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COMPARISONS OF ENERGY DEPENDENT POINT-WISE CROSS-SECTION GENERATION CODES : RESEND, RESENDD, RECENT

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Comparisons of Energy Dependent Point-wise Cross-Section Generation Codes : RESEND, RESENDD, RECENT

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In order to improve the current situation for production of group cross-section set , we performed intercomparison of energy dependent cross-section generation codes, i.e. RESEND, RESENDD and RECENT which are currently used in the nuclear data community. And also the results were contributed to the international comparisons of energy dependent cross-section generation codes, organized by Dr. Cullen of IAEA.

The ENDF/B V dosimetry file (Vol 531 tape) is adopted as the common input data file. We calculated cold (i.e. 0.0 Kelvin) energy dependent point-wise cross-sections and also calculated unshielded group averages in the 620 group SAND-II structures for the convenience of comparisons.

Through this assessment, we can not recommend to use the official version of RESEND code at all due to the erroneous cross-section generation for partial reaction cross-sections (other than total reaction) in the resolved resonance region and also for the cross-sections in the unresolved region . And for RESENDD code, it has problems following three points:

1) process error in the constant background cross section treatment in file-3 given by interpolation scheme 1,
2) insufficient data points generation in resolved resonance range for very narrow resonances, this affects resonance integrals by several tens percent overestimation for the worst case,
3) violating the process criteria in unresolved resonance range, in this range cross-sections other than the tabulated energies should be defined by interpolating the generated cross-sections at the tabulated energies(not the unresolved parameters).

Hence, at present stage, we recommend to use RECENT code to generate energy dependent point-wise cross-sections.

Keywords : Benchmark-test, Cross-section, Point-wise Cross-section-Generation-code, RESEND, RESENDD, RECENT, International Comparisons, Resonance Cross Sections.

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エネルギー依存断面積計算コードRESEND，RESENDD，RECENTの相互比較

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（1982年8月19日受理）

群定数セットの作成に関する現状を改善する為に，エネルギー依存断面積作成コードの比較を行った。取りあげたコードは，RESEND，RESENDD及びRECENTであり，いずれも現在核データ・コミュニティーで使われている。ここで得られた結果は，IAEAのDr. Cullenによって組織された，エネルギー依存断面積計算コード国際比較にも寄与した。

共通の入力データとしては，ENDF／B−Vのドジメトリー・ファイル（Vol 531）が選ばれた。0°kの温度に対するpoint−wise断面積が計算され，相互比較をやりやすくする為に620群のSAND−II群構造での平均断面積も計算された。

本研究から，RESENDの公式版の使用は全く推められない。それは，分離共鳴域の断面積については，全断面積の形しかチェックしない為に，他の部分断面積に多大の誤差をもたらすこと，また非分離域についても問題があることによる。さらにRESENDDについては，次の3点について問題がある；1）File 3の断面積に対して内挿公式1で与えられる断面積の取扱いに不備がある，2）非常に狭い分離共鳴レベルについて，発生データ点が十分でない為，最悪の場合，共鳴積分値に対して数十%の過大評価となる場合がある，3）非分離共鳴域の処理にあっては，非分離共鳴パラメータが与えられるエネルギー点以外での断面積は，非分離パラメータが与えられるエネルギー点での断面積の内挿によるべきであって，非分離パラメータの内挿であってはならないのに対して，これをおかしている。現時点では，エネルギー依存断面積の作成に対しては，RECENTの使用が推められる。

+　物理部

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1. Introduction

Recently so many attentions are given to codes for generating point cross-sections from resonance parameters of ENDF/B type data. At present, ENDF/B type data-treatment is thought as standard one for most applications of cross-section data. In spite of the fixed data processing procedures, energy dependent point-cross-sections generated from sevearal codes sometimes differe as much as 50 times among them(1).

We have been used the RESENDD(2) code for the generation of point data from resonance parameters for these several years. This procedure is thought as standard one for the most of the users including the reactor design and shielding in our country. This RESENDD code is a modified one of the official version of RESEND code(3) polished-up by the user's experiances. But none of the comparisons were made up to now about the code accuracy and performances between the two codes.

Recently we received a program RECENT(4) to calculate energy dependent point-wise cross-sections from ENDF/B file 2 and file 3: the same purpose as RESEND or RESENDD. At the same time, we received a letter urging to participate in the international comparisons , organized by Dr. Cullen of IAEA(5) , of energy dependent cross-section production codes .

Under these circumstances we decided to participate in the international comparisons of the energy dependent point-cross-section generation codes in order to point out the problems arised, or to clarify the problems involved in the code RESENDD. In addition, if we could, we would like to confirm the recommended code or procedures.

2. BENCHMARK Specifications

A. Evaluated Nuclear Data Library Adopted for Comparisons.

ENDF/B-V DOSIMETRY FILE. tape number: 531
All nuclides whose cross-sections are calculated by the resonance parameters.
Total Nuclides: 11
Number of Reactions: 14
for details, see Table 2.1

B. Testing Codes.

a. RECENT[4]
b. RESENDD[2]
c. RESEND[3]

C. Testing Condition.

Machine: FACOM M-200
FORTRAN HE-COMPILER.

D. Running Condition:

Generated cross-sections are for 0.0 degree in kelvin i.e. cold cross-sections.

a. RECENT
LINEAR: 0.1 % ; error tolerable limit for the general interpolation scheme to linear- linear interpolation scheme.
N.B. RECENT can not accept the data represented by general interpolation scheme.
RECENT: ERROR CRITERIA ;ERR= 0.1 %
No option for backward thinning.
i.e. File 2 + 3 ERR = 0.0
Where backward thinning:
data manipulation for eliminating unnecessary energy points after the whole cross section (resonance plus background) generation.

b. RESENDD
ERR: 0.1 %   AVERR: 0.0   LSIG: 1.0E-10

c. RESEND
ERR: 0.1 %   AVERR: 0.0

N.B. owing to the enormous cpu time consuming calculation for this RESEND code, we had to use the following error, as a tolerable limit for the nuclides specified below:

Au-197, Th-232 : ERR= 1.0 %
U-238 : ERR= 10.0 %

Where ERR: The maximum fractional errors used in reconstructing cross-sections: the differences between the generated and interpolated cross-sections at the neighboring generated points.

AVERR: 0.0 indicates exact treatment for distant resonances.

LSIG: Allowable lowest cross-section value. If a generated point cross-section is less than this LSIG value, the output cross-section is reset to LSIG.

E. Procedures for Comparisons

1. Comparisons of plotted data for each processed output. Plot is made in the same scale and in the same sheet.

2. Comparison of the group-averaged data by the SAND-II 620-group-structure[6] for each processed point-cross-section data. Group averaging was performed using GROUPIE[7] code with constant weighting fluxes. Ratios of the group averaged cross-sections for
   a. RECENT / RESENDD
   b. RESEND / RESENDD
   are given in the output lists and plotter output.

   N.B. see Appendix-1 for 620-group SAND-II structure.

Table 2.1 Nuclides and reactions adopted as comparisons.

No	Nuclide	MAT No	Resonance Energy	Bound.	Region	For-mulae	No of reson.	Reaction
1	Na-23	6311	6.0E+2	5.0E+5	resolved	MLBW	12	(n,gamma)
2	Np-237	6337	3.0E-1	1.3E+2	resolved	SLBW	170	(n,fiss)
			1.3E+2	4.0E+4	unresolv		134	
3	Au-197	6379	1.0E-5	4.83+3	resolved	MLBW	263	(n,gamma)
4	Th-232	6390	5.0	4.0E+3	resolved	MLBW	352	(n,fiss)
			4.0E+3	5.0E+4	unresolv		47	(n,gamma)
5	U-235	6395	1.0	8.2E+1	resolved	SLBW	130	(n,fiss)
			8.2E+1	2.5E+4	unresolv		137	
6	U-238	6398	1.0	4.0E+3	resolved	MLBW	164	(n,gamma)
			4.0E+3	1.49+5	unresolv		36	(n,fiss)
7	Pu-239	6399	1.0	3.01+2	resolved	SLBW	128	(n,gamma)
			3.01+2	2.5E+4	unresolv		94	(n,fiss)
8	Sc-45	6426	1.0E-5	9.69+4	resolved	MLBW	79	(n,gamma)
9	Fe-58	6432	1.0E-5	3.5E+5	resolved	SLBW	12	(n,gamma)
10	Cu-63	6435	10.	1.59+4	resolved	MLBW	19	(n,gamma)
11	In-115	6437	1.0E-5	1.00+3	resolved	SLBW	89	(n,gamma)

3. Discussion for the Results

I. Running Performance for Each Codes

Running performances are given in Table 3.1 to Table 3.4:

- Table 3.1 CPU time and generated data points,
- Table 3.2 Relative CPU time and relative generated data points to the RESENDD result,
- Table 3.3 CPU time per one generated data point,
- Table 3.4 CPU time per one resonance level(resolved + unresolved).

a. From these tables, required CPU time is shortest for RESENDD code, next is for RECENT and the last is RESEND. RESEND requires enormous cpu time for processing of the multi-level resonance parameters.

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II. Results for Each Nuclides

1.Na-23 (n,gamma)

a. Agreement between RECENT and RESENDD is perfect.

b. Difference between RESEND and the rests is very large. For 30 keV to 200 keV, RESEND overestimate the cross-section systematically up to 15 % . This overestimation severely affects the estimation of Na-void reactivity coefficient for fast reactors.
This difference is introduced by the the fact that the RESEND code do not check the partial cross sections at all other than the total cross section.

- Fig.3.1.1 Cross-section ratio for Na-23 (n,gamma) in SAND-II 620-group structure (1).
- Fig.3.1.2 Cross-section ratio for Na-23 (n,gamma) in SAND-II 620-group structure (2).

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2.Np-237 (n,fiss)

a. For the energy range from 120 eV to 200 eV , difference in the cross-section curve is large between the result from RECENT and the rests. (see Fig.3.2.3) This energy range is unresolved-range, and the unresolved resonance parameters are tabulated at 138 eV and 198 eV. In this energy range, RESEND or RESENDD generate cross sections other than the tabulated energies by interpolating resonance parameters.But this procedure is not recommended now. Cross-sections should be calculated for the tabulated energies in this unresolved resonance range, and cross-sections other than the tabulated energies should be defined by interpolating the generated cross-sections(not the unresolved parametrers).

b. For the energy range 5 keV to 40keV, RECENT gives systematically high results. (see Fig.3.2.4) Here RECENT results are given only 2 data points i.e. 4.954 keV and 40. keV, cross-sections are 0.01102 and 0.01178 barns respectively. On the other hand, both RESENDD and RESEND cross-sections exhibit some energy dependence. We cannot think this difference in the cross-section curve is introduced by the difference in the interpolation procedure adopted in those codes. Original data given in the ENDF/B file of resonance parameters, only 2 data points are given for this energy range. And this energy range is unresolved range. The difference in RECENT and others comes from the same reasons as previous one. From the recommendation in the CSEWG, the cross-sections should be interpolated, not for the parameters. RESENDD and RESEND code may be seen violating this recommendation.

c. The difference in the cross-section curve between RESEND and the rests is quite large, i.e. the ratio lies 0.2 to 2.0. This is mainly due to the process procedure error in the RESEND code, in this code no cross-section curve check for partial cross-sections are performed other than the total reaction.

Fig.3.2.1: Cross-section ratio for Np-237 (n,f) in SAND-II 620-group structure (1).
Fig.3.2.2: Cross-section ratio for Na-237 (n,f) in SAND-II 620-group structure (2).
Fig.3.2.3: Neutron cross-section of Np-237 (n,f) from 100 eV to 250 eV.
Fig.3.2.4: Neutron cross-section of Np-237 (n,f) from 4 keV to 50 keV.

....

3.Au-197 (n,gamma)

a. At about 4.8 keV; resolved and unresolved connecting point, cross-section curve for RESEND and RESENDD exibits unphysical shape. (see Fig.3.3.3) But this is due to the specification error of the resonance range in original data in ENDF/B-V, i.e. resonance range is defined from 1.0E-5 eV to 4.827 keV and last resolved resonance is assigned to this 4.827 keV. Then such a treatment found in RESENDD or RESEND is faithful one to the original data. But for the users ,RECENT treatment is more acceptable due to eliminating the damage from overestimation at the averaging process.

b. The difference between RESEND and the rests is large, i.e from 100 eV to 1 keV, generated cross-sections by RESEND are systematically high.

Fig.3.3.1: Cross-section ratio for Au-197 (n,gamma) in SAND-II 620-group structure (1).
Fig.3.3.2: Cross-section ratio for Au-197 (n,gamma) in SAND-II 620-group structure (2).
Fig.3.3.3: Neutron cross-section of Au-197 (n,gamma) from 4.5 keV to 5.25 keV.

