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## Evaluation of $^{235}U$, $^{238}U$, $^{6}Li$, and $^{27}Al$ Cross Sections

### Introduction and Summary

Good nuclear data are essential for accurate prediction of reactor parameters.  Several cross section libraries are currently available for use with GLASS physics calculations.  In recent Mark 15 and Mark 22 studies, cross section data were developed to provide more accurate buckling calculations for Mark 15 and Mark 22 charges.[1,2,3]  This report documents evaluation of these new data for universal application.  All new data described in this report are in the JOSHUA.STD dataset.  The names for these new cross section data in JOSHUA.STD are U235E4/5, U238MOD, LI6E4, and AL27E4.

Use of the new data is recommended for all GLASS calculations involving SR lattices.  GLASS results using the various sets of cross section data in JOSHUA.STD were evaluated against experimental data for Mark 22, Mark 15, Mark 16-30A, Mark 14-30A, Mark VR, and Mark VE lattices.  Use of the new data consistently gives better results for material buckling than use of any of the older data.  Use of the new data provides material buckling results which agree with experimental buckling results.  In most of the cases studied use of the new data gives results equal to older data results for the quantities $\rho^{28}$, C*, $\delta^{25}$, and $\delta^{28}$.

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*This copy contains microfiche for all GLASS calculations supporting DPST-85-288.

## Discussion

### Data Development

Most SRL cross section data is from the HAMMER code data library or from ENDF/B-III (Evaluated Nuclear Data Files B-Version III). HAMMER was the 1960's predecessor of the GLASS code and had cross sections for nuclides used in SR calculations. ENDF data is a set of data that is evaluated and maintained by the Cross Section Evaluation Working Group (CSEWG), a group of experts representing national laboratories and other interested organizations. Three versions of ENDF data are of use to SRL: ENDF/B-III of 1972; ENDF/B-IV of 1975; and ENDF/B-V of 1979. (Currently SRL processing codes are not compatible with ENDF/B-V formats.) Recent studies of Mark 15 and Mark 22 reactivity calculations led to generation of new SRL cross section data from ENDF data for $^{235}U$, $^{238}U$, $^{6}Li$, and and$^{27}Al$.[1,2] A summary of these developments follows.

Three cross section libraries for $^{235}U$ currently exist in the JOSHUA.STD.MULTIGRP dataset versions STANDARD and STD37. The libraries have the names U235, U235OLD, and U235E4/5. The origin of the U235OLD library is not well known. It is from the HAMMER code library in the mid-1960's but its experimental basis is unknown. The U235 library was developed in 1972 from ENDF/B-III data.[4] The only significant change made to the ENDF/B-III $^{235}U$ data at that time was 5% reduction in capture and fission cross sections over the energy range 0.101 - 25 keV. The U235E4/5 library was developed recently in an attempt to improve Mark 22 reactivity calculations.[2] The U235E4/5 data consists of pure ENDF/B-IV cross sections and modified ENDF/B-IV $\nu$ data. ENDF data for $^{235}U$ were modified between version IV and version V but the major impact of these modifications on SR lattice calculations is an increase in $\eta$

(where $\eta = \dfrac{\nu \sigma_f}{\sigma_f + \sigma_c}$ = number of neutrons emitted per neutron absorbed).

The $\nu$ modification was derived so thermal $\eta$ of U235E4/5 is equal to thermal $\eta$ of ENDF/B-V. MULTIGRP data for $^{235}U$ are illustrated in Figures 1-4.

Three cross section libraries for $^{238}U$ exist in the JOSHUA.STD.MULTIGRP dataset versions STANDARD and STD37. The libraries have the names U238, U238OLD, and U238MOD. The U238OLD library is from the HAMMER code library, just as U235OLD. The U238 library was developed in 1972 with the U235 library.[4] Several cross sections from ENDF/B-III were reduced when the U238 library was generated. A detailed accounting of the changes is given in Reference 4. The most recent $^{238}U$ library is U238MOD. This library is identical to the U238 library except the 6.65 eV resonance capture width is adjusted from 23.0 meV to 21.0 meV. This adjustment

yields agreement between measured and calculated Mark 15 buckling (see Table V).[1]  MULTIGRP data for $^{238}$U are illustrated in Figures 5-7.

Two cross section libraries for $^{27}$Al exist in the JOSHUA.STD.MULTIGRP dataset versions STANDARD and STD37.  The libraries have the names AL and AL27E4.  The AL library is from the HAMMER code library.  The AL27E4 library is pure ENDF/B-IV data.  The major difference between the AL27E4 and AL cross sections is that AL27E4 has a smaller epithermal neutron absorption cross section. MULTIGRP data for $^{27}$Al are illustrated in Figures 8 and 9.

Four cross section libraries exist for $^{6}$Li having the names LI6, LI6X, LI6E4, and LI6XE4.  However, the LI6 and LI6X libraries are identical, as are the LI6E4 and LI6XE4 libraries.  This allows inner and outer Mark 22 target contents to be distinguished in GLASS depletion edits.  The LI6 and LI6X libraries are from the HAMMER code library whereas LI6E4 and LI6XE4 are ENDF/B-IV data.  There is no major difference between the data, but the advantage of using ENDF data is knowing the experimental basis for the data.  MULTIGRP data for $^{6}$Li are illustrated in Figures 10 and 11.

## Lattice Measurements

Physics parameters were measured for several lattices in the Process Development Pile (PDP) and Subcritical Experiment (SE) facility in the 1960's and 1970's.  Results from Mark VE, Mark 14-30A, Mark 16-30A, Mark 15, and Mark 22 measurements are listed in Tables I-V.  Results for Mark VR are listed in Appendix A.  Details of the lattice contents and geometries along with results are given in References 1 and 4-11.

Evaluation of data was based on comparison of GLASS calculations of lattice integral parameters with results of SE and PDP experiments.  Integral parameters used in the comparison include the lattice material buckling and the quantities $\rho^{28}$, $C^*$, $\delta^{25}$ and $\delta^{28}$.  The quantities $\rho^{28}$, $C^*$, $\delta^{25}$, and $\delta^{28}$ represent neutron activation ratios in $^{235}$U and $^{238}$U, and are defined below:

$$\rho^{28} = \frac{\text{Epithermal }^{238}\text{U captures}}{\text{Thermal }^{238}\text{U captures}}$$

$$C^* = \frac{\text{Total }^{238}\text{U captures}}{\text{Total }^{235}\text{U fissions}}$$

$$\delta^{25} = \frac{\text{Epithermal } ^{235}\text{U fissions}}{\text{Thermal } ^{235}\text{U fissions}}$$

$$\delta^{28} = \frac{\text{Total } ^{238}\text{U fissions}}{\text{Total } ^{235}\text{U fissions}}$$

Measurements of C* were made indirectly as a ratio of C* in the lattice of interest to C* in a reference position having a well-thermalized spectrum. This ratio was then multiplied by an approximate expression for the $^{238}\text{U}/^{235}\text{U}$ activity ratio in the thermal reference position.

$$C^*_{\text{reported}} = \frac{N_{238} \, (g\sigma_a)_{238}}{N_{235} \, (g\sigma_f)_{235}} \quad X \quad \frac{C^*_{\text{lattice}}}{C^*_{\text{thermal reference}}}$$

Here $(g\sigma_a)_{238}$ and $(g\sigma_f)_{235}$ are effective (average) thermal cross sections based on the product of Wescott g factors and 2200 m/sec cross sections from SRL libraries. Thus experimental values reported for C* depend on $^{235}\text{U}$ and $^{238}\text{U}$ cross section data. In order to account for changes in $(g\sigma_a)_{238}$ and $(g\sigma_f)_{235}$ due to evaluation of new differential data for $^{238}\text{U}$ and $^{235}\text{U}$, experimental values of C* were corrected as shown below:

$$C^*_{\text{corrected}} = C^*_{\text{reported}} \frac{(\bar{\sigma}_a \, ^{238}/\bar{\sigma}_f \, ^{235}) \text{ new evaluation}}{(\bar{\sigma}_a \, ^{238}/\bar{\sigma}_f \, ^{235}) \text{ old evaluation}}$$

where $\bar{\sigma}_a ^{238}$ is the average thermal absorption cross section for $^{238}\text{U}$ and $\bar{\sigma}_f ^{235}$ is the average thermal fission cross section for $^{235}\text{U}$. Values for $\bar{\sigma}_a ^{238}$ and $\bar{\sigma}_f ^{235}$ were determined from GLASS calculations of thermal neutron spectra in dilute solutions of natural uranium and $D_2O$. Corrected C* values for each cross section set are listed in Tables II and A-2 as "measured" data.

## Lattice Calculations

GLASS calculations for Mark VE, Mark 14-30A, Mark 16-30A, Mark 15, and Mark 22 lattices were made using fuel and target contents listed in Table VI. The contents for Mark VE, Mark 30A, and Mark 15 assemblies are the same as listed in References 1, 7 and 11. Contents of Mark 14, Mark 16, and Mark 22 assemblies were modified to account for NTG errors.[7,10] Details of the Mark 14 and Mark 16 modifications are given in Reference 12. It was assumed that the Mark 16B low-k NTG recalibration results apply to Mark 14 and Mark 16 assemblies since they also have 3 fuel tubes and probably had similar NTG standards problems. However, the Mark 14 and Mark 16 fuel modifications only affect material buckling results and change them by only $10\mu$B. Details of the Mark 22 modifications, which have significant effect, are given in Reference 2.

