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EVALUATION OF Cm-247 NEUTRON CROSS-SECTIONS FROM 10^{-5} eV TO 15 MeV

G.Maino, E.Menapace, M.Vaccari, A.Ventura

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RIASSUNTO

Dopo una breve rassegna dei dati sperimentali più importanti, è descritta una valutazione delle sezioni d'urto neutroniche dell'isotopo Cm-247 nell'intervallo energetico 10^{-5} eV - 15 MeV.

ABSTRACT

After a short review of the most important experimental data, Cm-247 neutron cross section evaluation in the energy range 10^{-5} eV - 15 MeV is described.

CONTENTS

EVALUATION OF ^{247}Cm NEUTRON CROSS SECTIONS FROM 10^{-5} eV TO 15 MeV

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1. INTRODUCTION

The neutron cross sections of heavier Curium isotopes are important in power reactor fuel cycle problems and in the production chain of ^{252}Cf.

The present work describes an evaluation of ^{247}Cm neutron cross sections in the energy range 10^{-5} eV - 15 MeV and completes a previous study limited to the resonance region /1/.

2. GENERAL INFORMATION

Measurements of ^{247}Cm neutron data have not been found in scientific literature published after ref. /1/. Thus, our main sources of experimental information are still the following:

a) Measurements analyzed by Moore and Keyworth /2/: fission and capture cross sections of five Cm isotopes were determined in the energy range 20 eV - 3 MeV. As for ^{247}Cm, 29 resonances were identified in the interval 20 - 61 eV and multilevel two-fission-channel Reich-Moore parameters were assigned with the assumption Γ_γ = 40 meV.

b) Transmission measurements by Belanova et al. /3/; 5 resonances were identified in the interval 1-18 eV and single-level Breit-Wigner parameters, Γ_{tot} and Γ_n, were assigned. Assuming the same value, Γ_γ = 40 meV, as in ref. /2/, it is possible to estimate the corresponding fission widths, Γ_f.

Thermal cross sections and resonance integrals were measured by a number of authors: the values of σ_{nf} (2200 m/sec) given in refs. /3/, /4/, /5/, /6/, agree with one another within (large) experimental errors and range from 80 to 93 b, while a lower value, σ_{nf} = 72.3 b, is given in ref. /7/. Fewer measurements exist for $\sigma_{n\gamma}$ (2200 m/sec): refs. /3/,

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(°) ENEA, TIB/FICS, Bologna (Italy).

/4/, /7/ give values between 50 and 60 b, with large errors.

As for resonance integrals, the capture one seems to have a well-defined value of the order of 500 b, according to refs. /3/, /4/, /7/. The fission resonance integral (/3/, /4/, /5/, /6/, /7/, /8/, /9/) has more scattered values, ranging from 730 b to 1060 b, with large experimental errors.

Finally, the average number, $\bar{\nu}$, of neutrons emitted per fission at thermal energies has been taken from ref. /10/.

3. RESOLVED RESONANCE REGION

The limits of the resolved resonance region are 1 eV - 61 eV.

In this interval, 34 resonances have been considered: 5 of them, between 1 eV and 20 eV, are taken from ref. /3/, the remaining 29 resonances, between 20 and 61 eV, are from ref. /2/.

In Table I, the resonance parameters are written according to the ENDF/B formalisms. As in ref. /1/, a bound level has been added to reproduce the thermal cross sections. Since this set of parameters is the same as in ref. /1/, we do not repeat here the comments already made in that work, but would only remind the reader of an important point: the resonances of ref. /2/ have multilevel two-fission-channel Reich-Moore parameters, those of ref. /3/ single-level Breit-Wigner parameters: thus, the calculations of cross sections require the use of the two formalisms to cover the range 1-61 eV, and the contributions of two separate sets must be added at each energy point: in fact, we have adopted a Reich-Moore representation for all resonances by attributing $\Gamma_{f_B} = 0$ to the resonances below 20 eV, but, in the ENDF/B file, to prevent the resonances of the first set from interfering with the second, we have assigned to the first set spins slightly different from the correct half-integer value, $J = 9/2$, as can be seen in Table I.

The total, elastic, capture and fission cross sections in the resolved resonance region are shown in Fig. 1. The calculations have been performed by means of the CRESO code /11/.

4. AVERAGE PARAMETERS FOR THE UNRESOLVED REGION

The unresolved resonance region ranges from 61 eV to 10 keV: in this interval, calculations have been performed by means of the strength function formalism. The average parameters we have adopted are listed in Table II. Since nothing has been changed with respect to ref. /1/, we refer the reader to the description therein. For the sake of completeness we only quote the average parameters deduced from the resolved resonances of Table I (with the exception of S_1):

a) average s-wave resonance spacing: $\bar{D} = 1.2$ eV;

b) s-wave strength function: $S_o = 1.0 \times 10^{-4}$;

c) p-wave strength function: $S_1 = 1.8 \times 10^{-4}$;

d) average radiative width: $\bar{\Gamma}_\gamma = 40$ meV;

e) average fission width: $\bar{\Gamma}_f = 146$ meV.

5. THERMAL CROSS SECTIONS AND RESONANCE INTEGRALS

Experimental thermal cross sections are listed in Table III, the corresponding resonance integrals in Table IV. The bound level introduced in the resolved resonance set of Table I allows us to reproduce recommended values of thermal cross sections.

The capture resonance integral, calculated with a low-energy cutoff of 0.5 eV, turns out to be $I_{n\gamma}(E_n > 0.5 \text{ eV}) = 494$ b , in agreement with a number of measurements, while the calculated fission resonance integral is $I_{nf}(E_n > 0.5 \text{ eV}) = 662$ b, lower than the most recent experimental values, which are of the order 700 b, or more. It is possible that resonances have been missed, or fission widths underestimated in the low-energy interval 1-20 eV, where their influence on the computation of resonance integrals is stronger.

6. AVERAGE NUMBER, $\bar{\nu}$, OF NEUTRONS PER FISSION

The procedure of ref. /1/ has not been modified: the estimate of $\bar{\nu}$ is obtained through an empirical formula due to Howerton /12/, normalized to the thermal value $\bar{\nu}_{th} = 3.79 \pm 0.15$ of ref. /10/. The resulting function of neutron energy, $\bar{\nu}(E_n)$, has the form:

$$\bar{\nu}(E_n) = 3.79 + 0.202\ E_n \qquad (E_n \text{ in MeV}) .$$

7. THE CONTINUUM REGION

In the energy range 10 keV - 15 MeV direct and compound nucleus contributions to different processes have been evaluated through coupled-channel optical model and statistical Hauser-Feshbach calculations, respectively.

The reactions taken into account are the following: elastic (direct plus compound contributions), total and level inelastic (direct plus compound), capture, first and second chance fission, and (n,2n). Reactions having a threshold above 10 MeV, like (n,3n) and third chance fission have been neglected. Pre-equilibrium competitions are expected to become important only above 15 MeV.

7.1. Optical Model Calculations

Coupled-channel calculations have been performed by means of the JUPITOR /13/ and ADAPE /14/ codes: the former has been used in the range 10 keV - 8 MeV, the latter from 8 to 15 MeV, where the adiabatic approximation seems to be good enough.

The states actually coupled in the non-adiabatic calculations are the $9/2^-$, $11/2^-$, $13/2^-$ members of the ground-state band.

Table V gives the parameters of our deformed optical potential, already used for ^{245}Cm /15/ and ^{246}Cm /16/.

The quadrupole and hexadecapole deformations adopted in the present work, $\beta_2 = 0.25$ and $\beta_4 = 0.0$, are of the same order as the de-

formations of close Cm isotopes adopted in refs. /15/ and /16/, and are consistent with our choice of the nuclear radius parameter in Table V.

The coupled-channel calculations give the direct contribution to elastic and inelastic scattering: we have evaluated integral and differential cross sections (angular distributions) for the elastic scattering and excitation of the first two levels in the ground-state band. The compound-nucleus contributions to these processes have been obtained through Hauser-Feshbach calculations and added to the direct contributions in order to obtain a complete description of elastic and inelastic scattering.

7.2. Statistical model calculations

The compound-nucleus contributions to the reactions of interest in the continuum region have been evaluated by means of a modified version of the HAUSER*4 code /17/.

Three competing channels, neutron, gamma and fission are taken into account: the decay of the compound nucleus ^{248}Cm in the above-mentioned channels makes it possible to evaluate the compound elastic, radiative capture and first chance fission cross sections, respectively. The decay of the compound nucleus ^{247}Cm gives (n,2n) , (n,n'γ) and (n,n'f) cross sections, respectively. The decay channels of both nuclei are described by a number of parameters: energy, spin and parity of discrete levels and, for excitation of the continuum, level density parameters, to which, as is known, calculated cross sections are very sensitive. Level densities are described by means of a back-shifted Fermi gas formula: since this kind of simple macroscopic expression cannot give a realistic description of excited nuclei, its parameters do not have a physical meaning, but only allow us to fit experimental cross sections.

Moreover, the fission channel is characterized by a two-humped fission barrier for which height and curvature of the two saddle points are specified. Our choice of barrier parameters for the compound nucleus ^{248}Cm (first chance fission) agrees within experimental errors with the results of an analysis of experimental fission probabilities of even-even Actinides /18/; the barrier parameters for the compound nu-

cleus ^{247}Cm (second chance fission) are in agreement with those derived by means of a fission probability analysis in ref. /19/. The level density parameters in the same fission channel (^{247}Cm as decaying nucleus) allowed us to reproduce the experimental cross section for the neutron-induced fission of ^{246}Cm /16/. Moreover, the level density parameters in the neutron channel describing ^{247}Cm excited states in the continuum are consistently the same as in the gamma channel of ^{246}Cm, for which ^{247}Cm represents the compound nucleus /16/.

All the parameters relevant to the description of the three decay channels for both ^{247}Cm and ^{248}Cm are given in Table VI and fol.

8. RESULTS AND COMMENTS ON CROSS SECTIONS

The results of our cross section evaluation are presented in graphical form: Fig. 2 shows the fission cross section in comparison with the experimental data, Fig. 3 all the evaluated cross sections in the energy range 10 keV – 15 MeV. Finally, Figs. 4a-b-c-d-e show the elastic, capture, fission and total cross sections over the complete evaluation range 10^{-5} eV to 15 MeV.