....

4.Th-232 (n,fiss)

a. From 1 keV to 4 keV energy range, the results are rather different beteween RECENT and RESENDD. At 4 keV, resolved and unresolved data are connected. For this energy range, from 1 keV to 4 keV, a number of very narrow resolved levels are available as seen in Fig.3.4.3 . From the detailed analysis performed in Appendix A.2, this difference is introduced by the sparse data-points generation for very narrow resonances in RESENDD code.

b. For the energy range 4 keV to 500 keV,some cross-section values other than 0. (i.e. 1.E-10) are generated by RESENDD code, in this range cross-section should be 0.. This is due to LSIG option adopted in RESENDD code i.e. LSIG=1.0E-10 .

c. The difference between RESEND and the rests is large in the resonance region; i.e. RESEND code overestimate the cross-section systematically up to 20 %.

Fig.3.4.1: Cross-section ratio for Th-232 (n,f) in SAND-II 620-group structure (1).
Fig.3.4.2: Cross-section ratio for Th-232 (n,f) in SAND-II 620-group structure (2).
Fig.3.4.3: Neutron cross-section of Th-232 (n,f) from 1 keV to 4 keV.

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Th-232 (n,gamma)

a. The results from 1 kev to 4 kev are rather different (up to 10 %) beteween RECENT and RESENDD. At 4 keV, resolved and unresolved data are connected. For these energy region , from 1 keV to 4 keV, a number of resolved levels are available as seen in Fig.3.4.6 . The difference is due to erroneous cross-section generation by RESENDD and RESEND codes for very narrow resonances. (see details Appendix A.2)

Fig.3.4.4 Cross-section ratio for Th-232 (n,gamma) in SAND-II 620-group structure (1).
Fig.3.4.5 Cross-section ratio for Th-232 (n,gamma) in SAND-II 620-group structure (2).
Fig.3.4.6 Neutron cross-section of Th-232 (n,gamma) from 1 keV to 4 keV.

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5.U-235 (n,fiss)

a. Agreement between RECENT and RESENDD is quite well.
b. Difference between RESEND and others is maximum 15% systematically large.

Fig.3.5.1 Cross-section ratio for U-235 (n,f) in SAND-II 620-group structure (1).
Fig.3.5.2 Cross-section ratio for U-235 (n,F) in SAND-II 620-group structure (2).

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6.U-238 (n,fiss)

a. Agreement between RECENT and RESENDD is generally well except at about 35 eV and 1.2 keV.
b. At about 35 eV, resolved resonance peak cross-section is quite different (more than 50 times large) only for RESENDD code. i.e. The resonance cross-section of RESENDD at 36.6 eV is quite large compared with the rests.

GROUP	ENERGY RANGE	RESENDD	RECENT	RESEND
249	from 34 eV to 36 eV:	1.725E-4	3.201E-6	3.315E-6
250	from 36 eV to 38 eV:	1.616E-3	2.919E-4	2.904E-4

Original ENDF/B data are given by the followings;
Resonance parameter: s-wave

resonance energy = 3.667+1 eV
Γ = 5.683-2 ev
Γ f = 8.877-9 eV
smooth cross-section: from 1 ev to 4.0kev = 0.0 barns.

This difference is introduced by the same reason of Th-232 (n,f) or Th-232 (n,gamma) error cases. i.e. RESENDD code generates rather coarse energy data points for this very narrow resonance. It results to such an enormous differences when integrated. Generated cross sections are given in Fig.3.6.3 for each codes.

c. At about 1.3 kev , a gap is detected . A highest level parameters whose fission widths other than 0.0 is given at 1.267 keV. And this difference is attributed to the same reason as above. i.e. Erroneous coarse eneregy mesh generation for the lower energy part of this very narrow resonance cross-section. Generated cross-sections are given in Fig.3.6.4 for each codes.
d. Difference between RESEND and others is systematically large by maximum 40 %.

Fig.3.6.1 Cross-section ratio for U-238 (n,f) in SAND-II 620-group structure (1).
Fig.3.6.2 Cross-section ratio for U-238 (n,f) in SAND-II 620-group structure (2).
Fig.3.6.3 Neutron cross-section of U-238 (n,f) from 10 eV to 50 eV.
Fig.3.6.4 Neutron cross-section of U-238 (n,f) from 1 keV to 2 keV.

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U-238 (n,gamma)

a. Agreement between RECENT and RESENDD is generally well except at about 35ev and from 1keV to 5 keV.
b. At about 35 eV, resolved resonance peak cross-section is quite different (more than 50 times large) only for RESENDD code. i.e. The resonance cross-section of RESENDD at 36.6 eV is quite large compared with the rests.

GROUP	ENERGY RANGE	RESENDD	RECENT	RESEND
249	from 34 eV to 36 eV:	4.450E+2	7.962E+0	8.256E+0
250	from 36 eV to 38 eV:	4.172E-3	7.536E-4	7.495E+0
			(barns)	

Original data given in ENDF/B V.
Resonance parameter: s-wave
resonance energy = 3.667+1 eV

Γ = 5.683-2 ev
Γ g = 2.292-2 eV
smooth cross-section: from 1 ev to 4.0kev = 0.0 barns.

This difference is introduced by the same reason of U-238 (n,f) error case. i.e. RESENDD code generates rather coarse energy data points for this very narrow resonance. It results to such an enormous differences when integrated. Generated cross-sections are given in Fig.3.6.7 for each codes.

c. For the energy range from 1kev to 4 kev, difference is systematically large ; i.e. up to 10 % differences. In this energy range, a number of resolved resonance levels are available. And at 4 keV , resolved and unresolved resonance region is connected. And this difference is attributed to the same reason as above. i.e. Erroneous coarse eneregy mesh generation for the lower energy part of this very narrow resonance. Generated cross-sections are given in Fig.3.6.8 for each codes, but we cannot find out the differences of cross-section curve for each codes from such a dense resonance contained figure.

d. Difference between RESEND and others is systematically large by maximum 50 %.

Fig.3.6.5 Cross-section ratio for U-238 (n,gamma) in SAND-II 620-group structure (1).
Fig.3.6.6 Cross-section ratio for U-238 (n,gamma) in SAND-II 620-group structure (2).
Fig.3.6.7 Neutron cross-section of U-238 (n,gamma) from 10 eV to 50 eV.
Fig.3.6.8 Neutron cross-section of U-238 (n,gamma) from 1 keV to 5 keV.

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7.Pu-239 (n,fiss)

a. Agreement between RECENT and RESENDD is quite well. But small differences are detected at 1.61 keV, 2.8-3.6 keV, 9.2-9.6 keV, and maximum differences are 1%, 2% and 1% respectively. These energy range are unresolved resonance range, and the data are given as rather wide spacing. For example, original data of unresolved resonance parameters in ENDF/B V data are defined at following energies;
1.61 keV range: 1.51,1.53,1.54,1.55, 1.7,1.8 keV
2.8-3.6 keV range: 2.75,2.775,2.8, 2.9, 3.075, 3.25, 3.75,4.25 keV
9.2-9.6 keV range: 8.75,9.25, 9.50, 9.75 keV.
And generated cross-sections from each codes are given

in Fig.3.7.3. From this figure, there exist some problems in the processing code for unresolved resonance range. This error may be related to the error already stated in Np-237 unresolved range case, i.e. this error may be relating to the problem of cross-section-interpolation or resonance- parameter-interpolation process-phylosophy adopted in RECENT and the rests.

b. Difference between RESEND and others is systematically large by 4 % maximum, in the unresolved resonance range.

Fig.3.7.1 Cross-section ratio for Pu-239 (n,f) in SAND-II 620-group structure (1).
Fig.3.7.2 Cross-section ratio for Pu-239 (n,f) in SAND-II 620-group structure (2).
Fig.3.7.3 Neutron cross-section of Pu-239 (n,f) from 1 keV to 10 keV.

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8.Sc-45 (n,gamma)

a. Agreement between RECENT, RESENDD and RESEND is completely well.

Fig.3.8.1 Cross-section ratio for Sc-45 (n,gamma) in SAND-II 620-group structure (1).
Fig.3.8.2 Cross-section ratio for Sc-45 (n,gamma) in SAND-II 620-group structure (2).

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9.Fe-58 (n,gamma)

a. Agreement between RECENT and RESENDD is quite well except at 6.5 keV resonance.

b. At 6.5 keV resonance, as seen from Fig.3.9.3, enough data points are not generated for representing the resonance cross-section shape in the RESENDD output. In this figure, cross-section shape is somewhat curious for RESENDD, but this is caused by the interpolation scheme specified for this data, i.e. 2: linear-linear interpolation. More explicitely, RESENDD code generate following 2 energy glid ;
6.17617969E+3 eV cross-section value is 2.07784E-1 (b)
6.19900000E+3 eV cross-section value is 2.40762E+1 (b)
and interpolation scheme is 2(linear-linear).
Such a generation scheme for energy grid adopted in RESENDD code can not recommend, because too much cross section-change is occurred compared to the energy-grid-change. When such data points are plotted in log-log sheet, the results are quite the same in Fig.3.9.3.

Such type of errors are common errors in RESENDD code, already mentioned in Th-232,U-238 cases, and this error is due to the erroneous cross-section generation for very narrow resonances as seen in Appendix A.2. It is very important to generate cross-section curve to assure the calculated resonance integrals are the correct ones. Detailed discussion are given in Appendix A.2.

c. Differences between RESEND and others except 6.5 kev are systematically large by 10 % maximum.

Fig.3.9.1 Cross-section ratio for Fe-58 (n,gamma) in SAND-II 620-group structure (1).
Fig.3.9.2 Cross-section ratio for Fe-58 (n,gamma) in SAND-II 620-group structure (2).
Fig.3.9.3 Neutron cross-section of Fe-58 (n,gamma) from 6 keV to 6.5 keV.

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10.Cu-63 (n,gamma)

a. For the energy range 10 eV to 3keV, RECENT results differ quite large from the results of others. These differences is born from the improper treatment of back ground cross-section interpolation in RESEND and RESENDD codes. These two codes both cannot manipulate the interpolation correctly for the interpolation-scheme =1 case; i.e. constant interpolation case. As seen in Fig.3.10.3, RESEND and RESENDD cases are different constantly from 10 eV to 3 keV. For this energy range, back ground cross-section given in the original data in ENDF/B V file is 1.0E-2 and it's interpolation-code is 1.

Fig.3.10.1 Cross-section ratio for Cu-63 (n,gamma) in SAND-II 620-group structure (1).
Fig.3.10.2 Cross-section ratio for Cu-63 (n,gamma) in SAND-II 620-group structure (2).
Fig.3.10.3 Neutron cross-section of Cu-63 (n,gamma) from 1 eV to 10 keV.

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11.In-115 (n,gamma)

a. Agreement between RECENT and RESENDD is quite well.
b. Difference between RESEND and others is systematically large by 3 % maximum.

Fig.3.11.1 Cross-section ratio for Cu-63 (n,gamma) in

SAND-II 620-group structure (1).

Fig.3.11.2 Cross-section ratio for Cu-63 (n,gamma) in SAND-II 620-group structure (2).

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Table 3.1 Running performance of processing codes.

CPU time and generated data points.

No.	Nuclide	MAT	CPU-time (sec) RECENT	RESEND	RESENDD	Generated Points Number RECENT	RESEND	RESENDD
1	Na-23	6311	7	2	10	5155	1261	3973
2	Np-237	6337	145	110	146	33066	24673	32308
3	Au-197	6379	601	*3553	440	106530	*13026	54439
4	Th-232	6390	1685	*6746	724	216435	*14015	67167
5	U-235	6395	50	44	55	13000	10593	13422
6	U-238	6398	2353	**6266	960	231798	**8548	74069
7	Pu-239	6399	110	62	89	33485	6399	23892
8	Sc-45	6426	204	957	186	45462	16879	27573
9	Fe-58	6432	40	15	32	20535	6850	13082
10	Cu-63	6435	8	10	10	5836	3365	5356
11	In-115	6437	201	64	131	62391	17572	34637

Running conditions:
RECENT: LINEAR: 0.1 % ERR: 0.1 %
RESEND: ERR: 0.1 % AVERR: 0.0
RESENDD: ERR: 0.1 % AVERR: 0.0 LSIG:1.0E-10

According to the enormous running time,we had to change the error criteria for the *, ** cases.
* : ERR= 1.0 %
** : ERR= 10.0 %

Table 3.2 Performance of processing codes.

Relative CPU time and relative generated data points to RESENDD.

(Normalized to RESENDD result.)

