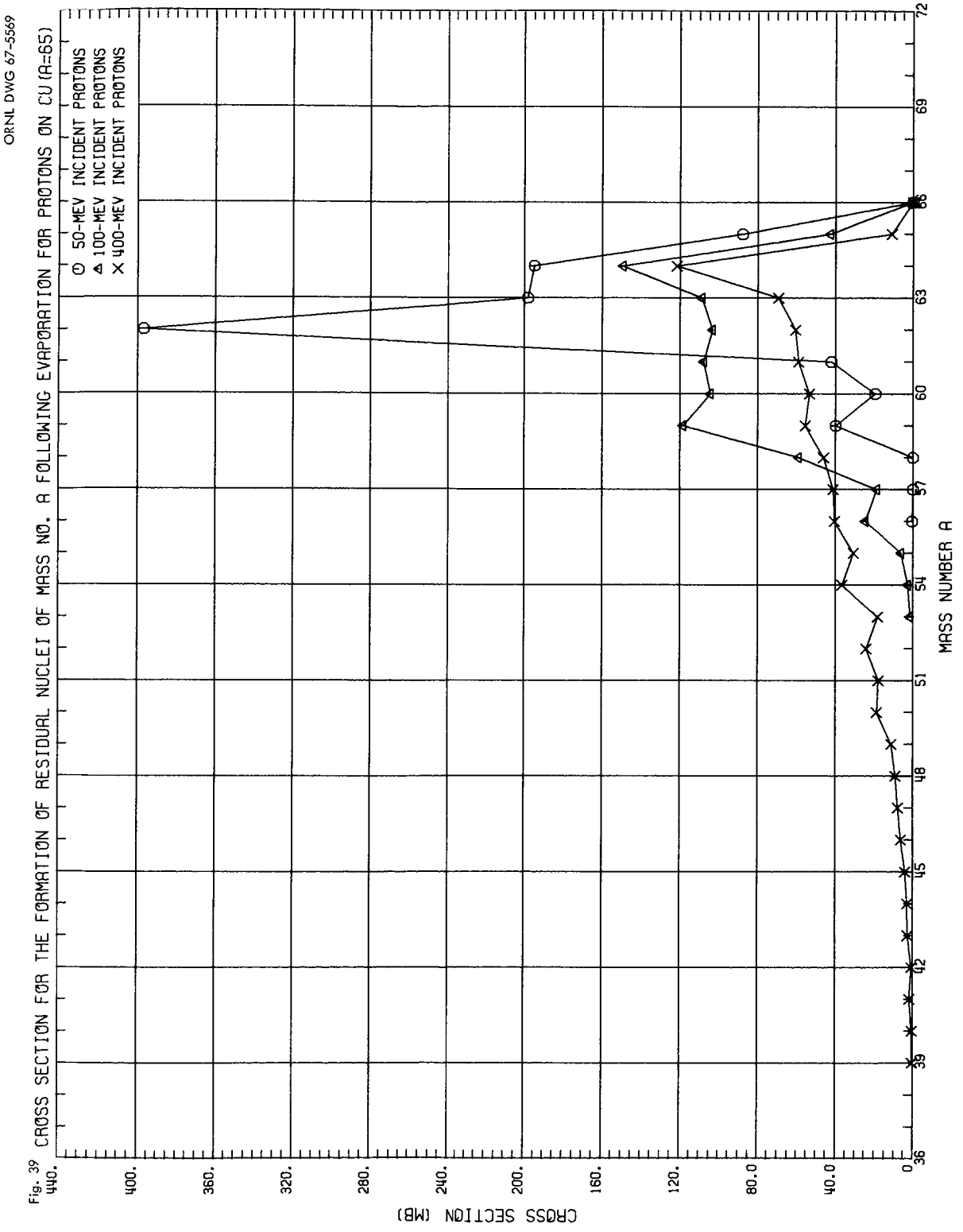

ORNL DWG 67-5569
CROSS SECTION FOR THE FORMATION OF RESIDUAL NUCLEI OF MASS NO. A FOLLOWING EVAPORATION FOR PROTONS ON CU (A=65)
50-MEV INCIDENT PROTONS
100-MEV INCIDENT PROTONS
400-MEV INCIDENT PROTONS
CROSS SECTION (MB)
MASS NUMBER A

Fig. 39

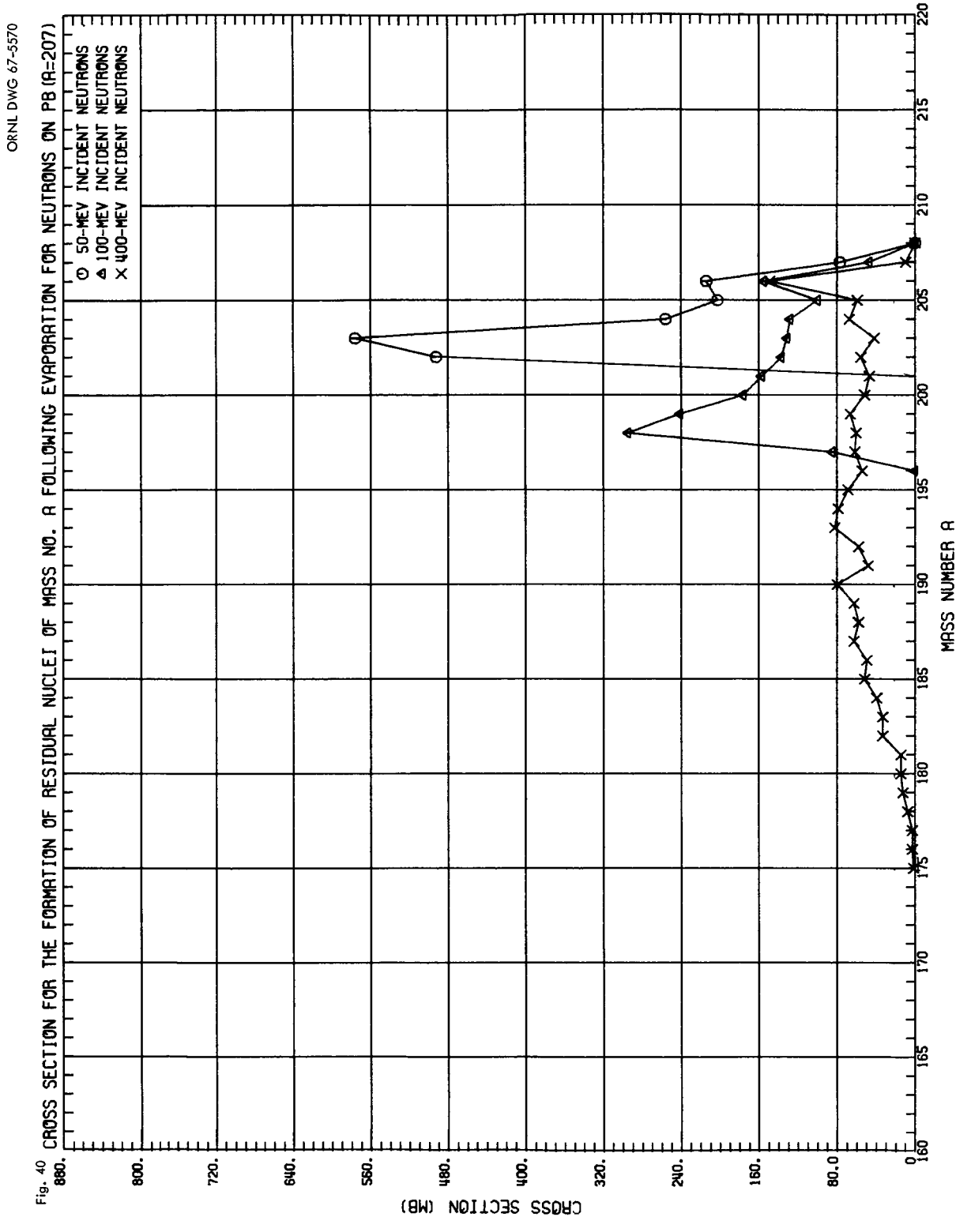

ORNL DWG 67-5570
CROSS SECTION FOR THE FORMATION OF RESIDUAL NUCLEI OF MASS NO. A FOLLOWING EVAPORATION FOR NEUTRONS ON PB (A=207)
○ 50-MEV INCIDENT NEUTRONS
△ 100-MEV INCIDENT NEUTRONS
× 400-MEV INCIDENT NEUTRONS
CROSS SECTION (MB)
880.
800.
720.
640.
560.
480.
400.
320.
240.
160.
80.0
0
160
165
170
175
180
185
190
195
200
205
210
215
220
MASS NUMBER A

Fig. 40

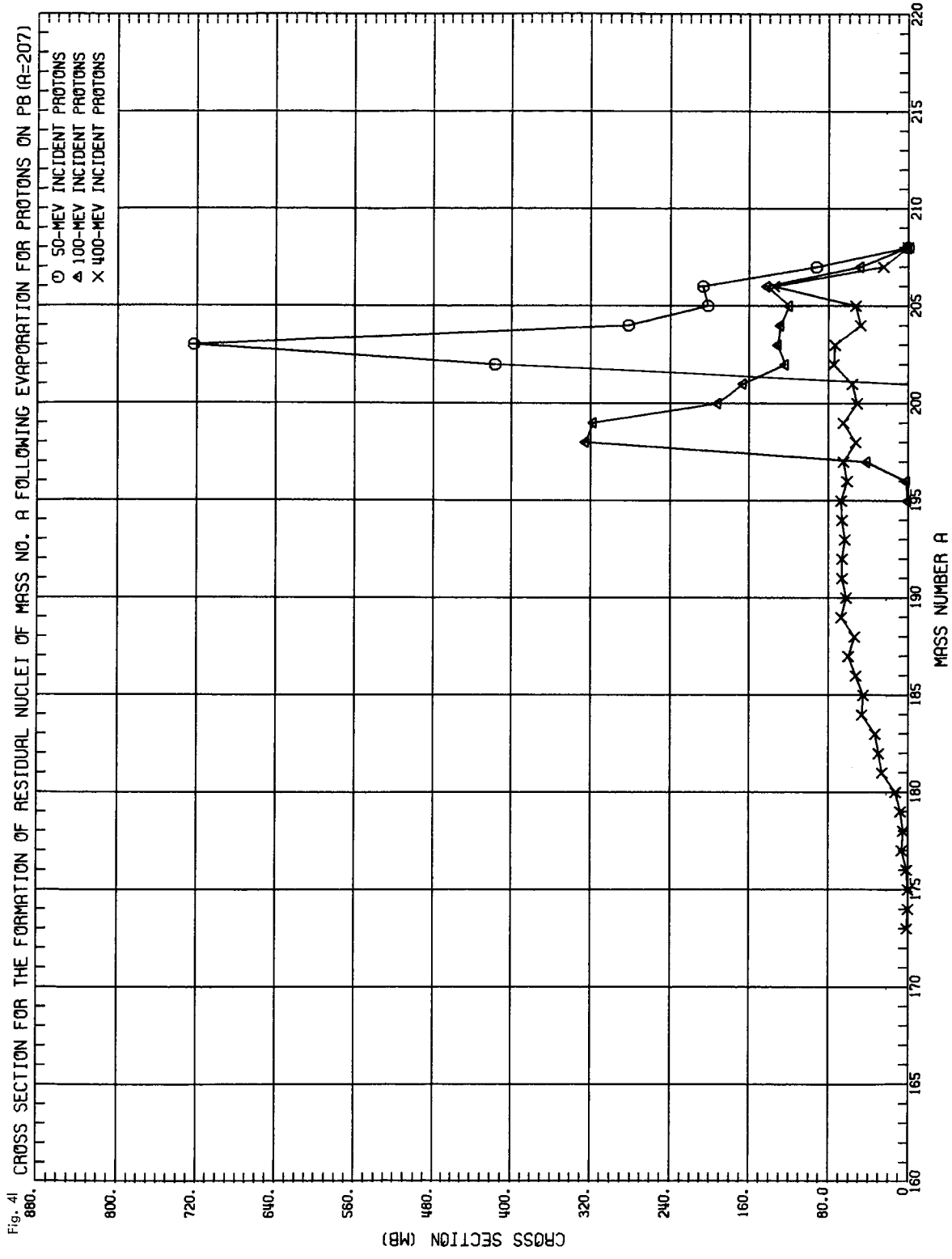

ORNL DWG 67-5571
CROSS SECTION FOR THE FORMATION OF RESIDUAL NUCLEI OF MASS NO. A FOLLOWING EVAPORATION FOR PROTONS ON PB (A=207)
O 50-MEV INCIDENT PROTONS
Δ 100-MEV INCIDENT PROTONS
× 400-MEV INCIDENT PROTONS
CROSS SECTION (MB)
880.
800.
720.
640.
560.
480.
400.
320.
240.
160.
80.0
0
160
165
170
175
180
185
190
195
200
205
210
215
220
MASS NUMBER A

Fig. 41

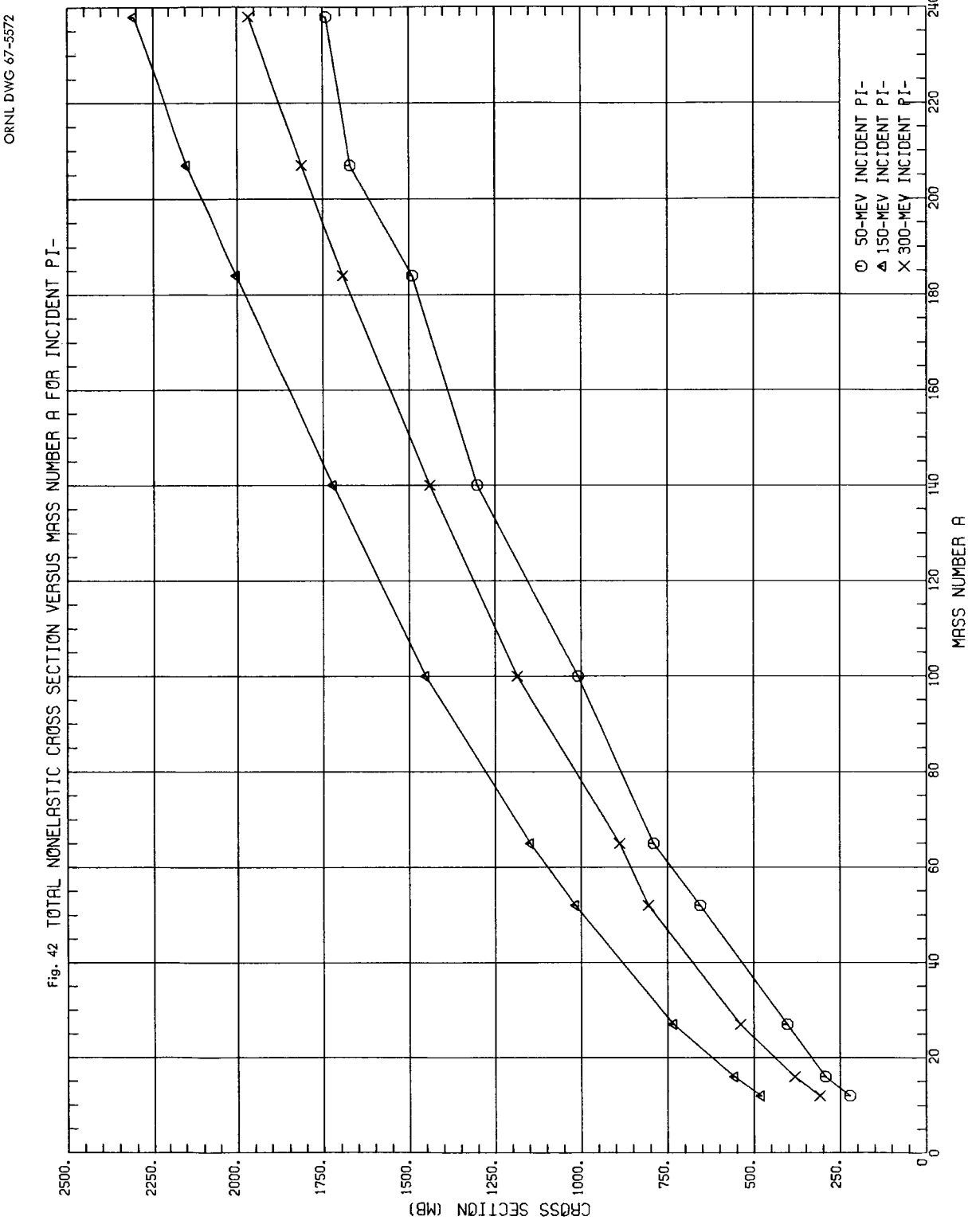


Fig. 42 TOTAL NONELASTIC CROSS SECTION VERSUS MASS NUMBER A FOR INCIDENT PI-

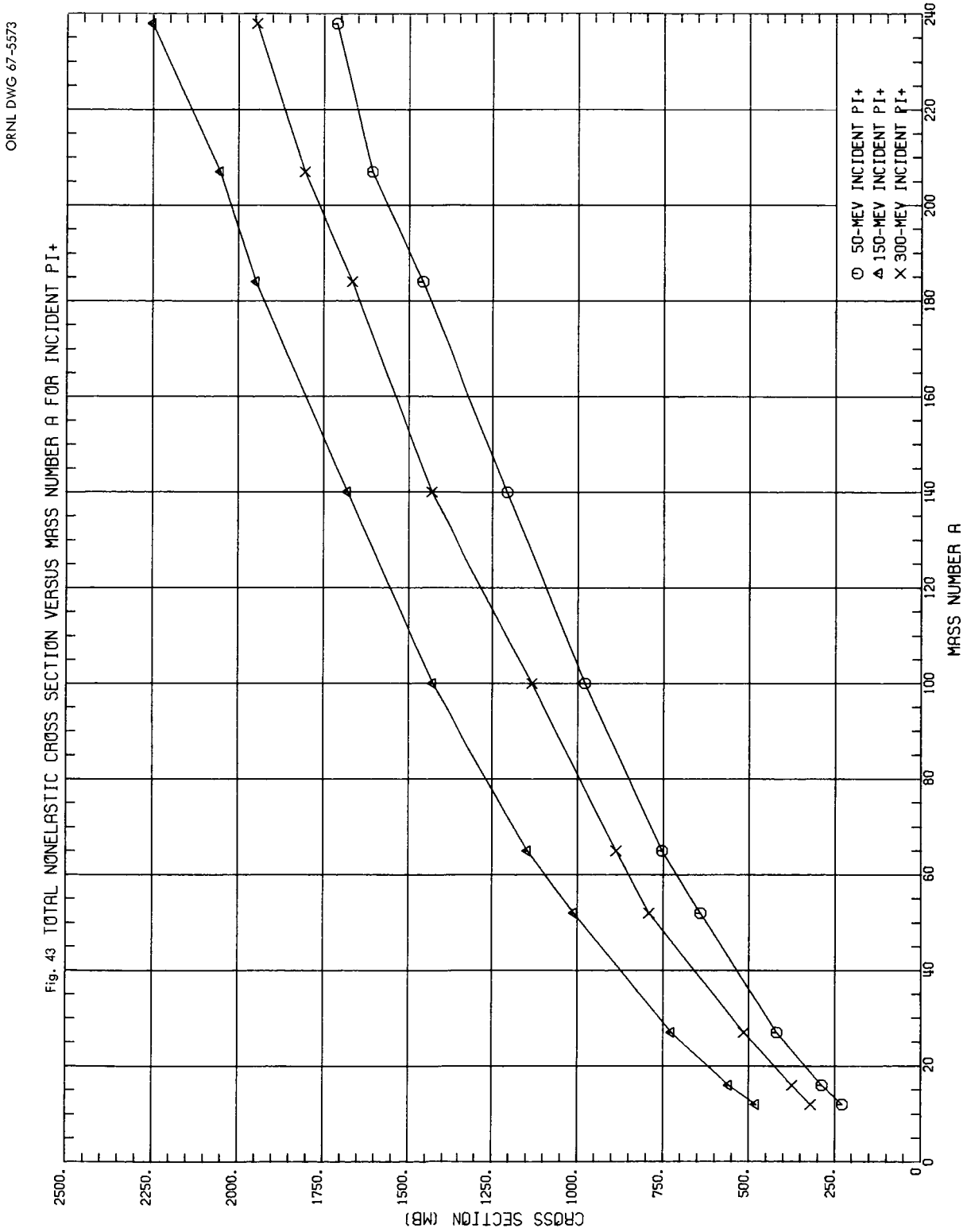

ORNL DWG 67-5573
TOTAL NONELASTIC CROSS SECTION VERSUS MASS NUMBER A FOR INCIDENT PI+
CROSS SECTION (MB)
MASS NUMBER A
50-MEV INCIDENT PI+
150-MEV INCIDENT PI+
300-MEV INCIDENT PI+
2500.
2250.
2000.
1750.
1500.
1250.
1000.
750.
500.
250.
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 43

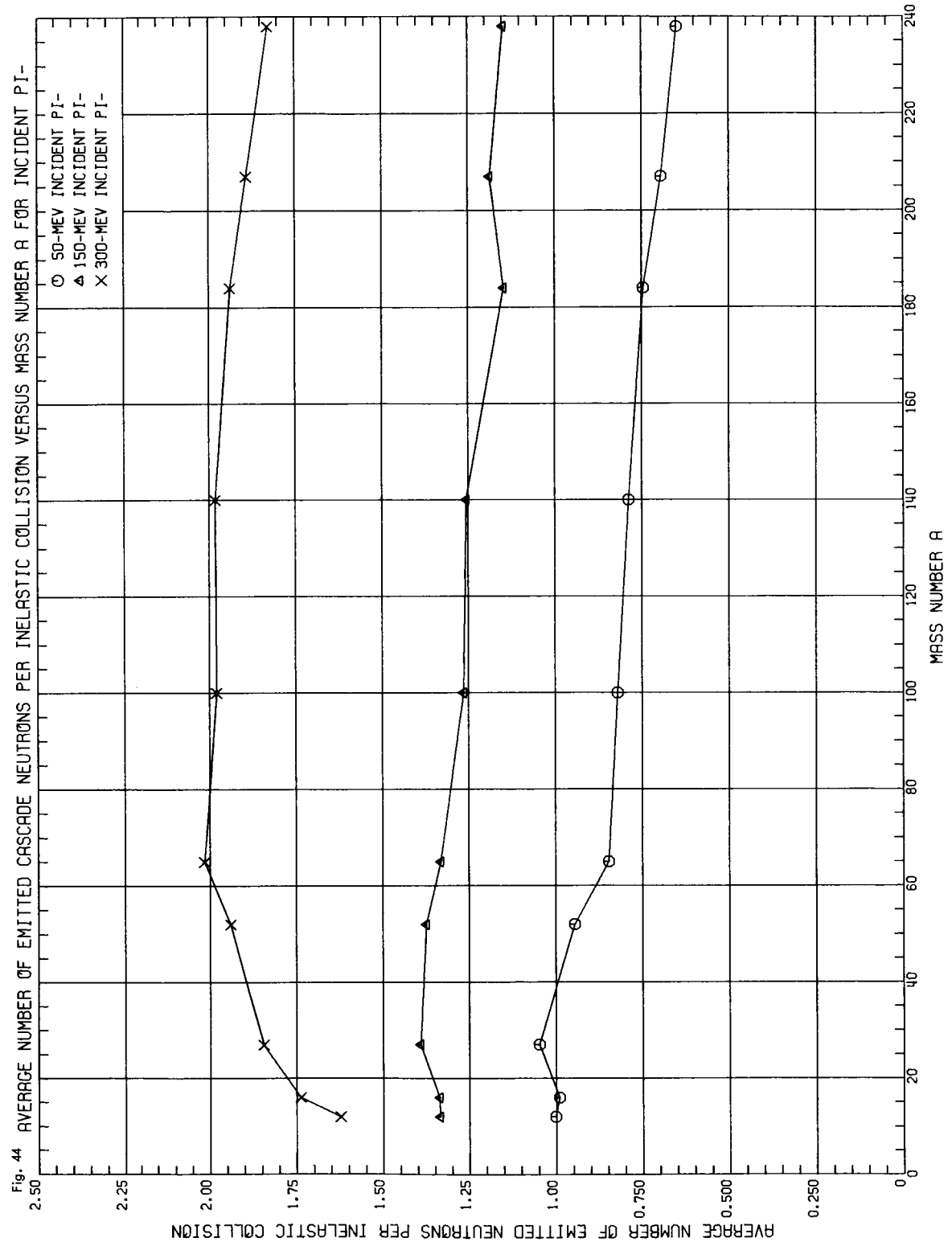

ORNL DWG 67-5574
AVERAGE NUMBER OF EMITTED CASCADE NEUTRONS PER INELASTIC COLLISION VERSUS MASS NUMBER A FOR INCIDENT PI-
50-MEV INCIDENT PI-
150-MEV INCIDENT PI-
300-MEV INCIDENT PI-
AVERAGE NUMBER OF EMITTED NEUTRONS PER INELASTIC COLLISION
MASS NUMBER A
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.750
0.500
0.250
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 44