If we compare our results with the ENDF/B-V evaluation /20/ we see that the corresponding major cross sections are of the same order in the continuum (E_n > 10 keV) while, in the resonance region, the present results are systematically higher than ENDF/B-V. One of the reasons for the discrepancy might be the random generation, below 20 eV, of resonances with $\bar{D} \simeq 4$ eV in ENDF/B-V. This average spacing is much higher than our recommended value, $\bar{D} = 1.2$ eV ; moreover, the resonance parameters of ref. /3/, adopted in the present work below $E_n = 20$ eV , were derived from experimental data.

9. ENERGY SPECTRA OF EMITTED NEUTRONS

In describing the energy distributions of neutrons emitted in various reactions, we have made the somewhat crude hypothesis that these distributions can be represented by simple evaporative formulae, thus

neglecting the pre-equilibrium contribution, expected to become important for emitted neutrons of $E' = 10$ MeV or more.

The first chance fission spectrum has been approximated by a standard Maxwellian formula:

$$f(E,E') = \alpha\sqrt{E'}\ \exp(-E'/\theta(E)) \quad .$$

Here, E is the incident neutron energy, E' the emitted neutron energy, $\theta(E)$ the effective temperature (in energy units), which has been taken as a function of E according to the data of ref. /21/.

The energy spectra for neutrons emitted in the reactions: $(n,n'\gamma)$ with continuum excitation, $(n,2n)$, $(n,n'f)$ are represented by evaporation formulae of the kind

$$g(E,E') = \beta E'\ \exp(-E'/\theta(E)) \quad .$$

$\theta(E)$ can be interpreted in these cases as the excitation temperature of the residual nucleus after emission of an $E' \simeq 0$ neutron: it has been evaluated for the residual nuclei ^{247}Cm and ^{246}Cm through the microscopic procedure of ref. /22/. $\theta(E)$ versus E is plotted in Fig. 5 for all the reactions taken into account, from their effective threshold up to 15 MeV.

10. CONCLUSIONS

Owing to the difficulties in producing this isotope and to the low target enrichment, the ^{247}Cm neutron data are scanty and not adequate to application needs. New differential measurements, mainly in the resonance region, are necessary, and might throw light on problems encountered in the present work, e.g. the discrepancy between evaluated and experimental fission resonance integrals, thus leading to substantial improvements in the knowledge of ^{247}Cm neutron cross sections.

The evaluated data have been compiled and written in files according to the ENDF/B-IV format rules /23/, by means of the SYSMF system of codes /24/.

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TABLE I

PARAMETERS FOR THE RESOLVED RESONANCE REGION

CURIUM-247

NIS 1
ISOTOPE 1 ZAI= 96247. ABN= 1.000 LFW= 1 NER= 2

RANGE 1 EL= 0.000010 EH= 61.0 LRU= 1 LRF= 3

SPI= 4.5 AP= 0.950000 NLS= 1

L-STATE 1 AWRI= 244.9480 AM= 0.0 L= 0 NRS= 35

	ER	AJ	GN	GG	GFA	GFB
1	-6.60000E-01	4.50006E+00	1.34046E-04	4.00000E-02	5.89690E-02	0.0
2	1.24700E+00	4.50001E+00	5.60000E-04	3.60000E-02	4.10000E-02	0.0
3	2.91900E+00	4.50002E+00	1.00000E-04	4.00000E-02	5.00000E-02	0.0
4	3.18900E+00	4.50003E+00	1.00000E-03	4.00000E-02	6.20000E-02	0.0
5	9.55000E+00	4.50004E+00	9.10000E-04	4.00000E-02	1.25090E-01	0.0
6	1.81000E+01	4.50005E+00	3.70000E-03	4.00000E-02	1.66300E-01	0.0
7	2.13000E+01	4.50000E+00	1.24610E-04	4.00000E-02	9.49563E-02	-3.09044E-01
8	2.40300E+01	4.50000E+00	4.41183E-05	4.00000E-02	-1.06382E-01	-2.76184E-02
9	2.53500E+01	4.50000E+00	1.00697E-05	4.00000E-02	-1.31568E-03	-2.46843E-02
10	2.61900E+01	4.50000E+00	1.53530E-05	4.00000E-02	-8.71297E-02	-1.32870E-01
11	2.80400E+01	4.50000E+00	5.82480E-05	4.00000E-02	3.55635E-02	1.74365E-02
12	3.02500E+01	4.50000E+00	3.44850E-03	4.00000E-02	-1.94639E-05	-3.98054E-03
13	3.06200E+01	4.50000E+00	1.88140E-04	4.00000E-02	3.90000E-02	-1.30000E-02
14	3.22300E+01	4.50000E+00	5.05266E-04	4.00000E-02	-3.16673E-05	-2.59683E-02
15	3.63600E+01	4.50000E+00	1.62807E-03	4.00000E-02	3.78786E-02	-2.31214E-02
16	3.77400E+01	4.50000E+00	2.45731E-05	4.00000E-02	-4.40610E-01	-1.14390E-01
17	3.77600E+01	4.50000E+00	1.33344E-03	4.00000E-02	-1.29840E-02	-1.58337E-05
18	3.95200E+01	4.50000E+00	6.28649E-06	4.00000E-02	-6.44736E-01	-6.02643E-02
19	3.99500E+01	4.50000E+00	9.48090E-05	4.00000E-02	1.49299E-01	1.77011E-02
20	4.06100E+01	4.50000E+00	3.18629E-05	4.00000E-02	-2.31624E-02	-2.48376E-02
21	4.12500E+01	4.50000E+00	6.61529E-04	4.00000E-02	-1.33975E-03	1.86603E-02
22	4.17600E+01	4.50000E+00	5.16975E-05	4.00000E-02	5.26121E-01	-1.98788E-02
23	4.33900E+01	4.50000E+00	1.91026E-04	4.00000E-02	-8.24429E-04	3.17557E-03
24	4.48700E+01	4.50000E+00	2.09663E-03	4.00000E-02	3.08349E-02	1.16506E-03
25	4.52100E+01	4.50000E+00	5.78250E-04	4.00000E-02	-1.41024E-02	-4.58976E-02
26	4.79200E+01	4.50000E+00	1.16989E-03	4.00000E-02	1.09859E-02	-1.53014E-01
27	4.88500E+01	4.50000E+00	6.80056E-03	4.00000E-02	6.73543E-02	1.46457E-02
28	5.00800E+01	4.50000E+00	2.36362E-03	4.00000E-02	-1.99200E-02	-3.50800E-02
29	5.06900E+01	4.50000E+00	3.18250E-03	4.00000E-02	4.47029E-02	7.29717E-03
30	5.17800E+01	4.50000E+00	1.66223E-03	4.00000E-02	-1.13096E-02	-2.69037E-03
31	5.21900E+01	4.50000E+00	1.26424E-03	4.00000E-02	1.79094E-03	-2.20906E-03
32	5.36300E+01	4.50000E+00	4.54041E-04	4.00000E-02	-8.59456E-02	2.38054E-01
33	5.51000E+01	4.50000E+00	5.34451E-04	4.00000E-02	4.62830E-05	3.79537E-02
34	5.61800E+01	4.50000E+00	6.59589E-04	4.00000E-02	1.42214E-02	5.47786E-02
35	5.96600E+01	4.50000E+00	1.57337E-02	4.00000E-02	1.59976E-02	-9.80024E-02

REICH-MOORE FORMULA REQUIRED

TABLE II

AVERAGE PARAMETERS FOR THE UNRESOLVED RESONANCE REGION

CURIUM-247

```
NIS          1
ISOTOPE      1      ZAI= 96247.          ABN=      1.000   LFW= 1   NER= 2

RANGE        2      EL=     61.000000     EH=   10000.0     LPU= 2   LRF= 1
                    SPI=   4.5    A= 0.950000   NLS= 2

GROUP NO.  1

 L-STATE  1     AWRI=    244.9480                                L= 0   NJS= 2
 (ES(I),I=1,  2)
   6.10000E+01 1.00000E+04
  J-STATE 1      MUF= 2
       D            AJ            AMUN          GNO           GG
   2.66667E+00 4.00000E+00 1.00000E+00 2.66667E-04 3.50000E-02
 (GF(I),I=1,  2)
   1.52000E-01 1.65000E-01
  J-STATE 2      MUF= 2
       D            AJ            AMUN          GNO           GG
   2.18182E+00 5.00000E+00 1.00000E+00 2.18182E-04 3.30000E-02
 (GF(I),I=1,  2)
   1.46000E-01 1.59000E-01
UNRESOLVED FORMULA REQUIRED.ONLY FISSION WIDTHS ARE ENERGY DEPENDENT

GROUP NO.  2

 L-STATE  2     AWRI=    244.9480                                L= 1   NJS= 4
 (ES(I),I=1,  2)
   6.10000E+01 1.00000E+04
  J-STATE 1      MUF= 2
       D            AJ            AMUN          GNO           GG
   3.42857E+00 3.00000E+00 1.00000E+00 6.17143E-04 3.70000E-02
 (GF(I),I=1,  2)
   1.56000E-01 1.69000E-01
  J-STATE 2      MUF= 2
       D            AJ            AMUN          GNO           GG
   2.66667E+00 4.00000E+00 2.00000E+00 4.80000E-04 3.50000E-02
 (GF(I),I=1,  2)
   1.52000E-01 1.65000E-01
  J-STATE 3      MUF= 2
       D            AJ            AMUN          GNO           GG
   2.18182E+00 5.00000E+00 2.00000E+00 3.92728E-04 3.30000E-02
 (GF(I),I=1,  2)
   1.46000E-01 1.59000E-01
  J-STATE 4      MUF= 2
       D            AJ            AMUN          GNO           GG
   1.84615E+00 6.00000E+00 1.00000E+00 3.32307E-04 3.10000E-02
 (GF(I),I=1,  2)
   1.36000E-01 1.48000E-01
UNRESOLVED FORMULA REQUIRED.ONLY FISSION WIDTHS ARE ENERGY DEPENDENT
```

TABLE III

THERMAL CROSS SECTIONS

Capture (b)	Year	Ref.	Comments
55	1971	4	Irradiation exp. ($\sigma_a - \sigma_f$)
58.0	1975	7	Irradiation exp. + eval.
60 ± 15	1980	3	Experiment quoted in a review paper
59.7	1980	1	Evaluated from exp. resonances plus a bound level; adopted in the present work

Fission (b)	Year	Ref.	Comments
80 ± 10	1971	4	Irradiation exp.
72.3	1975	7	Irradiation exp. + eval.
80 ± 7	1976	6	Reactor meas.
93 ± 6	1980	3	Exp. quoted in a review paper
81.6	1980	1	Evaluated from exp. res. plus a bound level; adopted in the present work