No.	Nuclide	MAT	Relative CPU-time RECENT	RESEND	RESENDD	Relative generated points RECENT	RESEND	RESENDD
1	Na-23	6311	0.7	0.2	1.0	1.30	0.32	1.0
2	Np-237	6337	1.36	0.75	1.0	1.02	0.76	1.0
3	Au-197	6379	1.37	*8.08	1.0	1.96	*0.24	1.0
4	Th-232	6390	2.33	*9.32	1.0	3.22	*0.21	1.0
5	U-235	6395	0.91	0.80	1.0	0.97	0.79	1.0
6	U-238	6398	2.45	**6.63	1.0	3.13	**0.12	1.0
7	Pu-239	6399	1.24	0.70	1.0	1.40	0.26	1.0
8	Sc-45	6426	1.10	5.15	1.0	1.67	0.61	1.0
9	Fe-58	6432	1.25	0.47	1.0	1.57	0.52	1.0
10	Cu-63	6435	0.80	1.00	1.0	1.09	0.63	1.0
11	In-115	6437	1.53	0.49	1.0	1.80	0.51	1.0

Running conditions:
RECENT: LINEAR: 0.1 % ERR: 0.1 %
RESEND: ERR: 0.1 % AVERR: 0.0
RESENDD: ERR: 0.1 % AVERR: 0.0 LSIG:1.0E-10

According to the enormous running time,we had to change the error criteria for the *, ** cases.
* : ERR= 1.0 %
** : ERR= 10.0 %

Table 3.3 Performamce of processing codes.

CPU time per one generated data point.

(in seconds.)

No.	Nuclide	MAT	RECENT	RESEND	RESENDD
1	Na-23	6311	1.36E-3	1.59E-3	2.51E-3
2	Np-237	6337	4.39E-3	4.45E-3	4.51E-3
3	Au-197	6379	5.64E-3	*2.72E-1	8.08E-3
4	Th-232	6390	7.79E-3	*4.81E-1	1.08E-2
5	U-235	6395	3.85E-3	4.15E-3	4.10E-3
6	U-238	6398	1.02E-2	**7.33E-1	1.30E-2
7	Pu-239	6399	3.29E-3	9.69E-3	3.73E-3
8	Sc-45	6426	4.49E-3	5.66E-2	6.75E-3
9	Fe-58	6432	1.95E-3	2.19E-3	2.45E-3
10	Cu-63	6435	1.37E-3	2.97E-3	1.87E-3
11	In-115	6437	3.22E-3	3.64E-3	3.78E-3

Running conditions:
RECENT: LINEAR: 0.1 % ERR: 0.1 %
RESEND: ERR: 0.1 % AVERR: 0.0
RESENDD: ERR: 0.1 % AVERR: 0.0 LSIG:1.0E-10

According to the enormous running time,we had to change the error criteria for the *, ** cases.
* : ERR= 1.0 %
** : ERR= 10.0 %

TABLE 3.4 Performance of processing codes.

CPU time per one resonance level(resolved+unresolved)

(in seconds.)

No.	Nuclide	MAT	RECENT	RESEND	RESENDD	form. no.r
1	Na-23	6311	0.58	0.17	0.83	MLBW 12
2	Np-237	6337	0.48	0.36	0.48	SLBW 304
3	Au-197	6379	2.29	*13.51	1.67	MLBW 263
4	Th-232	6390	4.22	*16.90	1.81	MLBW 399
5	U-235	6395	0.19	0.16	0.21	SLBW 267
6	U-238	6398	11.77	**31.33	4.80	MLBW 200
7	Pu-239	6399	0.50	0.28	0.40	SLBW 222
8	Sc-45	6426	2.58	12.11	2.35	MLBW 79
9	Fe-58	6432	3.33	1.25	2.67	SLBW 12
10	Cu-63	6435	0.42	0.52	0.52	MLBW 19
11	In-115	6437	2.26	0.72	1.47	SLBW 89

Running conditions:
RECENT: LINEAR: 0.1 % ERR: 0.1 %
RESEND: ERR: 0.1 % AVERR: 0.0
RESENDD: ERR: 0.1 % AVERR: 0.0 LSIG:1.0E-10

According to the enormous running time,we had to change the error criteria for the *, ** cases.
* : ERR= 1.0 %
** : ERR= 10.0 %

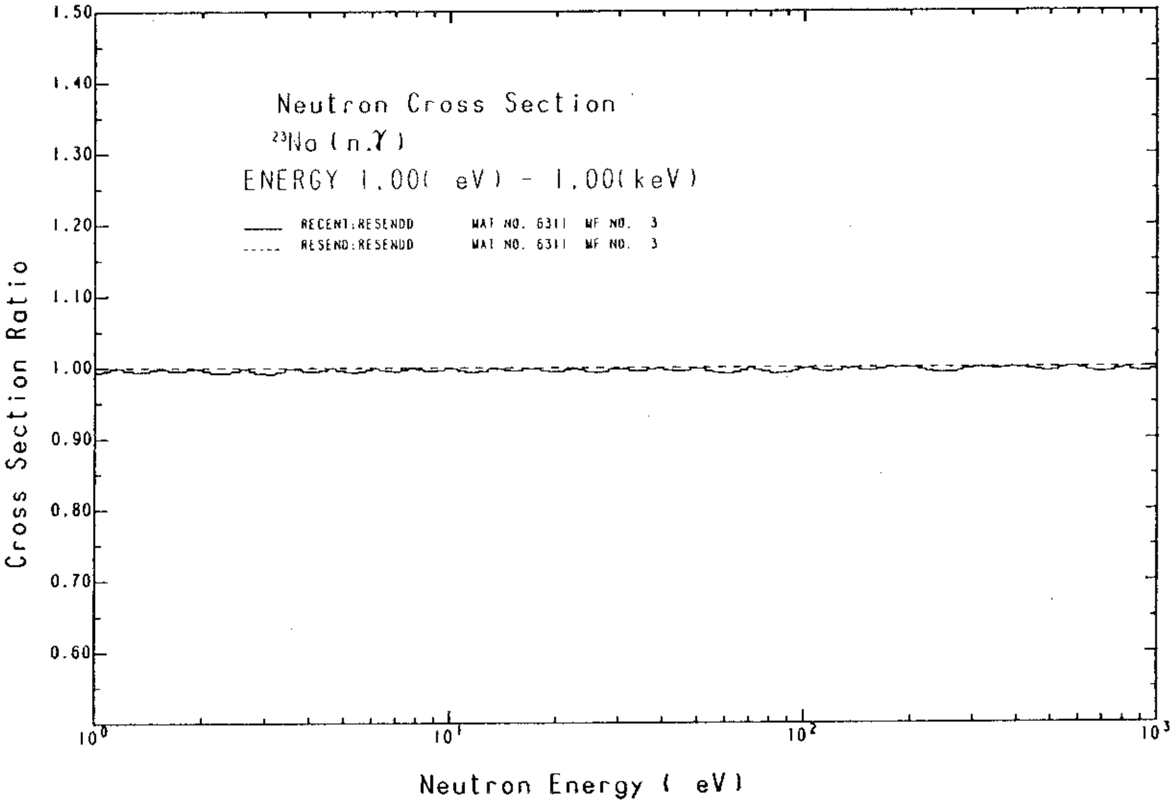

Fig.3.1.1 Cross-section ratio for Na-23 (n, gamma) in SAND-II 620-group structure (1)

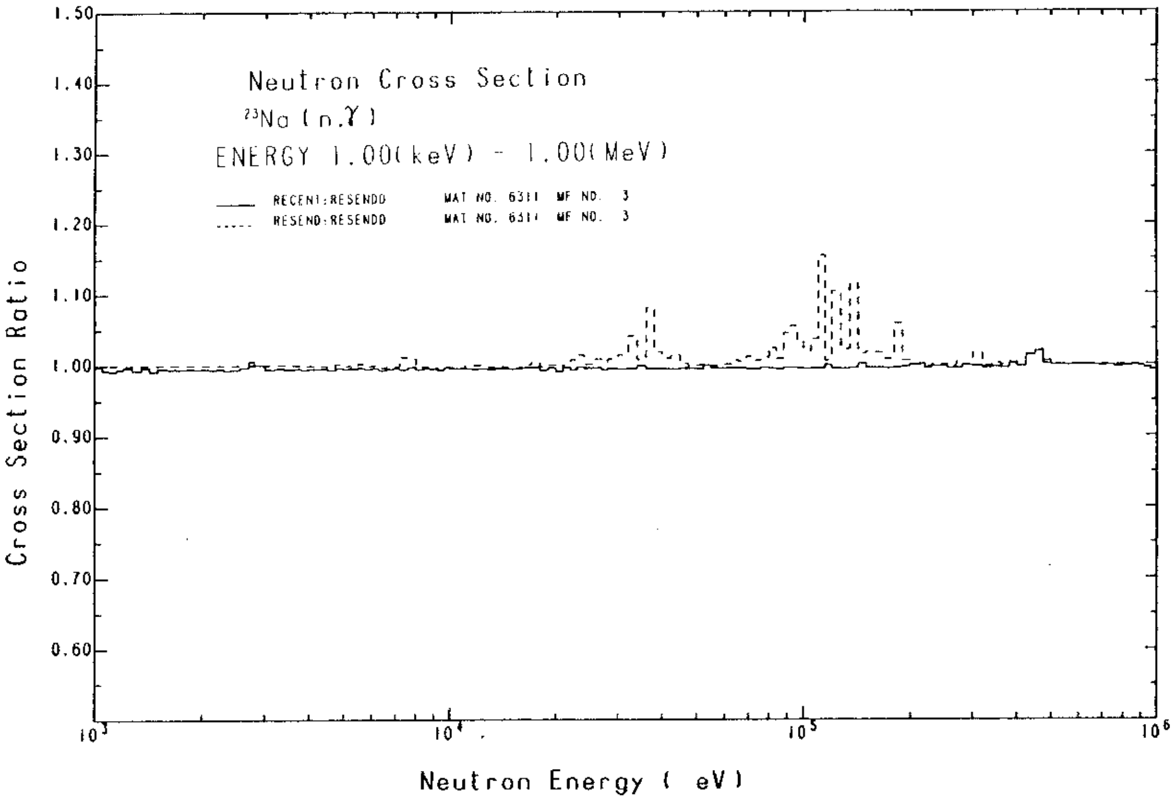

Fig.3.1.2 Cross-section ratio for Na-23 (n, gamma) in SAND-II 620-group structure (2)

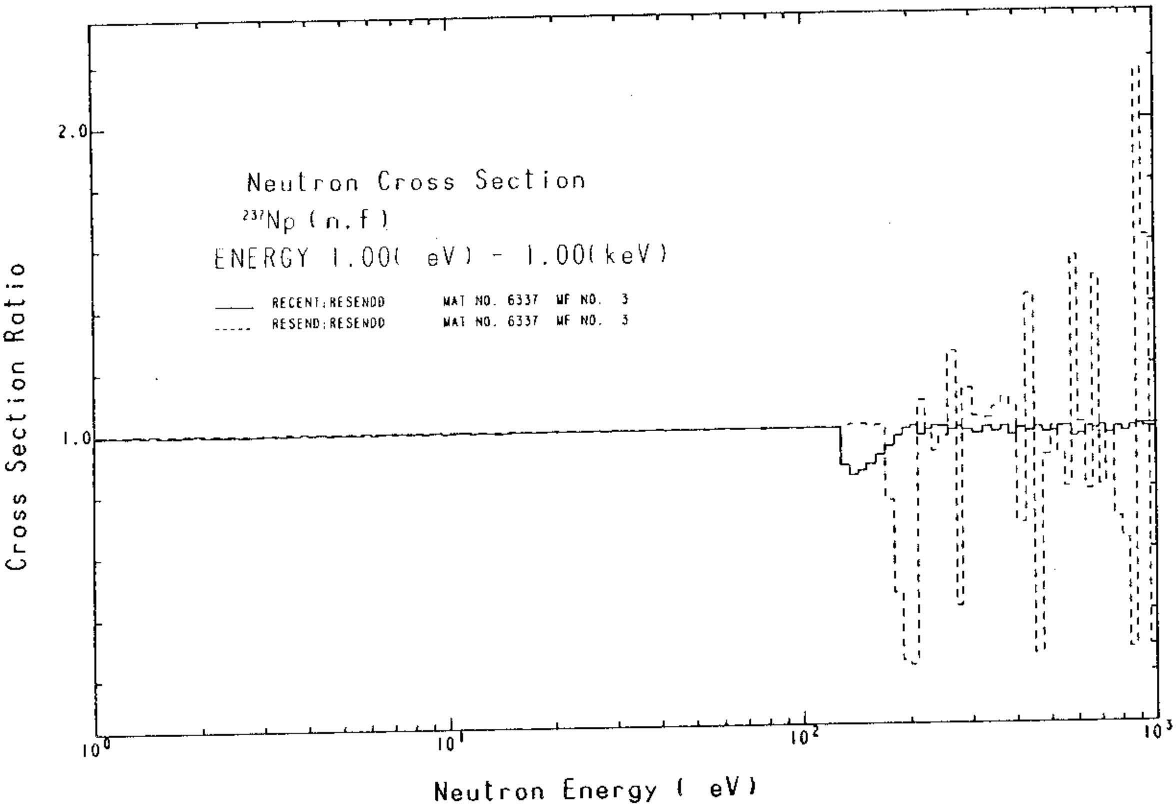

Fig.3.2.1 Cross-section ratio for Np-237 (n, f) in SAND-II 620-group structure (1)