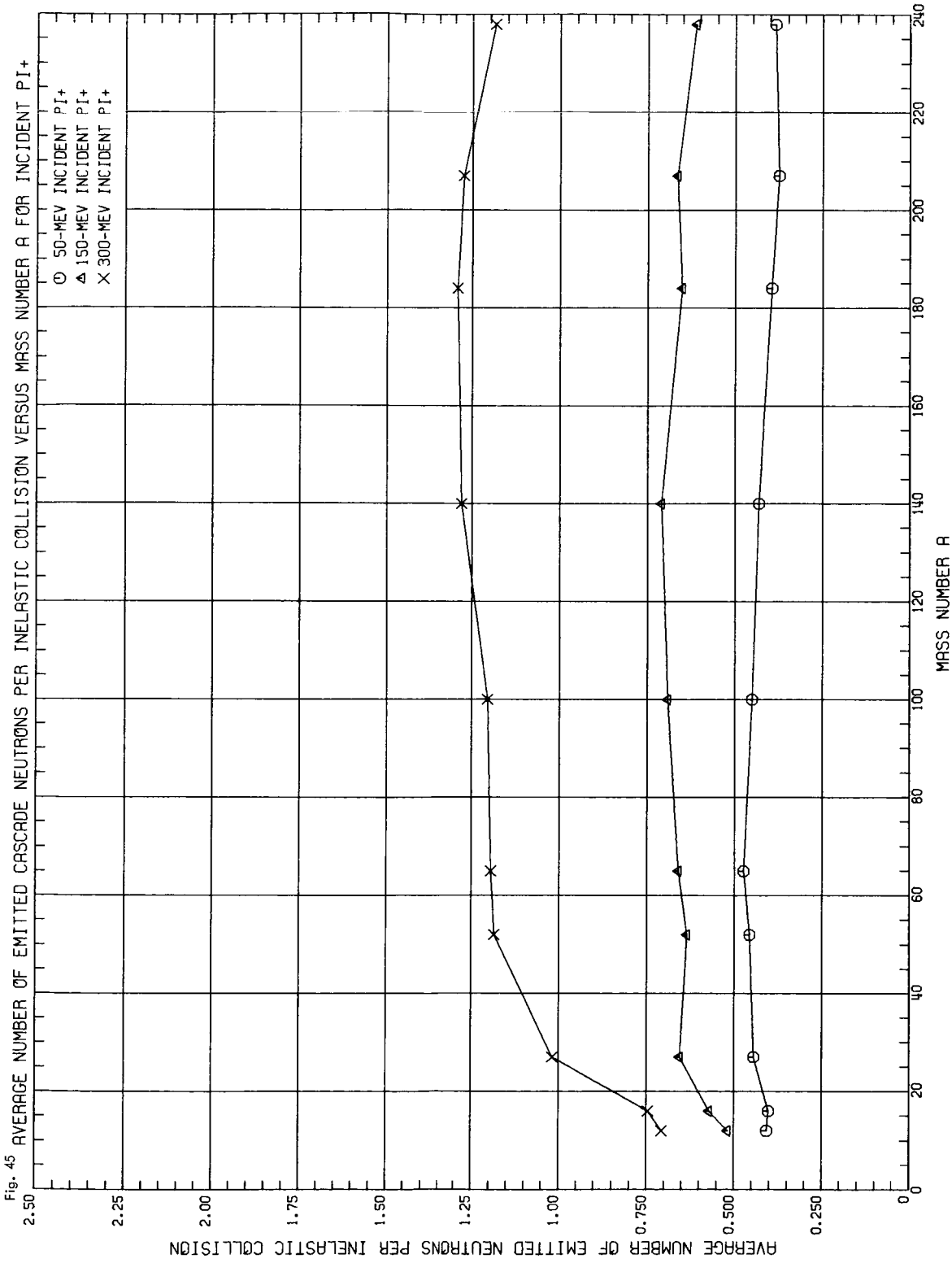
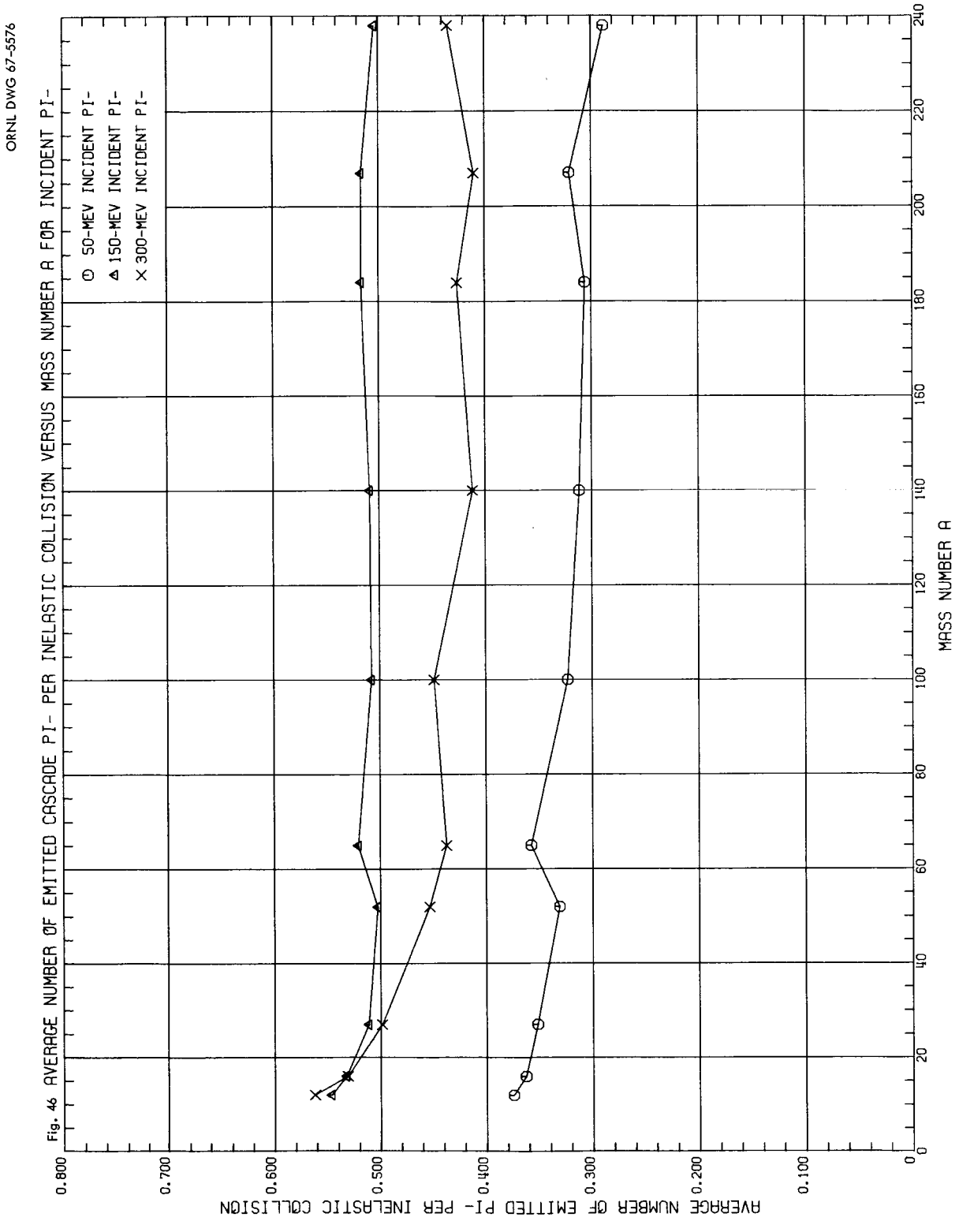
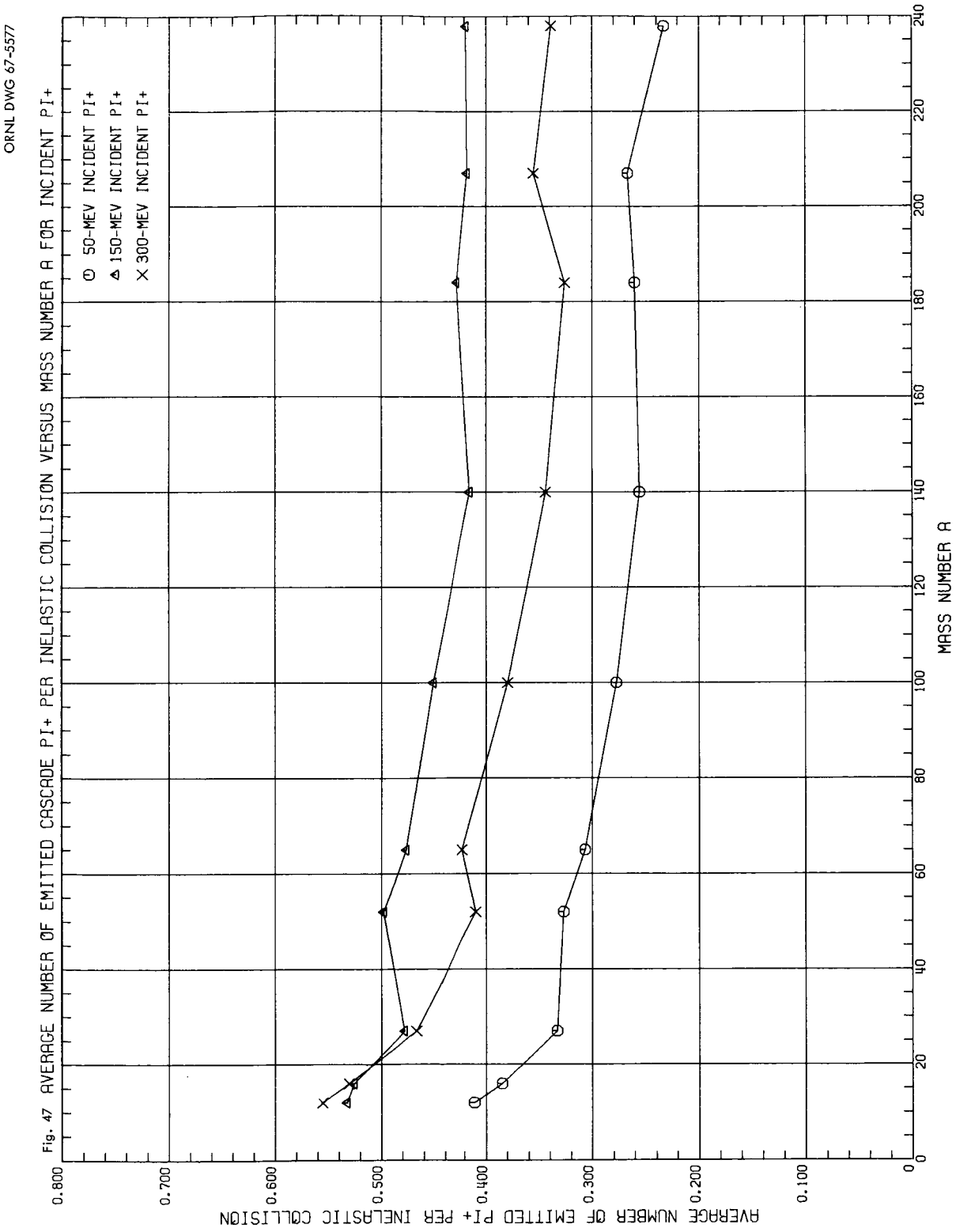

ORNL DWG 67-5575
AVERAGE NUMBER OF EMITTED CASCADE NEUTRONS PER INELASTIC COLLISION VERSUS MASS NUMBER A FOR INCIDENT PI+
50-MEV INCIDENT PI+
150-MEV INCIDENT PI+
300-MEV INCIDENT PI+
AVERAGE NUMBER OF EMITTED NEUTRONS PER INELASTIC COLLISION
MASS NUMBER A
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.750
0.500
0.250
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 45


ORNL DWG 67-5576
Fig. 46 AVERAGE NUMBER OF EMITTED CASCADE PI- PER INELASTIC COLLISION VERSUS MASS NUMBER A FOR INCIDENT PI-
50-MEV INCIDENT PI-
150-MEV INCIDENT PI-
300-MEV INCIDENT PI-
AVERAGE NUMBER OF EMITTED PI- PER INELASTIC COLLISION
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0
20
40
60
80
100
120
140
160
180
200
220
240
MASS NUMBER A


ORNL DWG 67-5577
Fig. 47 AVERAGE NUMBER OF EMITTED CASCADE PI+ PER INELASTIC COLLISION VERSUS MASS NUMBER A FOR INCIDENT PI+
50-MEV INCIDENT PI+
150-MEV INCIDENT PI+
300-MEV INCIDENT PI+
AVERAGE NUMBER OF EMITTED PI+ PER INELASTIC COLLISION
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0
20
40
60
80
100
120
140
160
180
200
220
240
MASS NUMBER A

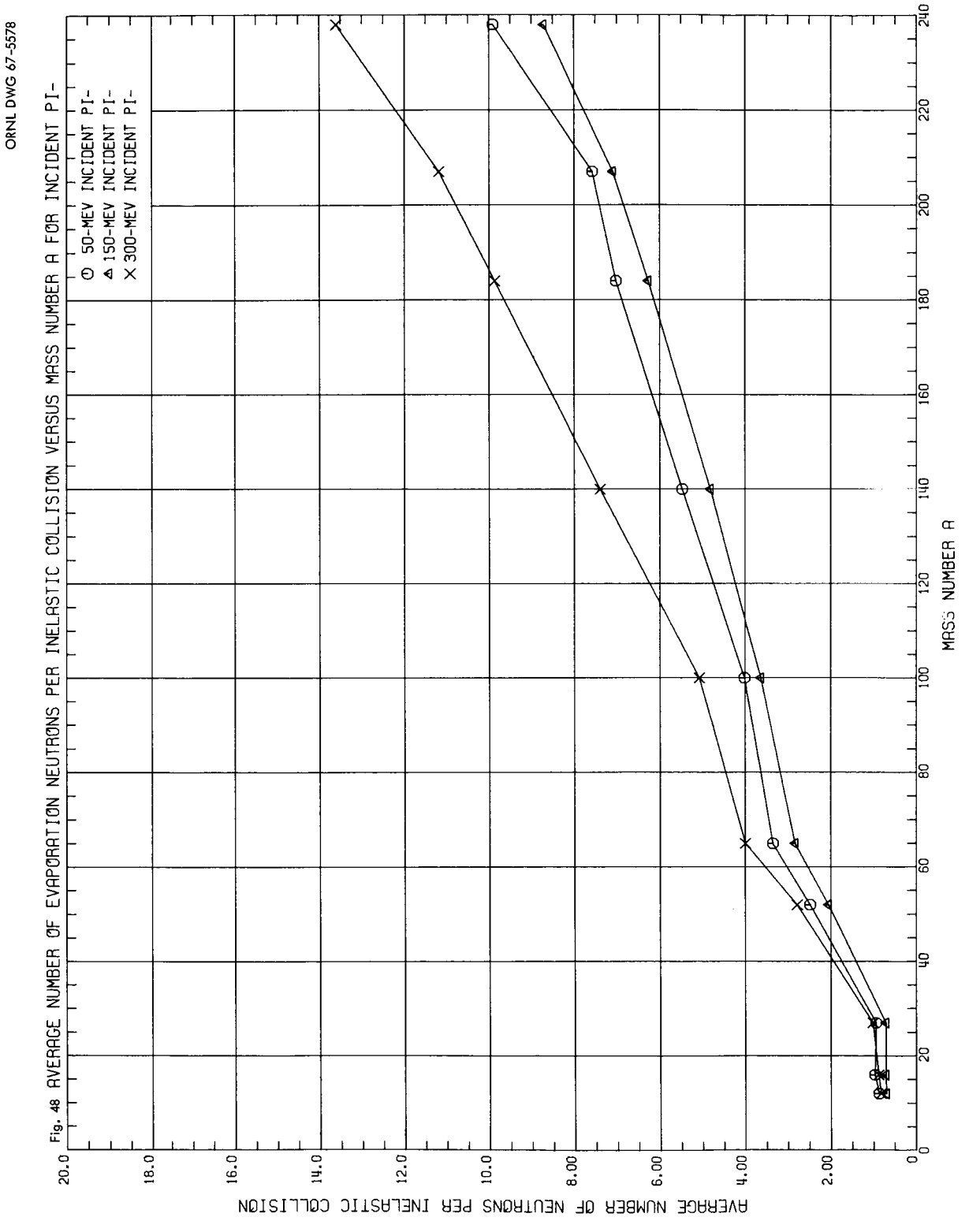

ORNL DWG 67-5578
AVERAGE NUMBER OF EVAPORATION NEUTRONS PER INELASTIC COLLISION VERSUS MASS NUMBER A FOR INCIDENT PI-
○ 50-MEV INCIDENT PI-
△ 150-MEV INCIDENT PI-
× 300-MEV INCIDENT PI-
AVERAGE NUMBER OF NEUTRONS PER INELASTIC COLLISION
MASS NUMBER A
0
2.00
4.00
6.00
8.00
10.0
12.0
14.0
16.0
18.0
20.0
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 48