GLASS buckling calculations for Mark 22, Mark 15, Mark 16-30A, Mark 14-30A, and Mark VE included representation of the stacked slug columns as axially homogeneous arrays of concentric cylinders. This homogenization included the following:

- o Aluminum end caps and uranium metal homogenized over the total length of the slug.

- o Nickel coating, present on Mark 15 and Mark VE, homogenized with the aluminum cladding.

For purposes of comparison with foil activation experiments, GLASS activation calculations ignored the presence of end caps. Instead, slugs were treated as homogeneous columns of uranium metal at density 18.9 gm/cc.

## Results

Overall results are better when the new cross sections are used. Comparisons using results from current calculations are presented in Tables I-V. Use of the new cross section data provides very good agreement between calculated and measured buckling. Calculated buckling improvements are 20-30 $\mu$B except for the Mark 22 lattice where the improvement is about 90 $\mu$B. Results for $\rho^{28}$, C*, $\delta^{25}$, and $\delta^{28}$ are generally about the same when the new data are used in place of older standard data.

Comparisons between calculations using RAHAB (the predecessor to GLASS) and measured data are described in Reference 4 for older SRL cross section data and Mark VE, Mark 14-30A, and Mark 16-30A lattices. Current GLASS calculations using what is believed to be the same data do not agree with results presented in Reference 4 (see Tables VII and VIII). Notes[13] of D. A. Sharp made in 1973 list several corrections (Tables IX and X) to the buckling results

presented in Reference 4 for Mark 14-30A and Mark 16-30A. These
corrections to Reference 4 yield results which closely agree with
current Mark 14-30A and Mark 16-30A results. Similar corrections
applied to Reference 4 Mark VE results would yield good agreement
with current calculations. Additionally, D. A. Sharp evaluated
integral transport (RAHAB) and Monte Carlo calculations for
experimentally measured lattices (Table XI).[13] No calculational
differences were found for uniform lattices. In mixed lattices, the
integral transport option gave a systematically low ratio of Mark
14/Mark 30A and Mark 16/Mark 30A fissions. Monte Carlo gives a
higher ratio, in good agreement with experiment, resulting in a
higher calculated buckling and better agreement with measured
buckling. Integral transport (the GLASS option used in this study)
buckling results should be corrected when comparing with measured
buckling. The correction factors are listed in Tables II and III.
It should be noted that when cell cross sections from GLASS are to
be used in GRIMHX, as JASON does, the GLASS option (Monte Carlo or
integral transport) will not have much effect.

Use of the new data is recommended for all GLASS calculations
involving SR lattices because the origins of the data are well
documented, and because the new data give good agreement with
integral measurements.

# REFERENCES

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2.  J. R. Chandler, "Mark 22 Reactivity," DPST-83-992, December 30, 1983.

3.  W. E. Graves, "Productivity of the Mark 22 Charge," DPST-86-627, August 5, 1983 (Secret).

4.  F. J. McCrosson and D. A. Sharp, "Evaluation of $^{235}U$ and $^{238}U$ Cross Sections," DPST-72-340, May 9, 1972.

5.  D. J. Pellarin, "Detailed Parameter Measurements in Uniform Lattices of Mark VR Assemblies," DPST-71-496, July 21, 1971, (Confidential).

6.  F. D. Benton, H. R. Fike, and W. B. Rogers, Jr., "Measurements With a Lattice of Slightly Enriched Uranium for the Production of $^{239}Pu$," DP-1029, July 1966 (Secret).

7.  J. R. Smotrel, "Mixed Lattice Measurements in the SE and PDP," DPST-71-517, October 13, 1971.

8.  D. J. Pellarin and N. P. Baumann, "Mark 14-Mark 30A Parameter Measurements, "Experimental Physics Division Quarterly Report, October, 1968 (Secret).

9.  J. D. Robertson, "Mark 16-30A Experiments in the PDP," DPST-69-490, August 26, 1969.

10. J. R. Smotrel, "Measured Physics Characteristics of the Mark 22 Lattice, "DP-1326, August, 1974 (Secret).

11. F. J. McCrosson, "Specifications for Uniform Lattices of Enriched Uranium Assemblies That Have Been Measured at Savannah River Laboratory," unpublished.

12. J. L. Hansen, "Low-K NTG Fuel Calibration - 1979-1981," RTR-1953, February 23, 1981.

13. D. A. Sharp, personal notes.

TABLE I

MARK VE MATERIAL BUCKLING

| Cross Section Set | FZ-0 $Bm^2$ | BZ $Bm^2$ |
|---|---|---|
| Original SRL Standard[1] | 730 $\mu$B | 614 $\mu$B |
| 1972 SRL Evaluation[2] | 792 | 688 |
| Current SRL Standard[3] | 848 | 752 |
| Proposed SRL Standard[4] | 866 | 772 |
| Experiment | 883 | 800 $\pm$10 |

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1   U235OLD, U238OLD, LI6, AL

2   U235, U238, LI6, AL

3   U235OLD, U238, LI6, AL

4   U235E4/5, U238MOD, LI6E4, AL27E4

TABLE II

LATTICE BUCKLING AND MARK 30A ACTIVATION PARAMETERS
IN MARK 14-30A LATTICES

| | | CALCULATIONS WITH VARIOUS DATA VERSIONS | | | |
|---|---|---|---|---|---|
| Parameter | Experiment | Original[1] SRL Standard | 1972 SRL[2] Evaluation | Current[3] SRL Standard | Proposed[4] SRL Standard |
| FZ-0 $B_m^2$ | 585 $\mu$B | 431 $\mu$B | 459 $\mu$B | 493 $\mu$B | 519 $\mu$B |
| Corrected[5] $B_m^2$ | | 495 $\mu$B | 523 $\mu$B | 557 $\mu$B | 583 $\mu$B |
| $\rho^{28}$ | 0.626 | 0.613 | 0.595 | 0.598 | 0.596 |
| C* measured | | 5.12 | 5.04 | 5.03 | 5.00 |
| C* calculated | | 5.12 | 4.96 | 5.00 | 4.91 |
| $\delta^{25}$ | 0.0806 | 0.077 | 0.078 | 0.076 | 0.081 |
| $\delta^{28}$ | 0.152 | 0.143 | 0.137 | 0.142 | 0.139 |

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1  U235OLD, U238OLD, LI6, AL

2  U235, U238, LI6, AL

3  U235OLD, U238, LI6, AL

4  U235E4/5, U238MOD, LI6E4, AL27E4

5  Correction factor +64 $\mu$B was applied to correct for RAHAB-Monte
   Carlo calculation differences.

## TABLE III

### LATTICE BUCKLING AND MARK 30A ACTIVATION PARAMETERS
### IN MARK 16-30A LATTICES

| | | CALCULATIONS WITH VARIOUS DATA VERSIONS | | | |
|---|---|---|---|---|---|
| Parameter | Experiment | Original[1] SRL Standard | 1972 SRL[2] Evaluation | Current[3] SRL Standard | Proposed[4] SRL Standard |
| FZ-0 $B_m^2$ | 557 $\mu$B | 422 $\mu$B | 447 $\mu$B | 485 $\mu$B | 518 $\mu$B |
| Corrected[5] $B_m^2$ | | 457 $\mu$B | 482 $\mu$B | 520 $\mu$B | 553 $\mu$B |
| $\rho^{28}$ | 0.717 | 0.698 | 0.680 | 0.679 | 0.681 |
| C* | Not measured | | | | |
| $\delta^{25}$ | 0.079 | 0.086 | 0.088 | 0.086 | 0.091 |
| $\delta^{28}$ | 0.160 | 0.146 | 0.140 | 0.145 | 0.142 |

1  U235OLD, U238OLD, LI6, AL

2  U235, U238, LI6, AL

3  U235OLD, U238, LI6, AL

4  U235E4/5, U238MOD, LI6E4, AL27E4

5  Correction factor +35 $\mu$B was applied to correct for RAHAB-Monte
   Carlo calculation differences.

## TABLE IV

### MARK 15 MATERIAL BUCKLING

| Cross Section Set | $B_m^2$, $\mu B$ |
|---|---|
| Original SRL Standard[1] | 540 |
| 1972 SRL Evaluation[2] | 630 |
| Current SRL Standard[3] | 705 |
| Proposed SRL Standard[4] | 726 |
| Mk15 Demonstration Charge Design[5] | 729 |
| LTR Measurement | 728 |

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1  U235OLD, U238OLD, LI6, AL

2  U235, U238, LI6, AL

3  U235OLD, U238, LI6, AL

4  U235E4/5, U238MOD, LI6E4, AL27E4

5  U235OLD, U238MOD, LI6, AL

## TABLE V

### MARK 22 MATERIAL BUCKLING

| [6]Li Targets, gm/ft | | | | | |
|---|---|---|---|---|---|
| Inner | Outer | Experiment | Original[1] SRL Standard | Current[2] SRL Standard | Proposed[3,4] SRL Standard |
| 3.339 | 1.223 | 262 $\mu$B | 174 $\mu$B | 147 $\mu$B | 239 $\mu$B |
| 3.339 | 1.129 | 374 | 283 | 256 | 347 |
| 3.339 | 0.923 | 608 | 527 | 499 | 588 |
| 2.946 | 1.223 | 348 | 259 | 232 | 324 |
| 2.946 | 1.129 | 473 | 377 | 341 | 431 |
| 2.946 | 0.923 | 702 | 611 | 584 | 673 |
| 2.641 | 1.223 | 439 | 336 | 309 | 400 |
| 2.641 | 1.129 | 550 | 443 | 416 | 506 |
| 2.641 | 0.923 | 796 | 687 | 660 | 749 |

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1  U235OLD, U238OLD, LI6, AL

2  U235, U238, LI6, AL

3  U235E4/5, U238MOD, LI6E4, AL27E4

4  These results differ slightly from results listed in Reference 2
   due to an error in control rod coolant temperature and purity in
   Reference 2 calculations.