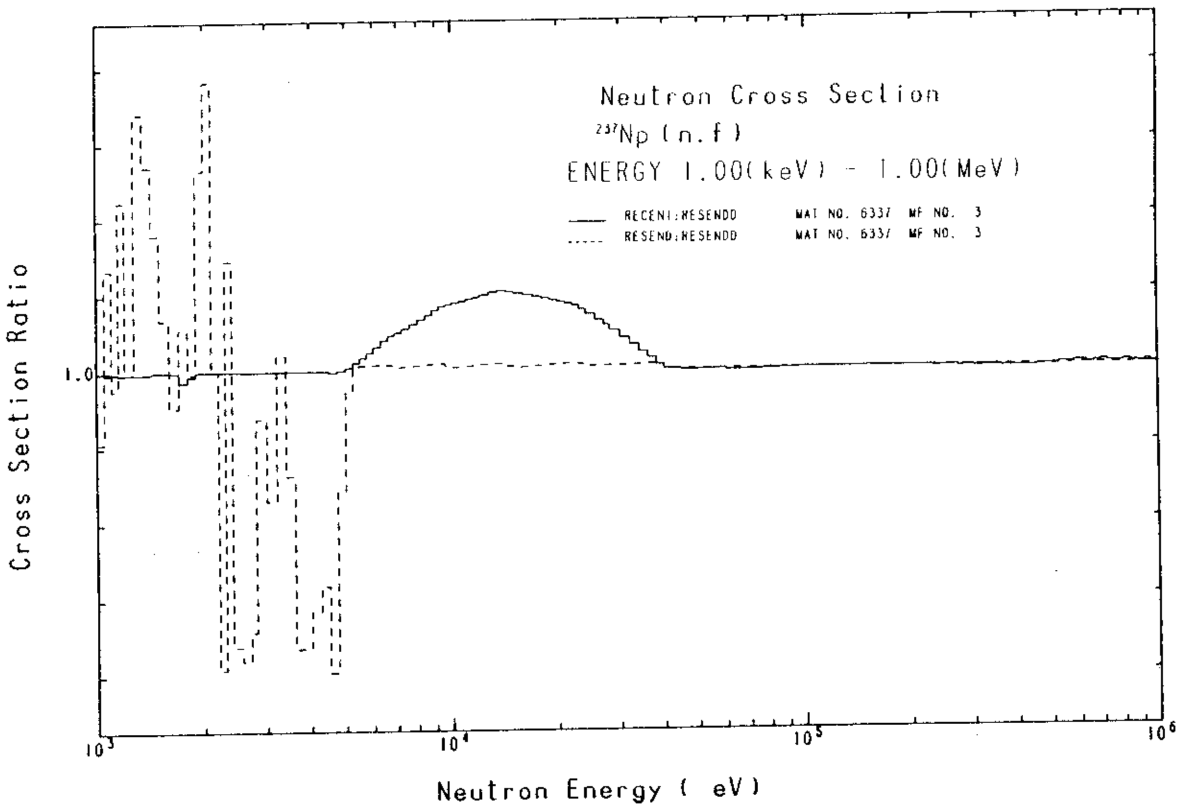

Fig.3.2.2 Cross-section ratio for Np-237 (n, f) in SAND-II 620-group structure (2)

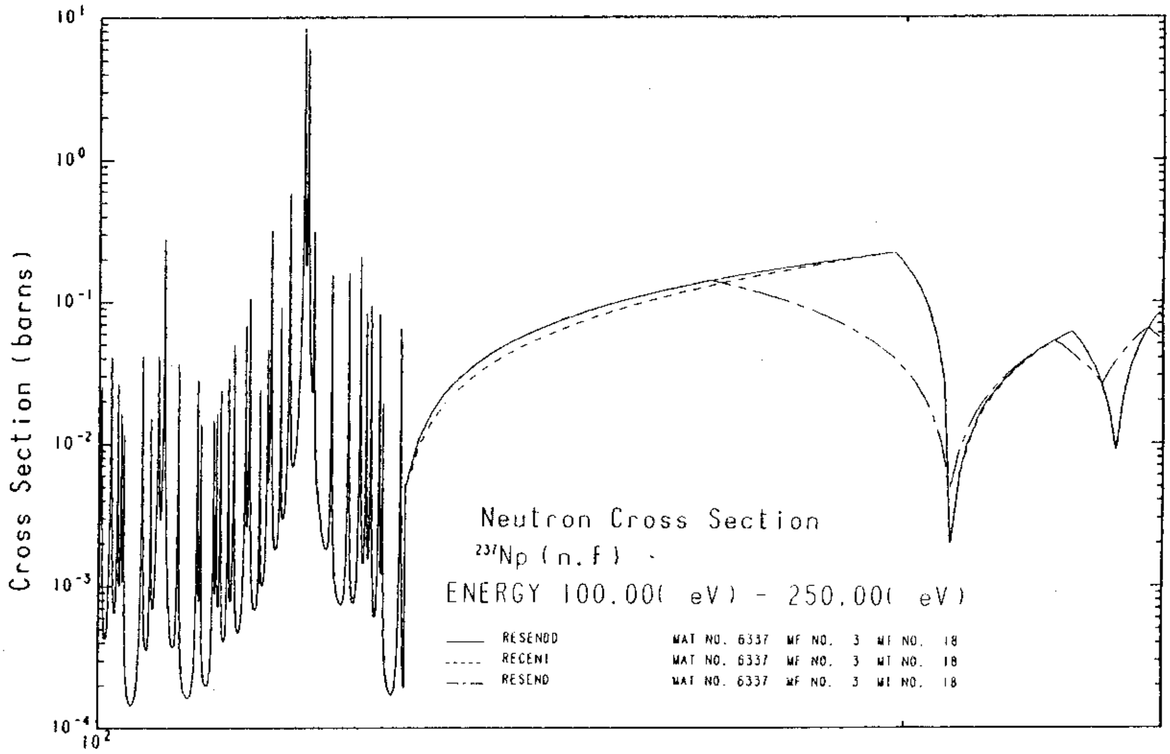

Fig.3.2.3 Neutron cross-section of Np-237 (n, f) from 100 eV to 250 eV

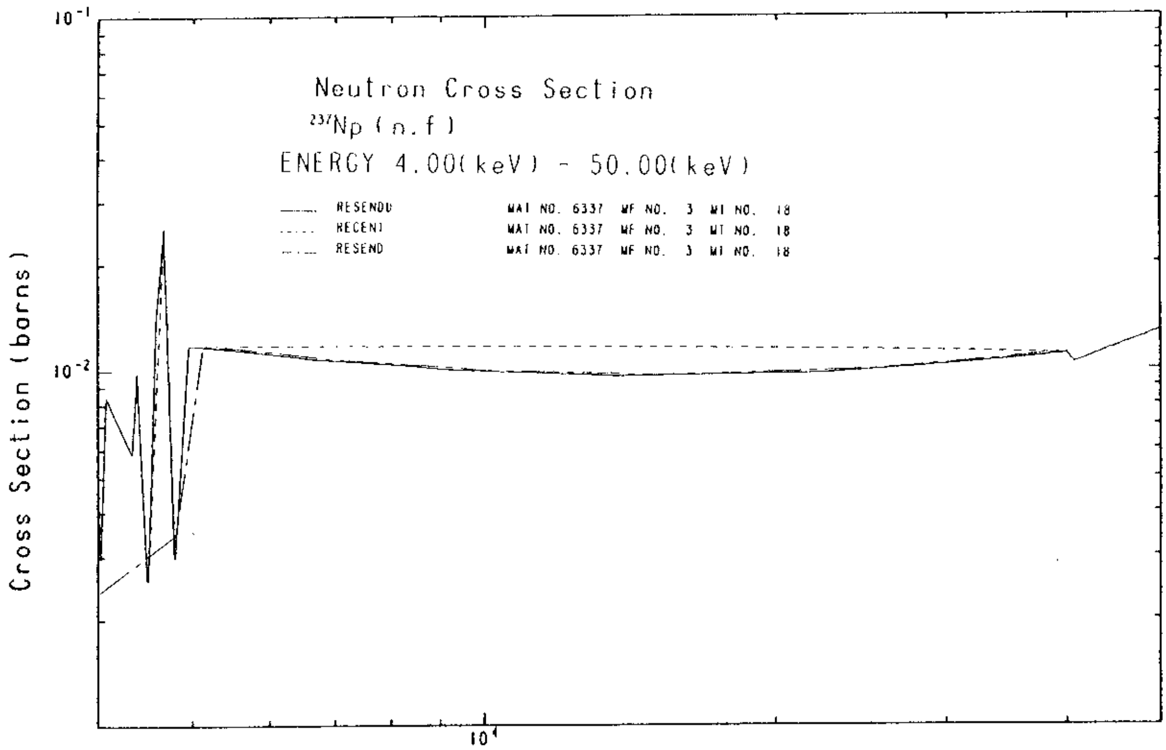

Fig.3.2.4 Nertron cross-section of Np-237 (n, f) from 4 keV to 50 keV

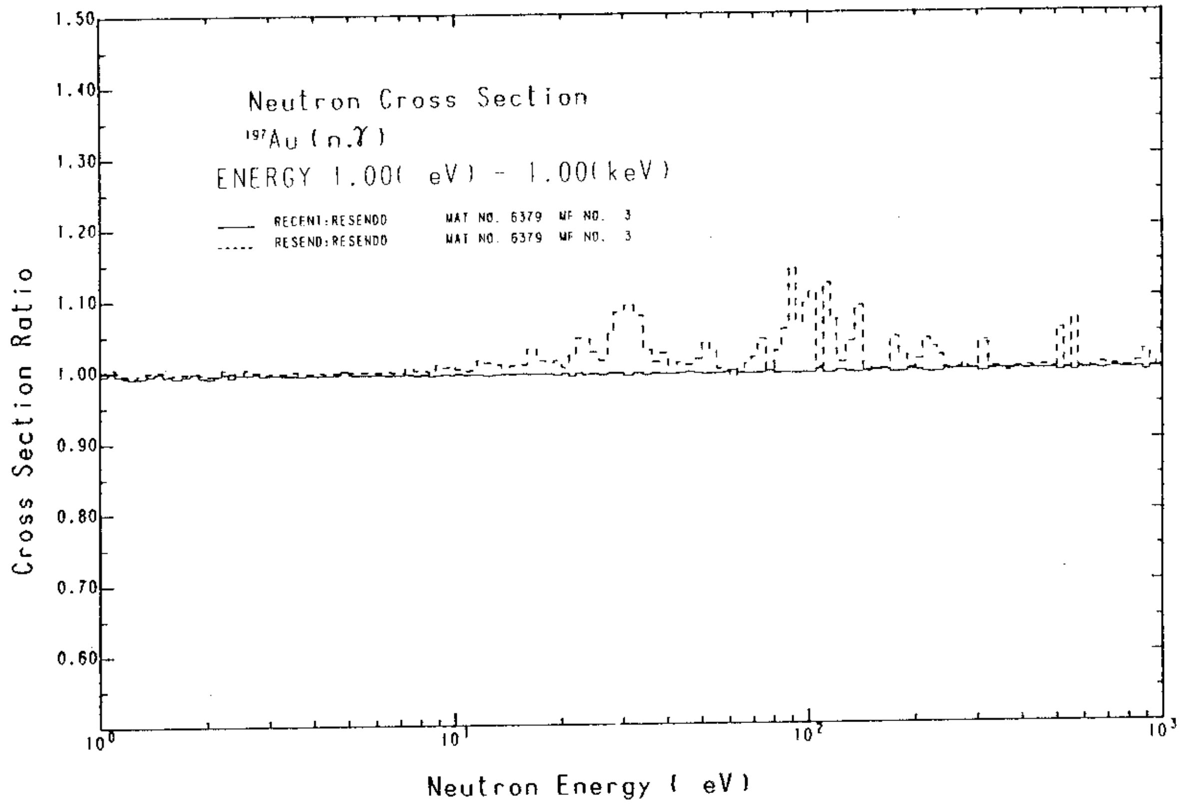

Fig.3.3.1 Cross-section ratio for Au-197 (n, gamma) in SAND-II 620-group structure (1)