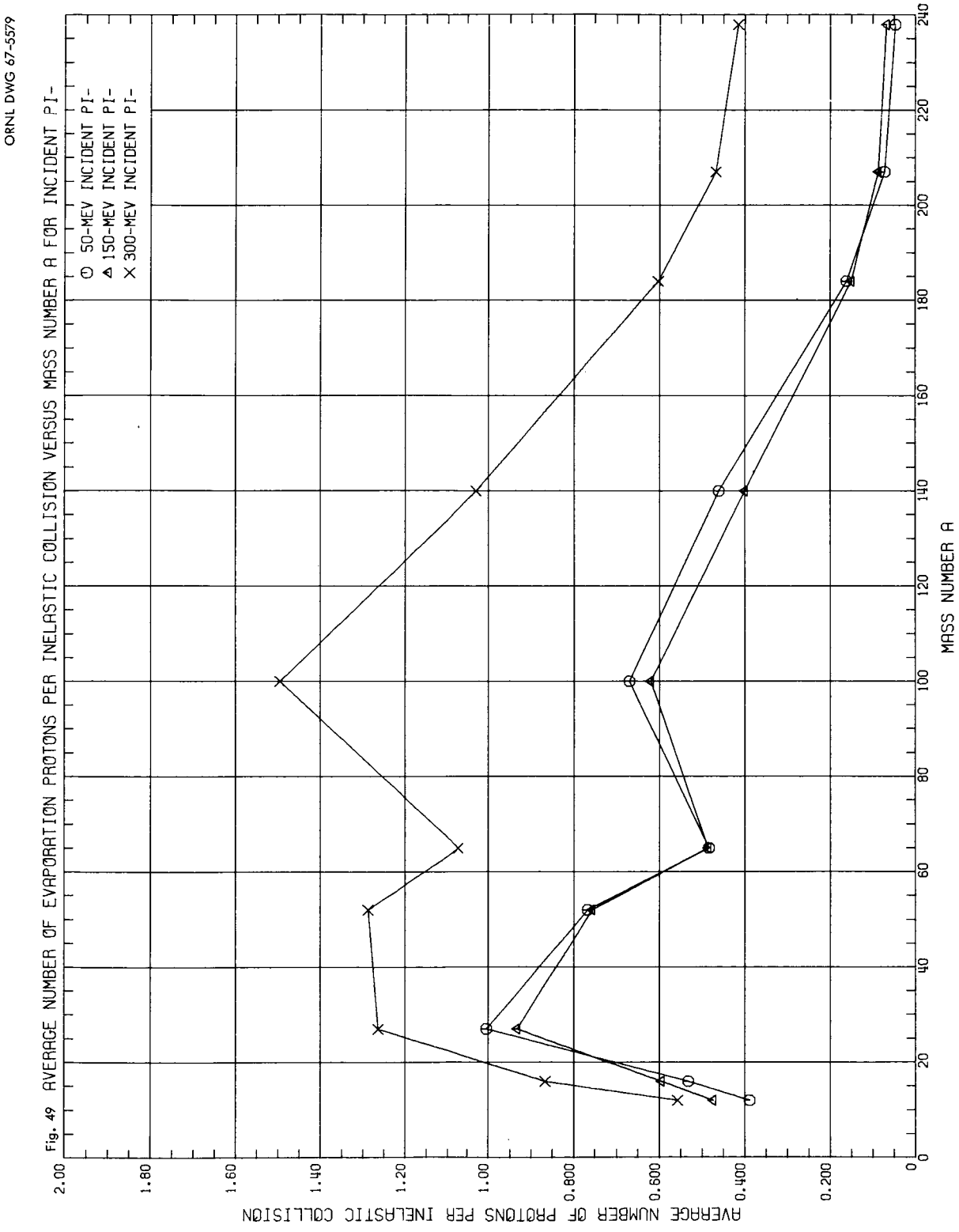
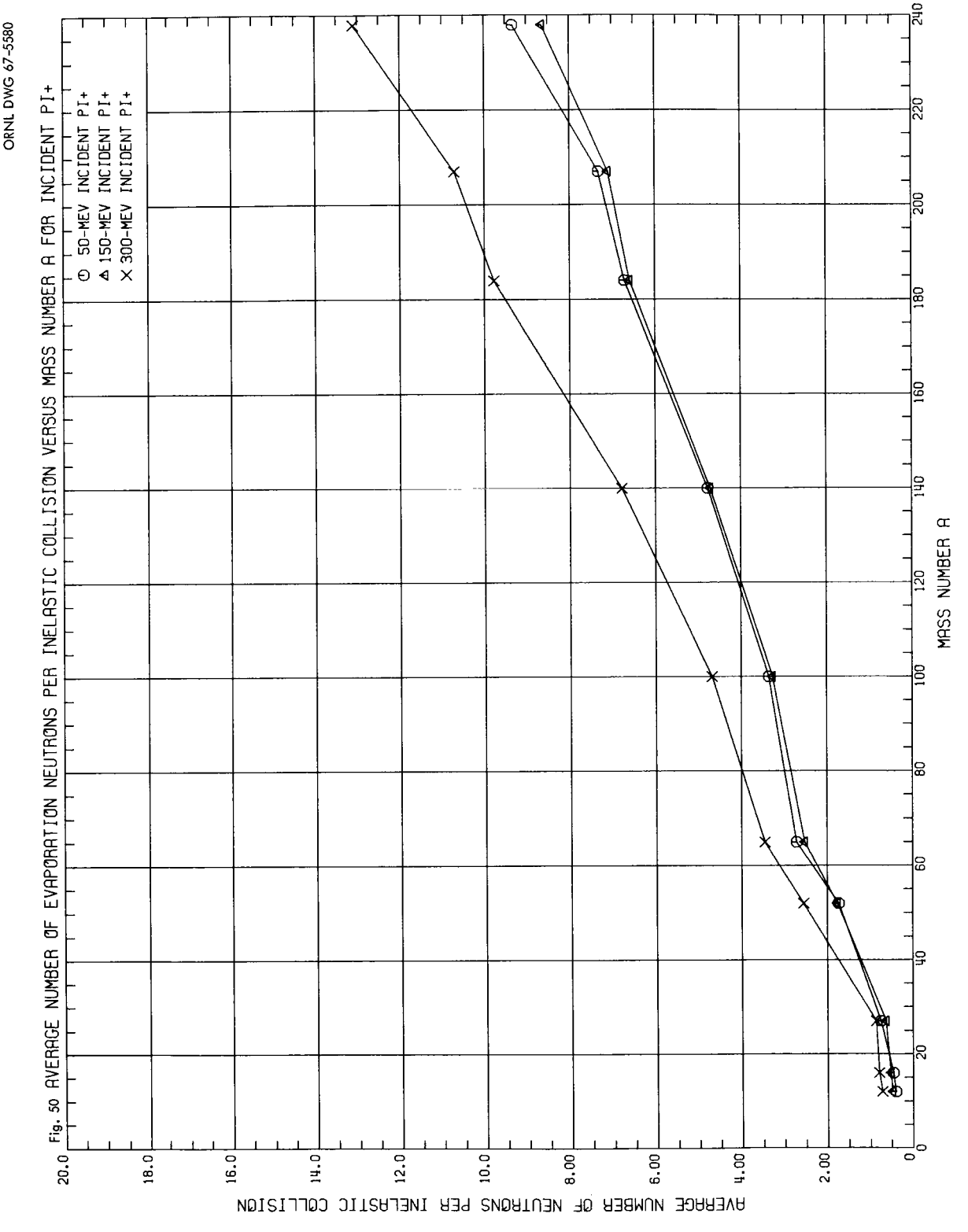
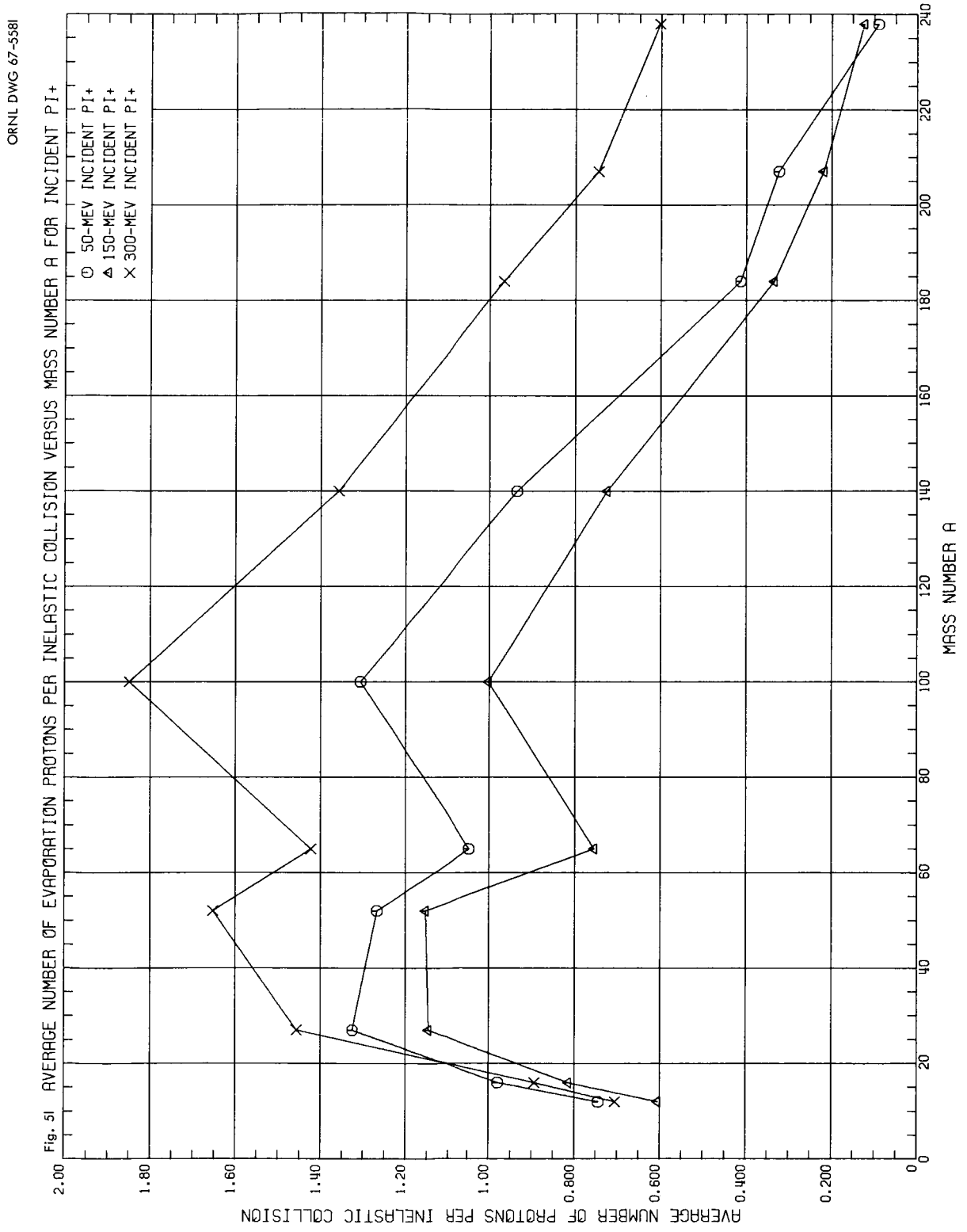


Fig. 49 AVERAGE NUMBER OF EVAPORATION PROTONS PER INELASTIC COLLISION VERSUS MASS NUMBER A FOR INCIDENT PI-


ORNL DWG 67-5580
Fig. 50 AVERAGE NUMBER OF EVAPORATION NEUTRONS PER INELASTIC COLLISION VERSUS MASS NUMBER A FOR INCIDENT PI+
50-MEV INCIDENT PI+
150-MEV INCIDENT PI+
300-MEV INCIDENT PI+
AVERAGE NUMBER OF NEUTRONS PER INELASTIC COLLISION
MASS NUMBER A
0
2.00
4.00
6.00
8.00
10.0
12.0
14.0
16.0
18.0
20.0
0
20
40
60
80
100
120
140
160
180
200
220
240


ORNL DWG 67-5581
Fig. 51 AVERAGE NUMBER OF EVAPORATION PROTONS PER INELASTIC COLLISION VERSUS MASS NUMBER A FOR INCIDENT PI+
50-MEV INCIDENT PI+
150-MEV INCIDENT PI+
300-MEV INCIDENT PI+
AVERAGE NUMBER OF PROTONS PER INELASTIC COLLISION
MASS NUMBER A
0
0.200
0.400
0.600
0.800
1.00
1.20
1.40
1.60
1.80
2.00
20
40
60
80
100
120
140
160
180
200
220
240

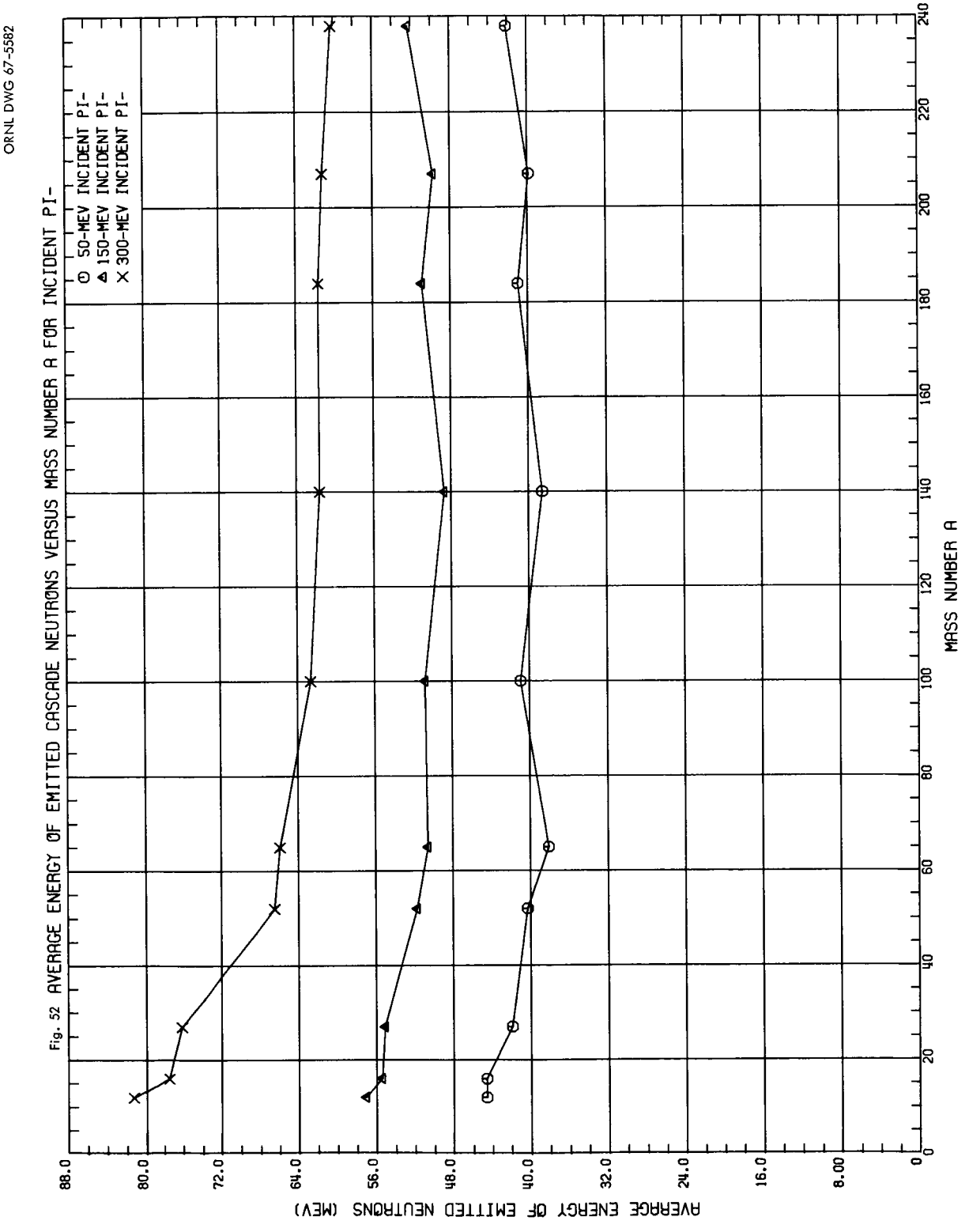


Fig. 52 AVERAGE ENERGY OF EMITTED CASCADE NEUTRONS VERSUS MASS NUMBER A FOR INCIDENT PI-

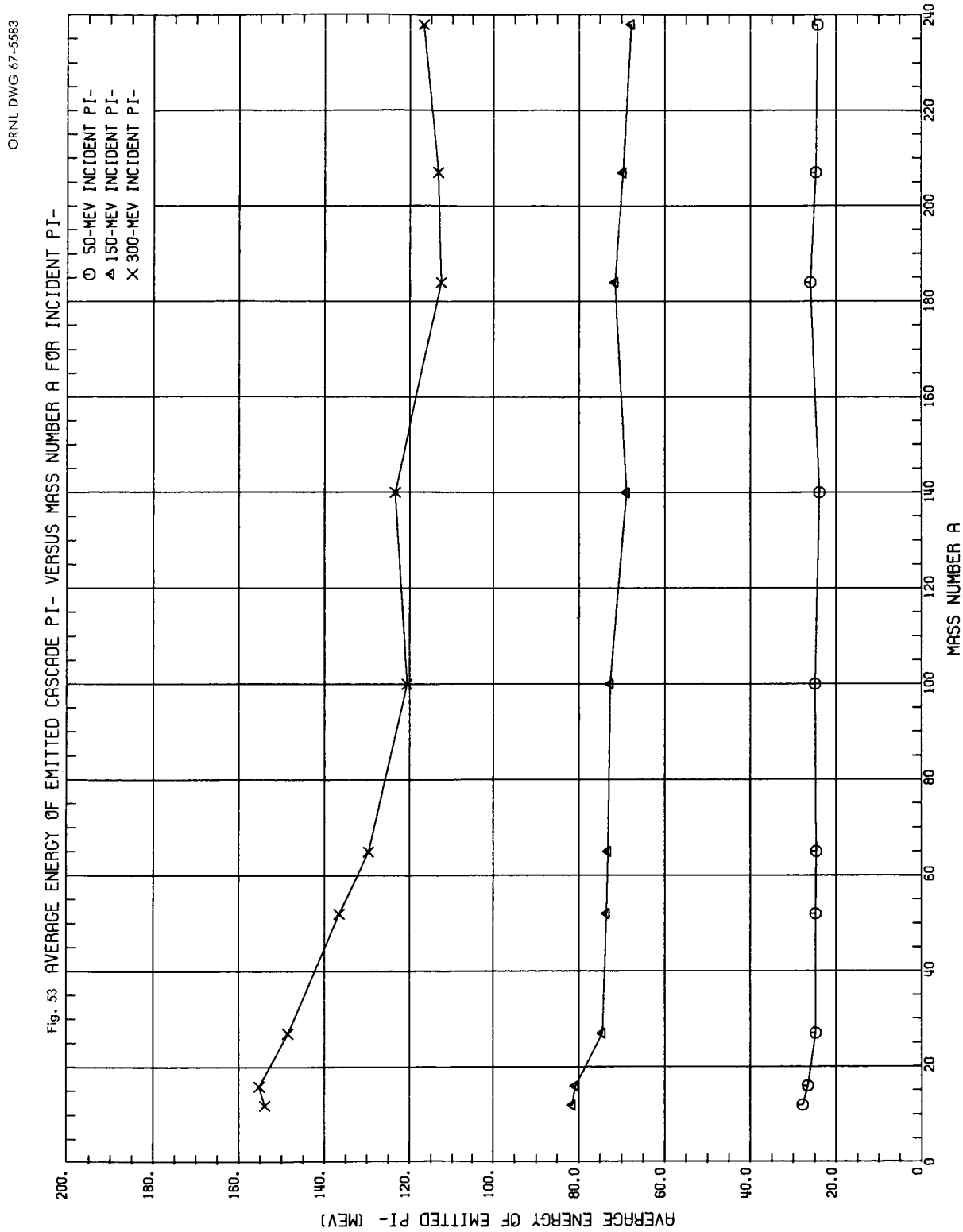


Fig. 53 AVERAGE ENERGY OF EMITTED CASCADE PI- VERSUS MASS NUMBER A FOR INCIDENT PI-

ORNL DWG 67-5584

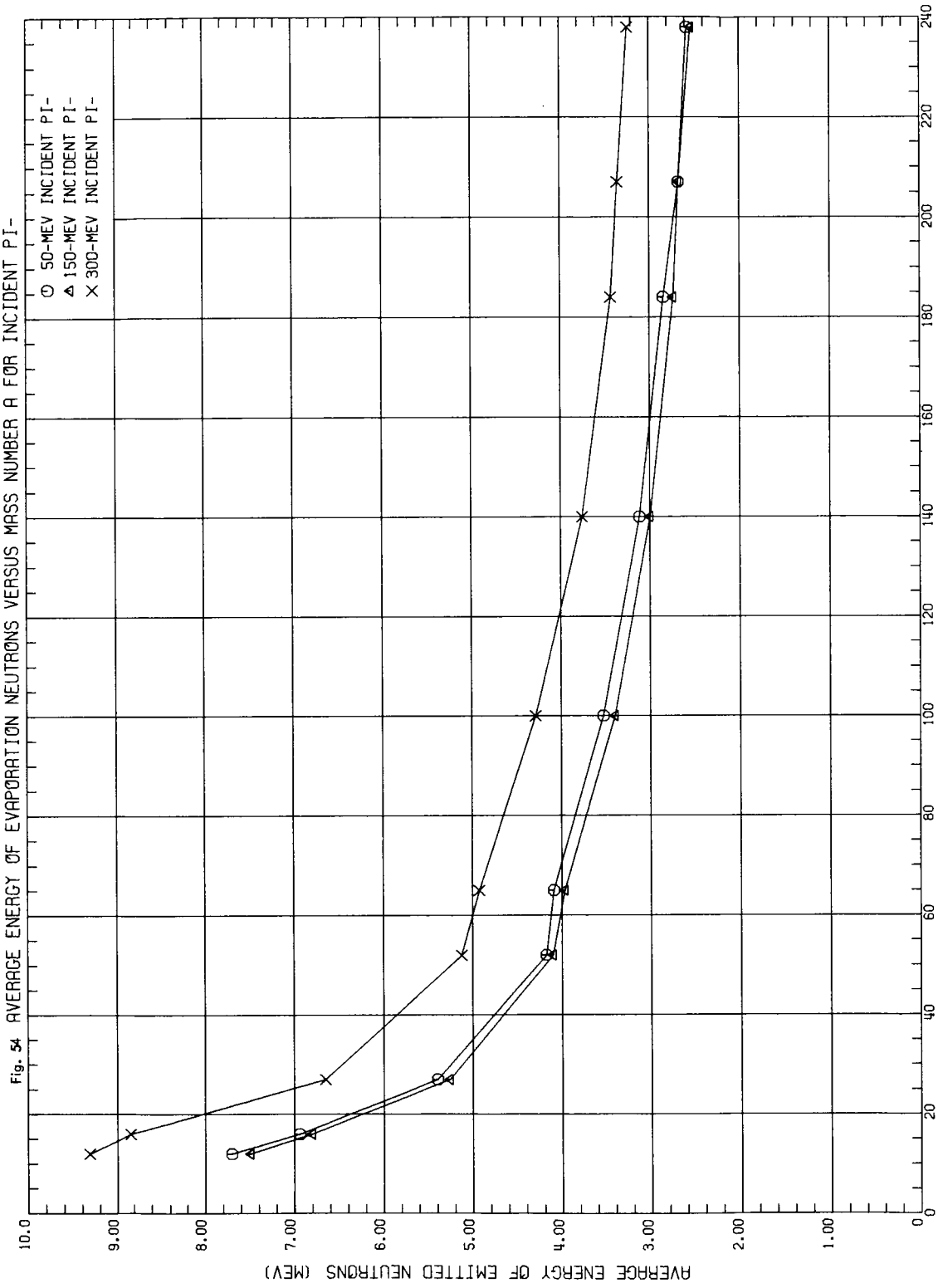
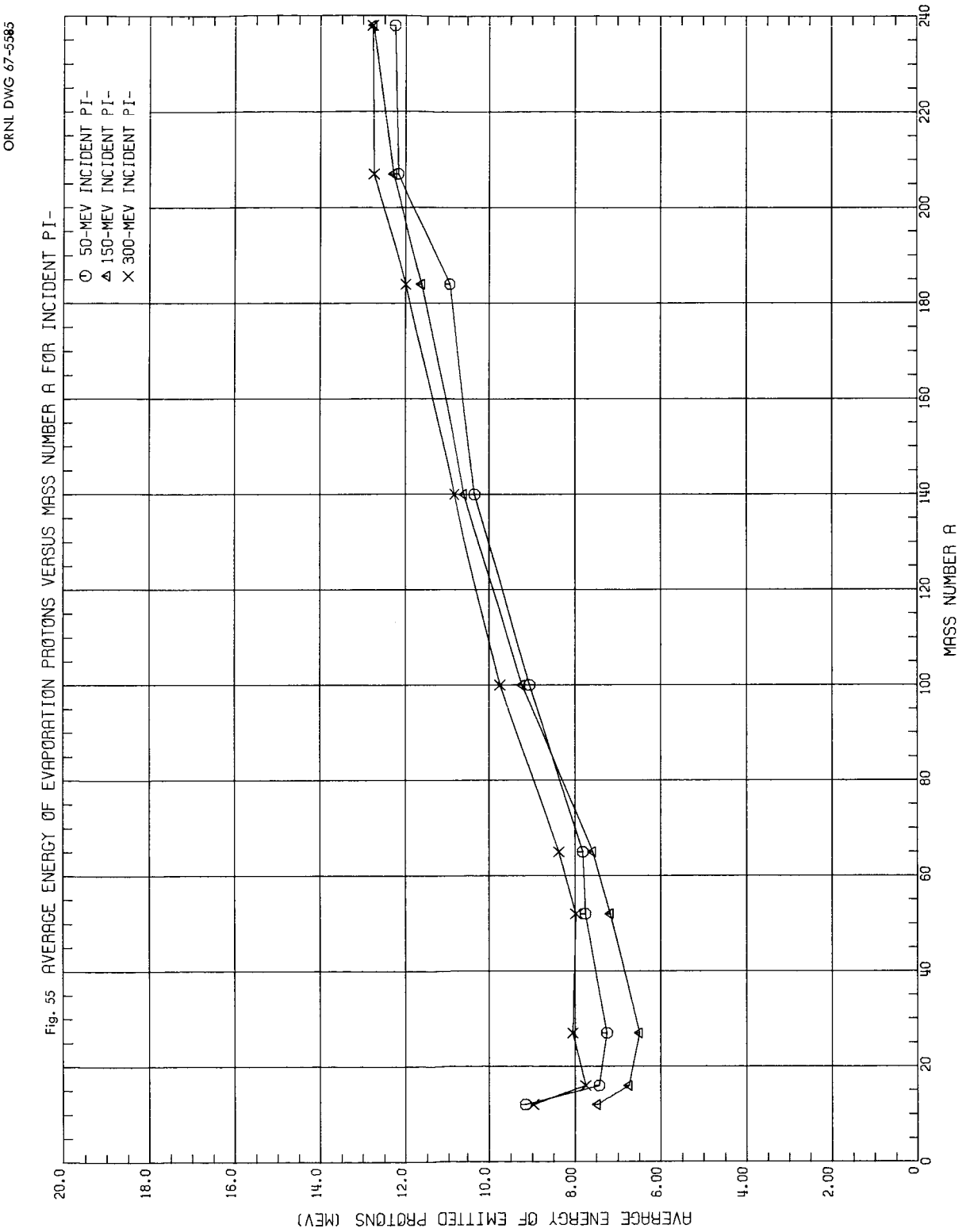