TABLE IV

RESONANCE INTEGRALS

Capture (b)	Year	Ref.	Comments
500	1971	4	Irradiation exp. $(I_a - I_f)$
500	1975	7	E > 0.625 eV
495 ± 40	1980	3	Quoted in a review paper
494	1982	–	Present work; evaluated from res. in Table I, plus continuum contr.; E > 0.5 eV

Fission (b)	Year	Ref.	Comments
1060 ± 110	1970	9	E > 0.5 eV
750 ± 50	1971	4	Irradiation exp.
935 ± 190	1971	8	E > 0.5 eV
778 ± 50	1972	5	Irradiation exp.; E > 0.625 eV
761	1975	7	E > 0.625 eV; recommended val.
730 ± 70	1976	6	Cadmium diff. method; E > 0.52 eV
774 ± 30	1980	3	Quoted in a review paper
662	1982	–	Present work; evaluated from res. in Table I, plus continuum contr.; E > 0.5 eV

TABLE V

DEFORMED OPTICAL MODEL POTENTIAL

$$\mathcal{V} = -(V+iW)\frac{1}{1+\exp[(r-R_a)/a]} - 4iW_D\frac{\exp[(r-R_b)/b]}{\{1+\exp[(r-R_b)/b]\}^2}$$

$$- V_{SO}\,\vec{\sigma}\cdot\vec{\ell}\,\frac{\lambda\!\!\!^{-}_{\pi}{}^2}{ar}\frac{\exp[(r-R_a)/a]}{\{1+\exp[(r-R_a)/a]\}^2}\ ; \quad \text{here:}$$

$R_{a,b} = R^{(o)}_{a,b}(1 + \beta_2 Y^o_2(\theta') + \beta_4 Y^o_4(\theta'))$ (θ' refers to the body-fixed system)

$\lambda\!\!\!^{-}_{\pi} = \lambda_\pi/2\pi$ (reduced pionic Compton wavelength)

$V = 47.01 - 0.267\ E_n - 0.00118\ E_n^2$ (MeV) (E_n in MeV)

$W = 0$

$$W_D = \begin{cases} 3.195 \text{ MeV} & (E_n \leq 2.25 \text{ MeV}) \\ 2.25 + 0.42\ E_n \text{ (MeV)} & (E_n \text{ in MeV}) \end{cases}$$

$V_{SO} = 7.2$ MeV

$R^{(o)}_a = 1.259$ fm ; $R^{(o)}_b = 1.237$ fm ;

$a = 0.66$ fm ; $b = 0.48$ fm ;

$\beta_2 = 0.25$; $\beta_4 = 0.0$

TABLE VI

DISCRETE LEVELS AND LEVEL DENSITY PARAMETERS FOR ^{246}Cm NEUTRON CHANNEL

Discrete levels /25/:

E (keV)	J^{π}
0.0	0^+
42.9	4^+
142.0	4^+
296.0	6^+
500.0	8^+

Continuum: E > 500 keV; level density described by the formula:

$$\rho(E,J) = \frac{(2J+1)}{24\sqrt{2}\sigma^3} \frac{\exp(2\sqrt{a(E-\Delta)})}{a^{1/4}(E-\Delta+T)^{5/4}} \exp\left[-J(J+1)/2\sigma^2\right]$$

where:

$\sigma^2 = cT$

$E-\Delta = aT^2-T$

$a = 24.0\ \mathrm{MeV}^{-1}$

$\Delta = -0.37\ \mathrm{MeV}$

$\sigma^2/T = 100\ \mathrm{MeV}$

TABLE VII

DISCRETE LEVELS AND LEVEL DENSITY PARAMETERS FOR ^{247}Cm

Neutron channel:

Discrete levels /25/

E (keV)	J^{π}
0.0	$9/2^-$
61.5	$11/2^-$
133.0	$13/2^-$
217.0	$15/2^-$
227.0	$5/2^+$
266.0	$7/2^+$
285.0	$7/2^+$
309.0	$(17/2^-)$
318.0	$9/2^+$

Continuum: E > 318 keV, level density formula as in table VI, with parameters:

$a = 25.2\ MeV^{-1}$

$\Delta = -0.69\ MeV$

$\sigma^2/T = 100\ MeV^{-1}$

Fission channel (^{247}Cm as fissioning nucleus):

Transition states at the first barrier peak described by a level density formula as in table VI, with parameters:

$a = 26.5\ MeV^{-1}$

$\Delta = -1.7\ MeV$

$\sigma^2/T = 98\ MeV^{-1}$

TABLE VIII

DISCRETE LEVELS AND LEVEL DENSITY PARAMETERS FOR ^{248}Cm

Gamma channel (^{248}Cm as decaying nucleus):

Discrete levels /25/

E (keV)	J^{π}
0.0	0.0^+
43.0	2.0^+
140.0	4.0^+
298.0	6.0^+
504.0	8.0^+

Continuum: E > 504 keV, level density formula as in table VI, with parameters

$$a = 24.5\ \mathrm{MeV}^{-1}$$
$$\Delta = -1.0\ \mathrm{MeV}$$
$$\sigma^2/T = 100\ \mathrm{MeV}^{-1}$$

Fission channel (^{248}Cm as fissioning nucleus):

Transition states at the first barrier peak described by a level density formula as in table VI, with parameters:

$$a = 28.0\ \mathrm{MeV}^{-1}$$
$$\Delta = -1.0\ \mathrm{MeV}$$
$$\sigma^2/T = 98\ \mathrm{MeV}^{-1}$$

TABLE IX

FISSION BARRIER PARAMETERS

.ssioning nucleus: ^{247}Cm

First peak		Second peak	
Height, E_A (MeV)	Curvature, $\hbar\omega_A$ (MeV)	E_B (MeV)	$\hbar\omega_B$ (MeV)
6.0	0.63	4.2	0.55

.ssioning nucleus: ^{248}Cm

First peak		Second peak	
Height, E_A (MeV)	Curvature, $\hbar\omega_A$ (MeV)	E_B (MeV)	$\hbar\omega_B$ (MeV)
6.1	0.90	4.2	0.55

FIGURE CAPTIONS

Fig. 1a,b,c,d — Total, elastic, capture and fission cross sections in the resolved resonance region.

Fig. 2 — Evaluated fission cross section in comparison with experimental data: O and □ , ref. /2/.

Fig. 3 — Neutron cross sections in the range 10 keV - 15 MeV.

Fig. 4a,b,c,d — Neutron cross sections over the complete evaluation range 10^{-5} eV – 15 MeV: a) total; b) elastic; c) capture and d) fission.

Fig. 5a,b,c — Effective temperature $\theta(E)$ versus incident neutron energy E, relative to the energy spectra of emitted neutrons in (n,2n), (n,f), (n,n'f) and (n,n'γ) reactions.

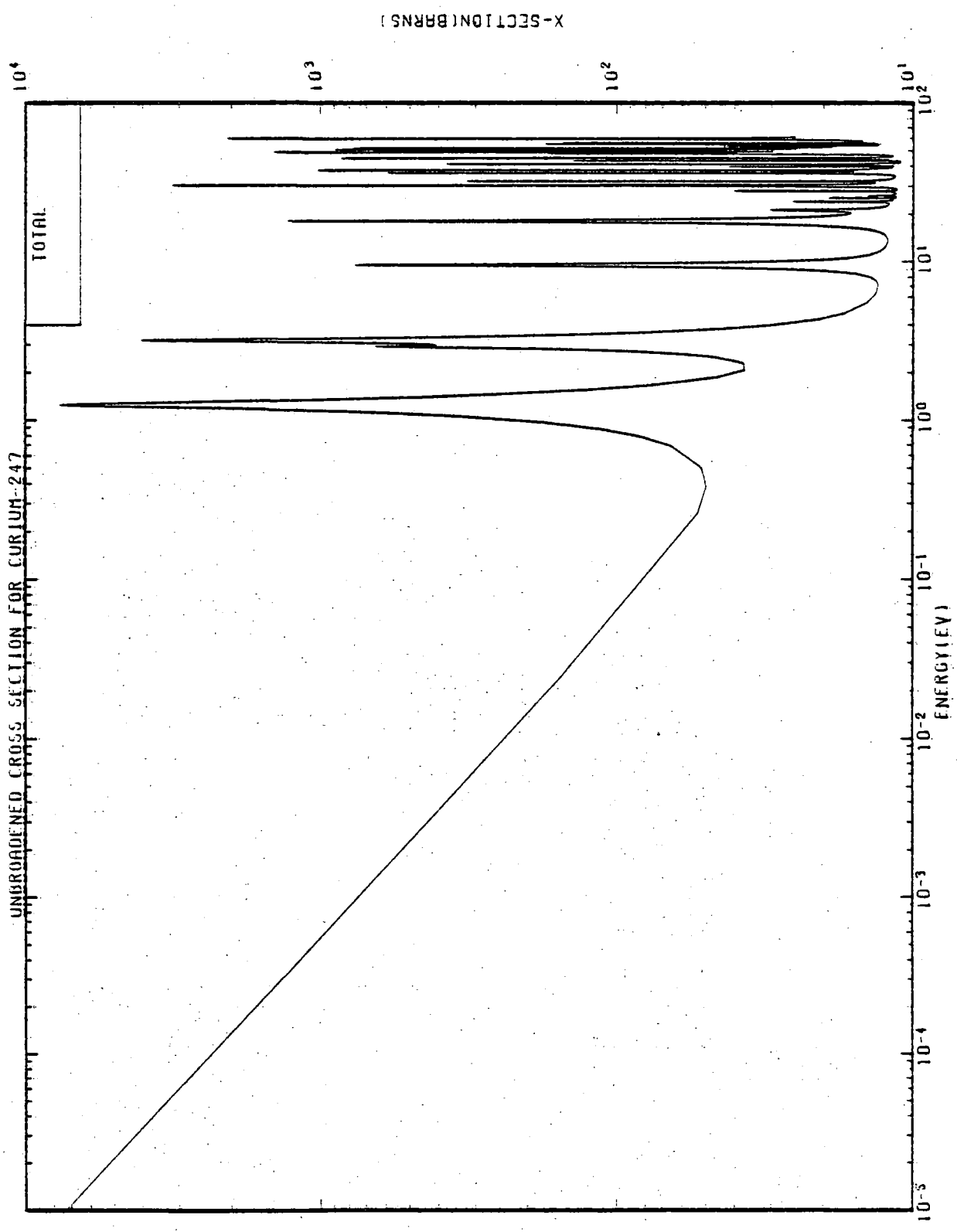

UNBROADENED CROSS SECTION FOR CURIUM-247
TOTAL
X-SECTION(BARNS)
ENERGY(EV)
10^4
10^3
10^2
10^1
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}