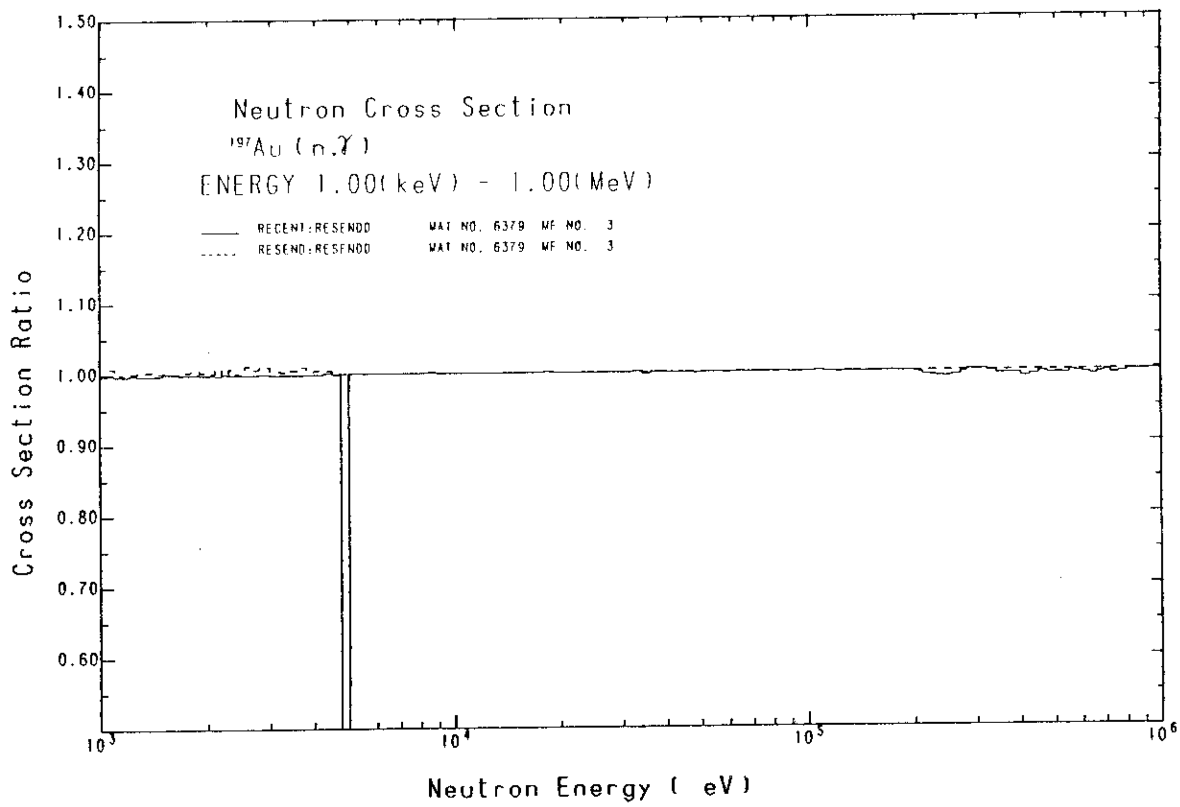

Fig.3.3.2 Cross-section ratio for Au-197 (n, gamma) in SAND-II 620-group structure (2)

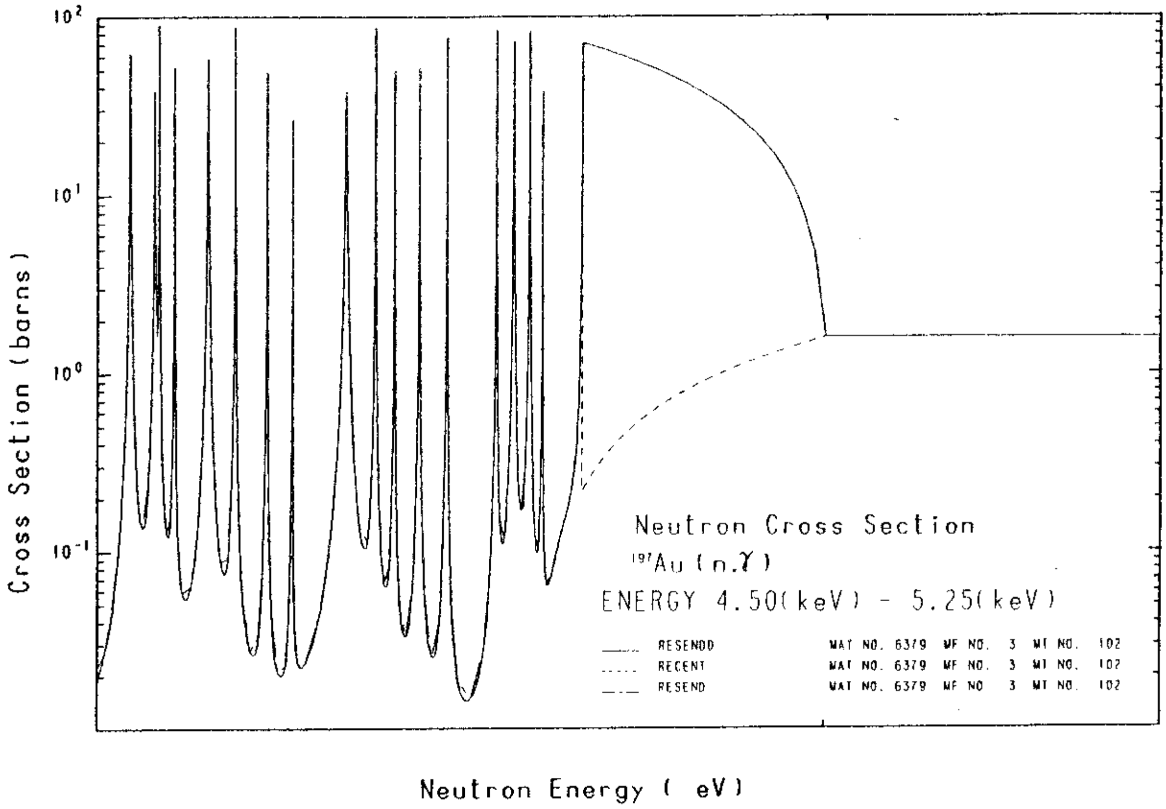

Fig.3.3.3 Neutron cross-section of Au-197 (n, gamma) from 4.5 keV to 5.25 keV

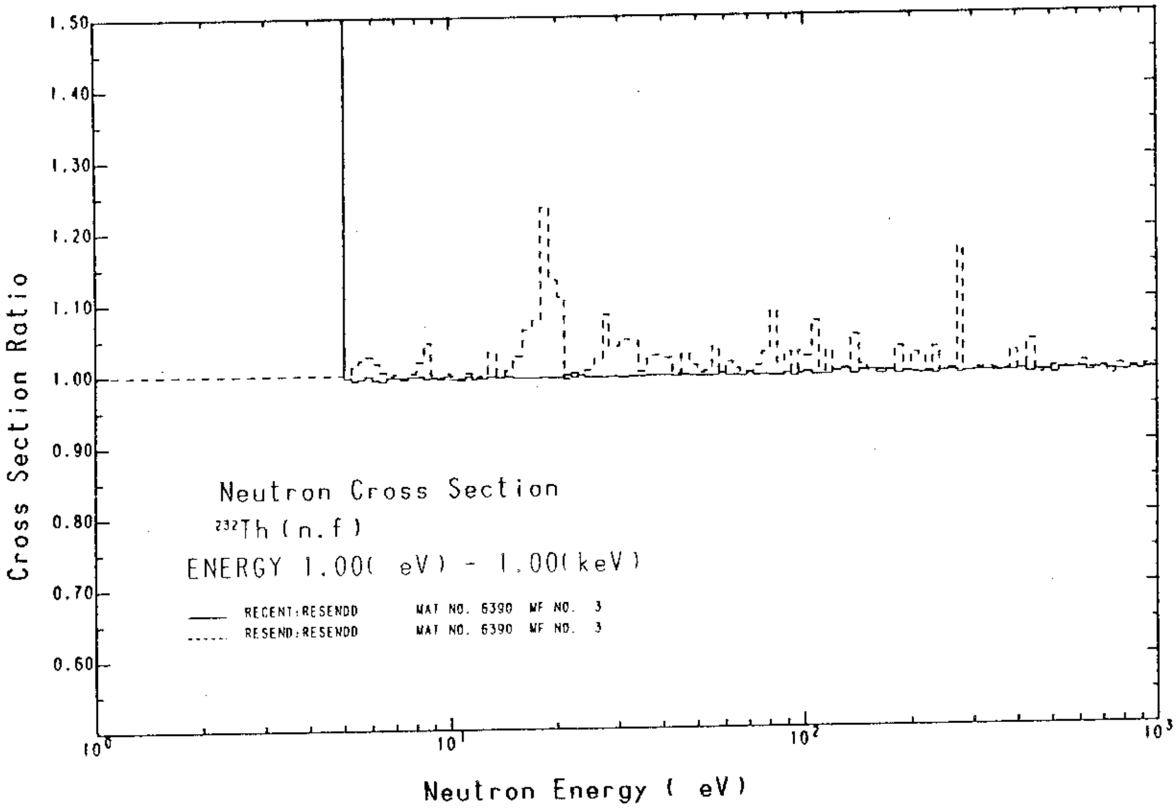

Fig.3.4.1 Cross-section ratio for Th-232 (n, f) in SAND-II 620-group structure (1)

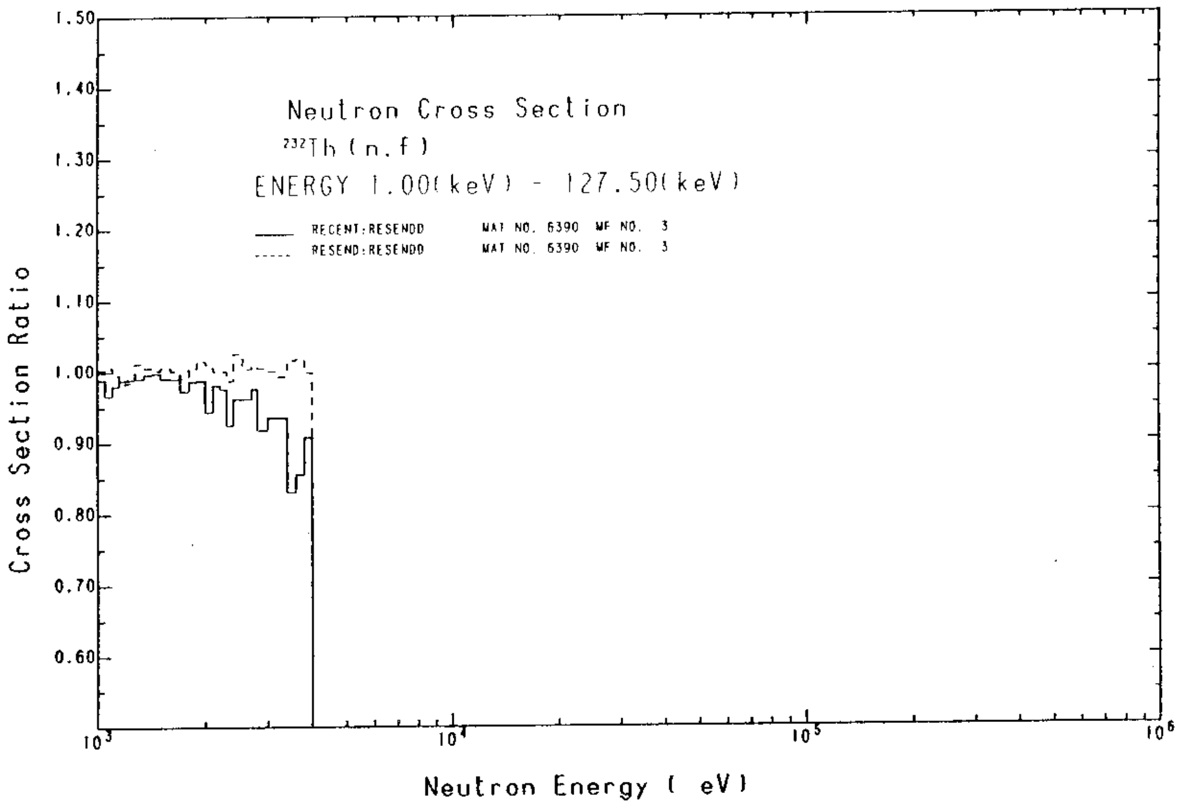

Fig.3.4.2 Cross section ratio for Th-232 (n, f) in SAND-II 620-group structure (2)