## TABLE VI

### ASSEMBLY CONTENTS, GM/FT

| ASSEMBLY | $^{234}U$ | $^{235}U$ | $^{236}U$ | $^{238}U$ | $^{6}LI$ |
|---|---|---|---|---|---|
| Mark VE | 0.959 | 136.7 | 1.013 | 14330 | - |
| Mark 14[1](PDP) | 2.566 | 135.0 | 35.11 | 20.20 | - |
| Mark 14[1](SE) | 2.943 | 136.2 | 35.86 | 19.00 | - |
| Mark 16[1](PDP) | 6.006 | 240.7 | 178.2 | 71.48 | 0.263 |
| Mark 16[1](SE) | 7.975 | 234.6 | 175.0 | 71.92 | 0.320 |
| Mark 30A(PDP) | - | 36.60 | - | 25567 | - |
| Mark 30A(SE) | - | 38.04 | - | 26748 | - |
| Mark 15 | - | 190.9 | 4.011 | 17157 | - |
| Mark 22[1] | 3.567 | 243.3 | 30.81 | 26.19 | Varies[2] |

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1  Contents listed in References 7-10 were modified to account for NTG errors

2  See Table V

## TABLE VII

### COMPARISON OF ACTIVATION PARAMETER CALCULATIONS
### FOR MARK 30A ASSEMBLIES

#### MARK 14-30A FZO LATTICE

| Parameter | 1972 Calculation-Ref. 4 | | Current Calculation | |
|---|---|---|---|---|
| | 1972[1] Standard | 1972[2] Evaluation | 1972[1] Standard | 1972[2] Evaluation |
| $\rho 28$ | 0.606 | 0.599 | 0.613 | 0.595 |
| C* | 5.03 | 4.90 | 5.12 | 4.96 |
| $\delta^{25}$ | 0.0752 | 0.0781 | 0.077 | 0.078 |
| $\delta^{28}$ | 0.136 | 0.141 | 0.143 | 0.137 |

#### MARK 16-30A FZO LATTICE

| Parameter | 1972 Calculation-Ref. 4 | | Current Calculation | |
|---|---|---|---|---|
| | 1972[1] Standard | 1972[2] Evaluation | 1972[1] Standard | 1972[2] Evaluation |
| $\rho 28$ | 0.702 | 0.696 | 0.698 | 0.680 |
| $\delta^{25}$ | 0.0870 | 0.0909 | 0.086 | 0.088 |
| $\delta^{28}$ | 0.138 | 0.151 | 0.146 | 0.140 |

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1  U235OLD, U238OLD, LI6, AL

2  U235, U238, LI6, AL

## TABLE VIII

## COMPARISON OF $B_m^2$ CALCULATIONS

| LATTICE | CROSS SECTION DATA | CALCULATION DATE | $B_m^2$ |
|---------|--------------------|------------------|---------|
| MK14-30A FZ0 | 1972 Standard[1] | 1972 - Ref. 4 | 465 |
|  |  | 1973 - Ref. 13 | 439 |
|  |  | 1985 | 431 |
|  | 1972 Evaluation[2] | 1972 - Ref. 4 | 492 |
|  |  | 1973 - Ref. 13 | 466 |
|  |  | 1985 | 459 |
| MK16-30A FZ0 | 1972 Standard[1] | 1972 - Ref. 4 | 457 |
|  |  | 1973 - Ref. 13 | 430 |
|  |  | 1985 | 422 |
|  | 1972 Evaluation[2] | 1972 - Ref. 4 | 481 |
|  |  | 1973 - Ref. 13 | 454 |
|  |  | 1985 | 447 |
| Mark VE FZ0 | 1972 Standard[1] | 1972 - Ref. 4 | 774 |
|  |  | 1985 | 724 |
|  | 1972 Evaluation[2] | 1972 - Ref. 4 | 824 |
|  |  | 1985 | 786 |
| Mark VE BZ | 1972 Standard[1] | 1972 - Ref. 4 | 661 |
|  |  | 1985 | 614 |
|  | 1972 Evaluation[2] | 1972 - Ref. 4 | 734 |
|  |  | 1985 | 688 |

[1] U235OLD, U238OLD, LI6, AL

[2] U235, U238, LI6, AL

## TABLE IX

### CORRECTIONS TO 1972 MARK 14-30A BUCKLING CALCULATION

| | |
|---|---:|
| RAHAB Calculation (2/23/72)<br>  Used U235, U238, and<br>  TESTALIB D-$D_2O$<br>  Experimental Mark 30A | 492 $\mu$B |
| Use of STANDARD D-$D_2O$<br>  instead of TESTALIB | − 6 $\mu$B |
| Changed atomic weights<br>  to correct error | − 6 $\mu$B |
| $\epsilon^1$ | − 4 $\mu$B |
| Use of production Mark 30A | − 10 $\mu$B |
| RAHAB (2/20/73) | 466 $\mu$B |

[1]Definition of $\epsilon$ is unknown.

## TABLE X

### CORRECTIONS TO 1972 MARK 16-30A BUCKLING CALCULATION

| | |
|---|---|
| RAHAB Calculation (2/23/72)<br>  Used U235, U238, and<br>  TESTALIB D-D$_2$O<br>  Experimental Mark 30A | 481 $\mu$B |
| Use of STANDARD D-D$_2$O<br>  instead of TESTALIB | - 12 $\mu$B |
| Changed atomic weights | - 6 $\mu$B |
| Use of production Mark 30A | - 9 $\mu$B |
| | ———— |
| RAHAB (2/20/73) | 454 $\mu$B |

## TABLE XI

### COMPARISON OF INTEGRAL TRANSPORT AND MONTE CARLO MIXED LATTICE CALCULATIONS[1]

| LATTICE | CALCULATED PARAMETER | RAHAB2 | MONTE2 |
|---------|---------------------|--------|--------|
| Mark 14-30A | $B_m^2$ | 465 | $529\pm7$ |
| Mark 14-30A | $\dfrac{\text{Target Thermal Flux}}{\text{Fuel Thermal Flux}}$ | 0.874 | $0.843\pm.004$ |
| Mark 16-30A | $B_m^2$ | 447 | $483\pm7$ |
| Mark 16-30A | $\dfrac{\text{Target Thermal Flux}}{\text{Fuel Thermal Flux}}$ | 1.210 | $1.242\pm.006$ |