Fig. 1a

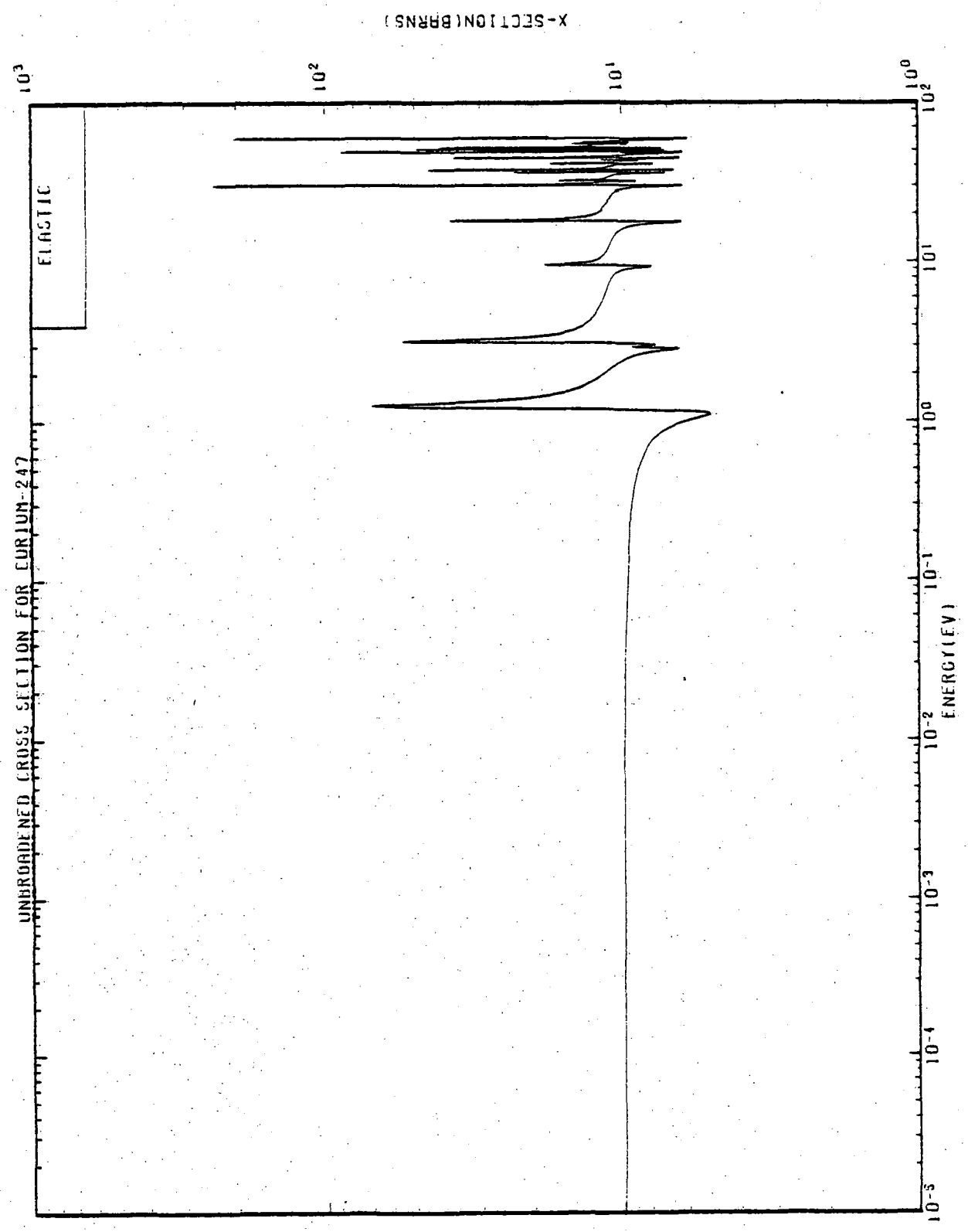

UNBROADENED CROSS SECTION FOR CURIUM-247
ELASTIC
X-SECTION(BARNS)
ENERGY(EV)
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}

Fig. 1b

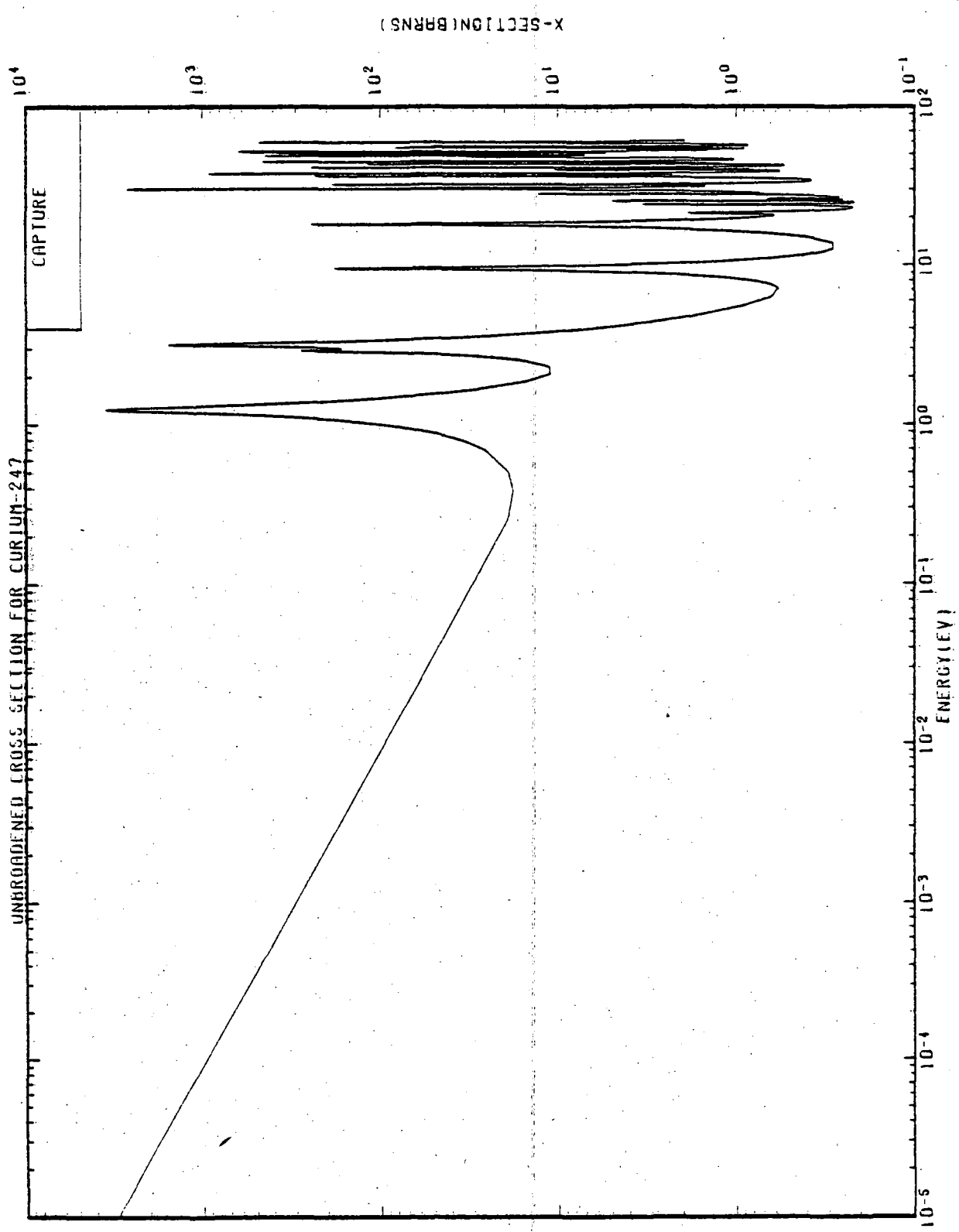

UNBROADENED CROSS SECTION FOR CURIUM-242
CAPTURE
X-SECTION(BARNS)
ENERGY(EV)
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}

Fig. 1c

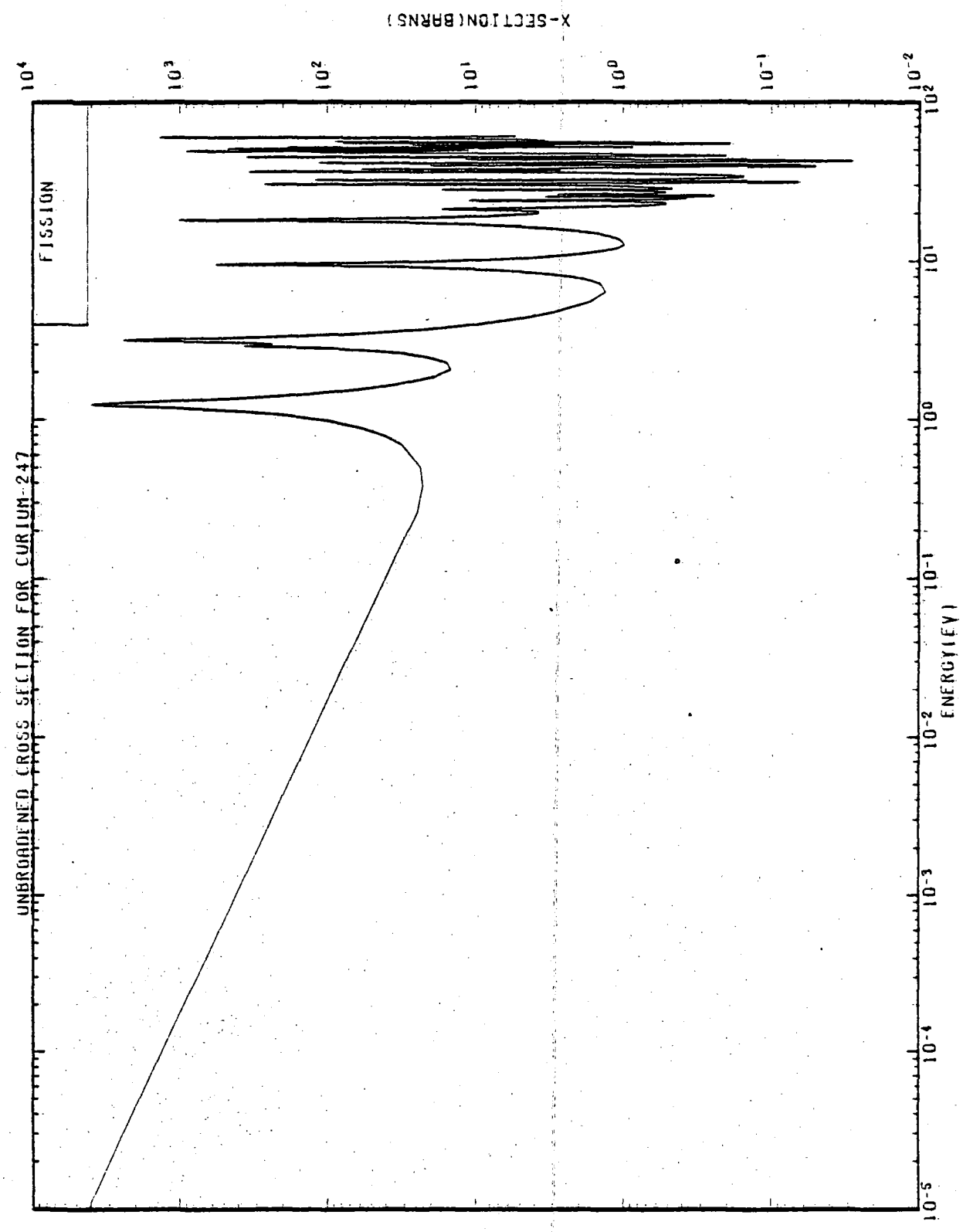

UNBROADENED CROSS SECTION FOR CURIUM-247
FISSION
X-SECTION(BARNS)
ENERGY(EV)
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}