Fig. 54 AVERAGE ENERGY OF EVAPORATION NEUTRONS VERSUS MASS NUMBER A FOR INCIDENT PI-


ORNL DWG 67-5585
Fig. 55 AVERAGE ENERGY OF EVAPORATION PROTONS VERSUS MASS NUMBER A FOR INCIDENT PI-
○ 50-MEV INCIDENT PI-
△ 150-MEV INCIDENT PI-
× 300-MEV INCIDENT PI-
AVERAGE ENERGY OF EMITTED PROTONS (MEV)
MASS NUMBER A
20.0
18.0
16.0
14.0
12.0
10.0
8.00
6.00
4.00
2.00
0
20
40
60
80
100
120
140
160
180
200
220
240

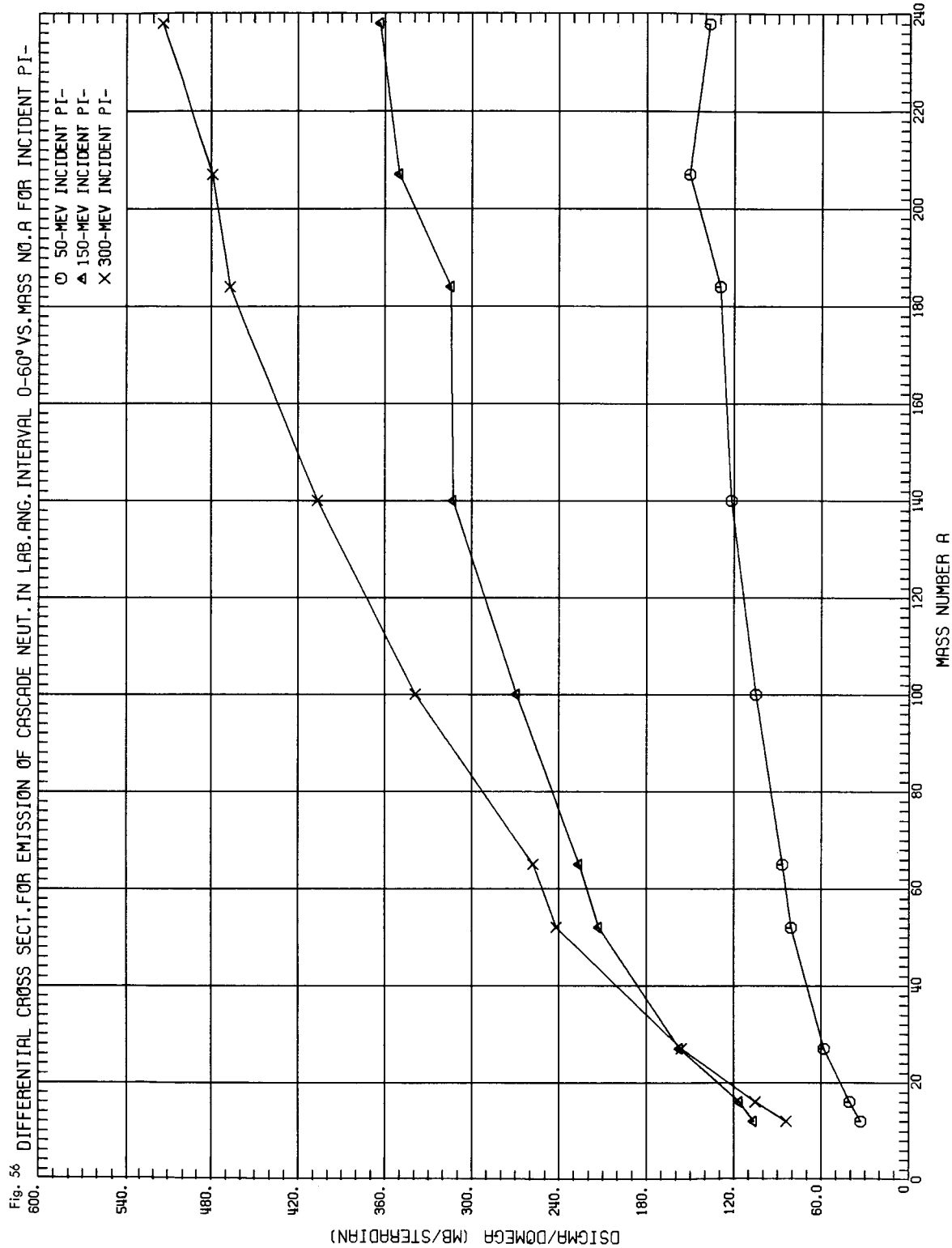
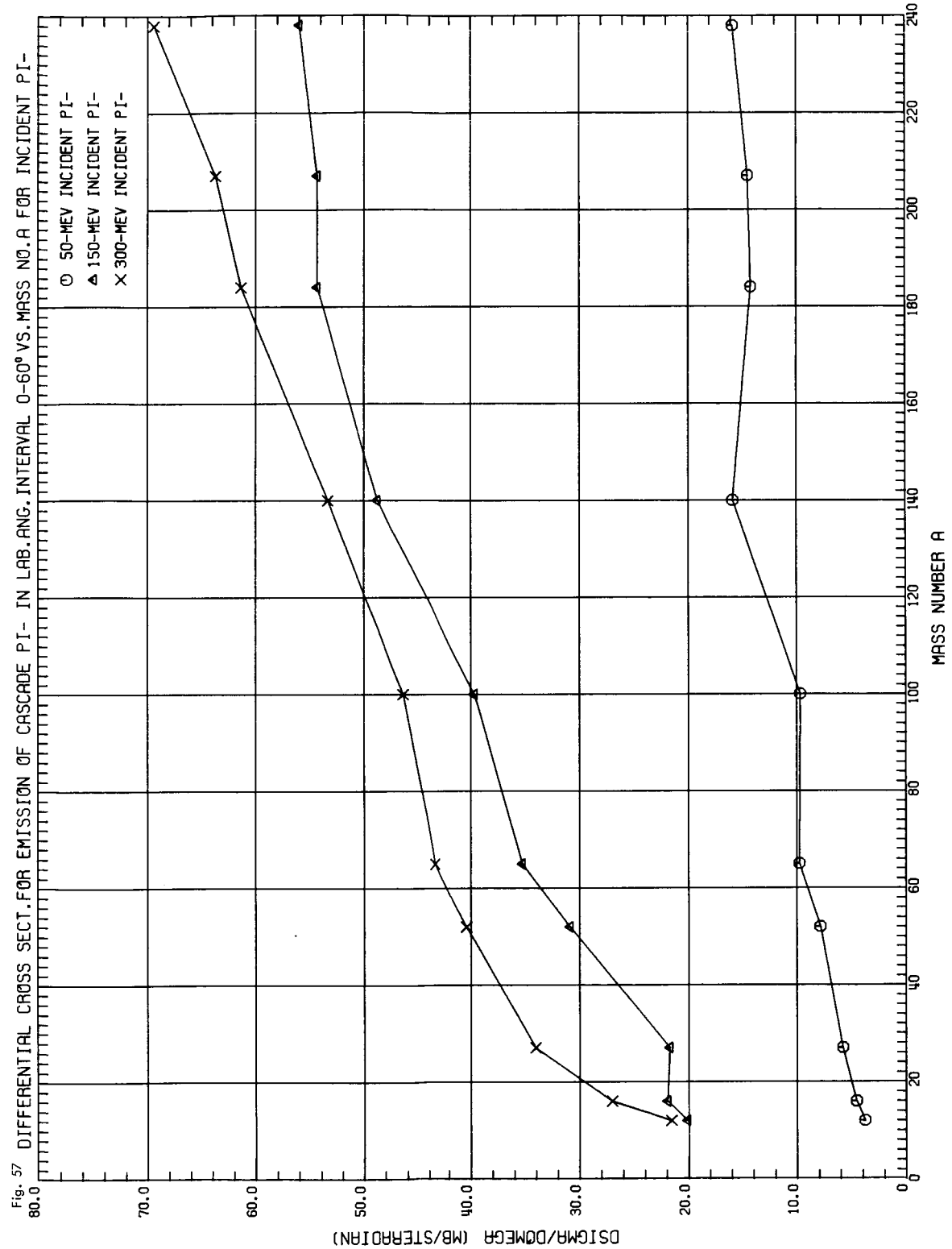

ORNL DWG 67-5586
DIFFERENTIAL CROSS SECT.FOR EMISSION OF CASCADE NEUT.IN LAB.ANG.INTERVAL 0-60° VS.MASS NO.A FOR INCIDENT PI-
O 50-MEV INCIDENT PI-
▲ 150-MEV INCIDENT PI-
X 300-MEV INCIDENT PI-
DSIGMA/DOMEGA (MB/STERADIAN)
MASS NUMBER A
600.
540.
480.
420.
360.
300.
240.
180.
120.
60.0
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 56


ORNL DWG 67-5587
Fig. 57 DIFFERENTIAL CROSS SECT.FOR EMISSION OF CASCADE PI- IN LAB.ANG.INTERVAL 0-60° VS.MASS NO.A FOR INCIDENT PI-
50-MEV INCIDENT PI-
150-MEV INCIDENT PI-
300-MEV INCIDENT PI-
DSIGMA/DOMEGA (MB/STERADIAN)
MASS NUMBER A
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0
0
20
40
60
80
100
120
140
160
180
200
220
240

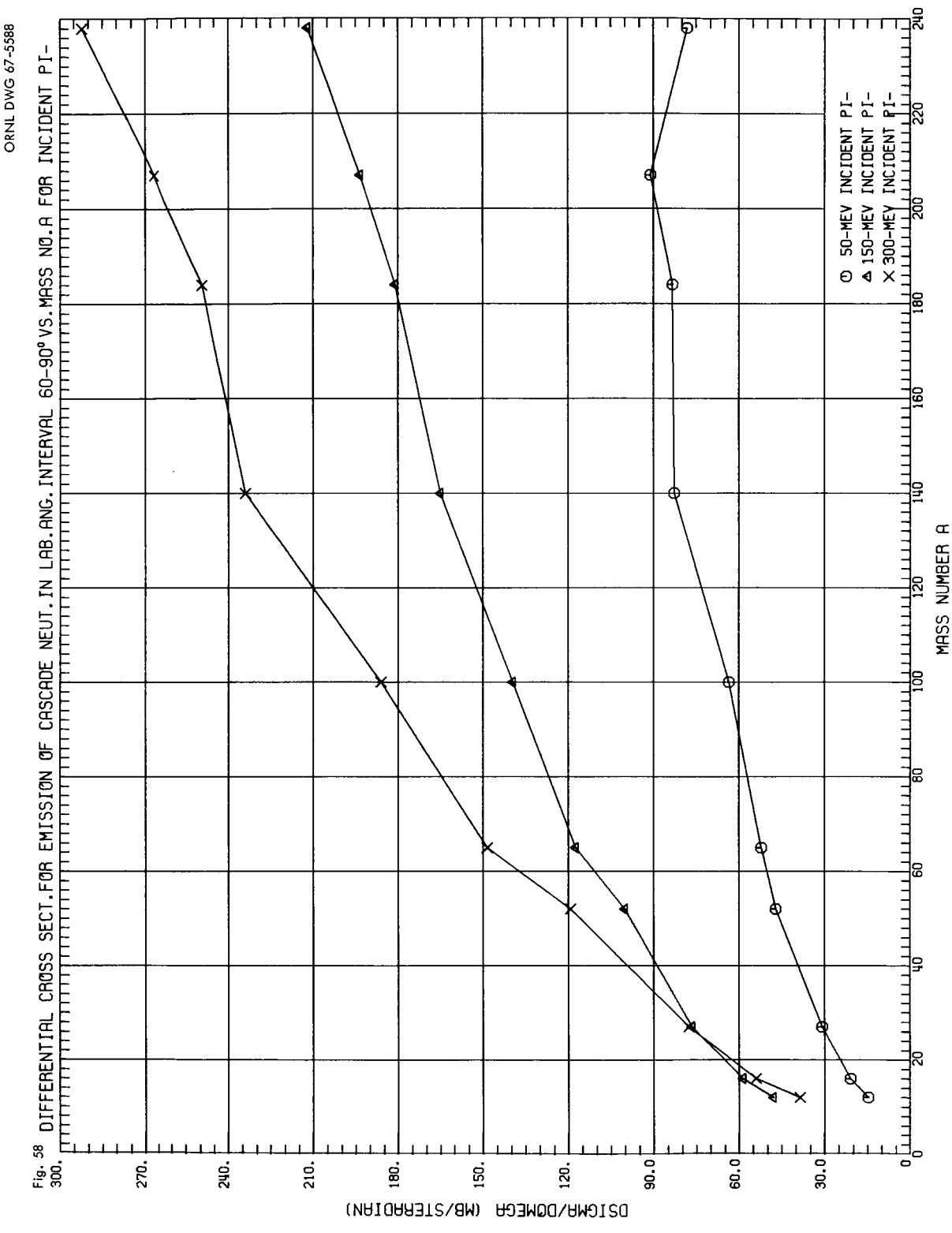


Fig. 58 DIFFERENTIAL CROSS SECT.FOR EMISSION OF CASCADE NEUT.IN LAB.ANG.INTERVAL 60-90° VS.MASS NO.A FOR INCIDENT PI-

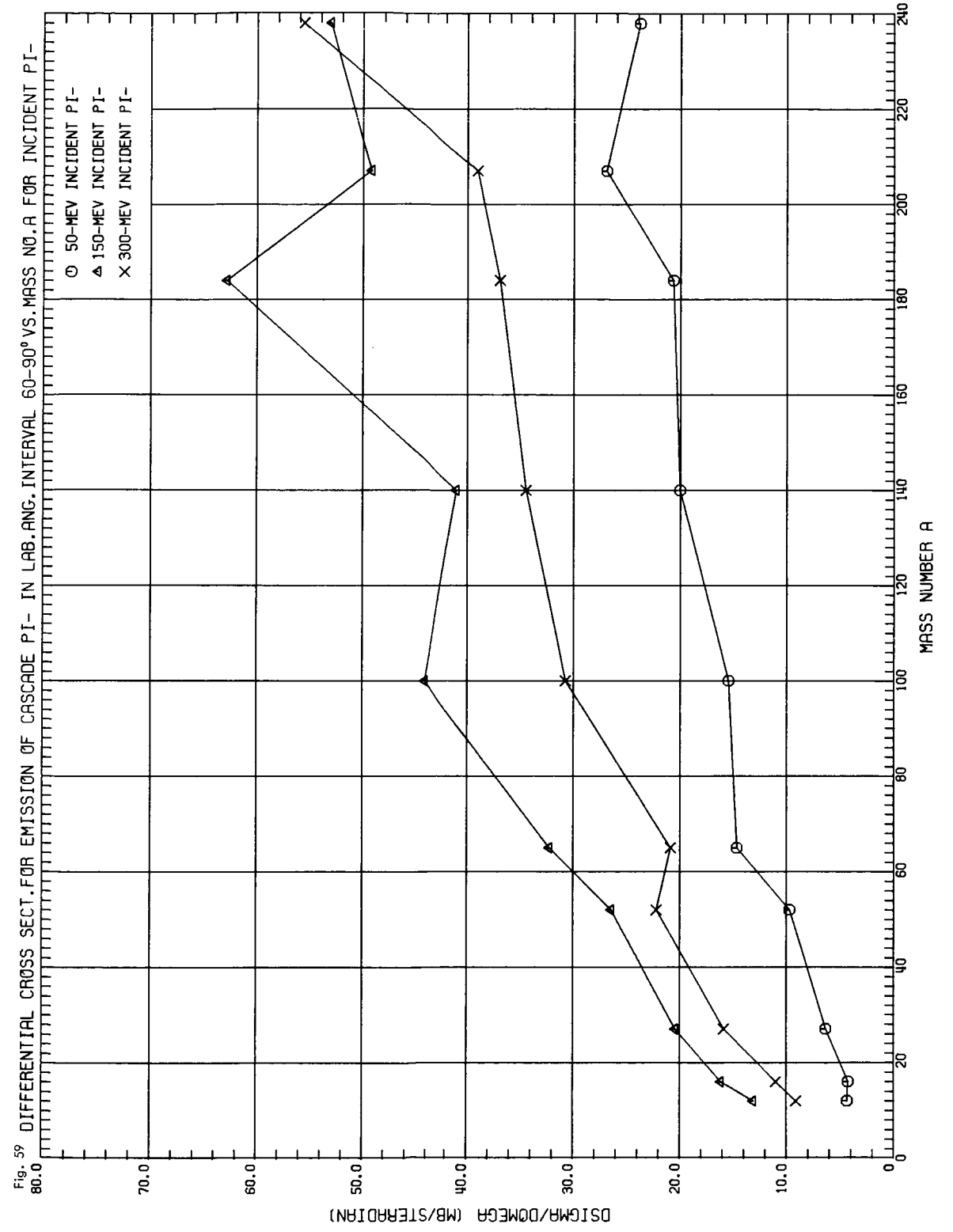

ORNL DWG 67-5589
DIFFERENTIAL CROSS SECT.FOR EMISSION OF CASCADE PI- IN LAB.ANG.INTERVAL 60-90° VS.MASS NO.A FOR INCIDENT PI-
○ 50-MEV INCIDENT PI-
△ 150-MEV INCIDENT PI-
× 300-MEV INCIDENT PI-
DSIGMA/DOMEGA (MB/STERADIAN)
MASS NUMBER A
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 59

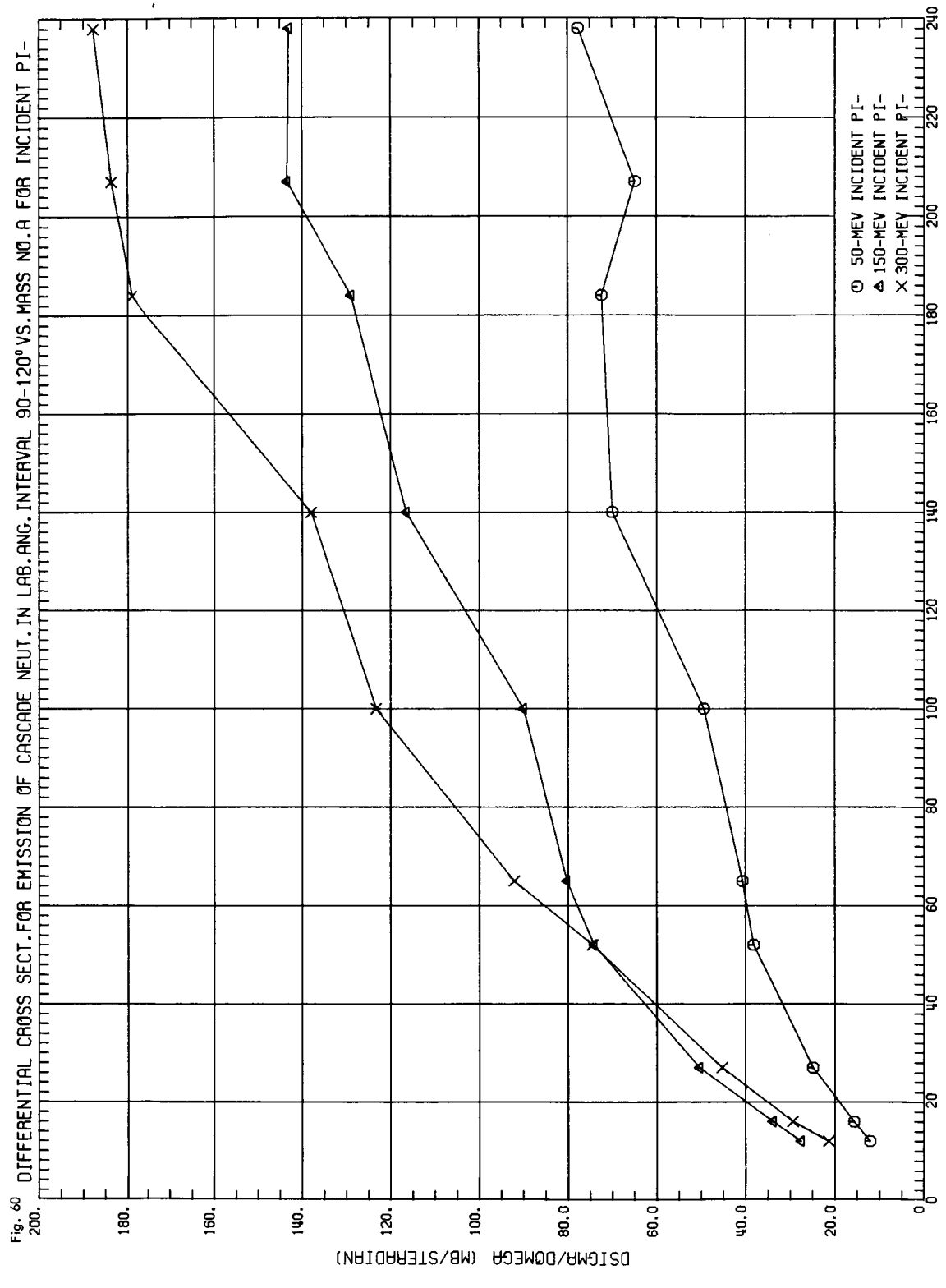

ORNL DWG 67-5590
DIFFERENTIAL CROSS SECT.FOR EMISSION OF CASCADE NEUT.IN LAB.ANG.INTERVAL 90-120°VS.MASS NO.A FOR INCIDENT PI-
DSIGMA/DOMEGA (MB/STERADIAN)
MASS NUMBER A
50-MEV INCIDENT PI-
150-MEV INCIDENT PI-
300-MEV INCIDENT PI-
200.
180.
160.
140.
120.
100.
80.0
60.0
40.0
20.0
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 60