1. This table taken from Reference 13.

2. Measured Mark 14-30A $B_m^2 = 585\,\mu B$.

3. Measured Mark 16-30A $B_m^2 \simeq 557\,\mu B$.

# FIGURE 1
## MULTIGRP DATA
## TOTAL U235 CROSS SECTION



Resolved resonance region data
contained in NUCPARAM records

resolved
resonance
region

Legend
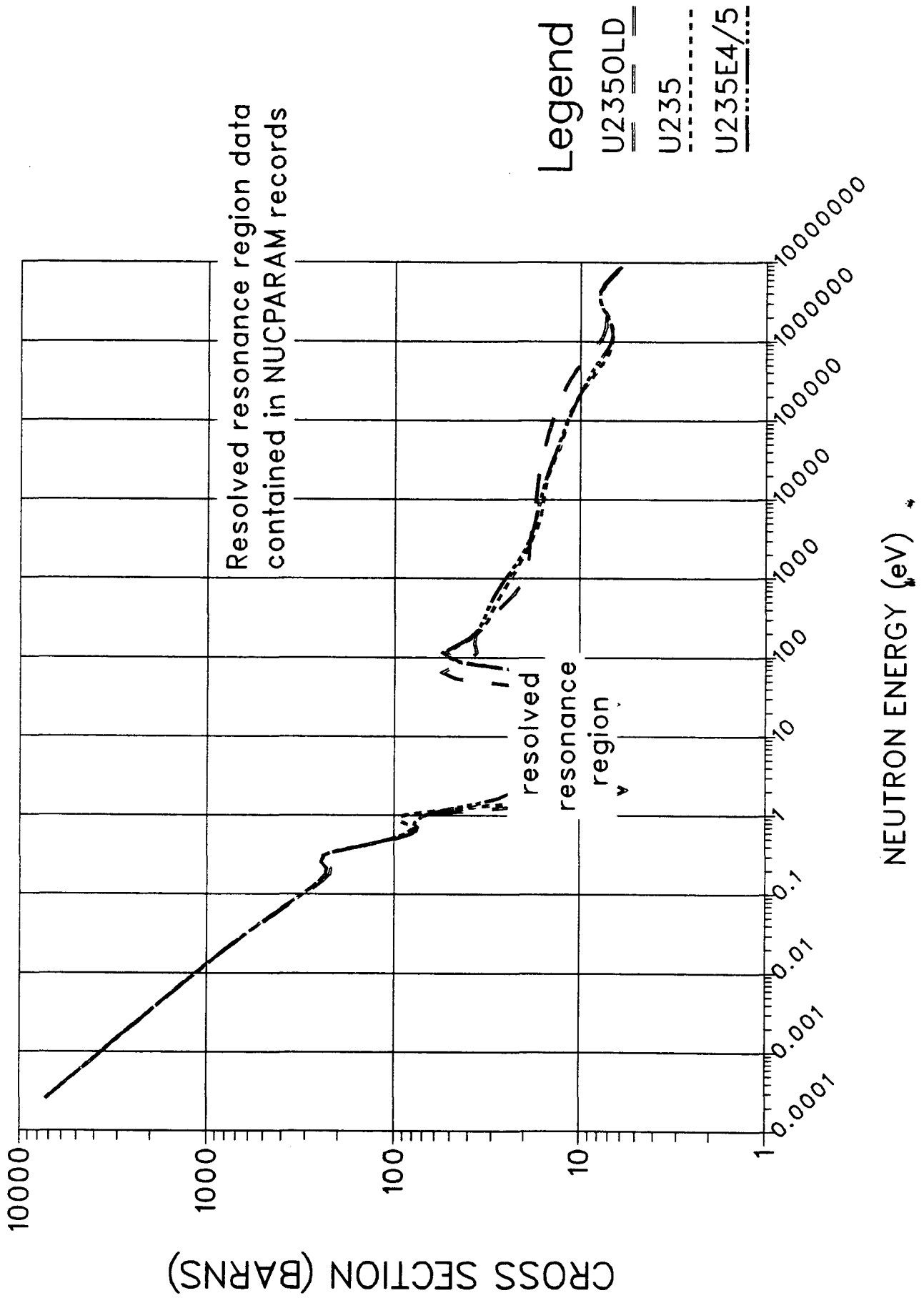U235OLD
U235
U235E4/5

NEUTRON ENERGY (eV)

CROSS SECTION (BARNS)

FIGURE 2
MULTIGRP DATA
U235 FISSION CROSS SECTION
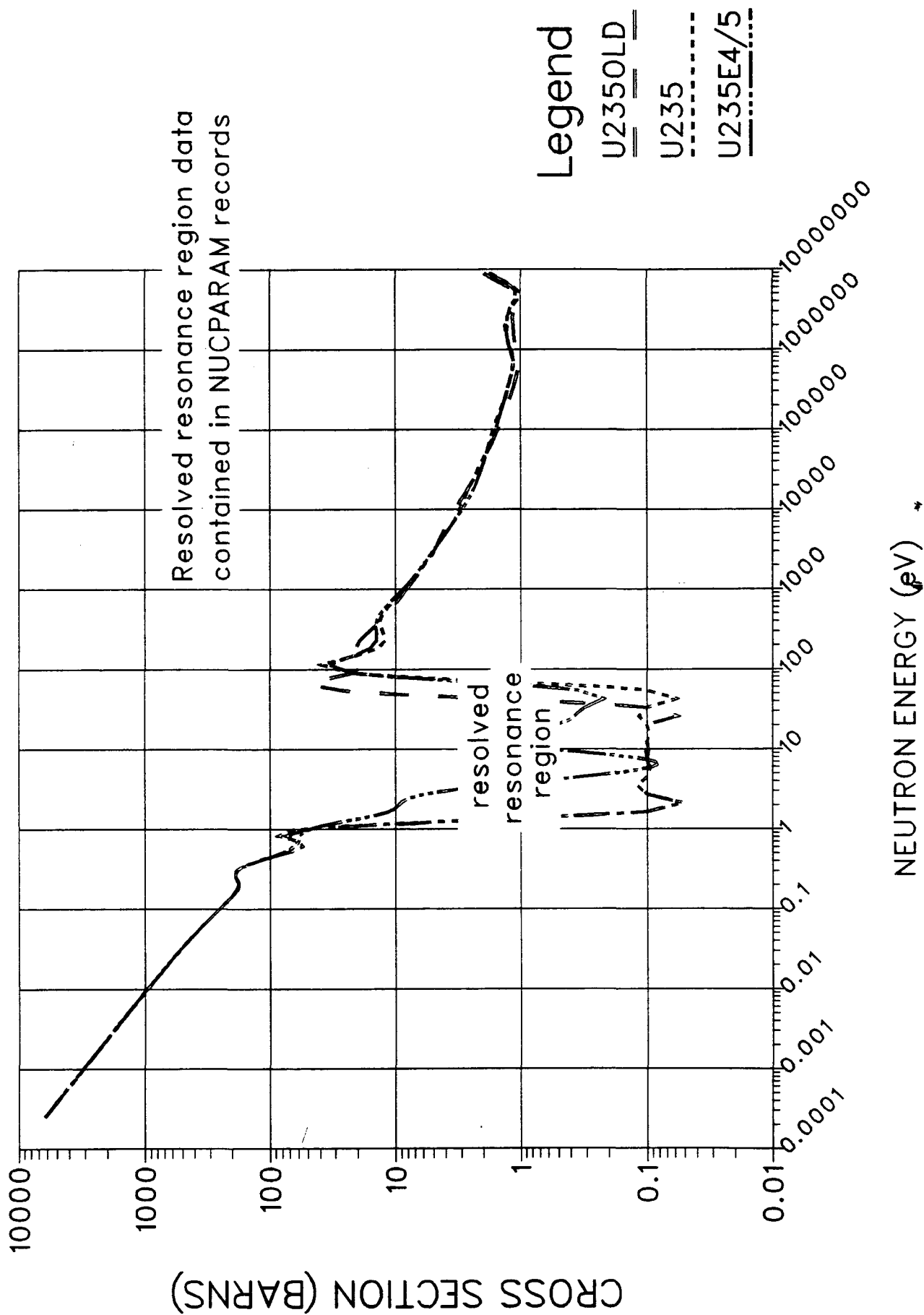
FIGURE 3
MULTIGRP DATA
U235 CAPTURE CROSS SECTION