Fig. 1d

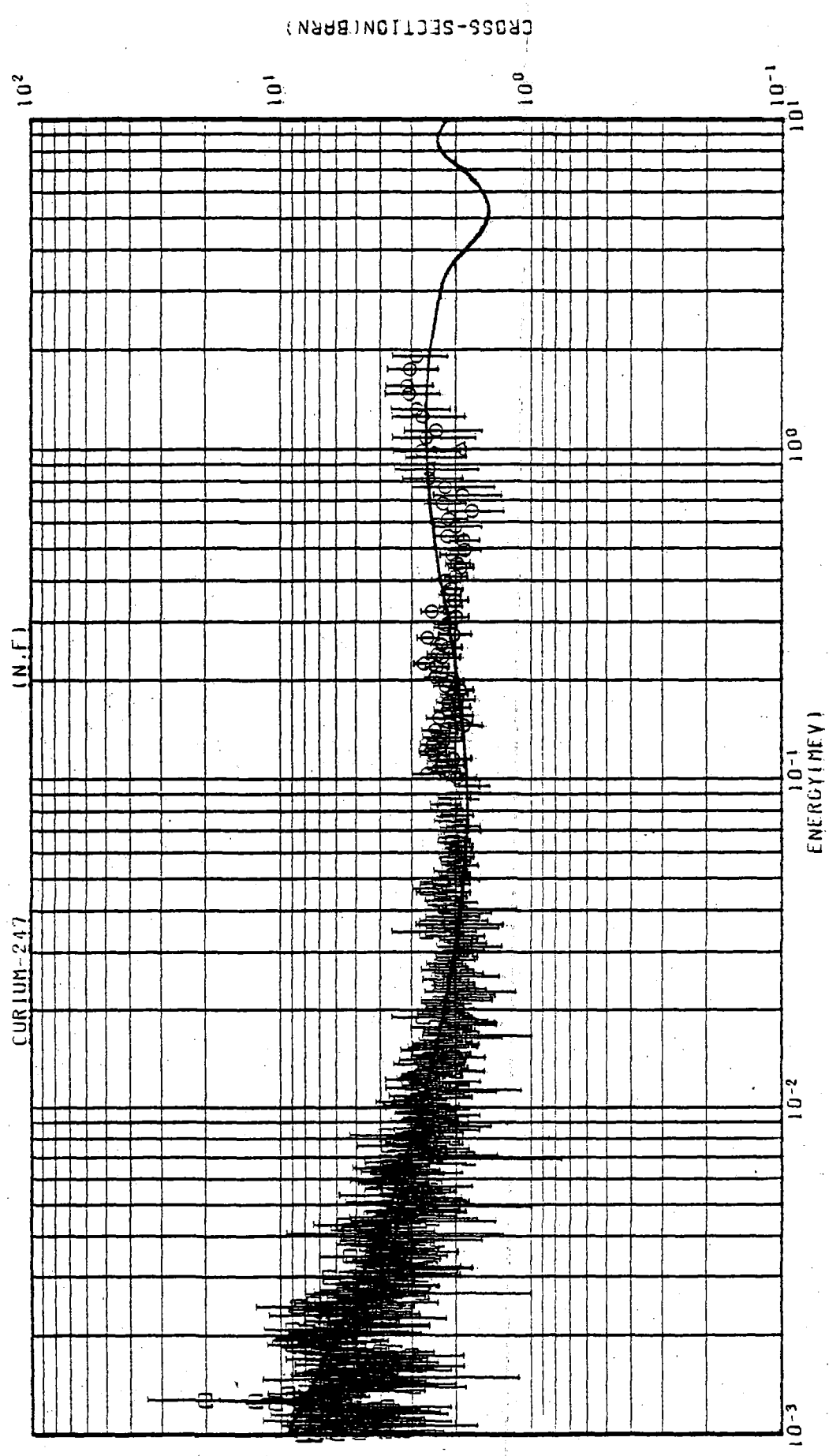

CROSS-SECTION(BARN)
CURIUM-247
(N,F)
ENERGY(MEV)
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}

Fig. 2

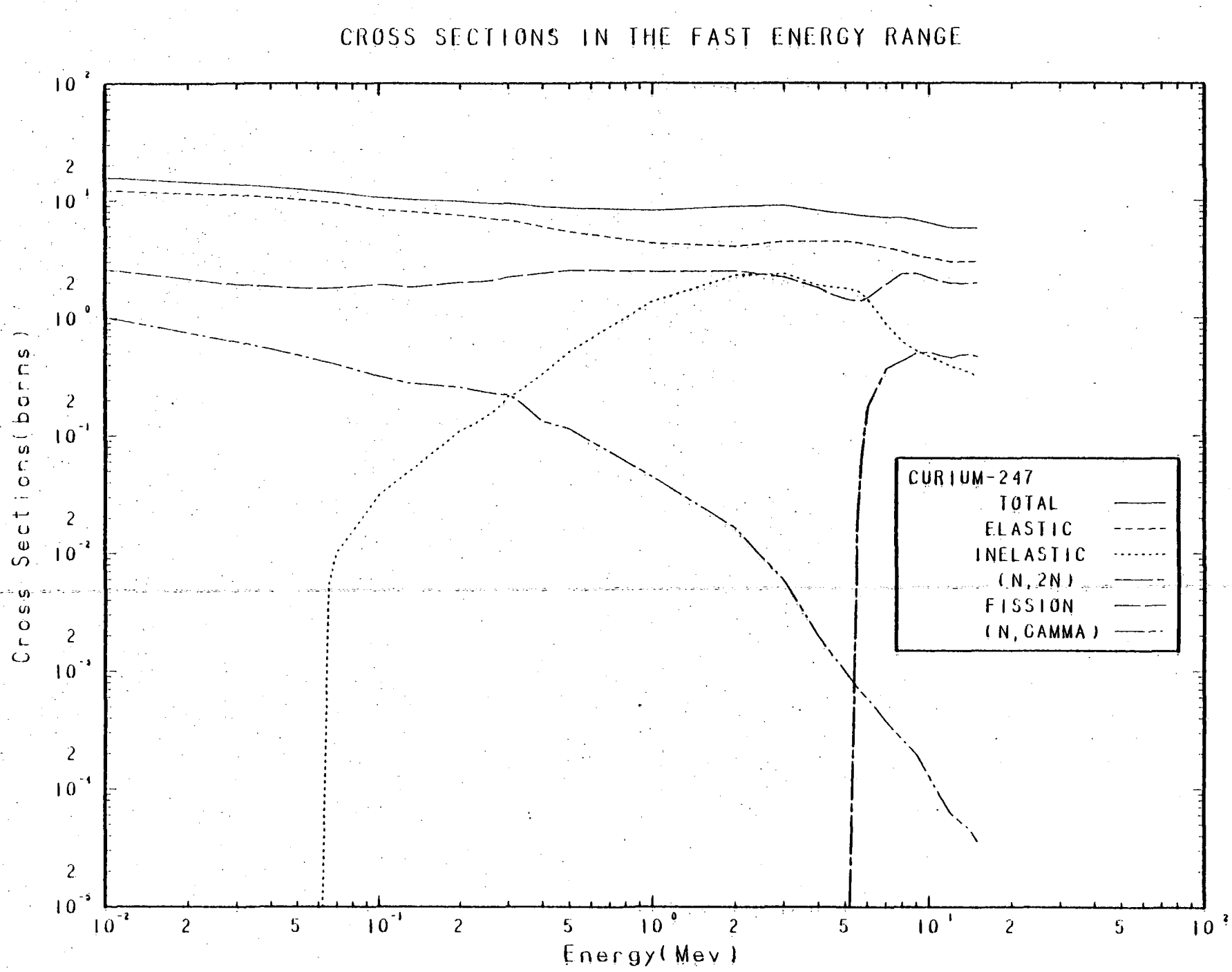

CROSS SECTIONS IN THE FAST ENERGY RANGE
Cross Sections(barns)
Energy(Mev)
CURIUM-247
TOTAL
ELASTIC
INELASTIC
(N,2N)
FISSION
(N,GAMMA)