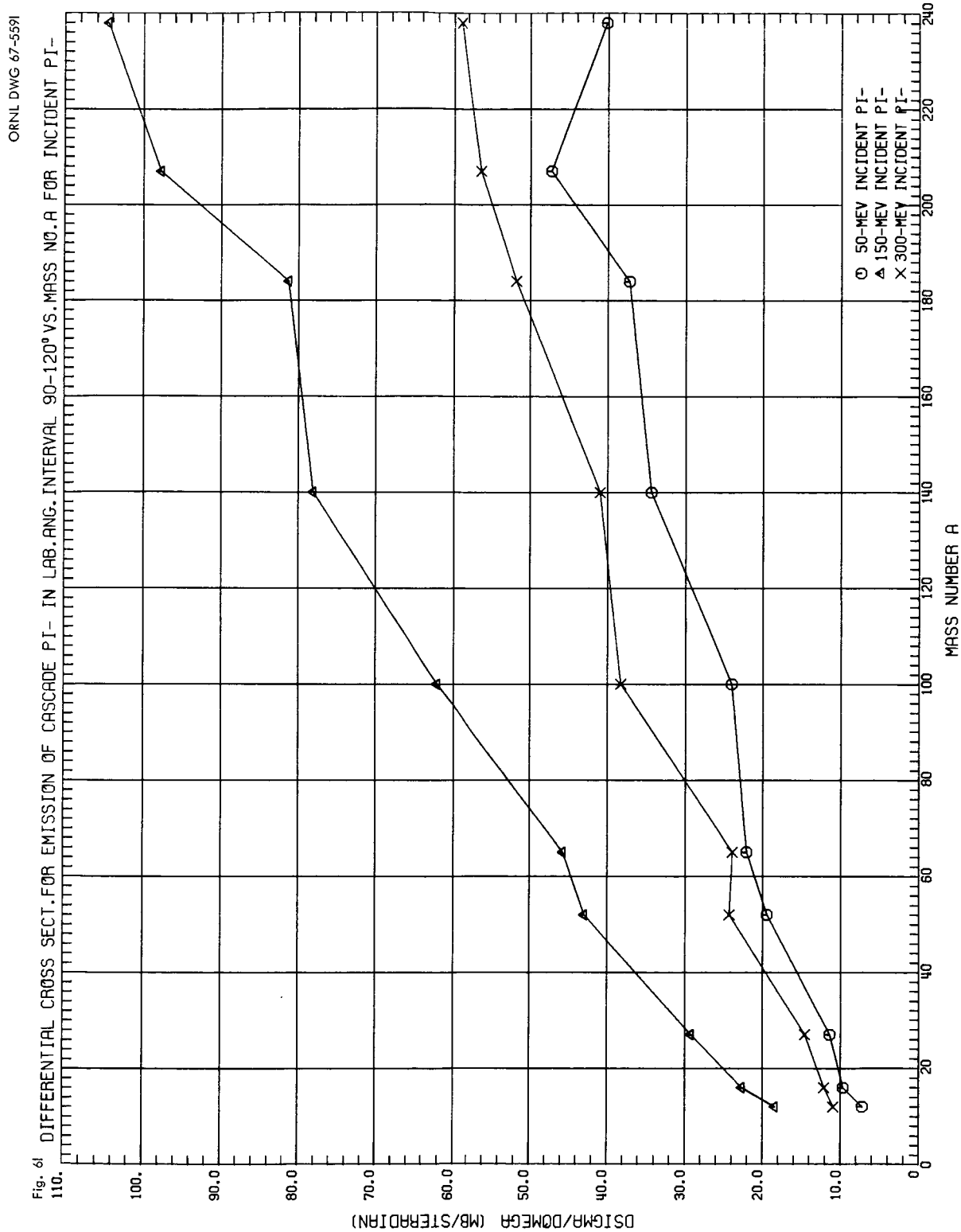

ORNL DWG 67-5591
DIFFERENTIAL CROSS SECT.FOR EMISSION OF CASCADE PI- IN LAB.ANG.INTERVAL 90-120° VS.MASS NO.A FOR INCIDENT PI-
110.
100.
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0
20
40
60
80
100
120
140
160
180
200
220
240
DSIGMA/DOMEGA (MB/STERADIAN)
MASS NUMBER A
○ 50-MEV INCIDENT PI-
△ 150-MEV INCIDENT PI-
× 300-MEV INCIDENT PI-

Fig. 61

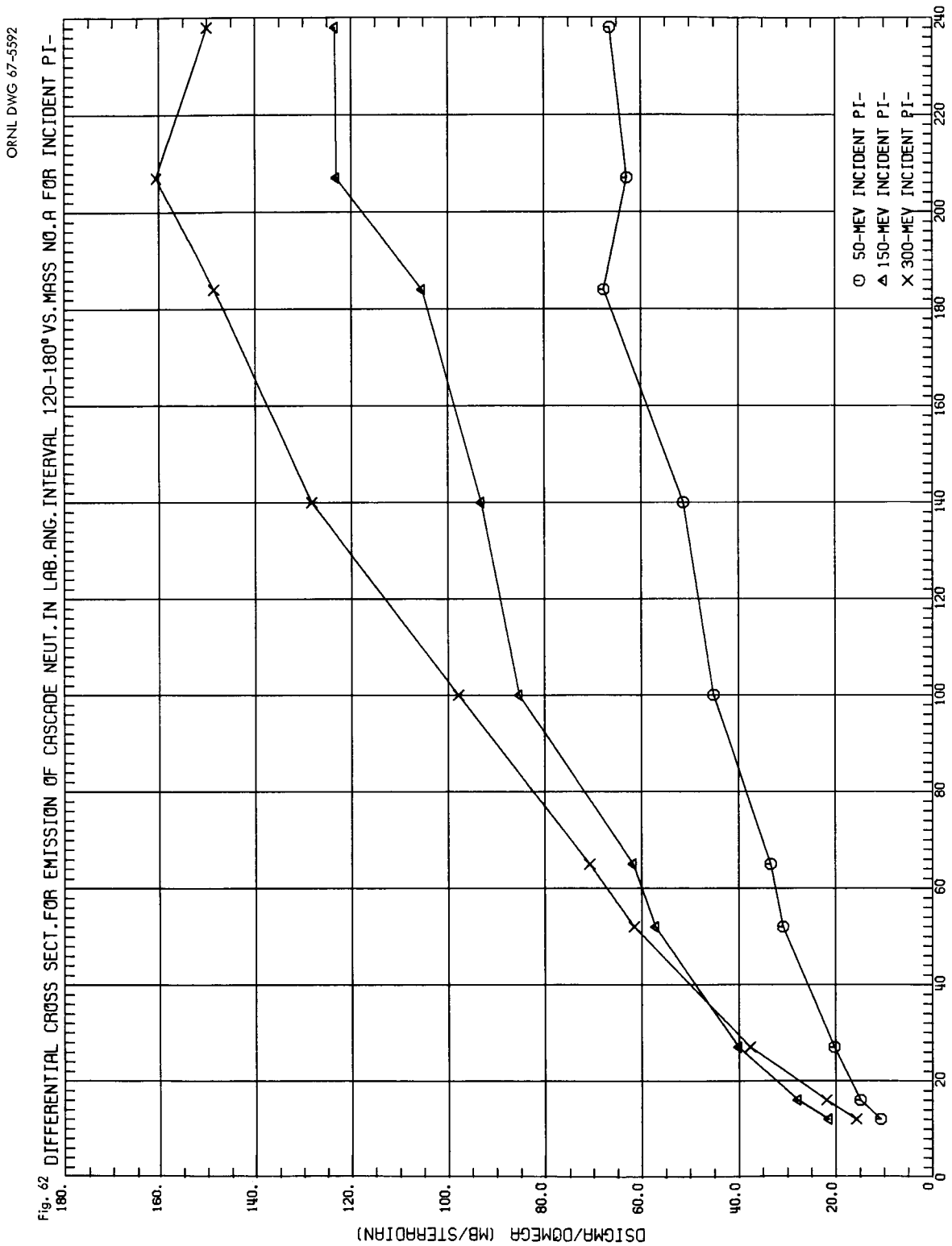

ORNL DWG 67-5592
DIFFERENTIAL CROSS SECT.FOR EMISSION OF CASCADE NEUT.IN LAB.ANG.INTERVAL 120-180° VS.MASS NO.A FOR INCIDENT PI-
DSIGMA/DOMEGA (MB/STERADIAN)
MASS NUMBER A
50-MEV INCIDENT PI-
150-MEV INCIDENT PI-
300-MEV INCIDENT PI-
180.
160.
140.
120.
100.
80.0
60.0
40.0
20.0
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 62

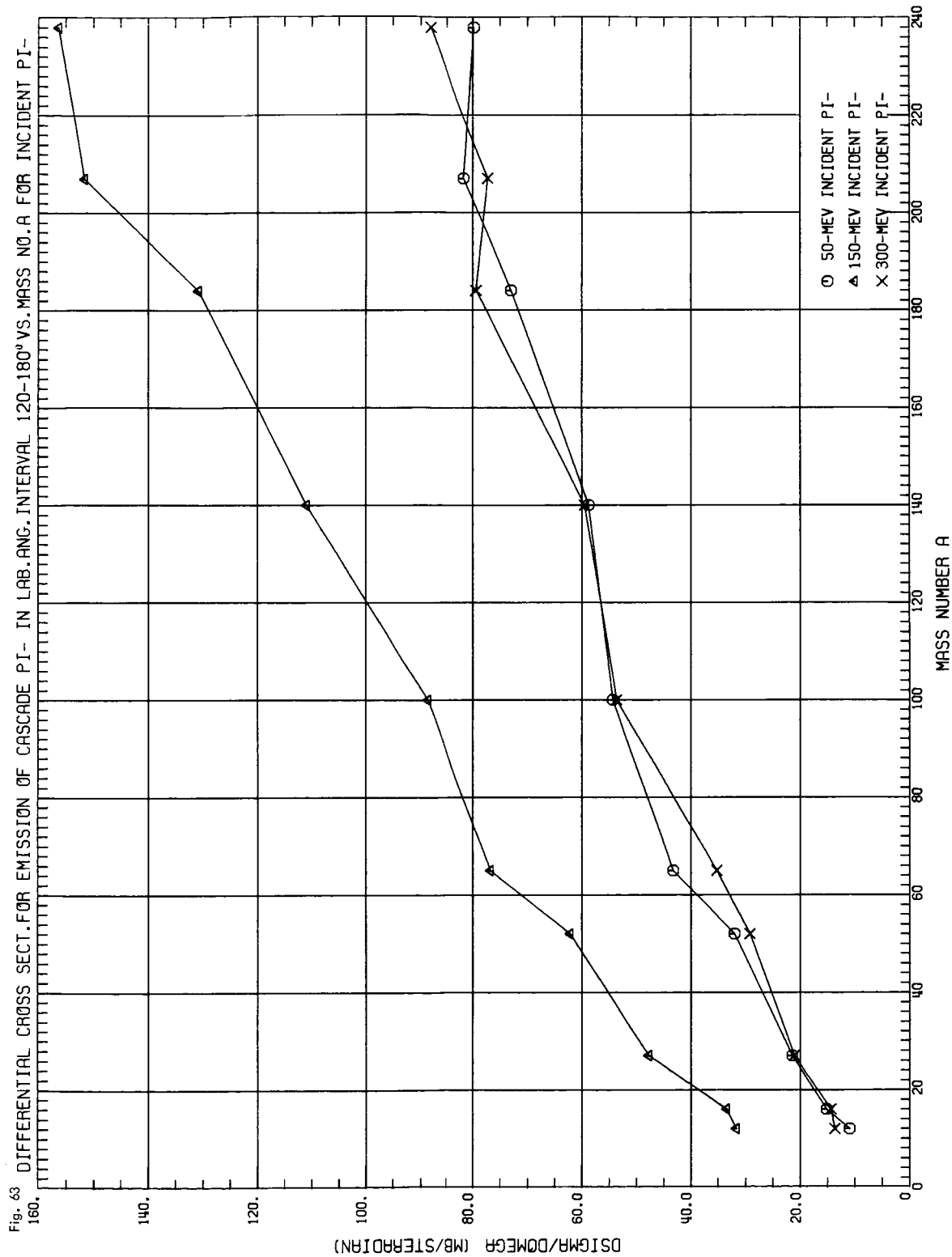

ORNL DWG 67-5593
DIFFERENTIAL CROSS SECT.FOR EMISSION OF CASCADE PI- IN LAB.ANG.INTERVAL 120-180°VS.MASS NO.A FOR INCIDENT PI-
DSIGMA/DOMEGA (MB/STERADIAN)
MASS NUMBER A
50-MEV INCIDENT PI-
150-MEV INCIDENT PI-
300-MEV INCIDENT PI-

Fig. 63

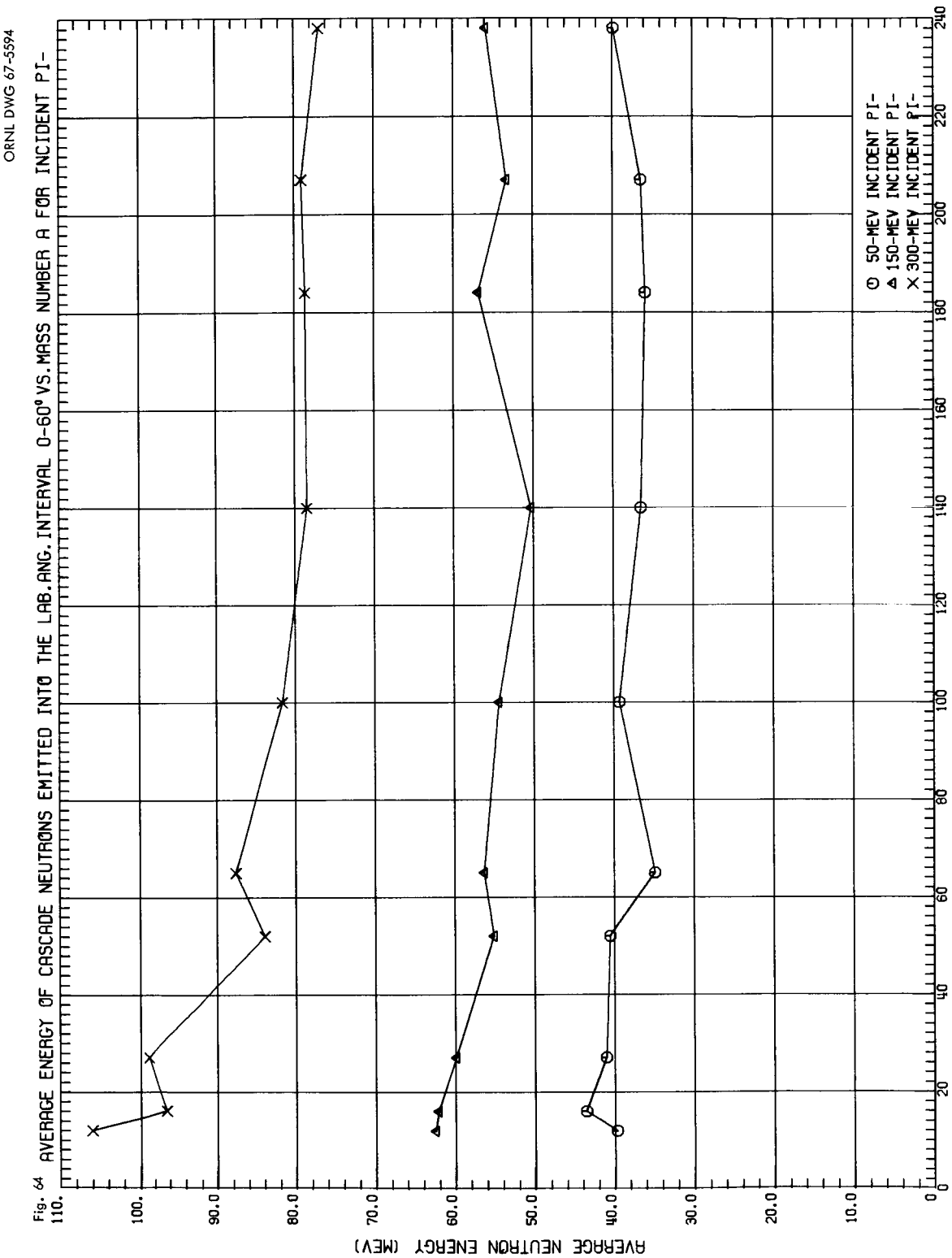

ORNL DWG 67-5594
AVERAGE ENERGY OF CASCADE NEUTRONS EMITTED INTO THE LAB. ANG. INTERVAL 0-60° VS. MASS NUMBER A FOR INCIDENT PI-
AVERAGE NEUTRON ENERGY (MEV)
MASS NUMBER A
50-MEV INCIDENT PI-
150-MEV INCIDENT PI-
300-MEV INCIDENT PI-

Fig. 64 110.

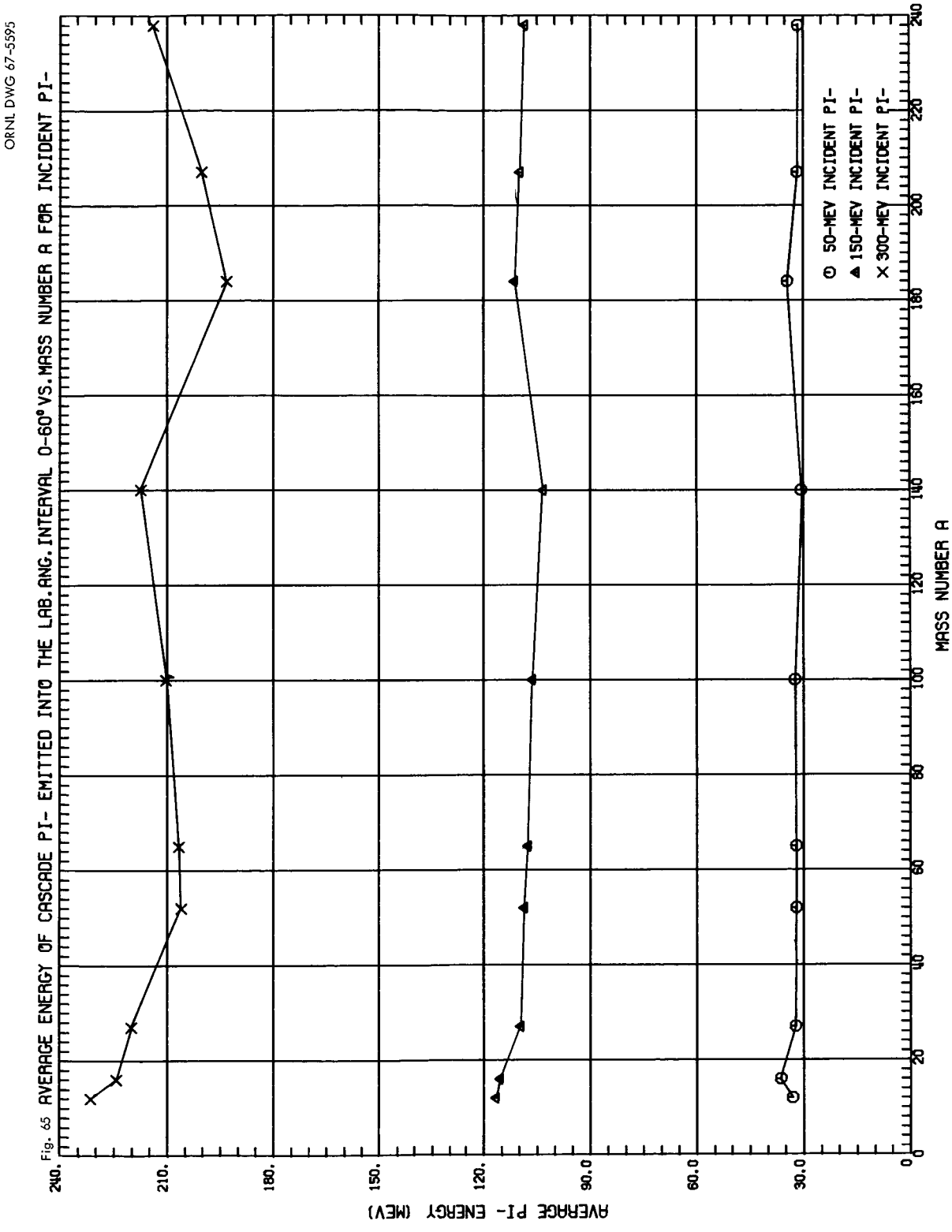

ORNL DWG 67-5595
AVERAGE ENERGY OF CASCADE PI- EMITTED INTO THE LAB. ANG. INTERVAL 0-60° VS. MASS NUMBER A FOR INCIDENT PI-
AVERAGE PI- ENERGY (MEV)
240.
210.
180.
150.
120.
90.0
60.0
30.0
0
20
40
60
80
100
120
140
160
180
200
220
240
MASS NUMBER A
○ 50-MEV INCIDENT PI-
▲ 150-MEV INCIDENT PI-
× 300-MEV INCIDENT PI-