Legend
U235OLD
U235
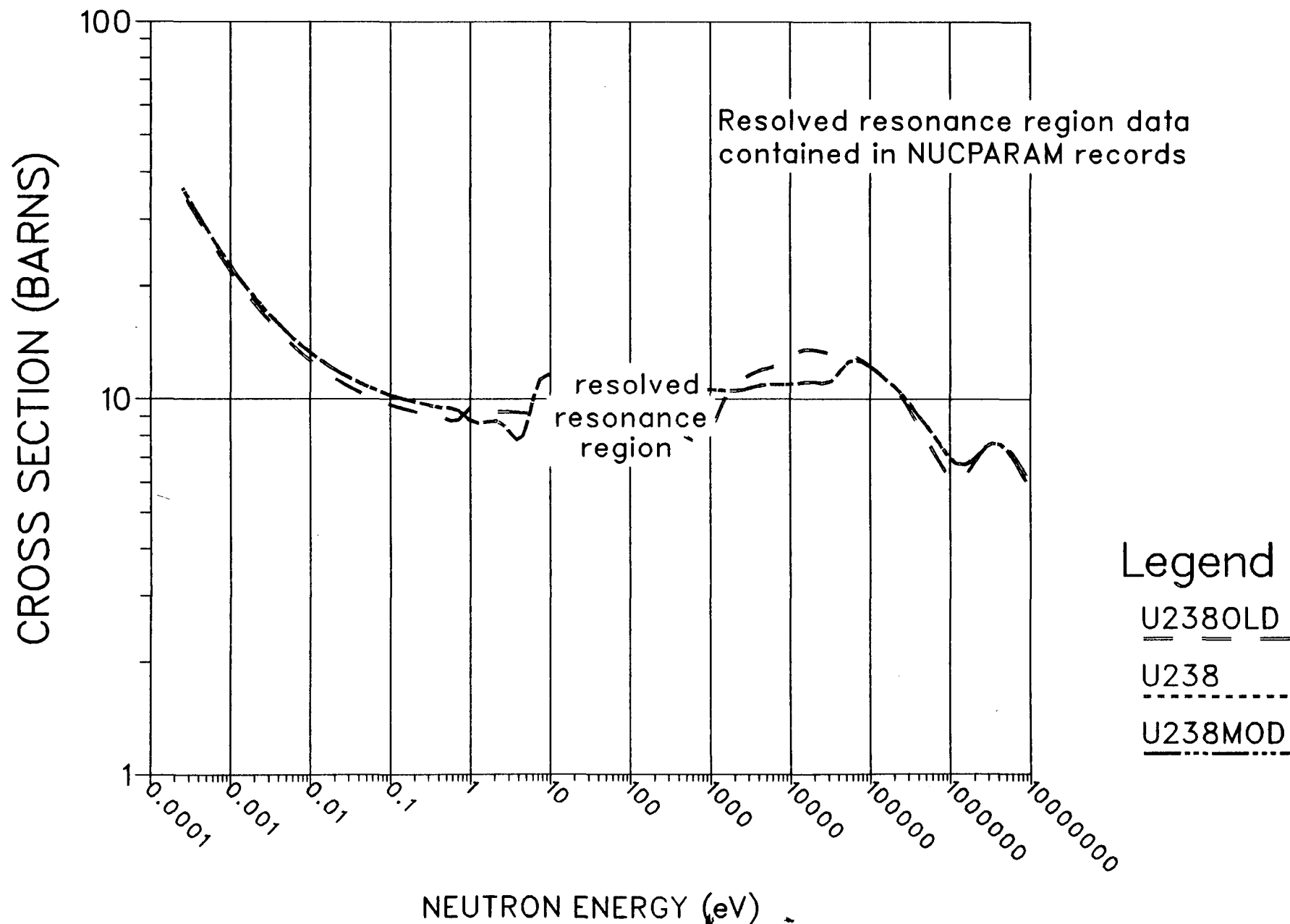U235E4/5
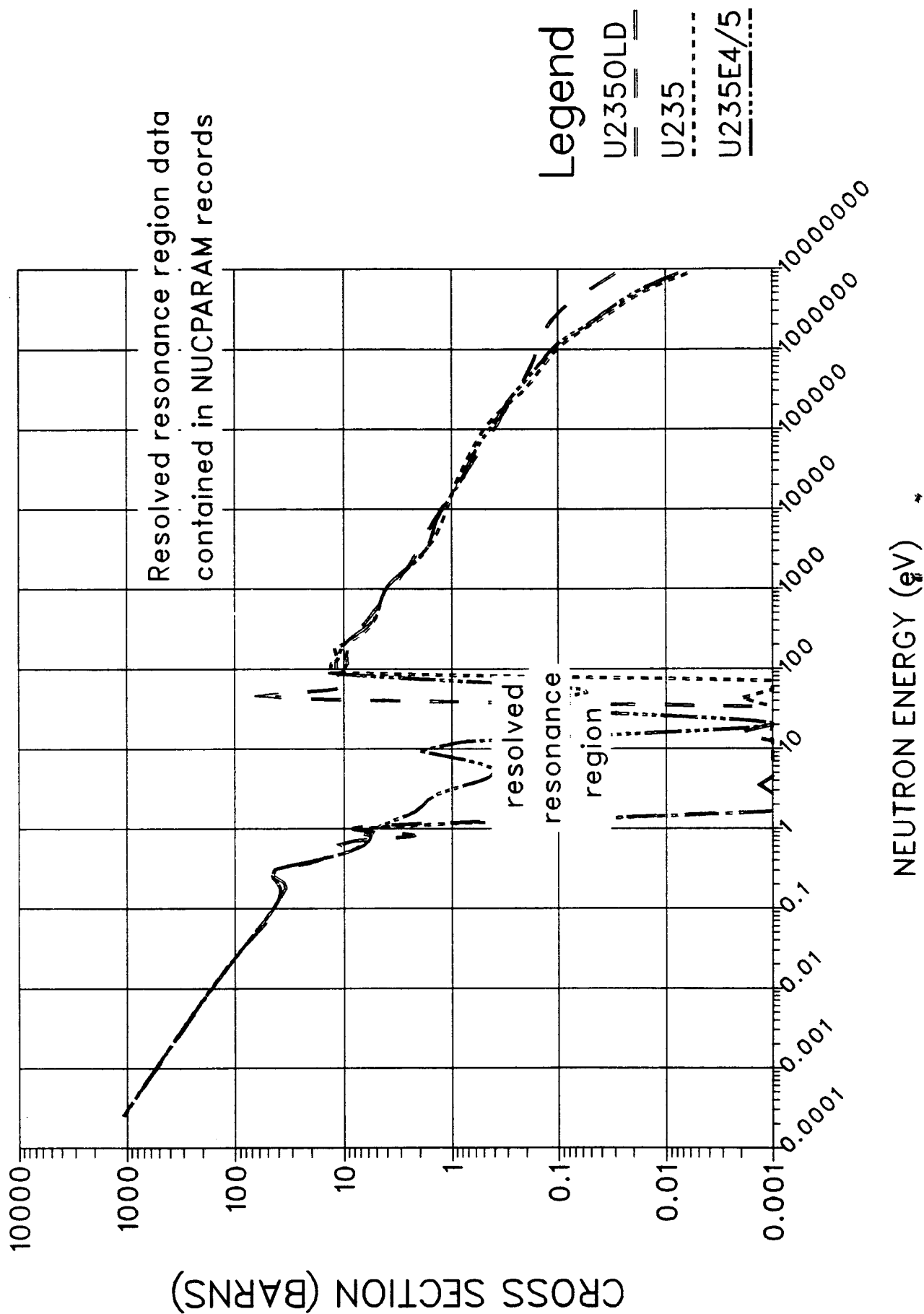
FIGURE 4
MULTIGRP DATA
U235 NU



NEUTRON ENERGY (eV)

NU

Legend
U235OLD
U235
U235E4/5

CMS LASFRGRAFIX 1200. DATE=85.037. TIME=11 09.56. RANGE=T4983. ROX=1.934
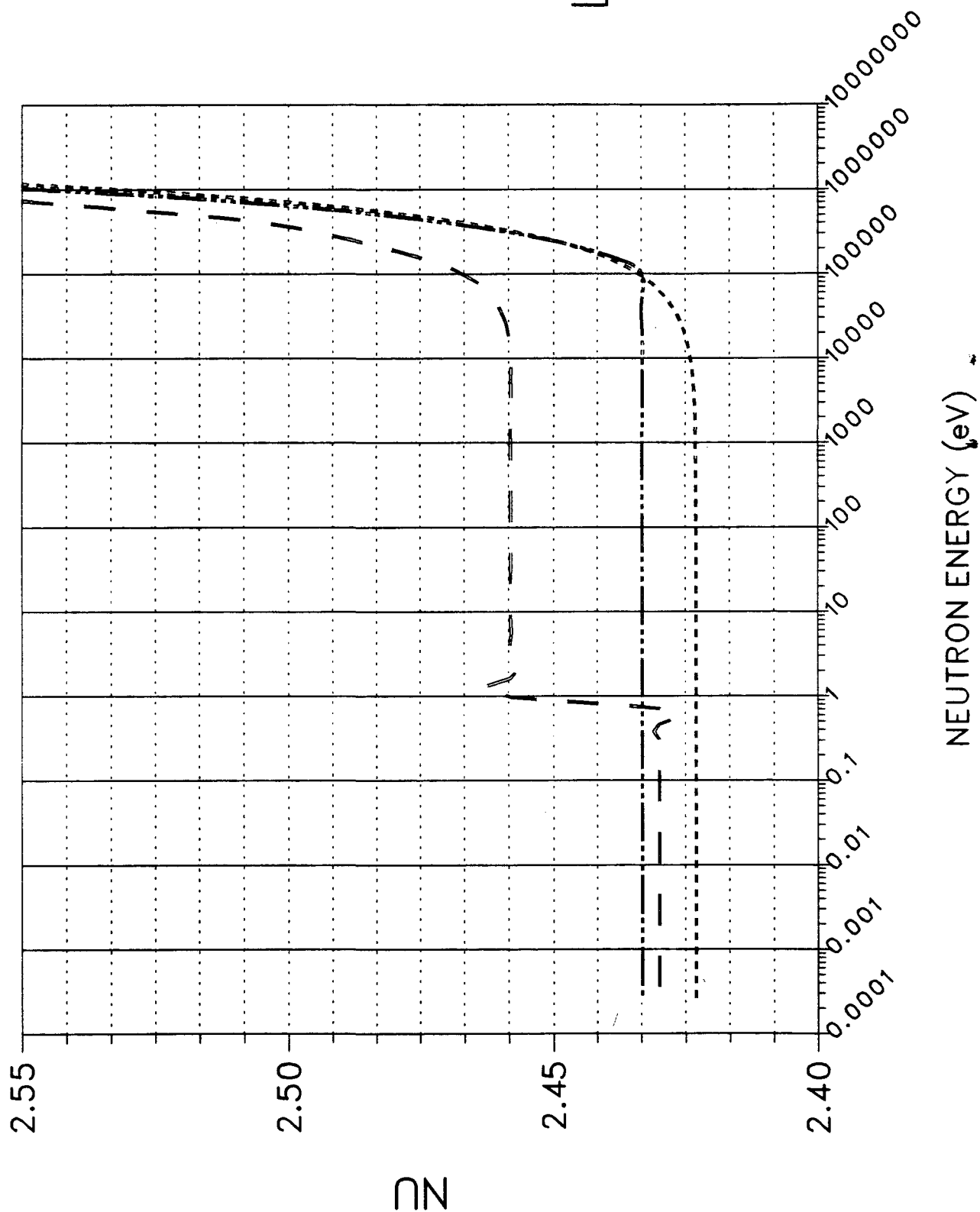
# FIGURE 5
## MULTIGRP DATA
## TOTAL U238 CROSS SECTION