Fig. 3

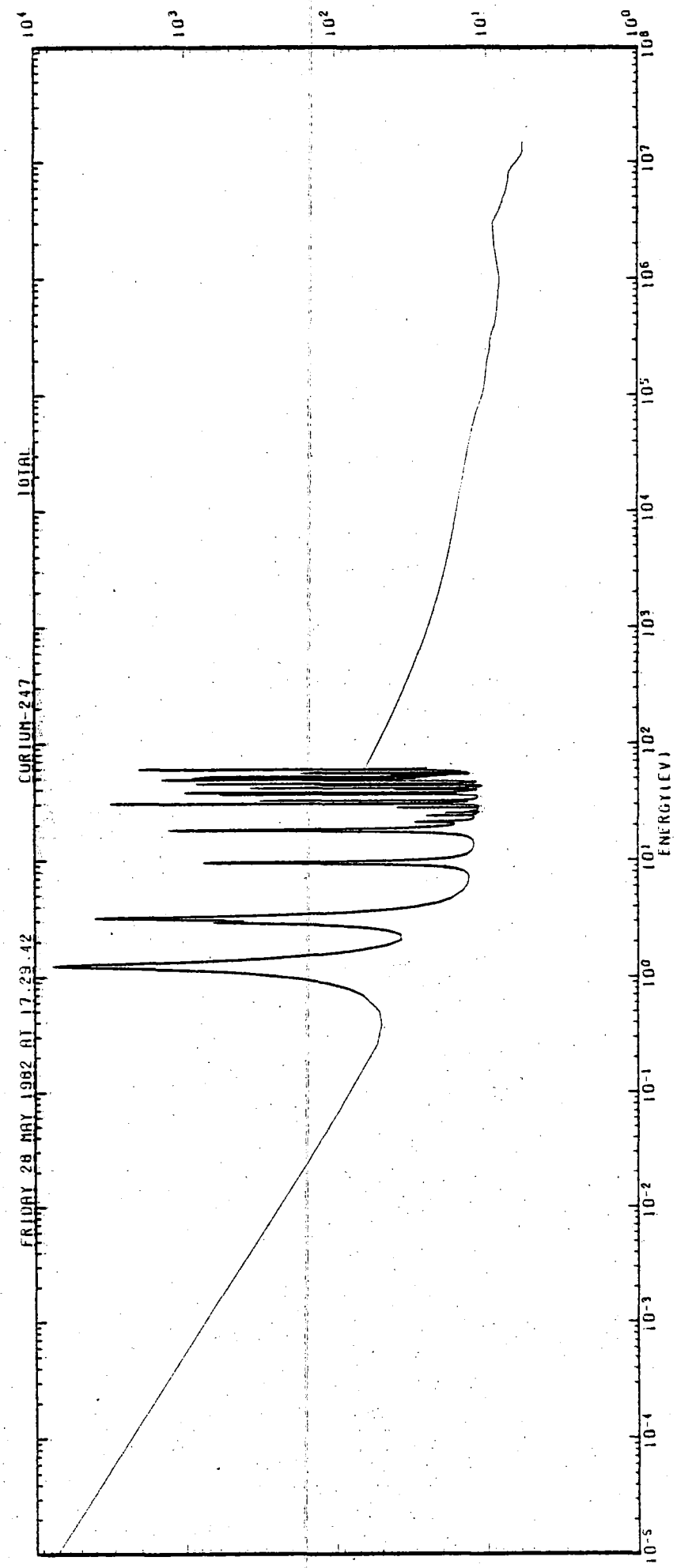

CROSS-SECTION(BARN)
ENERGY(EV)
TOTAL
CURIUM-247
FRIDAY 28 MAY 1982 AT 17.29.42

Fig. 4a

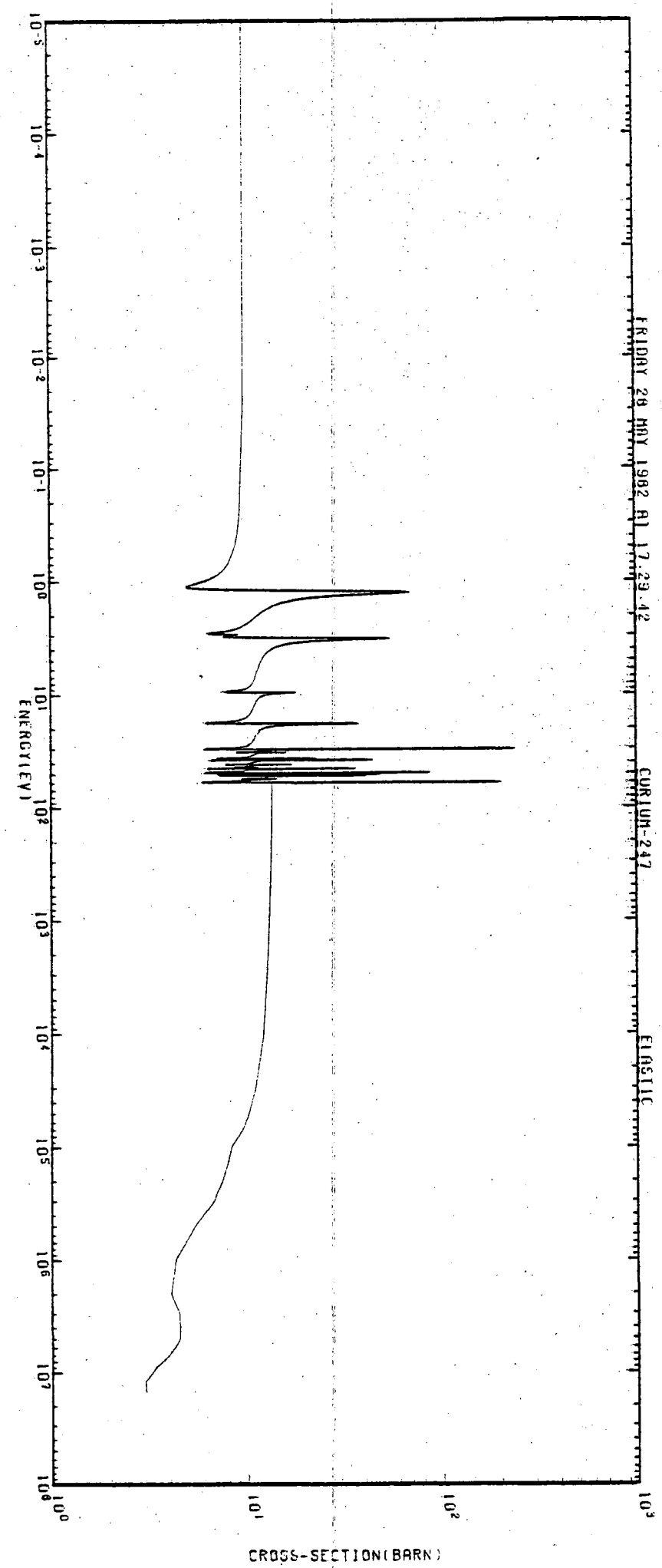

CURIUM-247
ELASTIC
FRIDAY 29 MAY 1982 AT 17:29:42
ENERGY(EV)
CROSS-SECTION(BARN)

Fig. 4b

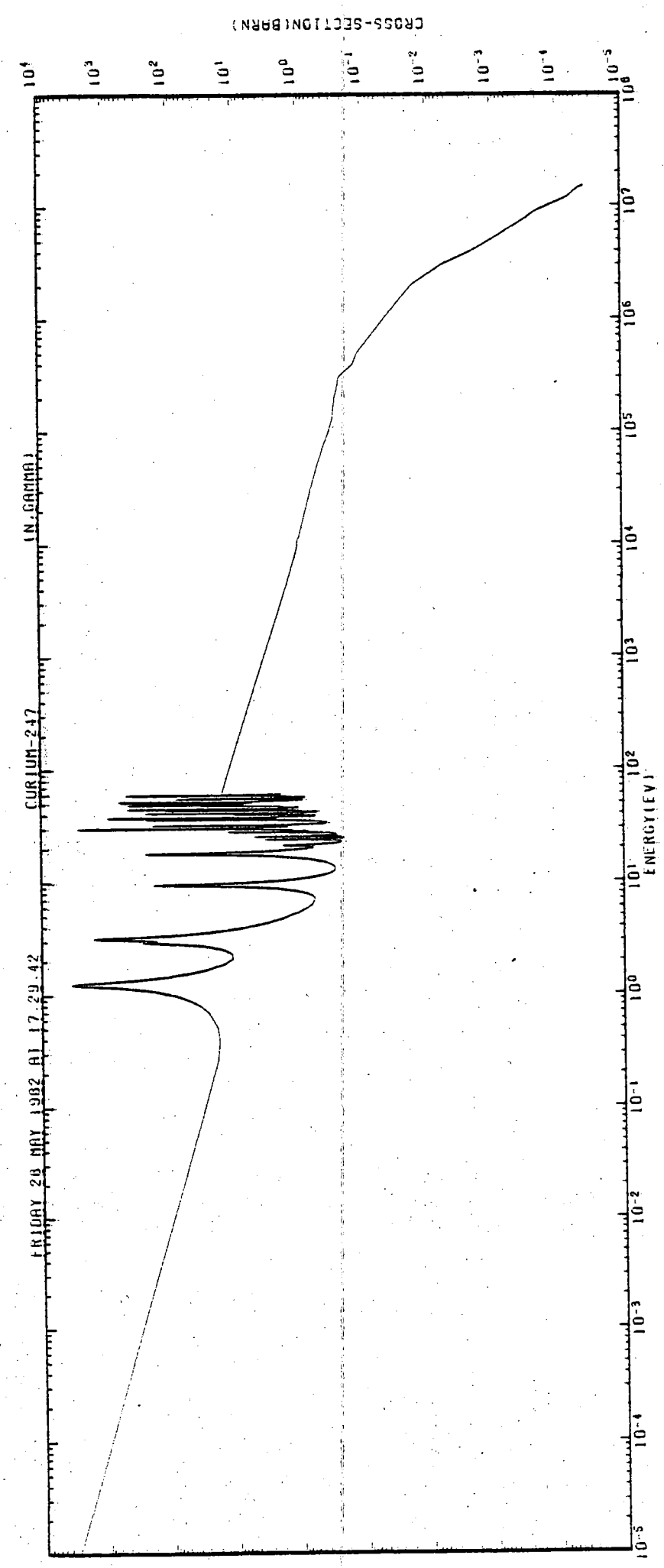

FRIDAY 28 MAY 1982 AT 17:29:42
CURIUM-247
(N,GAMMA)
CROSS-SECTION(BARN)
ENERGY(EV)