Fig. 65

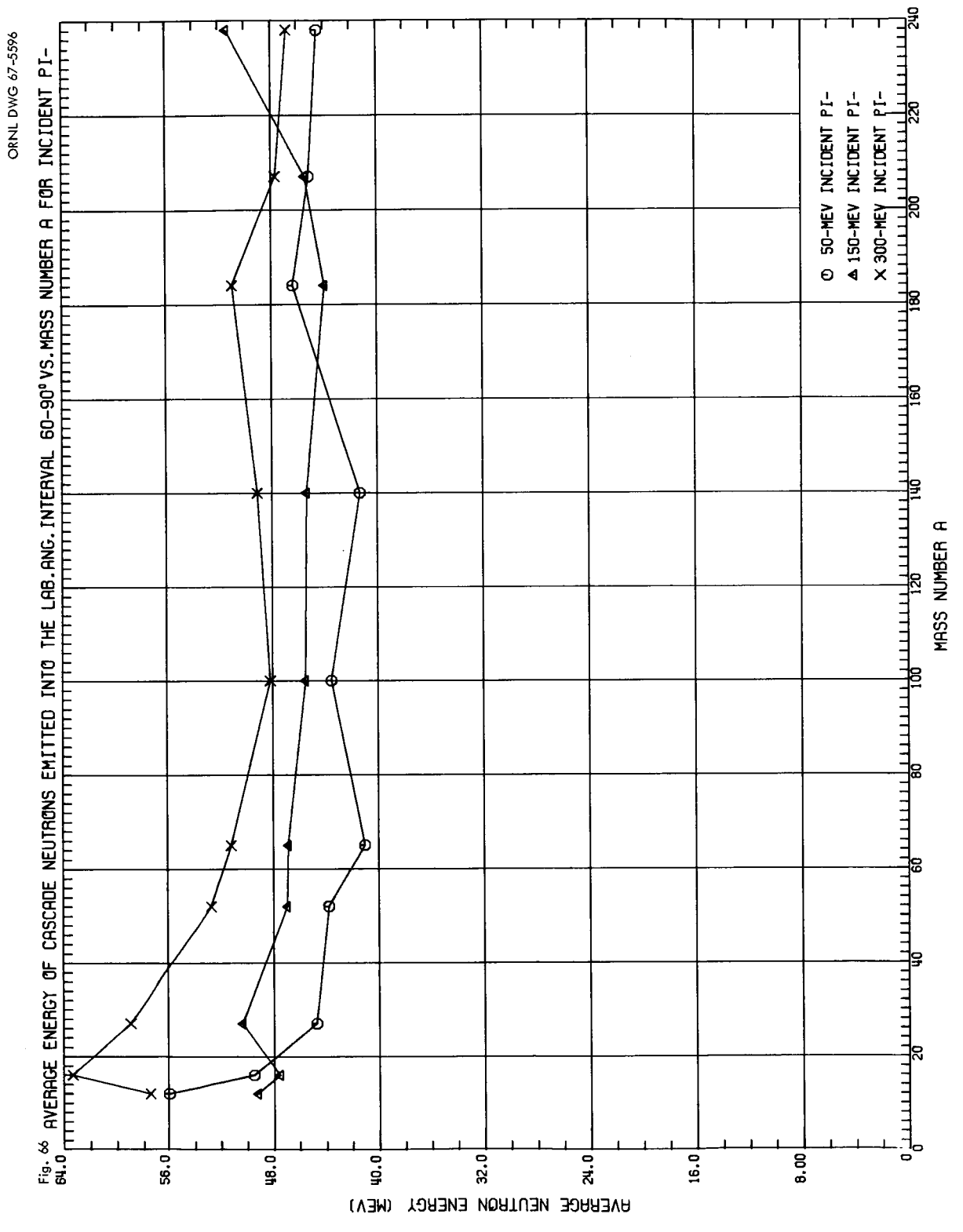
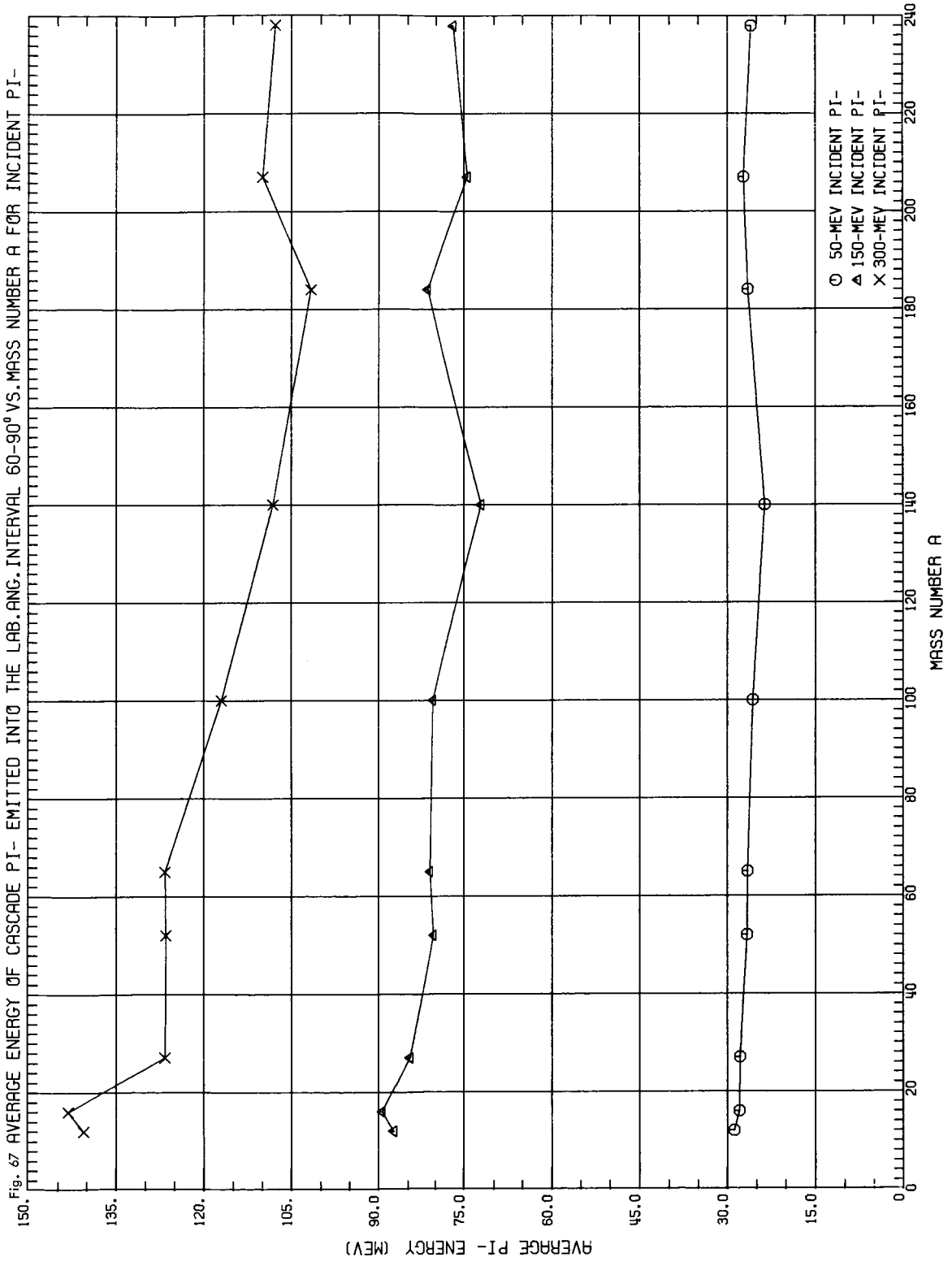

ORNL DWG 67-5596
AVERAGE ENERGY OF CASCADE NEUTRONS EMITTED INTO THE LAB. ANG. INTERVAL 60-90° VS. MASS NUMBER A FOR INCIDENT PI-
AVERAGE NEUTRON ENERGY (MEV)
64.0
56.0
48.0
40.0
32.0
24.0
16.0
8.00
0
20
40
60
80
100
120
140
160
180
200
220
240
MASS NUMBER A
○ 50-MEV INCIDENT PI-
△ 150-MEV INCIDENT PI-
× 300-MEV INCIDENT PI-

Fig. 66


ORNL DWG 67-5597
Fig. 67 AVERAGE ENERGY OF CASCADE PI- EMITTED INTO THE LAB. ANG. INTERVAL 60-90° VS. MASS NUMBER A FOR INCIDENT PI-
AVERAGE PI- ENERGY (MEV)
MASS NUMBER A
50-MEV INCIDENT PI-
150-MEV INCIDENT PI-
300-MEV INCIDENT PI-
150.
135.
120.
105.
90.0
75.0
60.0
45.0
30.0
15.0
0
20
40
60
80
100
120
140
160
180
200
220
240

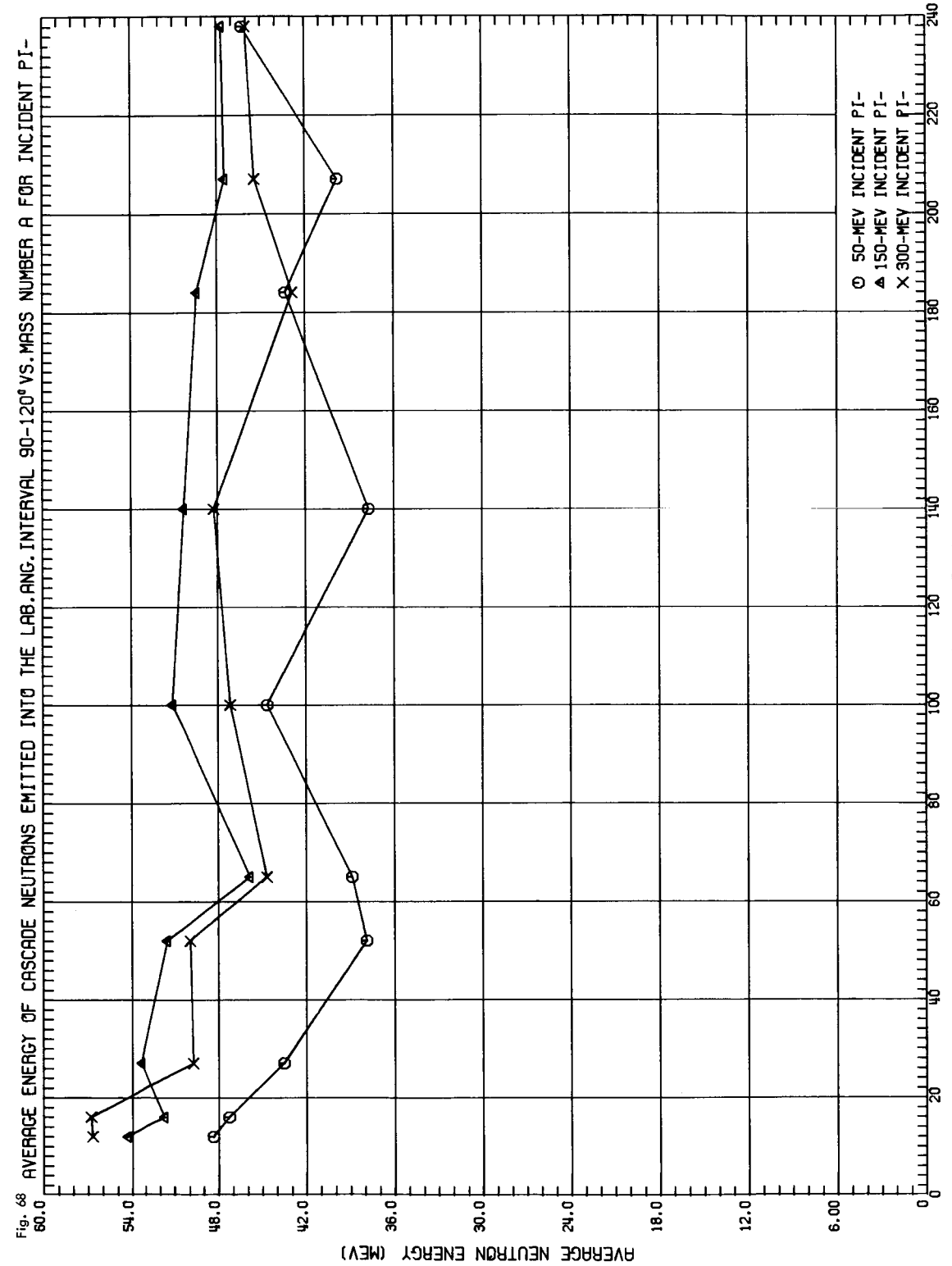

ORNL DWG 67-5598
AVERAGE ENERGY OF CASCADE NEUTRONS EMITTED INTO THE LAB. ANG. INTERVAL 90-120° VS. MASS NUMBER A FOR INCIDENT PI-
AVERAGE NEUTRON ENERGY (MEV)
MASS NUMBER A
50-MEV INCIDENT PI-
150-MEV INCIDENT PI-
300-MEV INCIDENT PI-
60.0
54.0
48.0
42.0
36.0
30.0
24.0
18.0
12.0
6.00
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 68

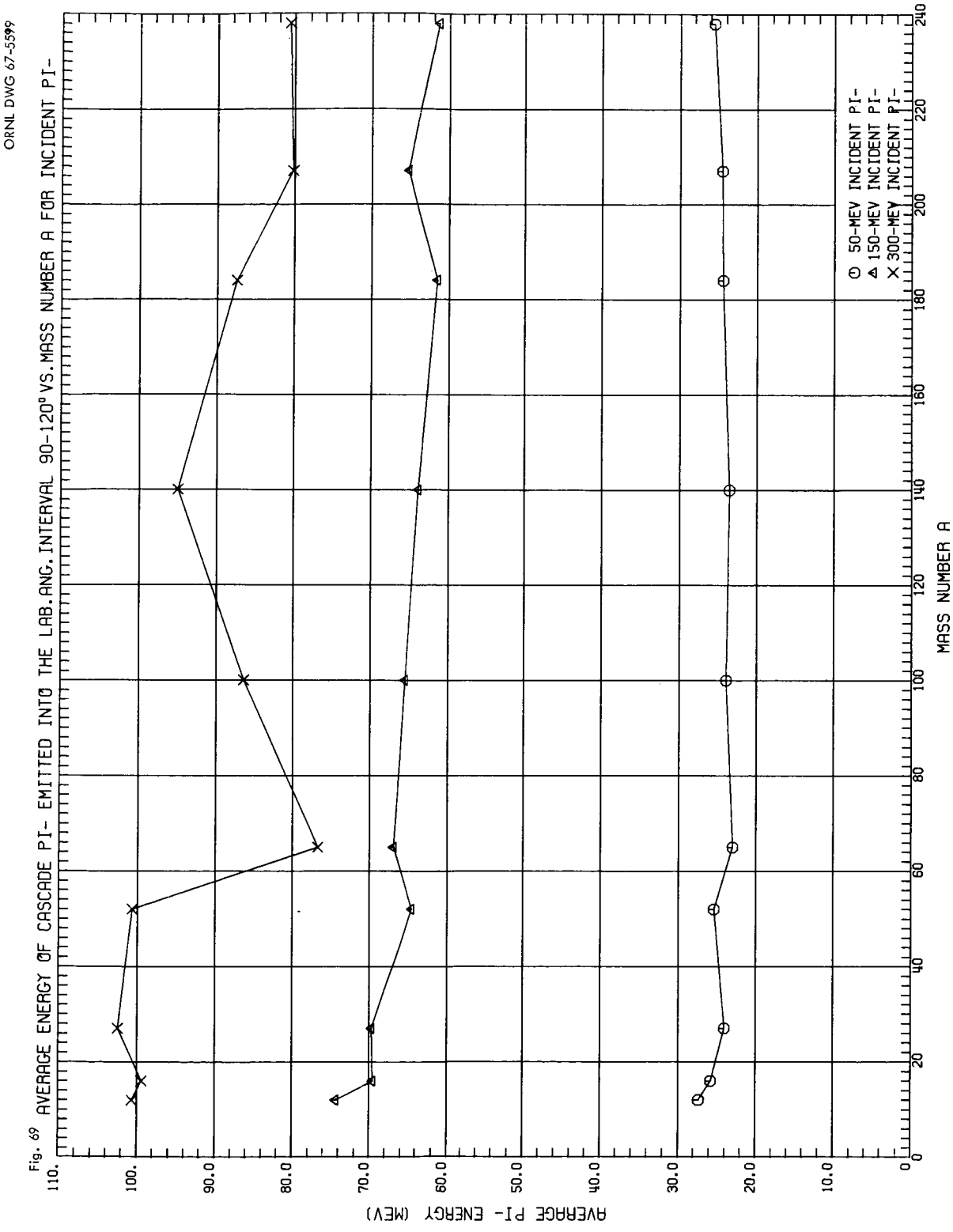

ORNL DWG 67-5599
AVERAGE ENERGY OF CASCADE PI- EMITTED INTO THE LAB. ANG. INTERVAL 90-120° VS. MASS NUMBER A FOR INCIDENT PI-
AVERAGE PI- ENERGY (MEV)
MASS NUMBER A
50-MEV INCIDENT PI-
150-MEV INCIDENT PI-
300-MEV INCIDENT PI-
110.
100.
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 69

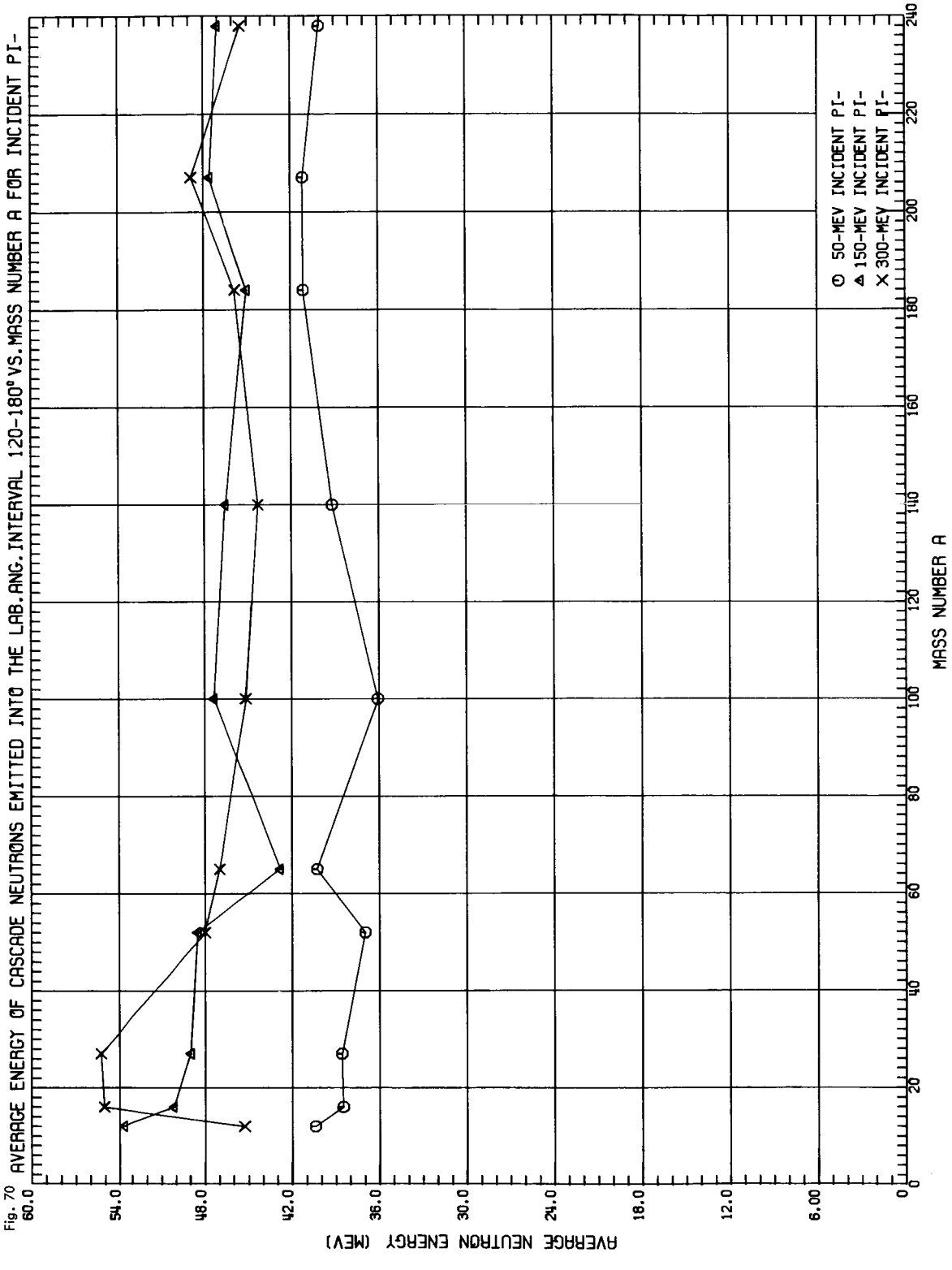

ORNL DWG 67-5600
AVERAGE ENERGY OF CASCADE NEUTRONS EMITTED INTO THE LAB. ANG. INTERVAL 120-180° VS. MASS NUMBER A FOR INCIDENT PI-
AVERAGE NEUTRON ENERGY (MEV)
MASS NUMBER A
50-MEV INCIDENT PI-
150-MEV INCIDENT PI-
300-MEV INCIDENT PI-
60.0
54.0
48.0
42.0
36.0
30.0
24.0
18.0
12.0
6.00
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 70

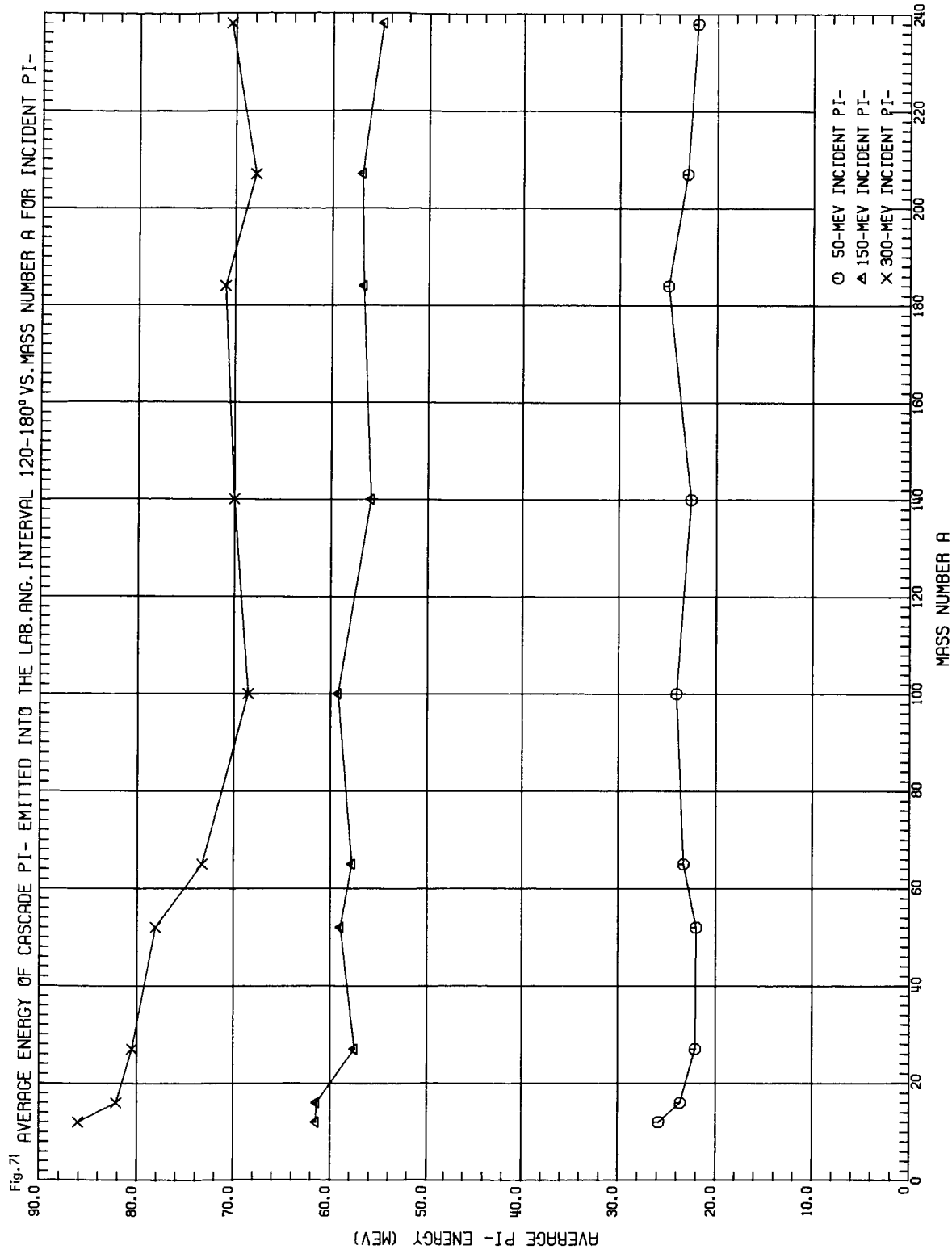

ORNL DWG 67-5601
AVERAGE ENERGY OF CASCADE PI- EMITTED INTO THE LAB. ANG. INTERVAL 120-180° VS. MASS NUMBER A FOR INCIDENT PI-
AVERAGE PI- ENERGY (MEV)
MASS NUMBER A
50-MEV INCIDENT PI-
150-MEV INCIDENT PI-
300-MEV INCIDENT PI-
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 71