# FIGURE 6
# MULTIGRP DATA
# U238 FISSION CROSS SECTION

Legend

U238OLD

U238-U238MOD
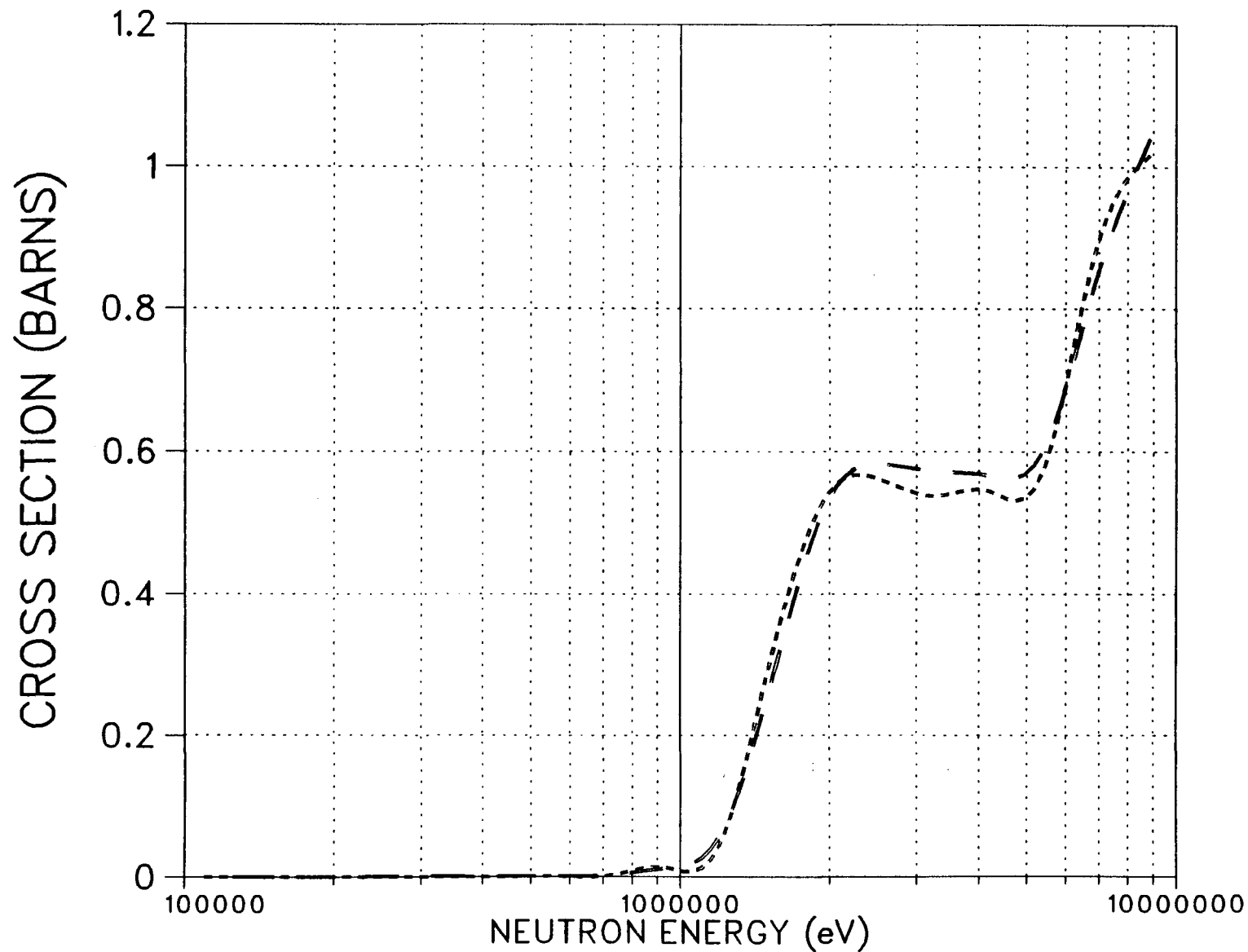
FIGURE 7
MULTIGRP DATA
U238 CAPTURE CROSS SECTION

QMS LASERGRAFIX 1200. DATE=85.037. TIME=17.03.07. BADGE=T4983. BOX=1034
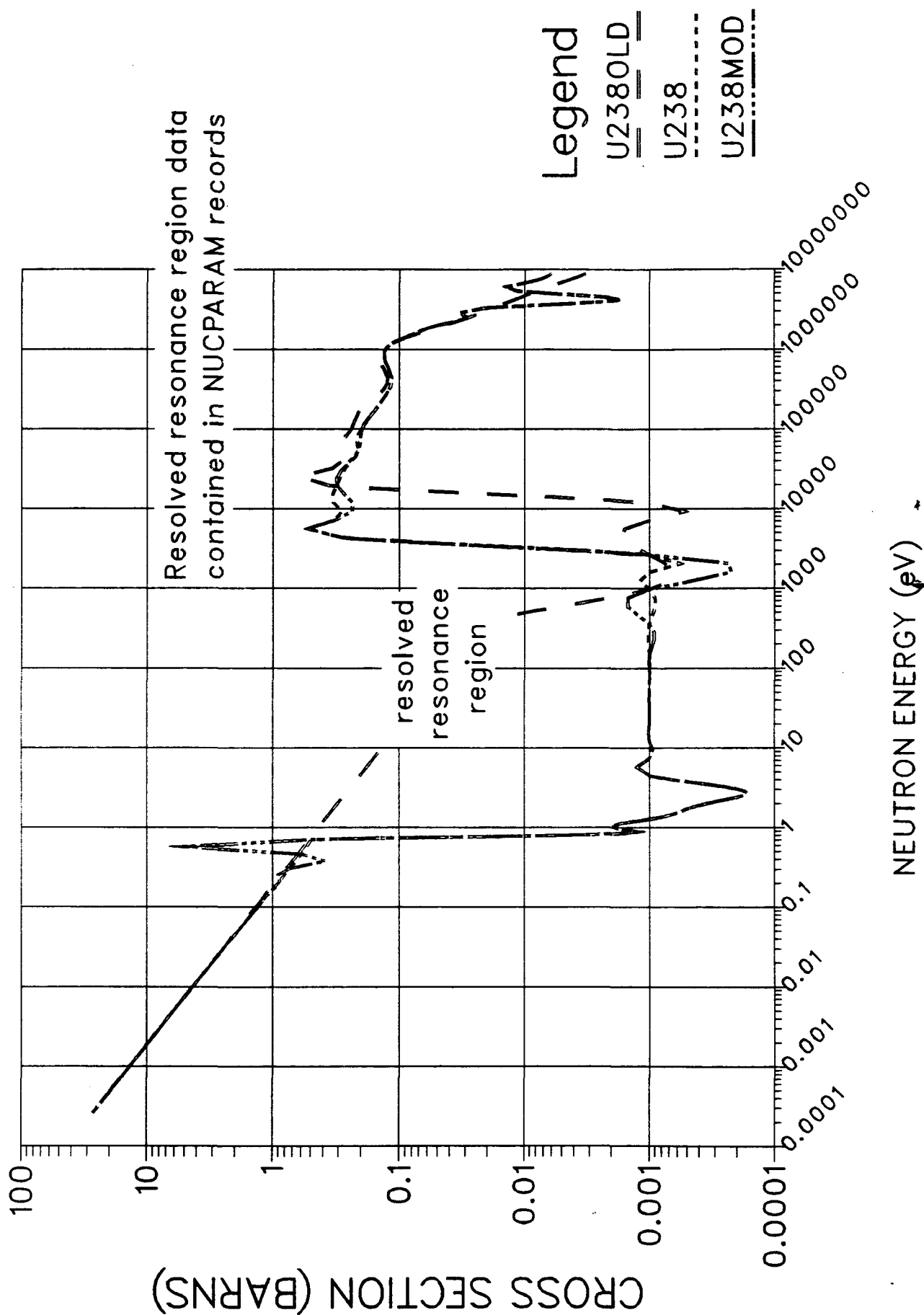
FIGURE 8
MULTIGRP DATA
TOTAL AL CROSS SECTION

CROSS SECTION (BARNS)