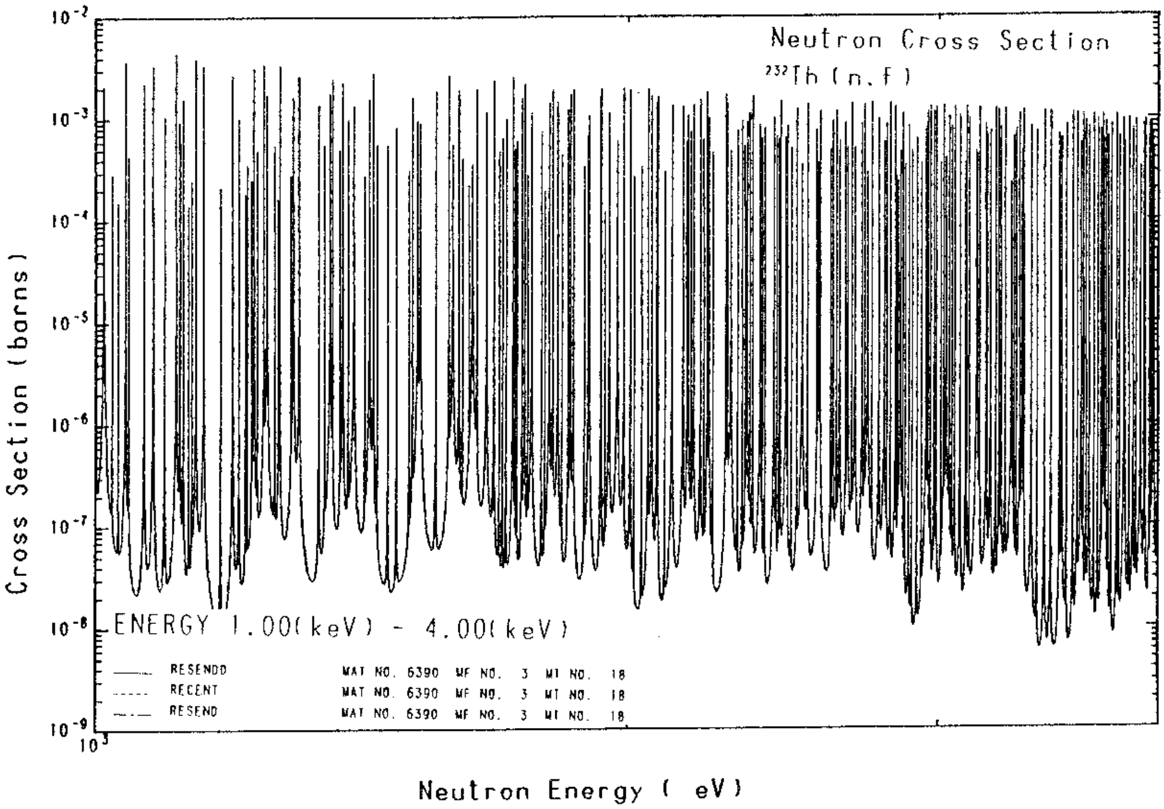

Fig.3.4.3 Neutron cross-section of Th-232 (n, f) from 1 keV to 4 keV

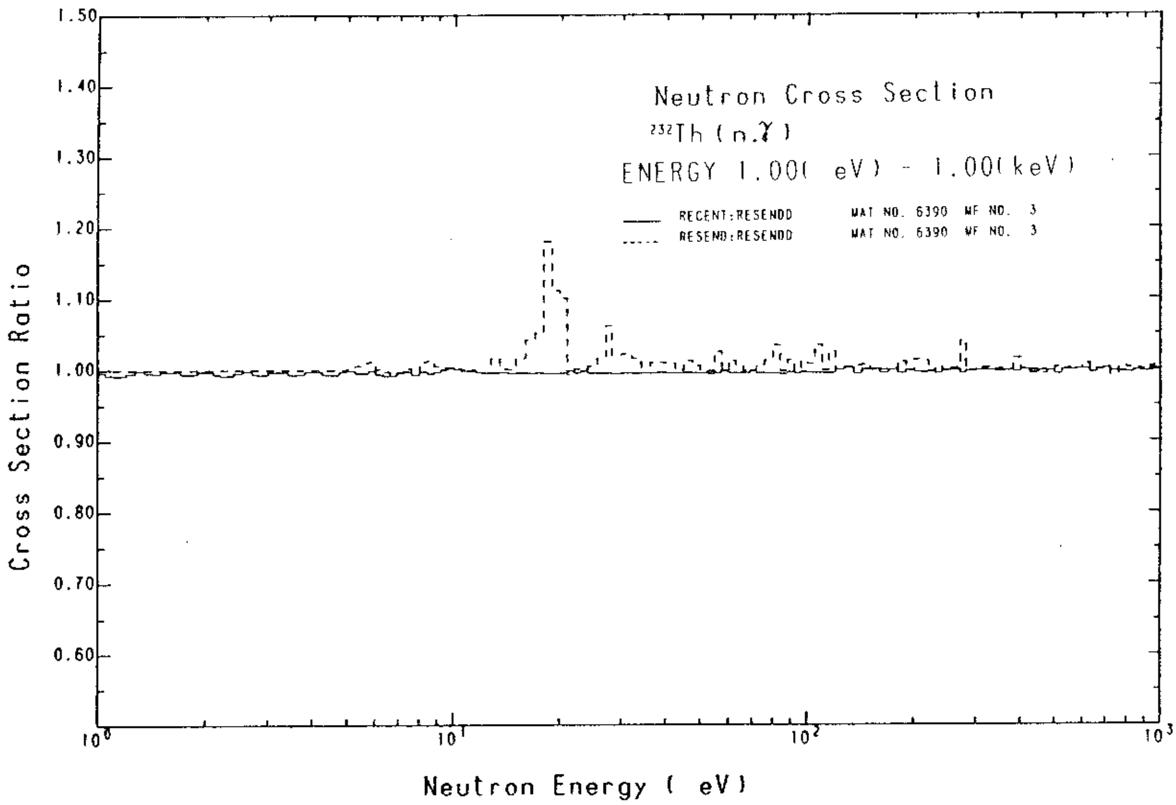

Fig.3.4.4 Cross-section ratio for Th-232 (n, gamma) in SAND-II 620-group structure (1)

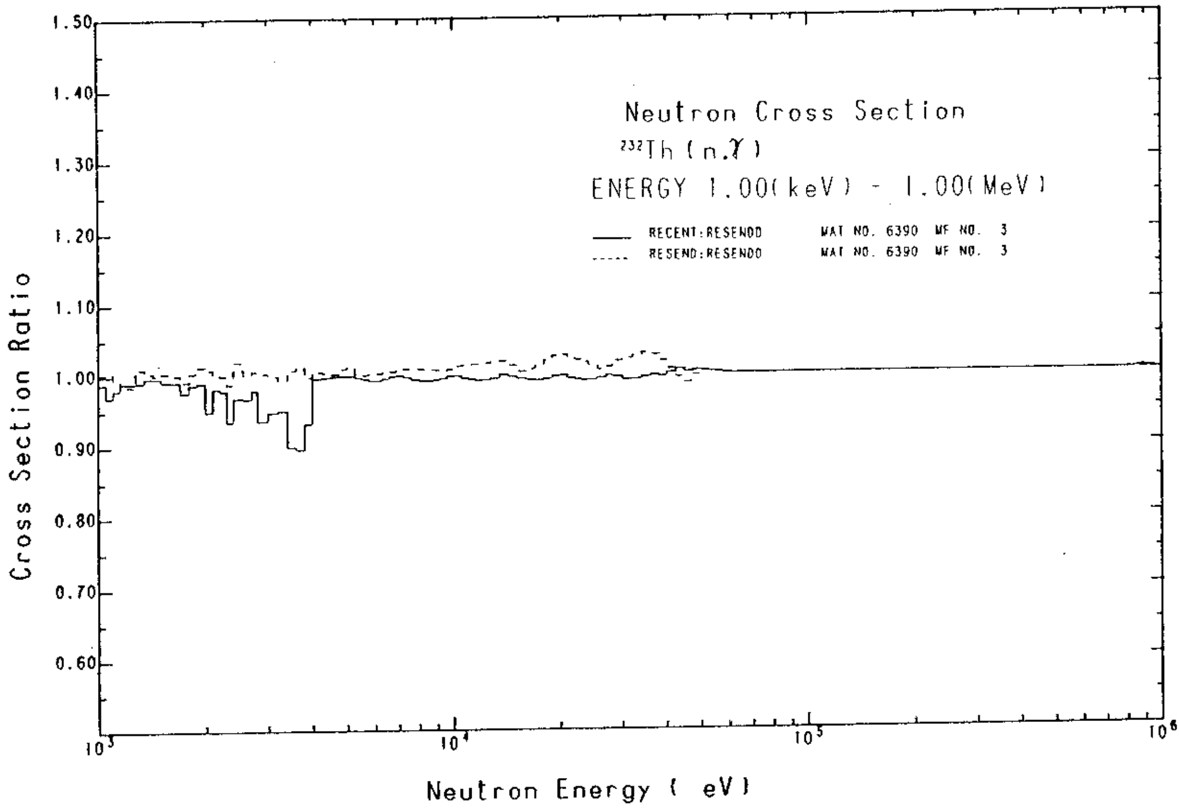

Fig.3.4.5 Cross-section ratio for Th-232 (n, gamma) in SAND-II 620-group structure (2)