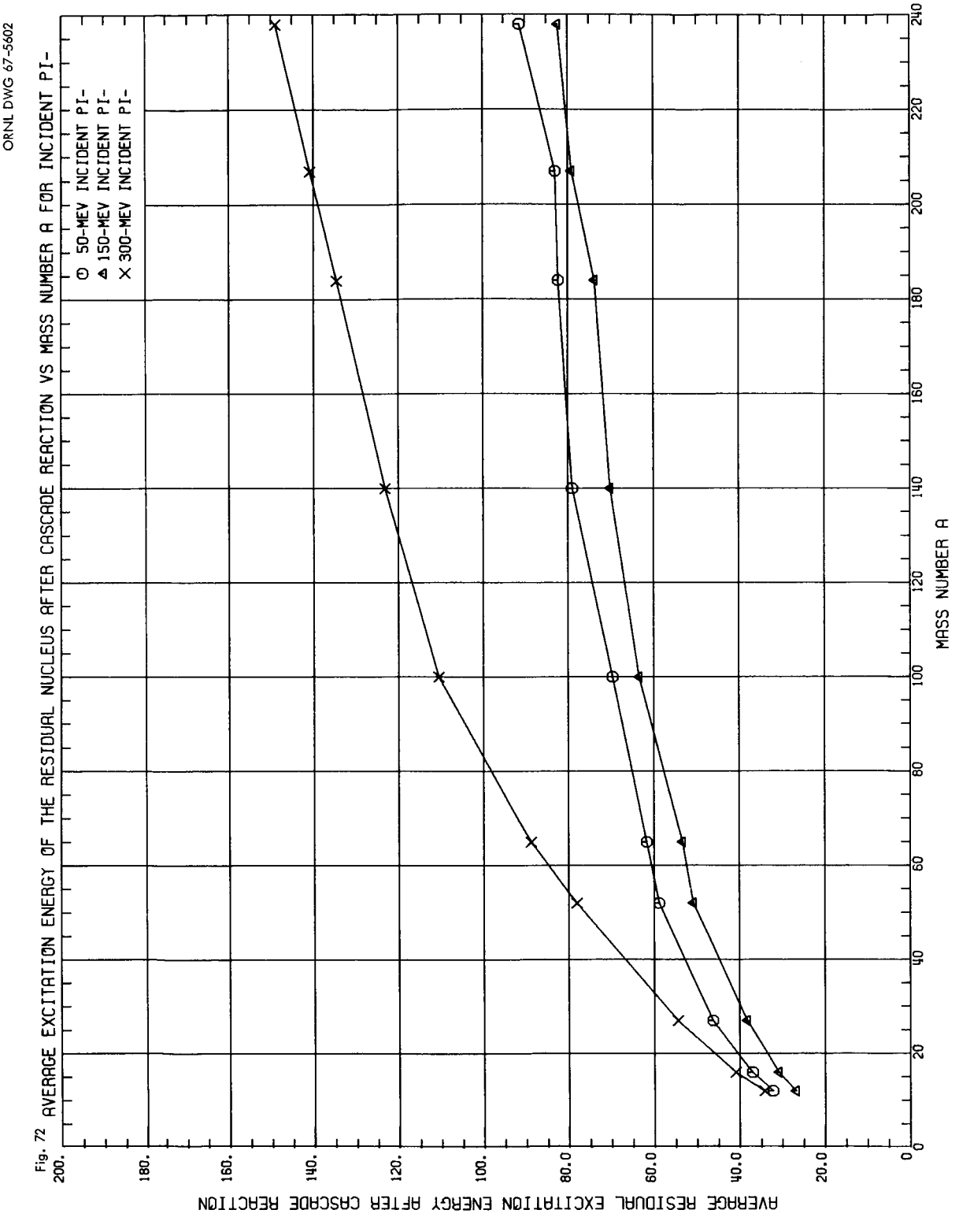

ORNL DWG 67-5602
AVERAGE EXCITATION ENERGY OF THE RESIDUAL NUCLEUS AFTER CASCADE REACTION VS MASS NUMBER A FOR INCIDENT PI-
50-MEV INCIDENT PI-
150-MEV INCIDENT PI-
300-MEV INCIDENT PI-
AVERAGE RESIDUAL EXCITATION ENERGY AFTER CASCADE REACTION
MASS NUMBER A
200.
180.
160.
140.
120.
100.
80.0
60.0
40.0
20.0
0
20
40
60
80
100
120
140
160
180
200
220
240

Fig. 72

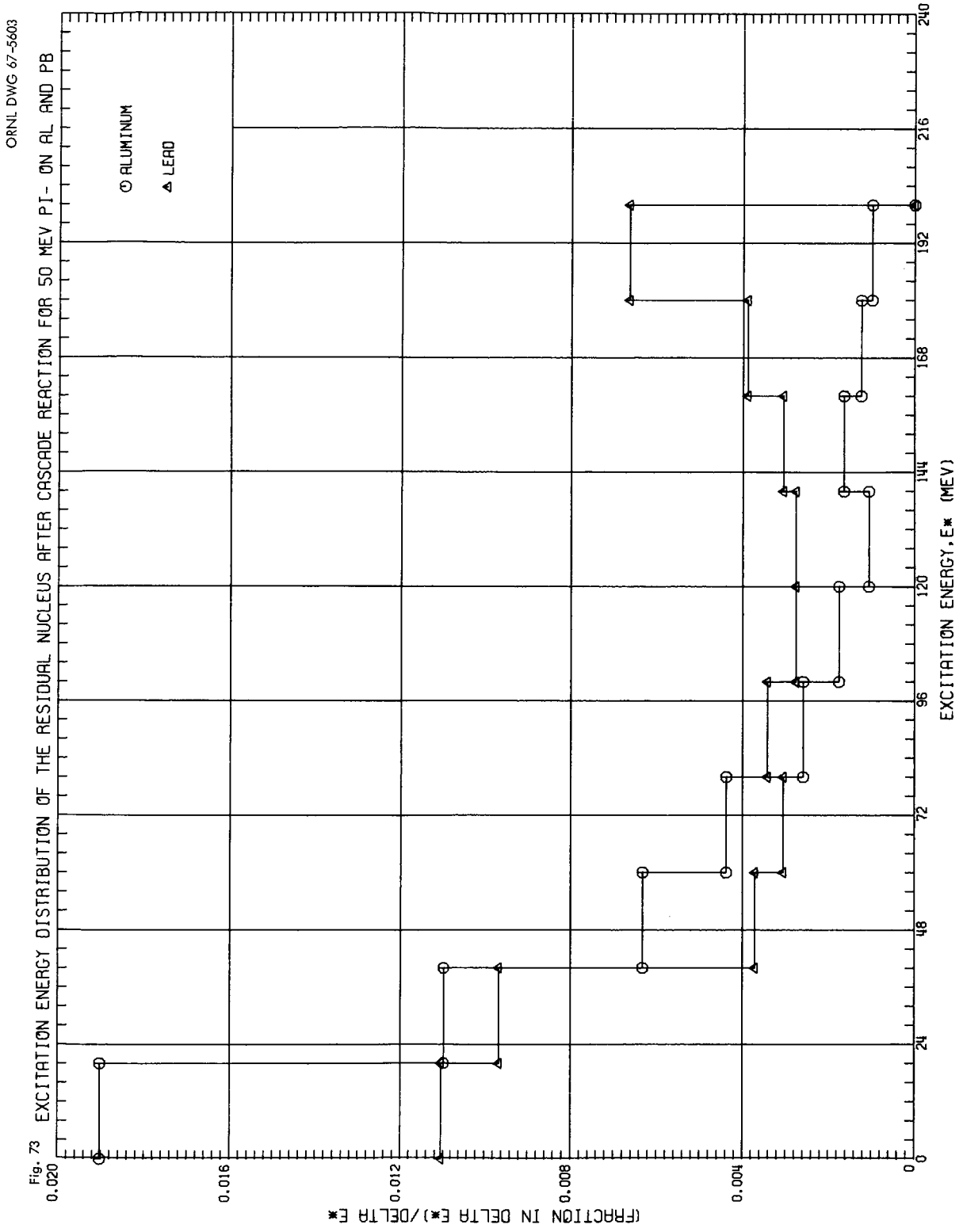

ORNL DWG 67-5603
EXCITATION ENERGY DISTRIBUTION OF THE RESIDUAL NUCLEUS AFTER CASCADE REACTION FOR 50 MEV PI- ON AL AND PB
ALUMINUM
LEAD
FRACTION IN DELTA E*)/DELTA E*
EXCITATION ENERGY, E* (MEV)
0.020
0.016
0.012
0.008
0.004
0
24
48
72
96
120
144
168
192
216
240

Fig. 73

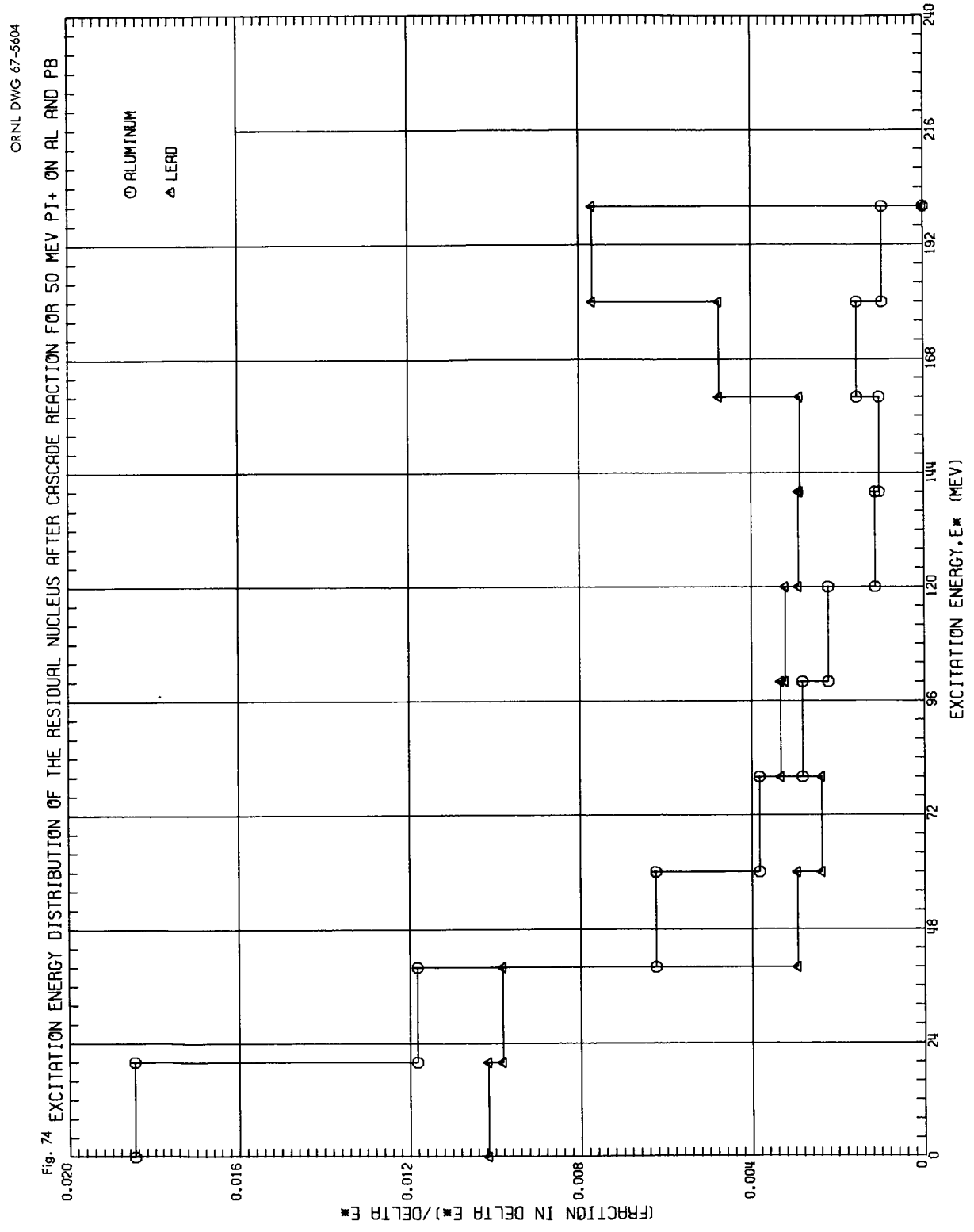

ORNL DWG 67-5604
EXCITATION ENERGY DISTRIBUTION OF THE RESIDUAL NUCLEUS AFTER CASCADE REACTION FOR 50 MEV PI+ ON AL AND PB
ALUMINUM
LEAD
(FRACTION IN DELTA E*)/DELTA E*
0.020
0.016
0.012
0.008
0.004
0
24
48
72
96
120
144
168
192
216
240
EXCITATION ENERGY, E* (MEV)

Fig. 74

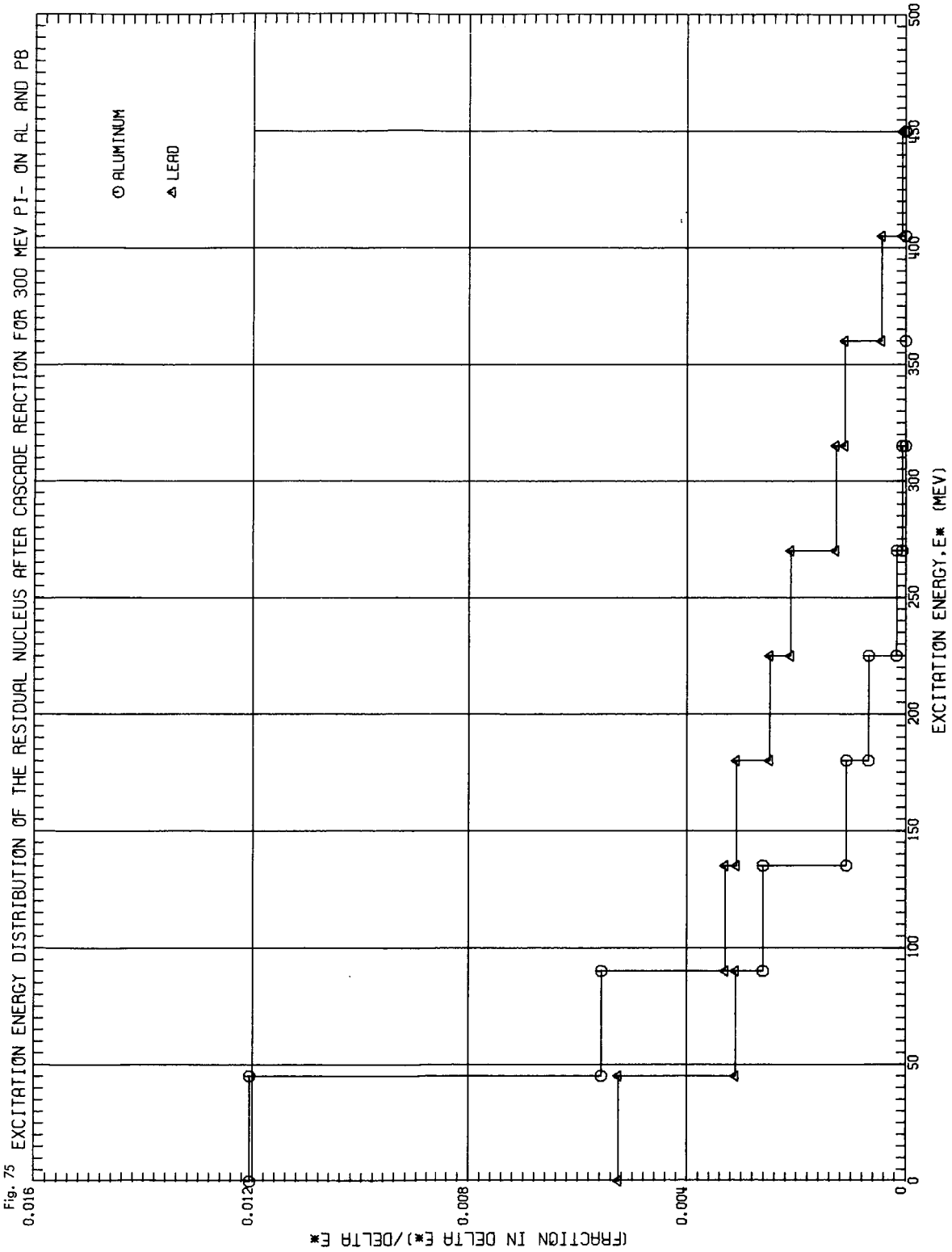

ORNL DWG 67-5605
EXCITATION ENERGY DISTRIBUTION OF THE RESIDUAL NUCLEUS AFTER CASCADE REACTION FOR 300 MEV PI- ON AL AND PB
ALUMINUM
LEAD
(FRACTION IN DELTA E*)/DELTA E*
EXCITATION ENERGY, E* (MEV)
0.016
0.012
0.008
0.004
0
50
100
150
200
250
300
350
400
450
500

Fig. 75

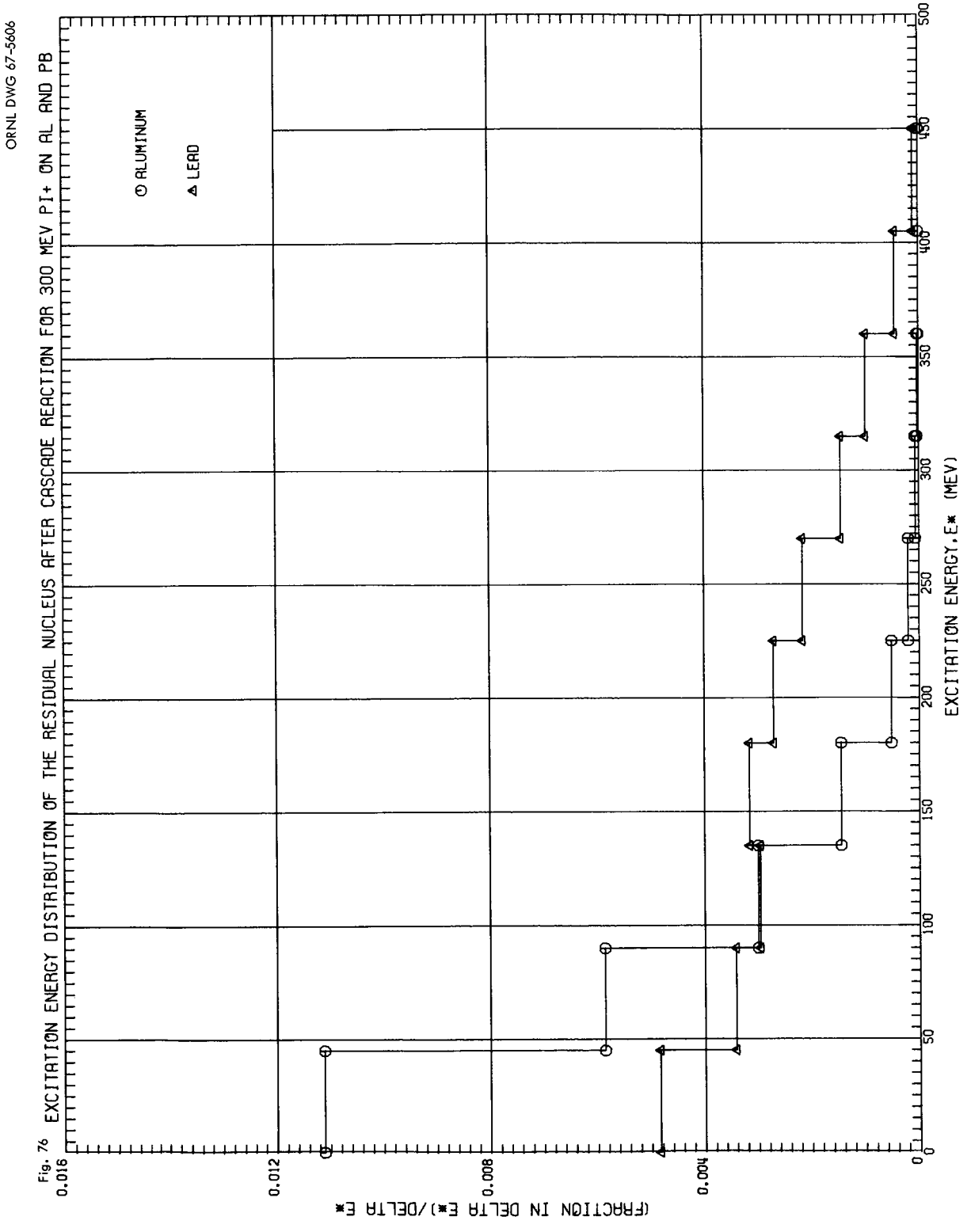

ORNL DWG 67-5606
EXCITATION ENERGY DISTRIBUTION OF THE RESIDUAL NUCLEUS AFTER CASCADE REACTION FOR 300 MEV PI+ ON AL AND PB
ALUMINUM
LEAD
(FRACTION IN DELTA E*)/DELTA E*
EXCITATION ENERGY, E* (MEV)
0.016
0.012
0.008
0.004
0
50
100
150
200
250
300
350
400
450
500

Fig. 76

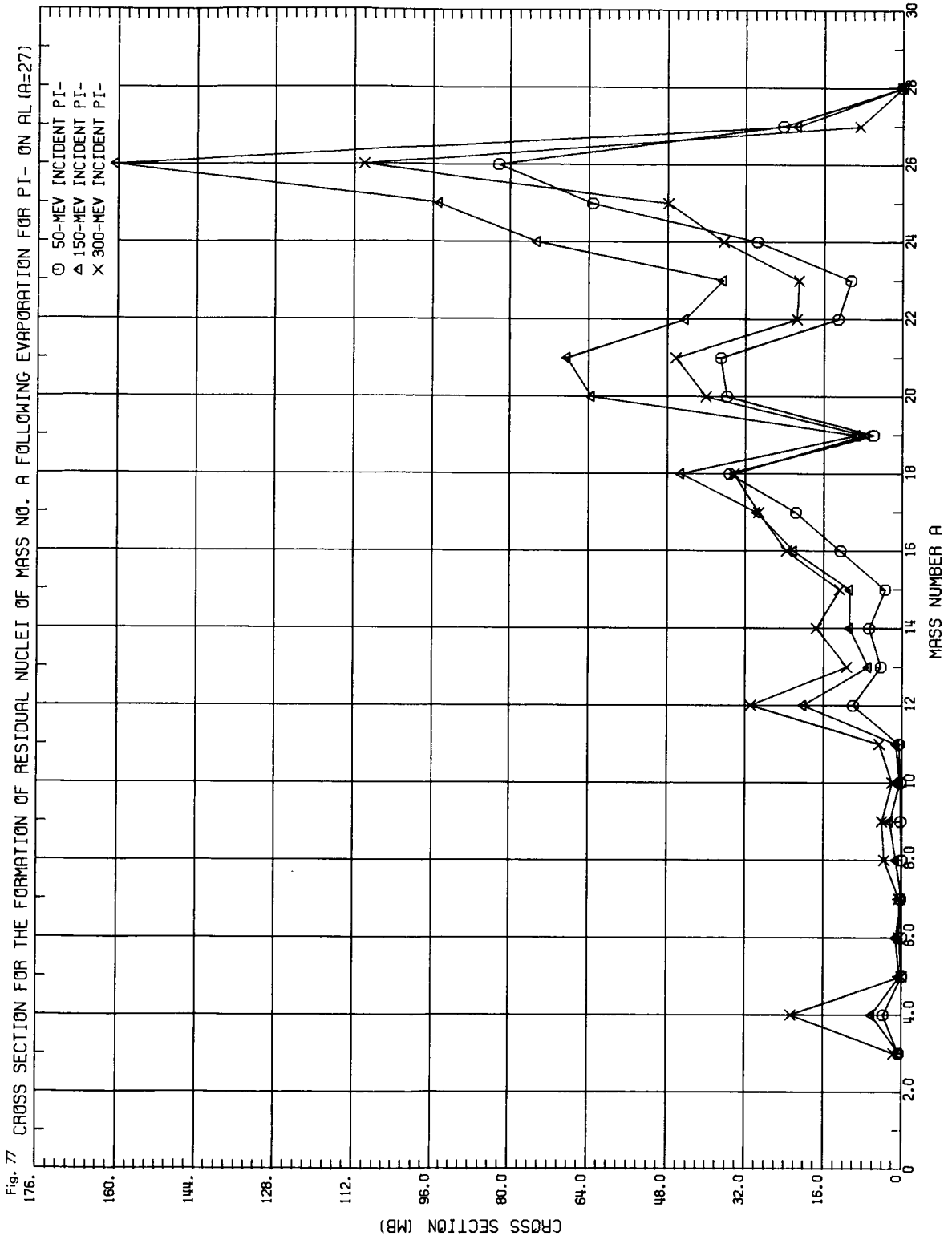

ORNL DWG 67-5607
CROSS SECTION FOR THE FORMATION OF RESIDUAL NUCLEI OF MASS NO. A FOLLOWING EVAPORATION FOR PI- ON AL (A=27)
50-MEV INCIDENT PI-
150-MEV INCIDENT PI-
300-MEV INCIDENT PI-
CROSS SECTION (MB)
MASS NUMBER A