NEUTRON ENERGY (eV)
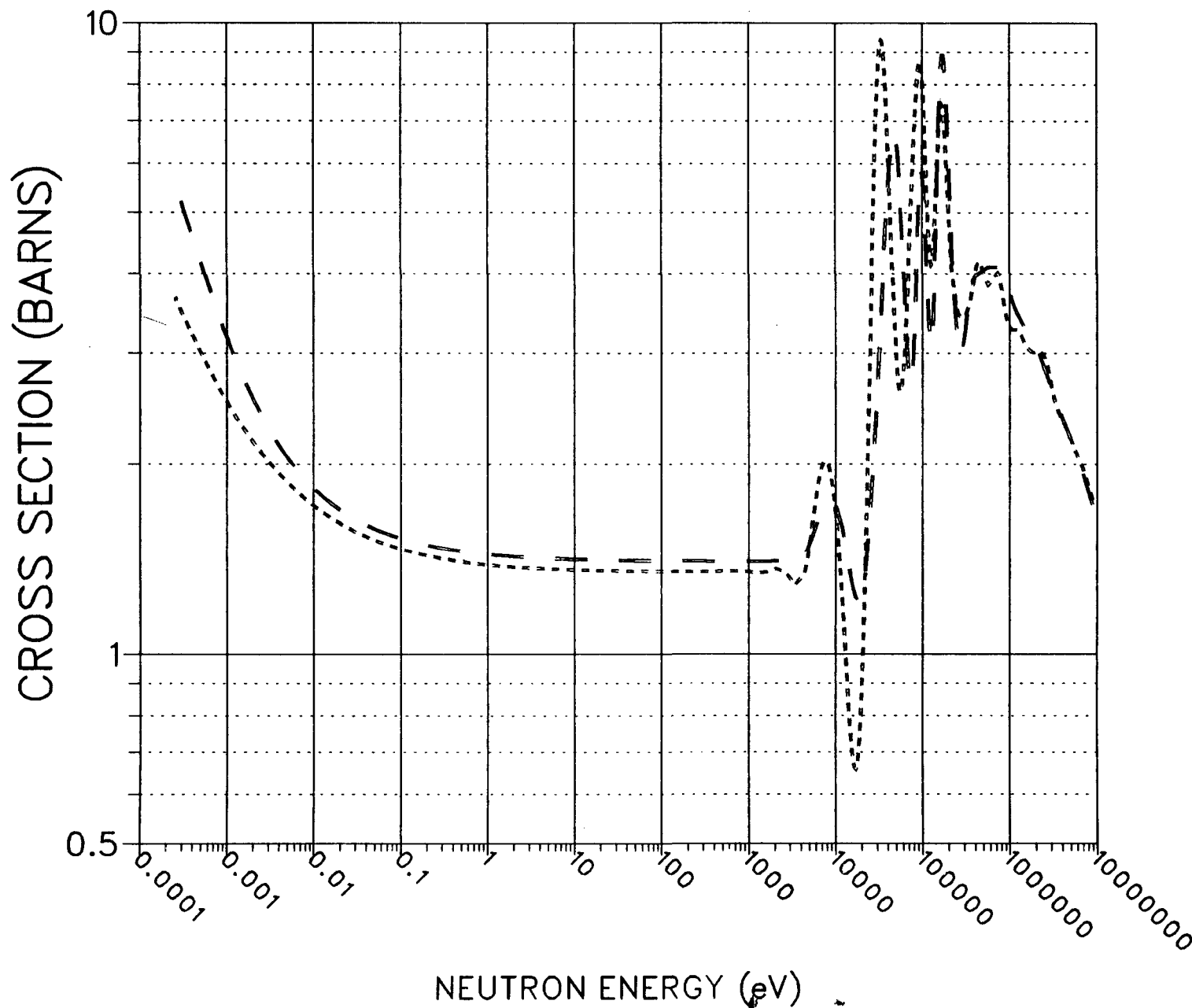
Legend

AL — —

AL27E4 ----------

FIGURE 9
MULTIGRP DATA
AL CAPTURE CROSS SECTION
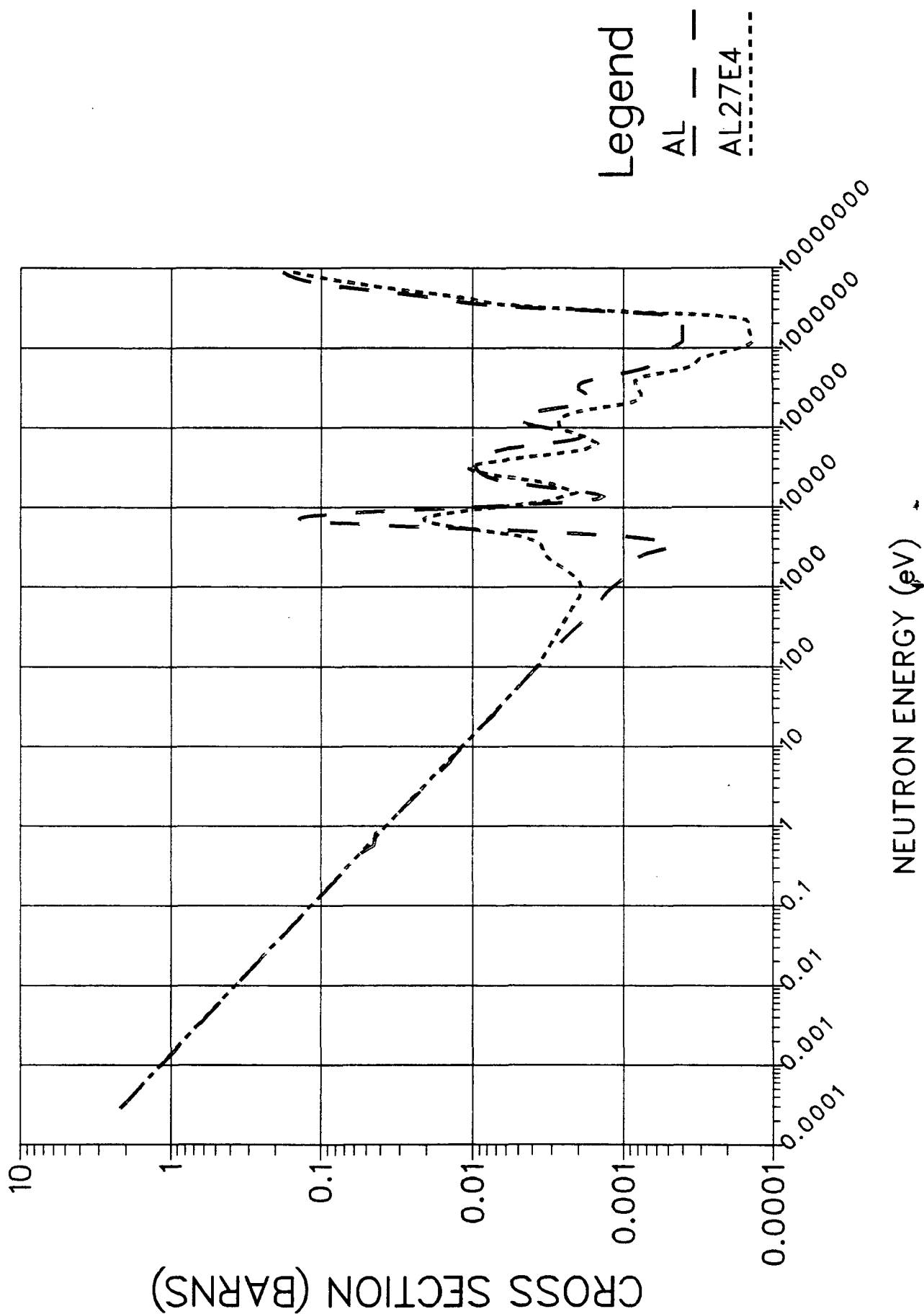
FIGURE 10
MULTIGRP DATA
TOTAL LI6 CROSS SECTION