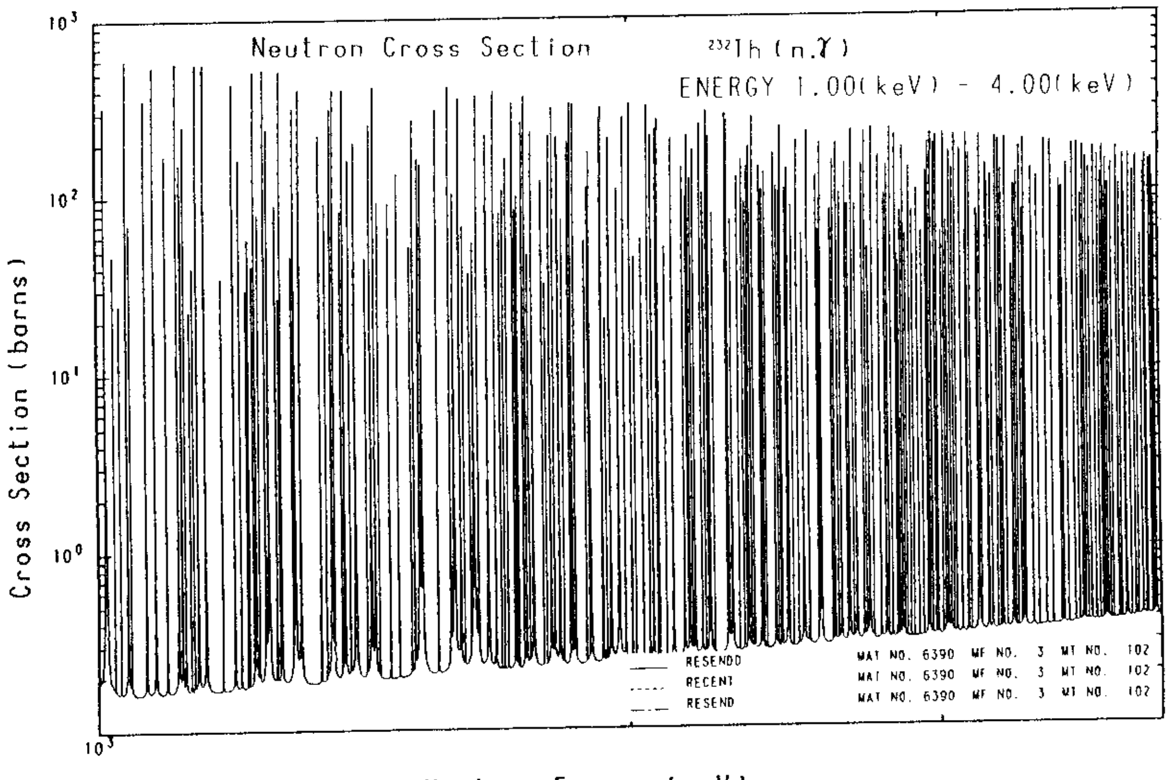

Fig.3.4.6 Neutron cross-section of Th-232 (n, gamma) from 1 keV to 4 keV

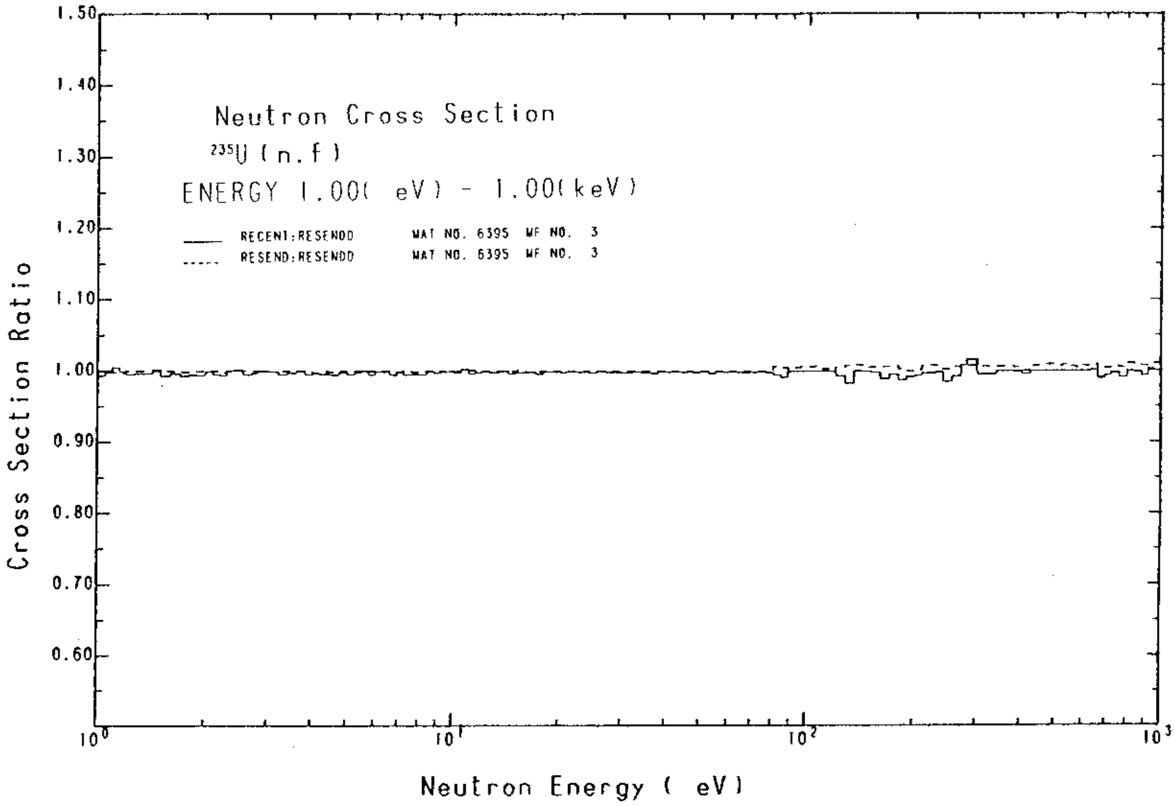

Fig.3.5.1 Cross-section ratio for U-235 (n, f) in SAND-II 620-group structure (1)

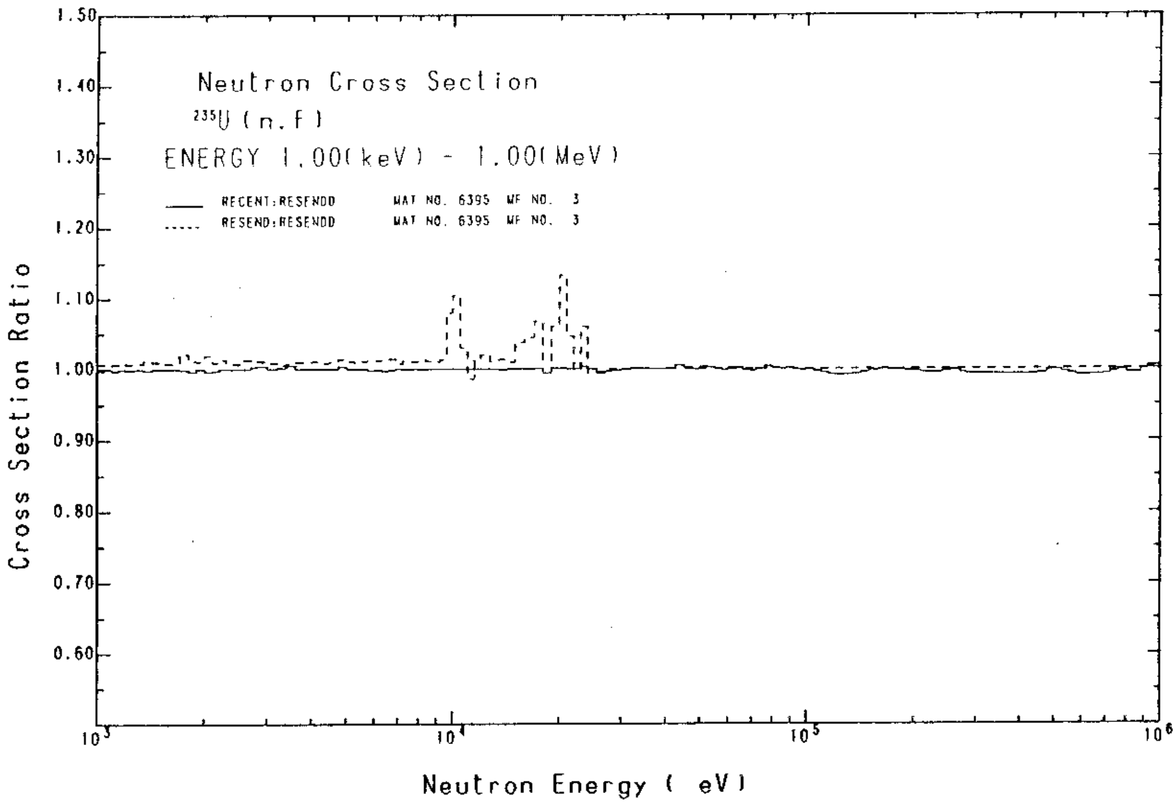

Fig.3.5.2 Cross-section ratio for U-235 (n, f) in SAND-II 620-group structure (2)

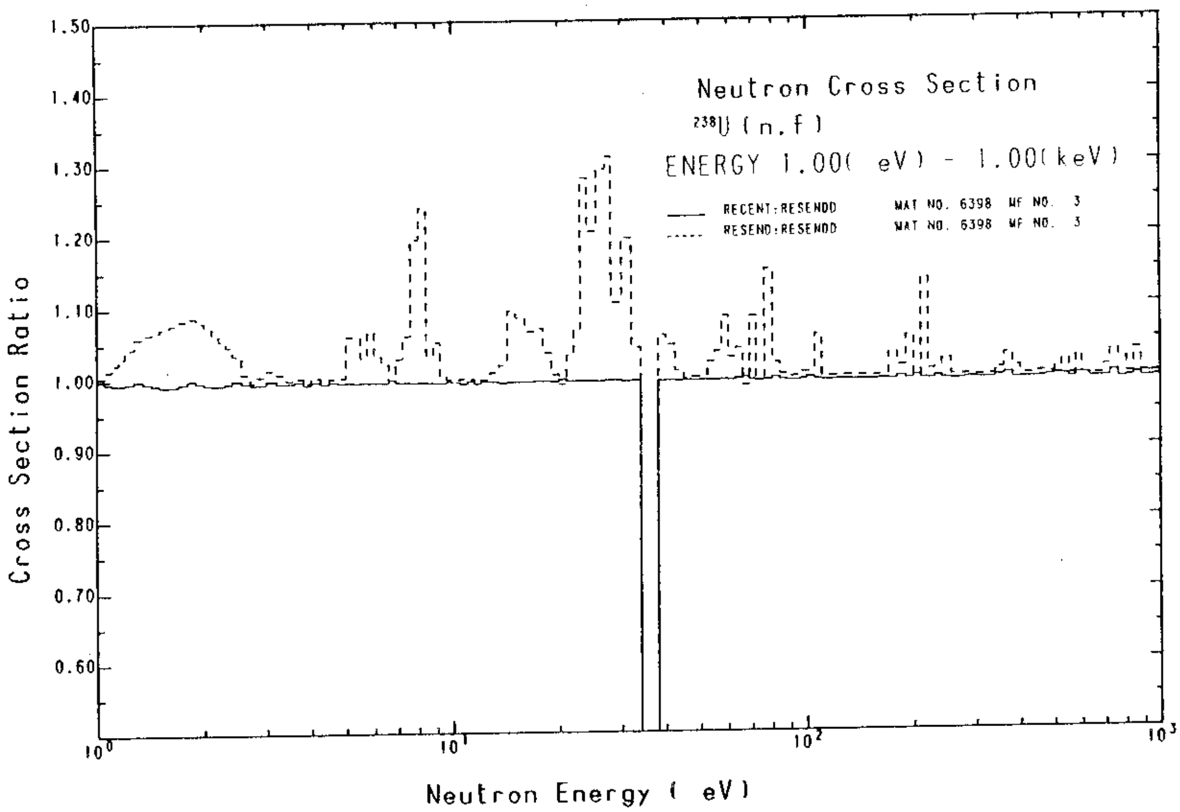

Fig.3.6.1 Cross-section ratio for U-238 (n, f) in SAND-II 620-group structure (1)

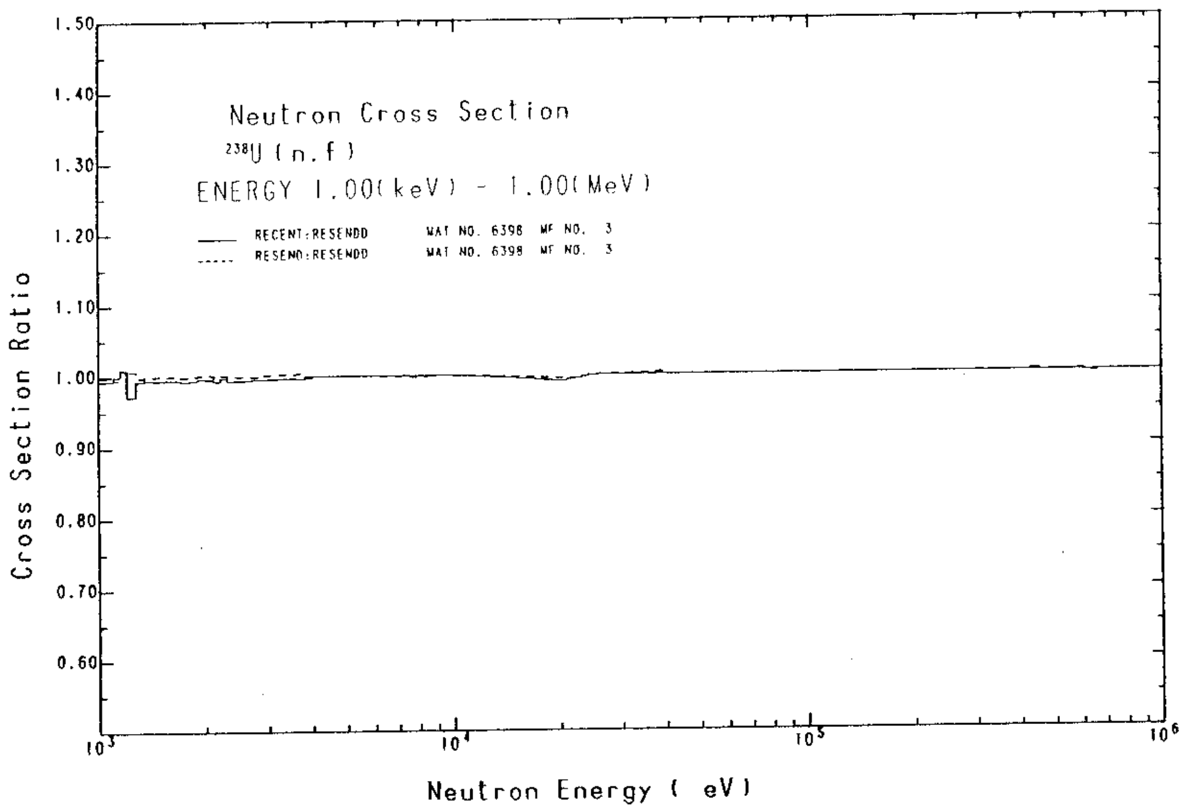

Fig.3.6.2 Cross-section ratio for U-238 (n, f) in SAND-II 620-group structure (2)