Fig. 4c

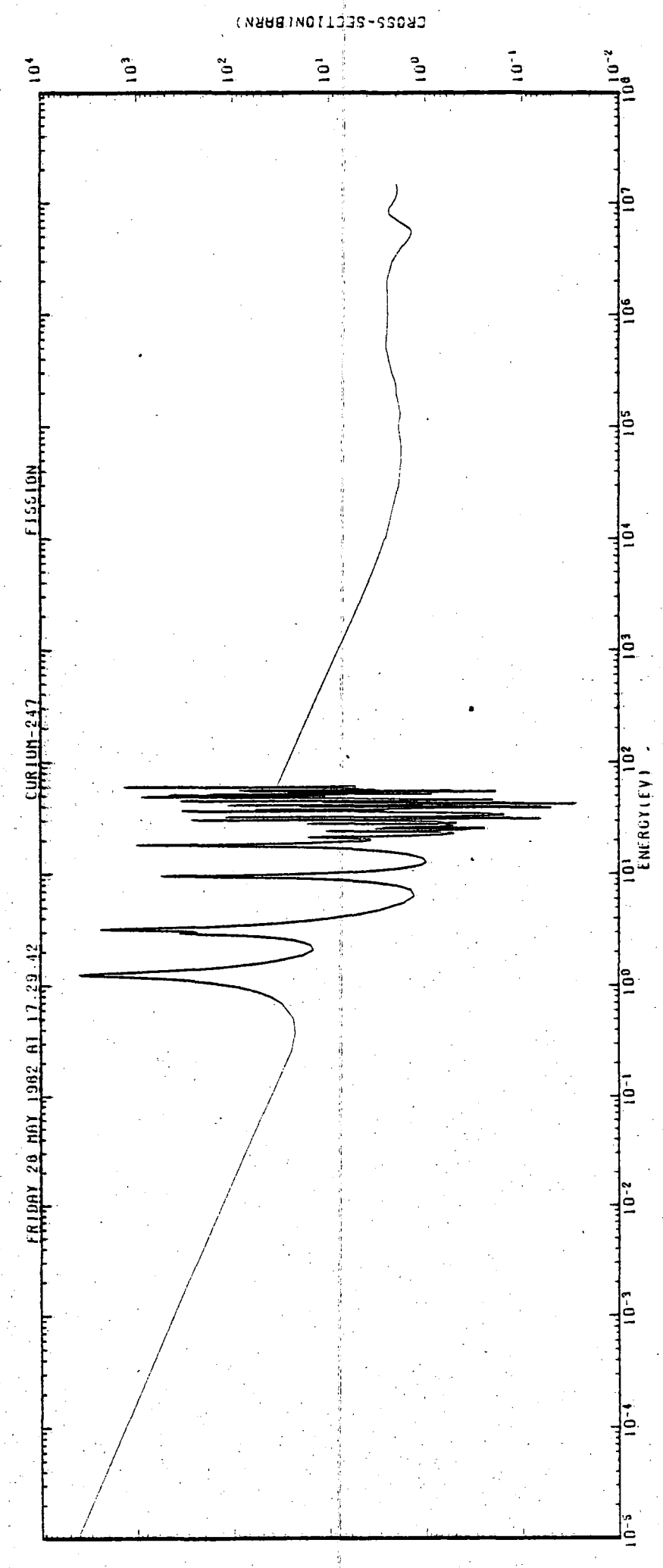
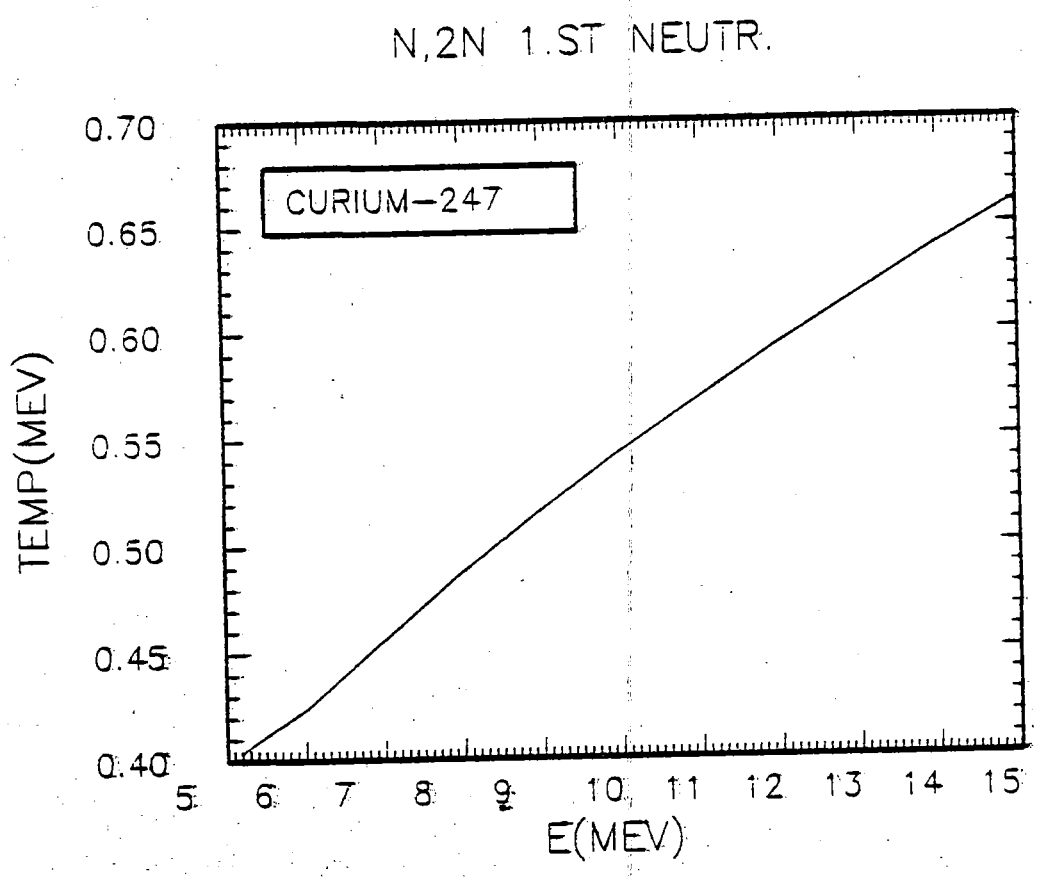

FRIDAY 20 MAY 1982 AT 17.29.42
CURIUM-247
FISSION
CROSS-SECTION(BARN)
ENERGY(EV)

Fig. 4d


N,2N 1.ST NEUTR.
CURIUM-247
TEMP(MEV)
0.70
0.65
0.60
0.55
0.50
0.45
0.40
5
6
7
8
9
10
11
12
13
14
15
E(MEV)

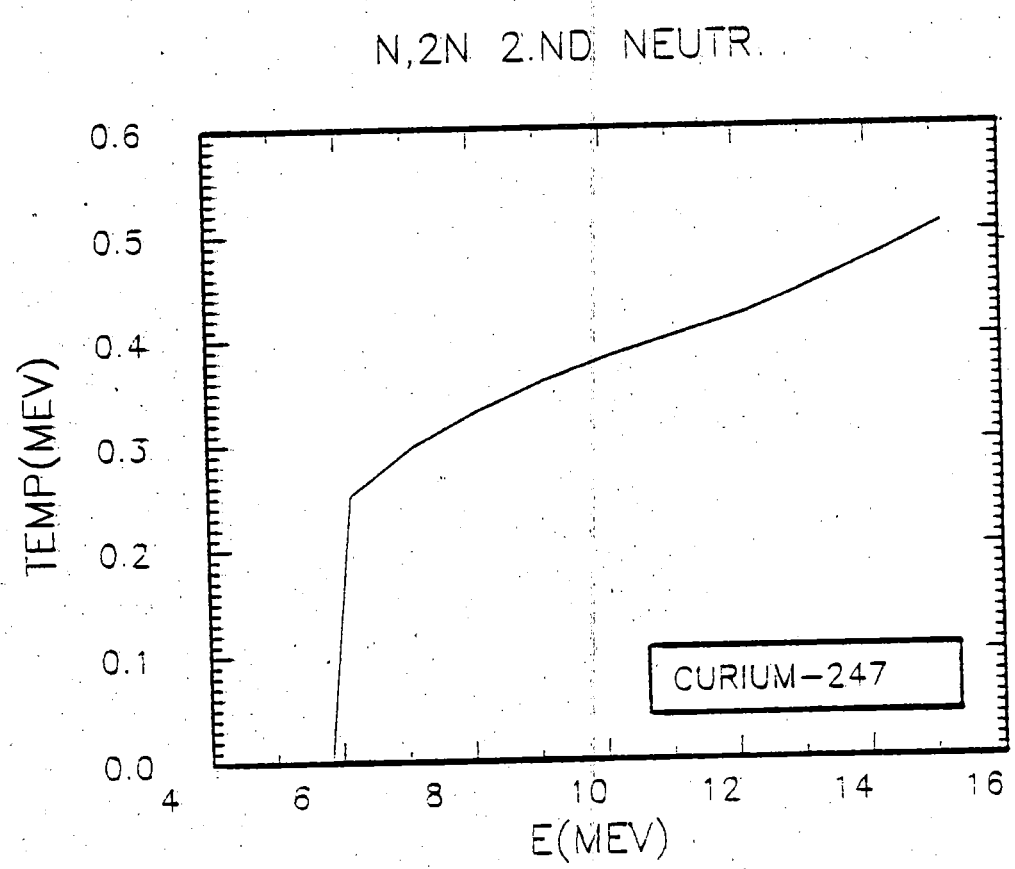
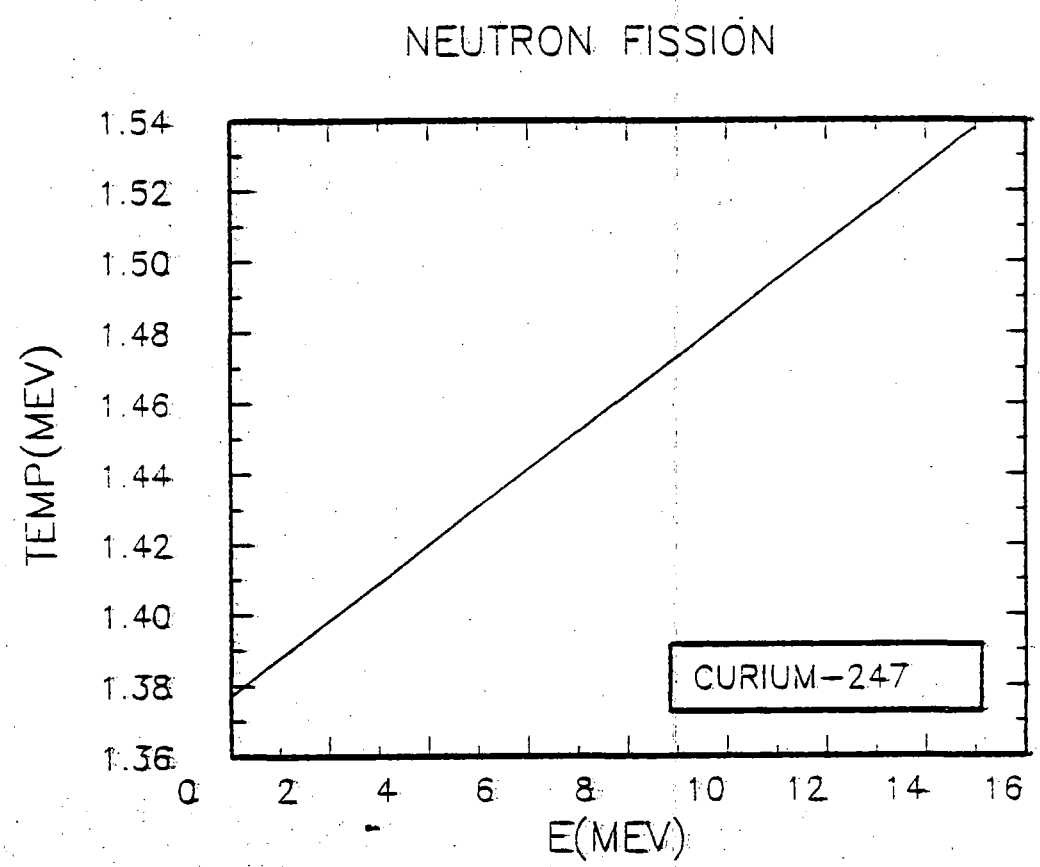