Legend
LI6 — —
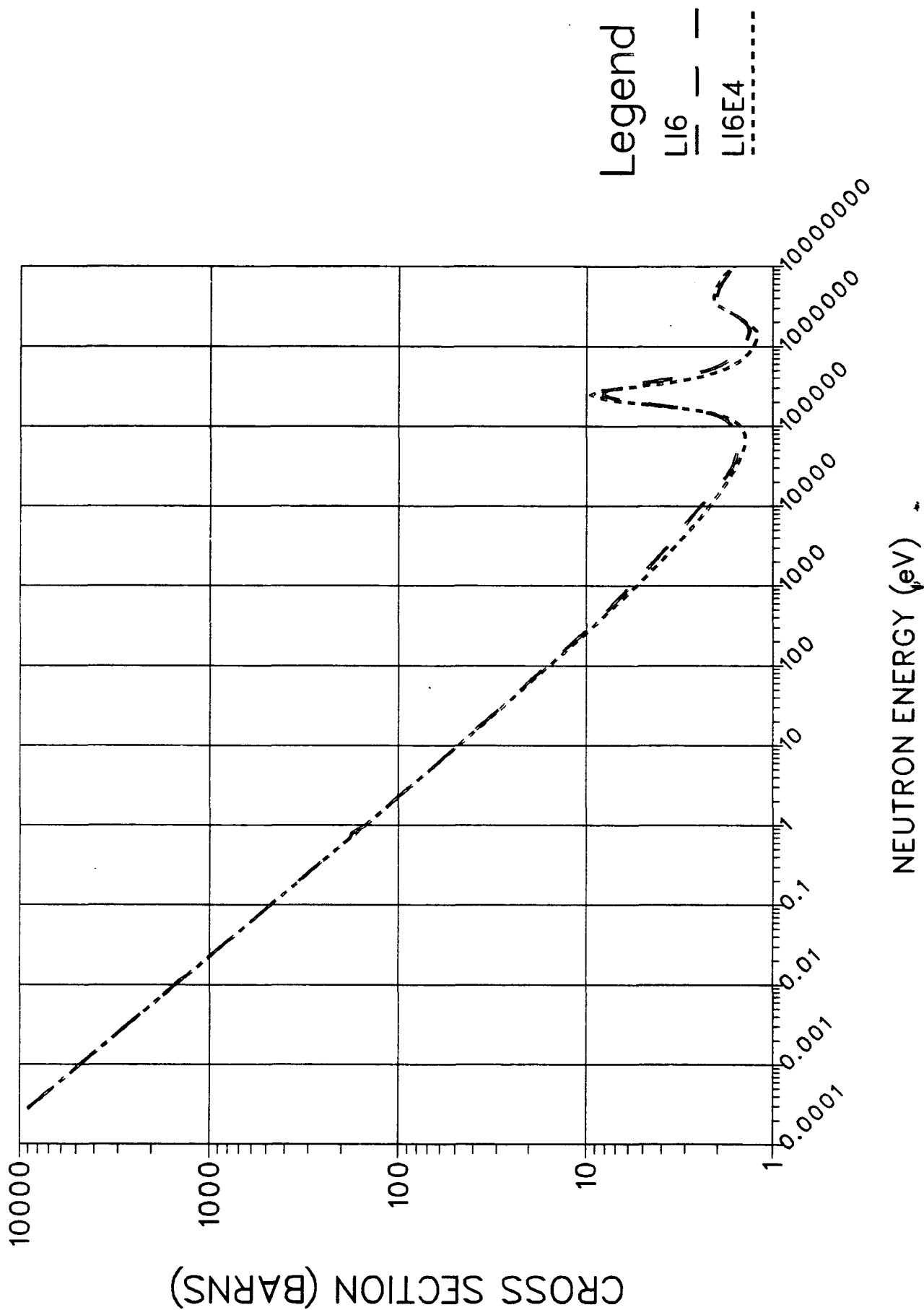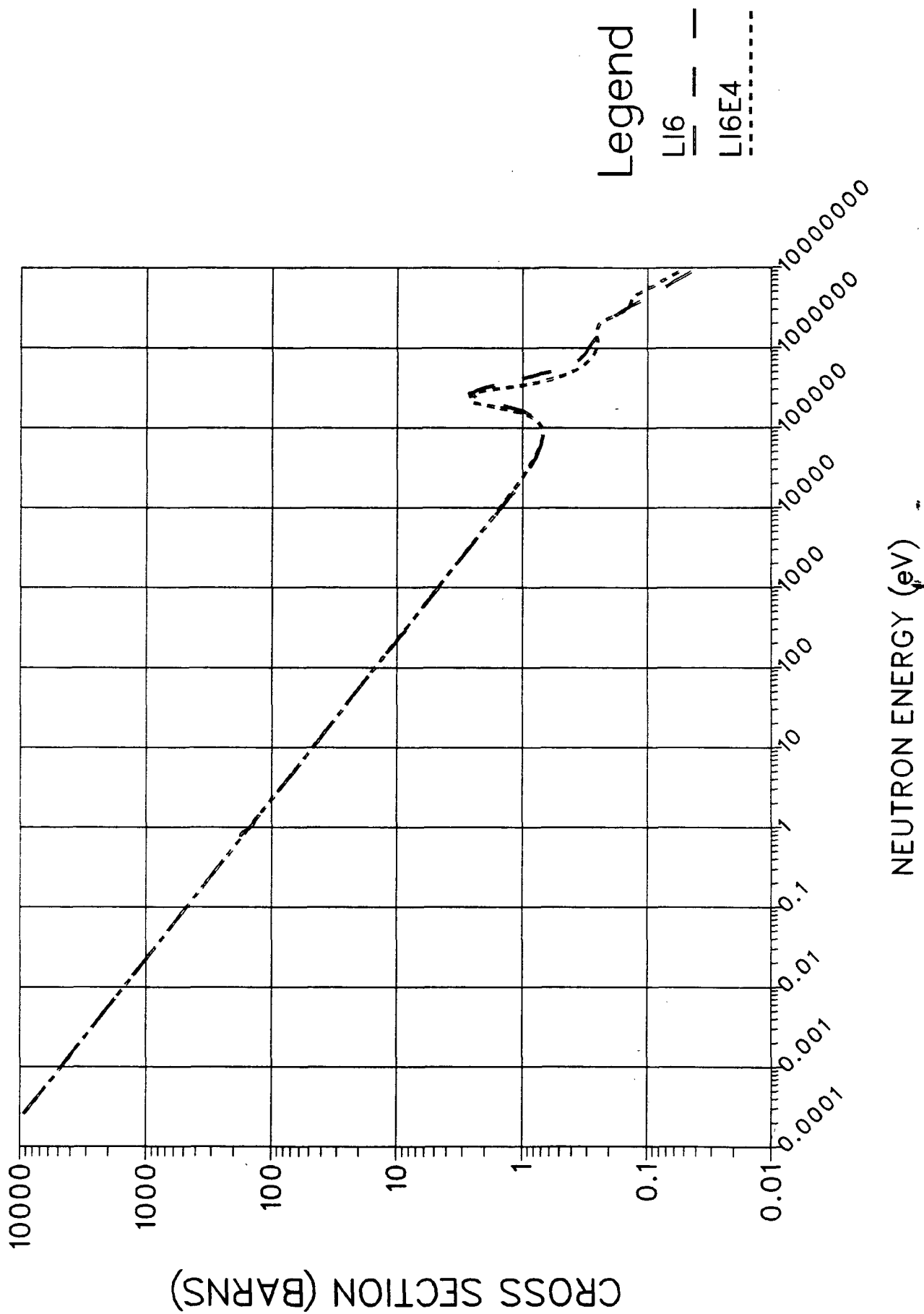LI6E4 ·······

NEUTRON ENERGY (eV)

CROSS SECTION (BARNS)

FIGURE 11
MULTIGRP DATA
LI6 CAPTURE CROSS SECTION



NEUTRON ENERGY (eV)

CROSS SECTION (BARNS)

Legend
LI6  — —
LI6E4  .......

## APPENDIX A

## MARK VR CALCULATIONS

Physics parameters were measured for the Mark VR lattice in the Subcritical Experiment (SE) facility in 1971.  Documentation for these measurements is not as complete as documentation for the other lattices considered in this study.  Buckling results from recent calculations differ significantly from measured Mark VR results and also differ from calculations reported in Reference 4.  Since input for the Reference 4 calculations is not documented, comparison with current input is not possible.  For these reasons Mark VR results were not included in the main text of this report.  However, for completeness Mark VR results are presented in this Appendix.

Mark VR assembly contents used for current calculations are listed in Table A-1.  The source for Table A-1 is Reference 11, which is unpublished.  The Mark VR assemblies used in the experiments had their end caps machined to bare uranium metal, so no end cap homogenization was performed for either buckling or activation calculations.  However, the nickel coating on the slug surface was homogenized with the aluminum cladding.  Details of Mark VR assembly geometry are contained in Reference 5 and 11.

Results of Mark VR calculations are listed in Table A-2. Comparisons between current calculations using cross section data from 1972 and calculations made in 1972 and provided in Table A-3. Mark VR results uphold the trend showing the new data provide better results, even when the calculational discrepancy is taken into account.  In fact, normalization of current results to match results from 1972 calculations yields 691 $\mu$B buckling for use of the new data.  This is in good agreement with the measured value 684 $\mu$B.

TABLE A-1

MARK VR CONTENTS[1]

| REGION NAME | ISOTOPE | CONCENTRATION ($10^{24}$ ATOMS/$cm^3$) |
|---|---|---|
| Coolant[2] | | |
| Inner Housing | Al | 6.051 ($10^{-2}$) |
| | $^{10}B$ | 3.044 ($10^{-7}$) |
| Coolant[2] | | |
| Cladding | Al | 5.969 ($10^{-2}$) |
| | $^{10}B$ | 3.253 ($10^{-7}$) |
| | Ni | 1.507 ($10^{-3}$) |
| Inner Fuel | $^{234}U$ | 3.405 ($10^{-6}$) |
| | $^{235}U$ | 4.1659($10^{-4}$) |
| | $^{236}U$ | 1.544 ($10^{-5}$) |
| | $^{238}U$ | 4.740 ($10^{-2}$) |
| Cladding | Al | 5.989 ($10^{-2}$) |
| | $^{10}B$ | 3.264 ($10^{-7}$) |
| | Ni | 1.136 ($10^{-3}$) |
| Coolant[2] | | |
| Cladding | Al | 5.970 ($10^{-2}$) |
| | $^{10}B$ | 3.254 ($10^{-7}$) |
| | Ni | 1.488 ($10^{-3}$) |
| Outer Fuel | Same as "Inner Fuel" | Same as "Inner Fuel" |
| Cladding | Al | 5.971 ($10^{-2}$) |
| | $^{10}B$ | 3.254 ($10^{-7}$) |
| | Ni | 1.456 ($10^{-3}$) |
| Moderator | D | 6.625 ($10^{-2}$) |
| | H | 2.594 ($10^{-4}$) |
| | O | 3.325 ($10^{-2}$) |

1. Taken from Reference 11.

2. Coolant isotopes and concentrations are the same as the moderator.

## TABLE A-2

### MARK VR PARAMETERS

| Parameter | Experiment | Original[1] SRL Standard | 1972 SRL[2] Evaluation | Current[3] SRL Standard | Proposed[4] SRL Standard |
|---|---|---|---|---|---|
| BZ $B_m^2$ | 684$\mu$B | 393$\mu$B | 470$\mu$B | 534$\mu$B | 553$\mu$B |
| $\rho 28$ | 1.31 | 1.32 | 1.30 | 1.29 | 1.31 |
| C* measured | | 1.14 | 1.12 | 1.12 | 1.11 |
| C* calculated | | 1.16 | 1.12 | 1.12 | 1.11 |
| $\delta^{25}$ | 0.119 | 0.128 | 0.133 | 0.128 | 0.139 |
| $\delta^{28}$ | 0.085 | 0.084 | 0.081 | 0.084 | 0.082 |

---

1  U235OLD, U238OLD, LI6, AL

2  U235, U238, LI6, AL

3  U235OLD, U238, LI6, AL

4  U235E4/5, U238MOD, LI6E4, AL27E4

TABLE A-3

COMPARISONS OF PRESENT AND PAST
MARK VR CALCULATIONS

| PARAMETER | 1972 CALCULATION-REF. 4 | | CURRENT CALCULATION | |
| | 1972[1] STANDARD | 1972[2] EVALUATION | 1972[1] STANDARD | 1972[2] EVALUATION |
| --- | --- | --- | --- | --- |
| $B_m^2$ | $532\mu B$ | $608\mu B$ | $393\mu B$ | $470\mu B$ |
| $\rho 28$ | 1.27 | 1.28 | 1.32 | 1.30 |
| C* | 1.14 | 1.12 | 1.16 | 1.12 |
| $\delta^{25}$ | 0.124 | 0.132 | 0.128 | 0.133 |
| $\delta^{28}$ | 0.0840 | 0.0840 | 0.084 | 0.081 |

1  U235OLD, U238OLD, LI6, AL

2  U235, U238, LI6, AL