Fig. 77

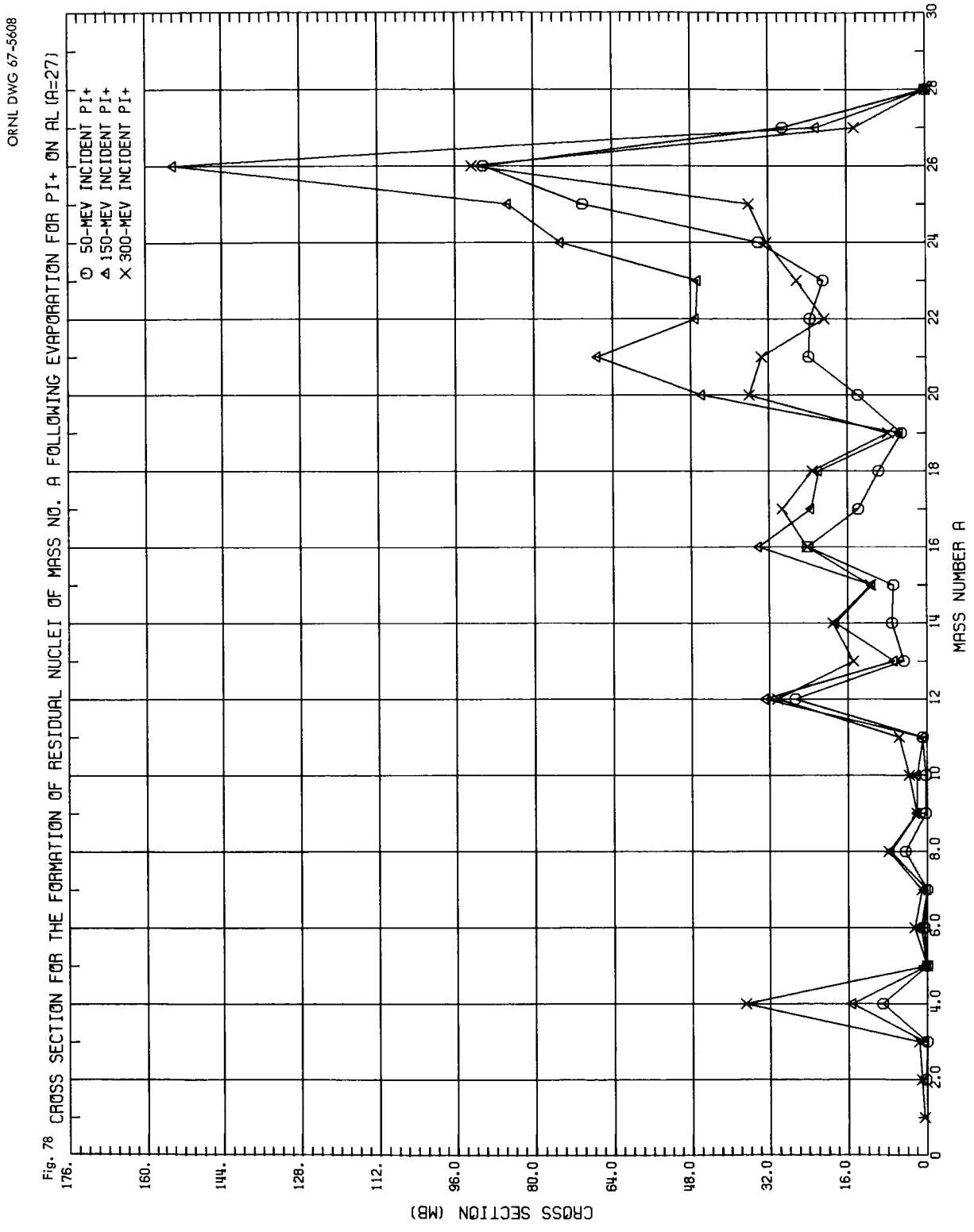

ORNL DWG 67-5608
CROSS SECTION FOR THE FORMATION OF RESIDUAL NUCLEI OF MASS NO. A FOLLOWING EVAPORATION FOR PI+ ON AL (A=27)
50-MEV INCIDENT PI+
150-MEV INCIDENT PI+
300-MEV INCIDENT PI+
CROSS SECTION (MB)
MASS NUMBER A
176.
160.
144.
128.
112.
96.0
80.0
64.0
48.0
32.0
16.0
0
2.0
4.0
6.0
8.0
10
12
14
16
18
20
22
24
26
28
30

Fig. 78

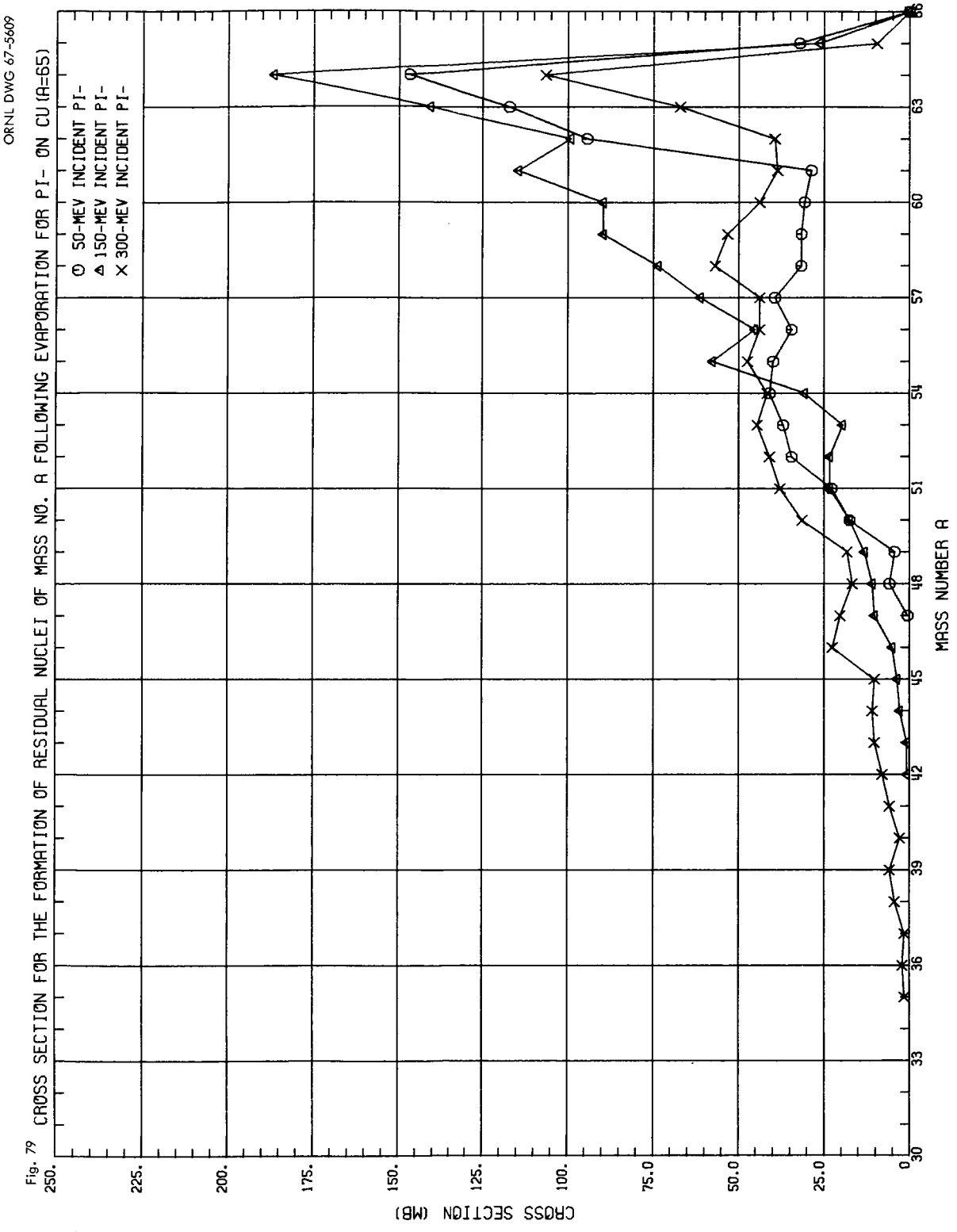

ORNL DWG 67-5609
CROSS SECTION FOR THE FORMATION OF RESIDUAL NUCLEI OF MASS NO. A FOLLOWING EVAPORATION FOR PI- ON CU (A=65)
○ 50-MEV INCIDENT PI-
△ 150-MEV INCIDENT PI-
× 300-MEV INCIDENT PI-
CROSS SECTION (MB)
250.
225.
200.
175.
150.
125.
100.
75.0
50.0
25.0
0
30
33
36
39
42
45
48
51
54
57
60
63
66
MASS NUMBER A

Fig. 79

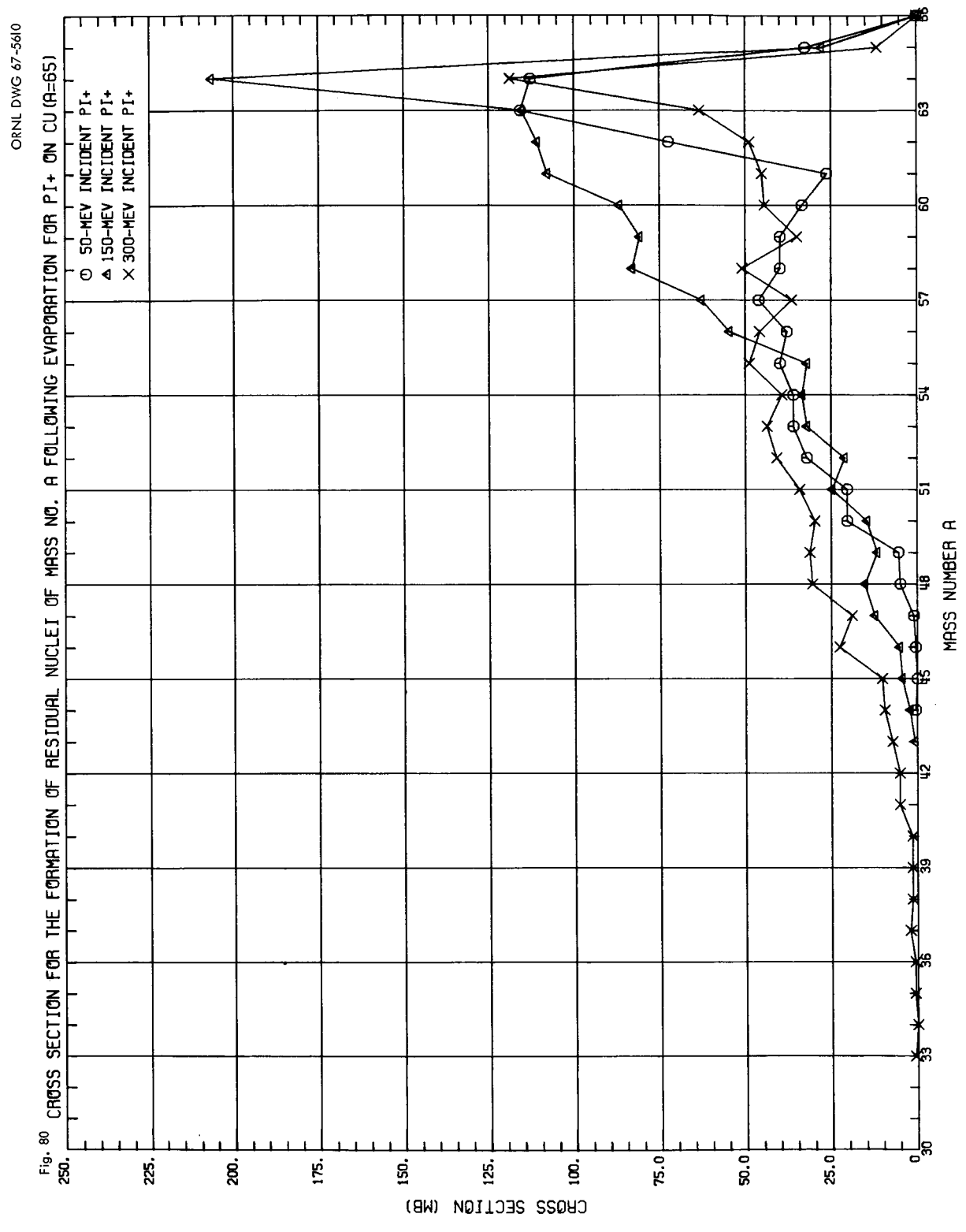

ORNL DWG 67-5610
CROSS SECTION FOR THE FORMATION OF RESIDUAL NUCLEI OF MASS NO. A FOLLOWING EVAPORATION FOR PI+ ON CU (A=65)
50-MEV INCIDENT PI+
150-MEV INCIDENT PI+
300-MEV INCIDENT PI+
CROSS SECTION (MB)
MASS NUMBER A
250.
225.
200.
175.
150.
125.
100.
75.0
50.0
25.0
0
30
33
36
39
42
45
48
51
54
57
60
63
66

Fig. 80

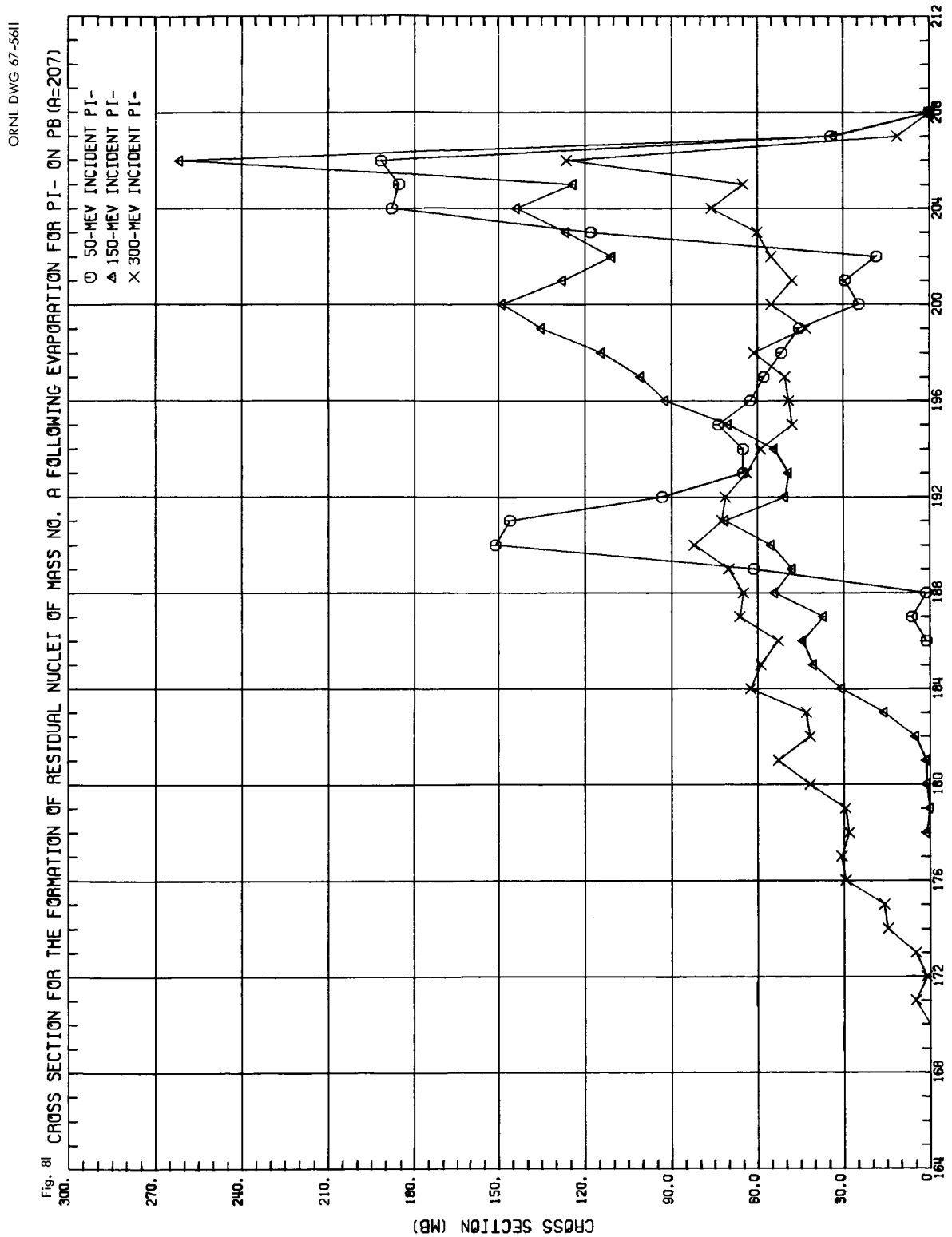

ORNL DWG 67-5611
CROSS SECTION FOR THE FORMATION OF RESIDUAL NUCLEI OF MASS NO. A FOLLOWING EVAPORATION FOR PI- ON PB (A=207)
○ 50-MEV INCIDENT PI-
△ 150-MEV INCIDENT PI-
× 300-MEV INCIDENT PI-
CROSS SECTION (MB)
300.
270.
240.
210.
180.
150.
120.
90.0
60.0
30.0
0
164
168
172
176
180
184
188
192
196
200
204
208
212
MASS NUMBER A

Fig. 81

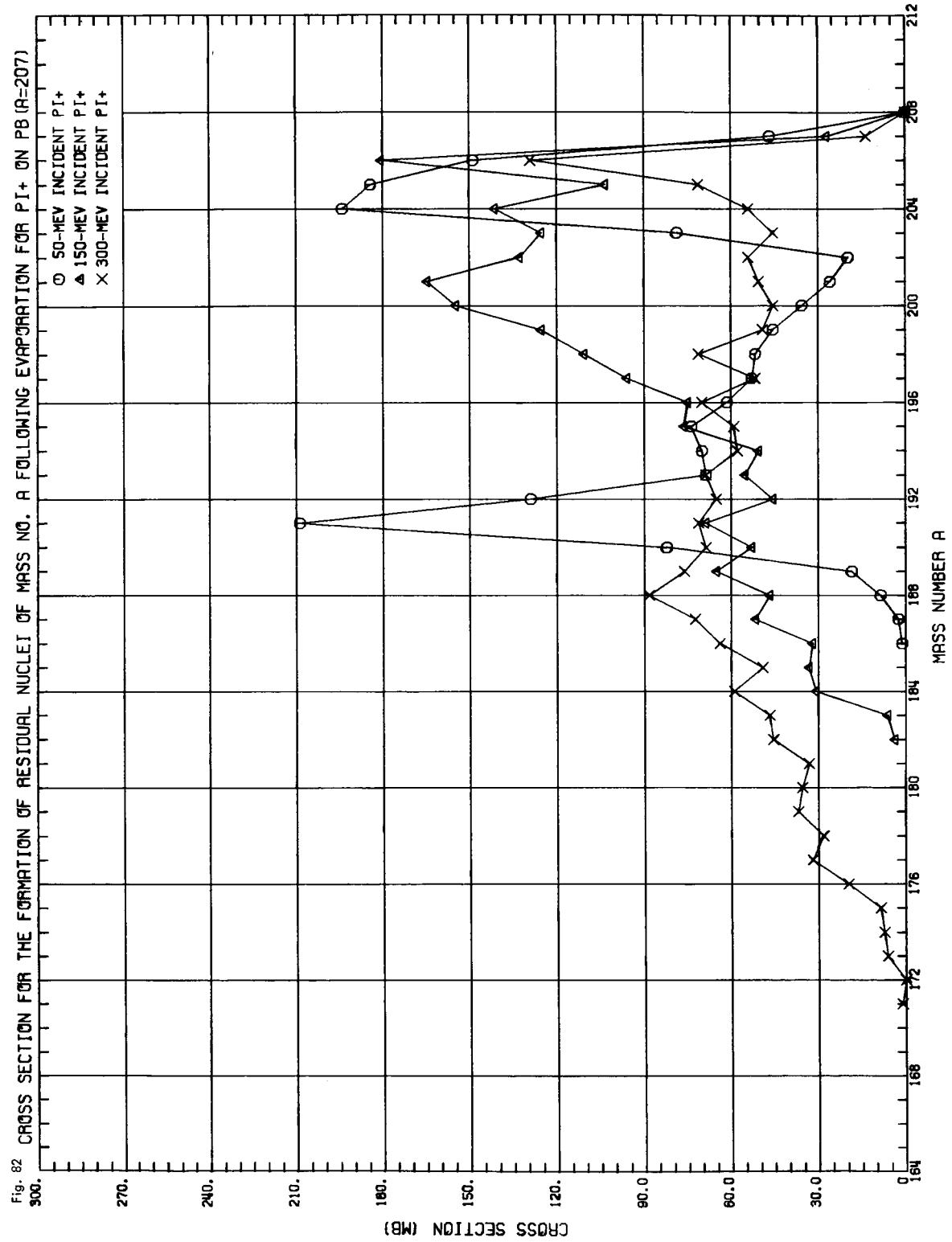

ORNL DWG 67-5612
CROSS SECTION FOR THE FORMATION OF RESIDUAL NUCLEI OF MASS NO. A FOLLOWING EVAPORATION FOR PI+ ON PB (A=207)
50-MEV INCIDENT PI+
150-MEV INCIDENT PI+
300-MEV INCIDENT PI+
CROSS SECTION (MB)
MASS NUMBER A
300.
270.
240.
210.
180.
150.
120.
90.0
60.0
30.0
0
164
168
172
176
180
184
188
192
196
200
204
206
212

Fig. 82