N,2N 2.ND NEUTR.
CURIUM-247
TEMP(MEV)
0.6
0.5
0.4
0.3
0.2
0.1
0.0
4
6
8
10
12
14
16
E(MEV)

Fig. 5a


NEUTRON FISSION
TEMP(MEV)
1.54
1.52
1.50
1.48
1.46
1.44
1.42
1.40
1.38
1.36
0
2
4
6
8
10
12
14
16
E(MEV)
CURIUM-247

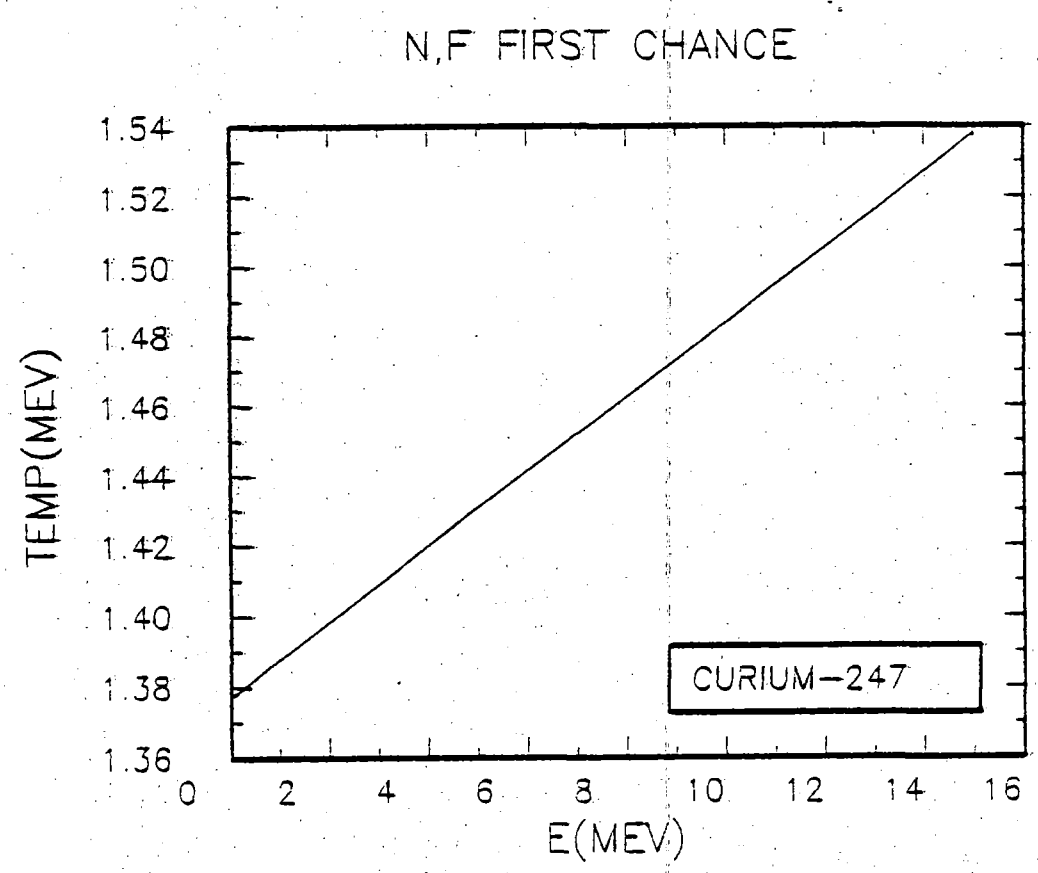
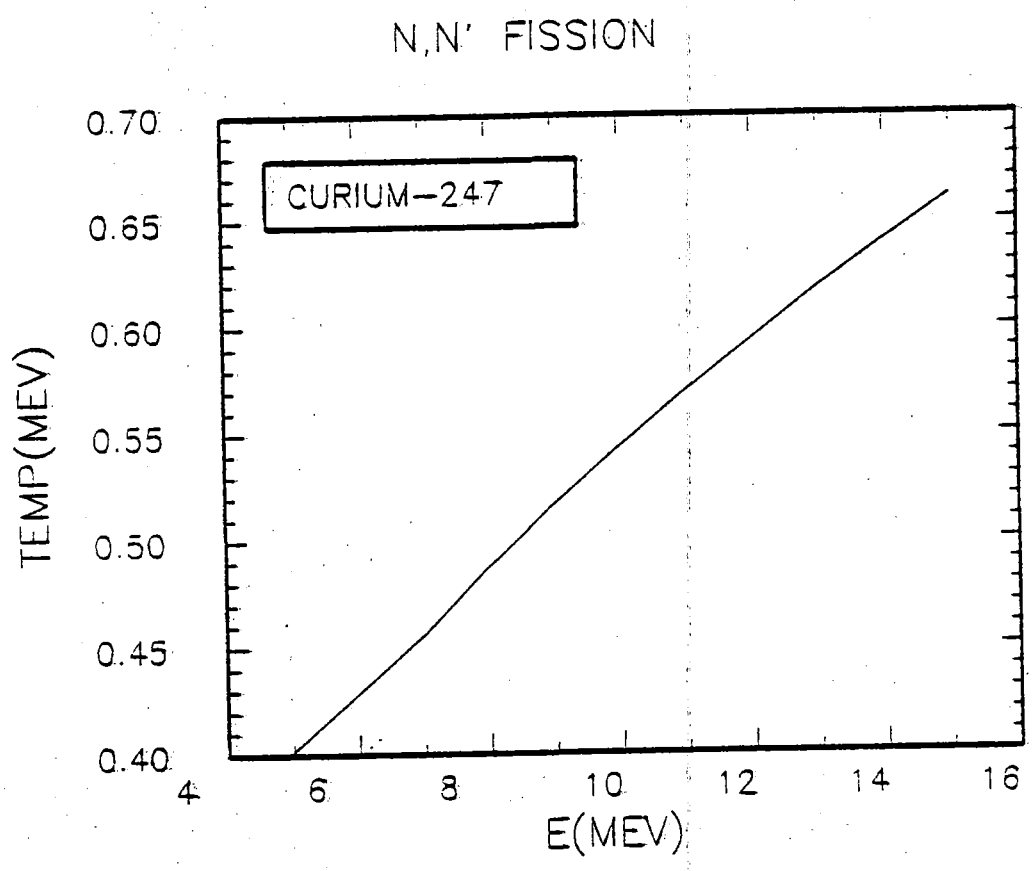

N,F FIRST CHANCE
TEMP(MEV)
1.54
1.52
1.50
1.48
1.46
1.44
1.42
1.40
1.38
1.36
0
2
4
6
8
10
12
14
16
E(MEV)
CURIUM-247

Fig. 5b


N,N' FISSION
CURIUM-247
TEMP(MEV)
0.70
0.65
0.60
0.55
0.50
0.45
0.40
4
6
8
10
12
14
16
E(MEV)

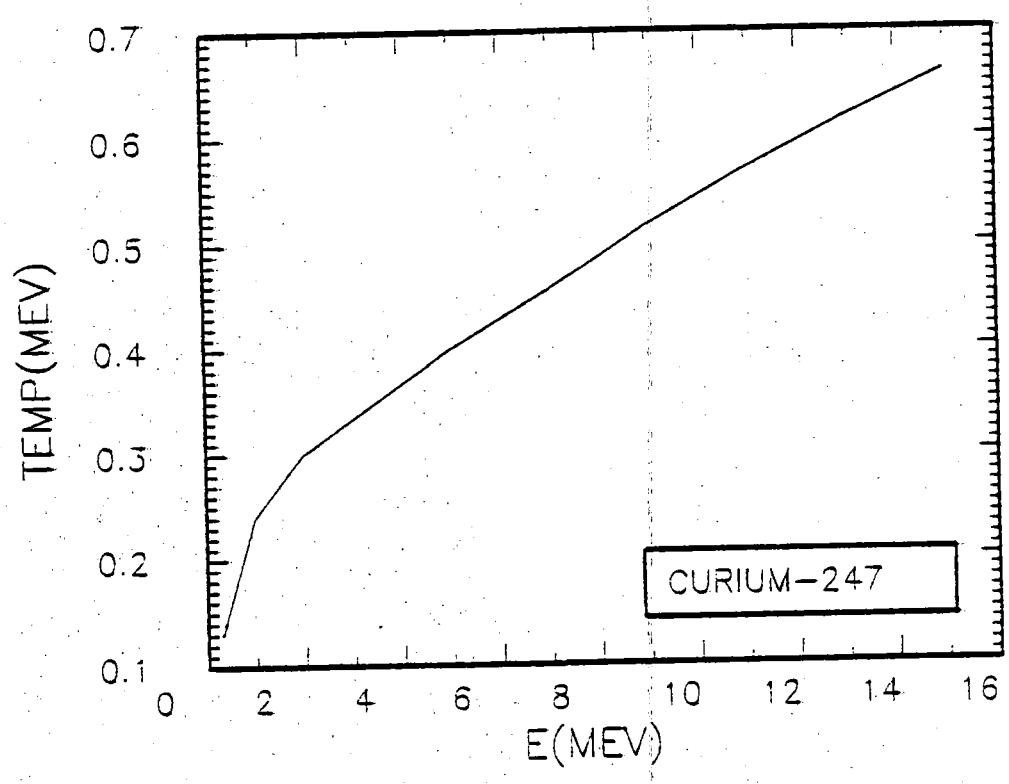

INELASTIC CONT.
CURIUM-247
TEMP(MEV)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2
4
6
8
10
12
14
16
E(MEV)

Fig. 5c