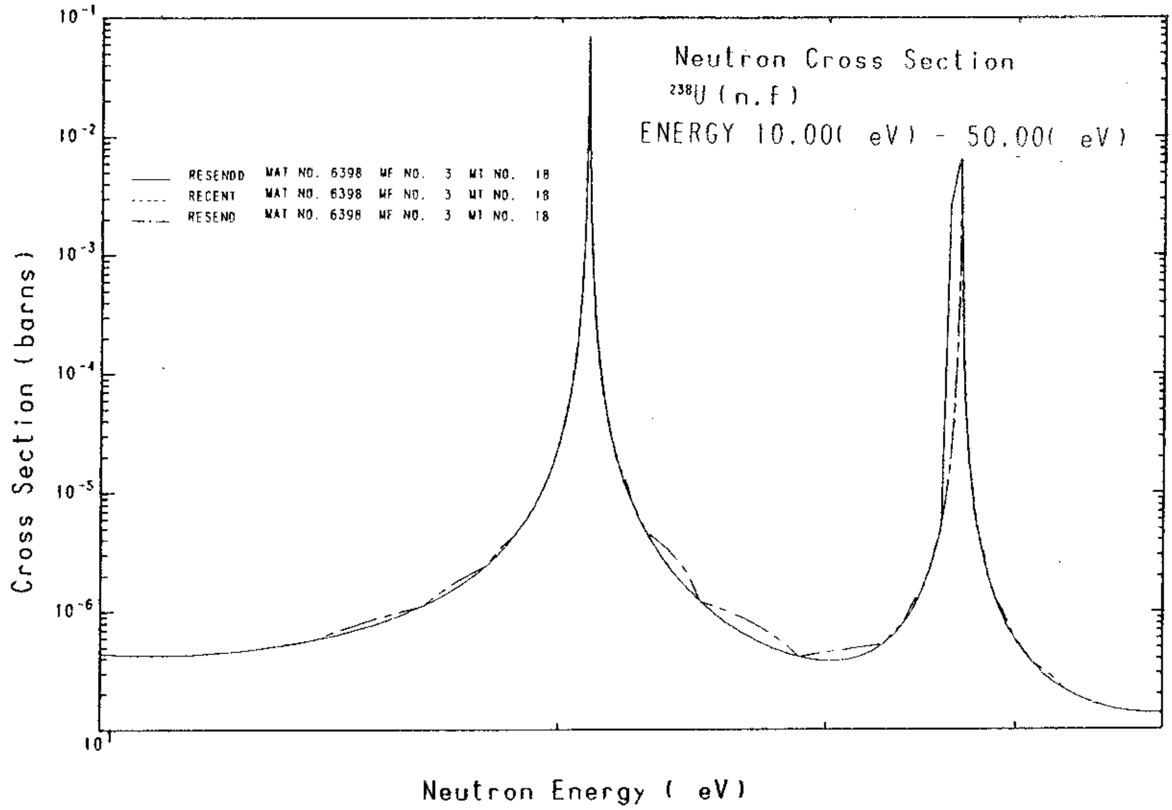

Fig.3.6.3 Neutron cross-section of U-238 (n, f) from 10 eV to 50 eV

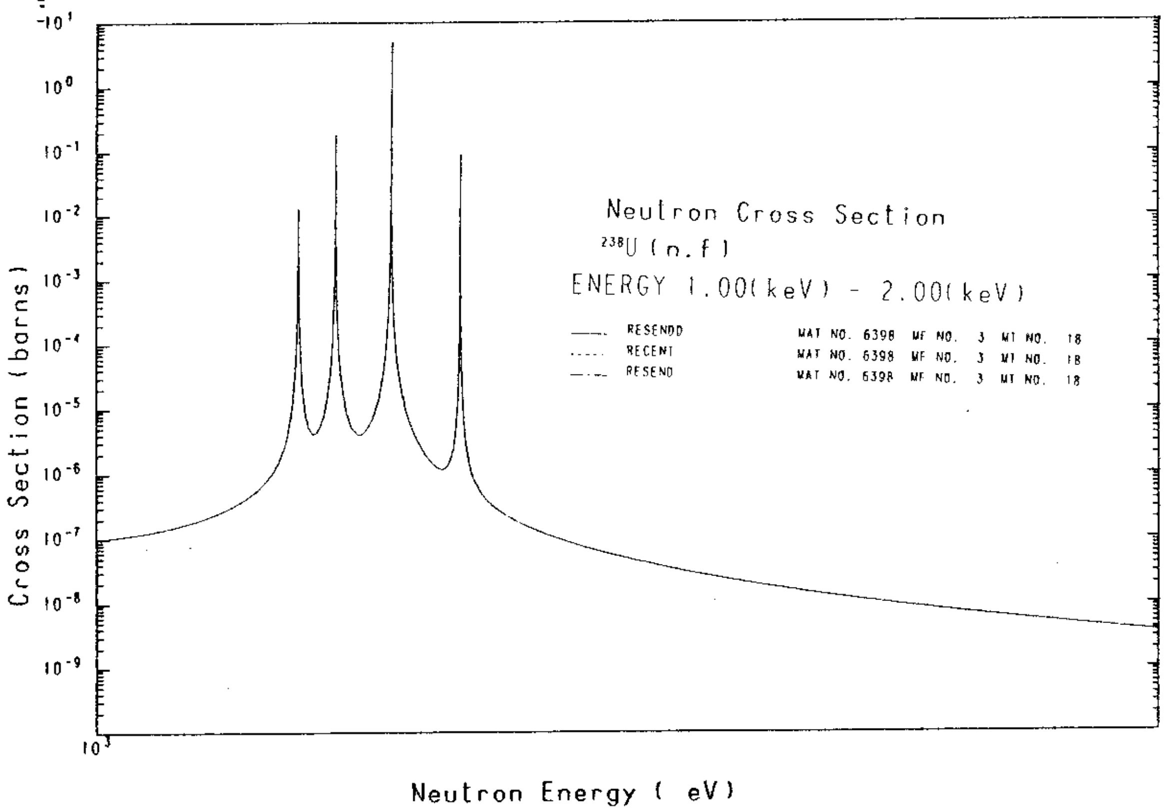

Fig.3.6.4 Neutron cross-section of U-238 (n, f) from 1 keV to 2 keV

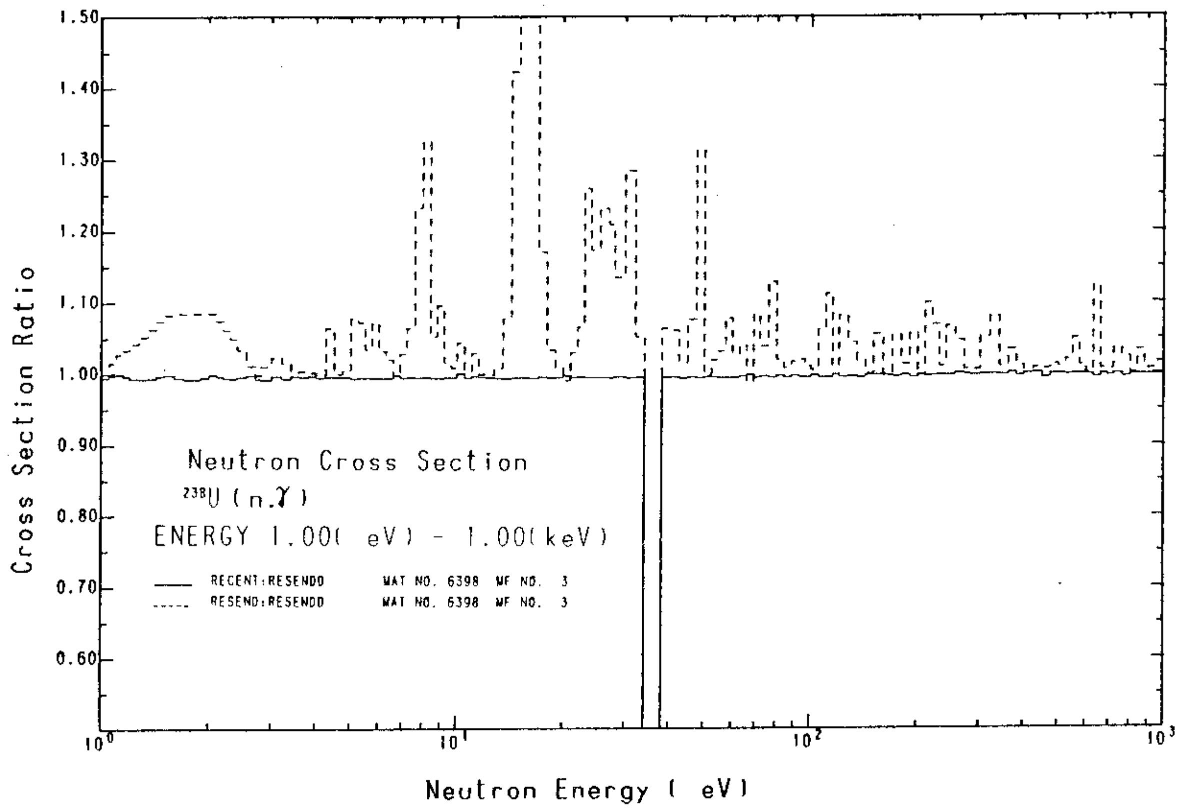

Fig.3.6.5 Cross-section ratio for U-238 (n, gamma) in SAND-II 620-group structure (1)

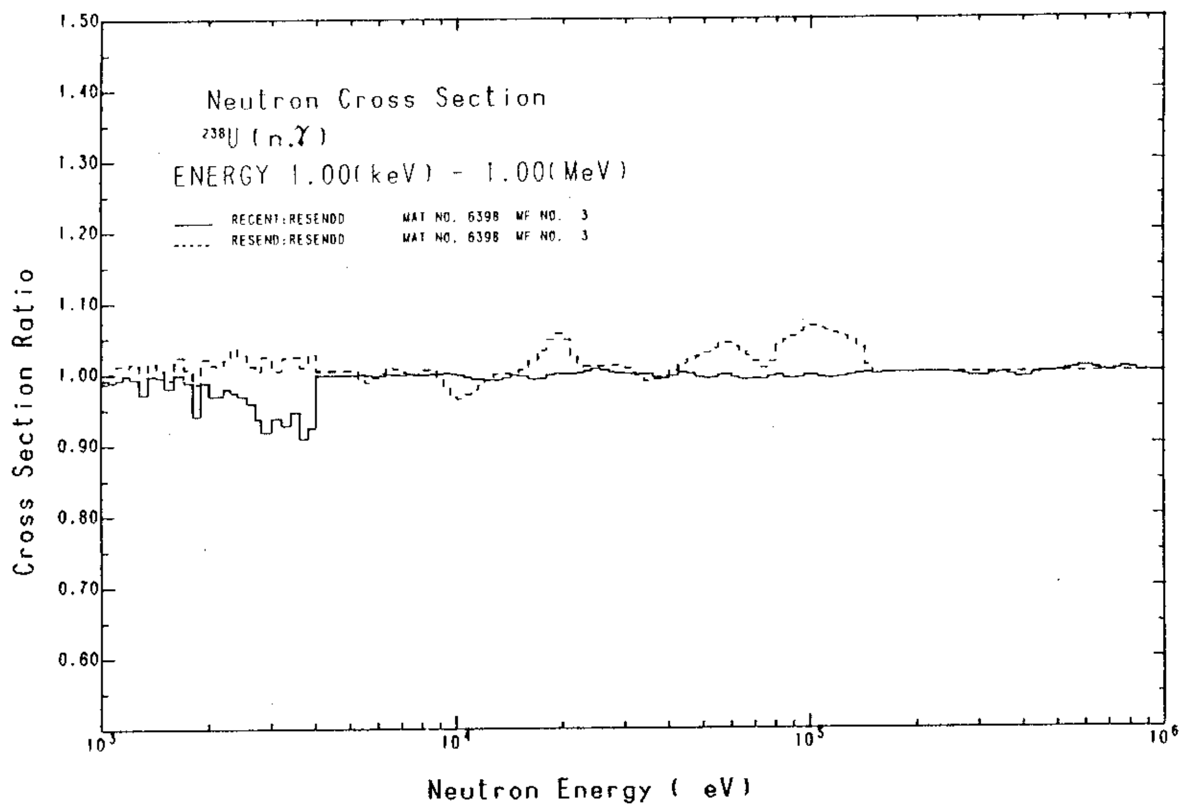

Fig.3.6.6 Cross-section ratio for U-238 (n, gamma) in SAND-II 620-group structure (2)

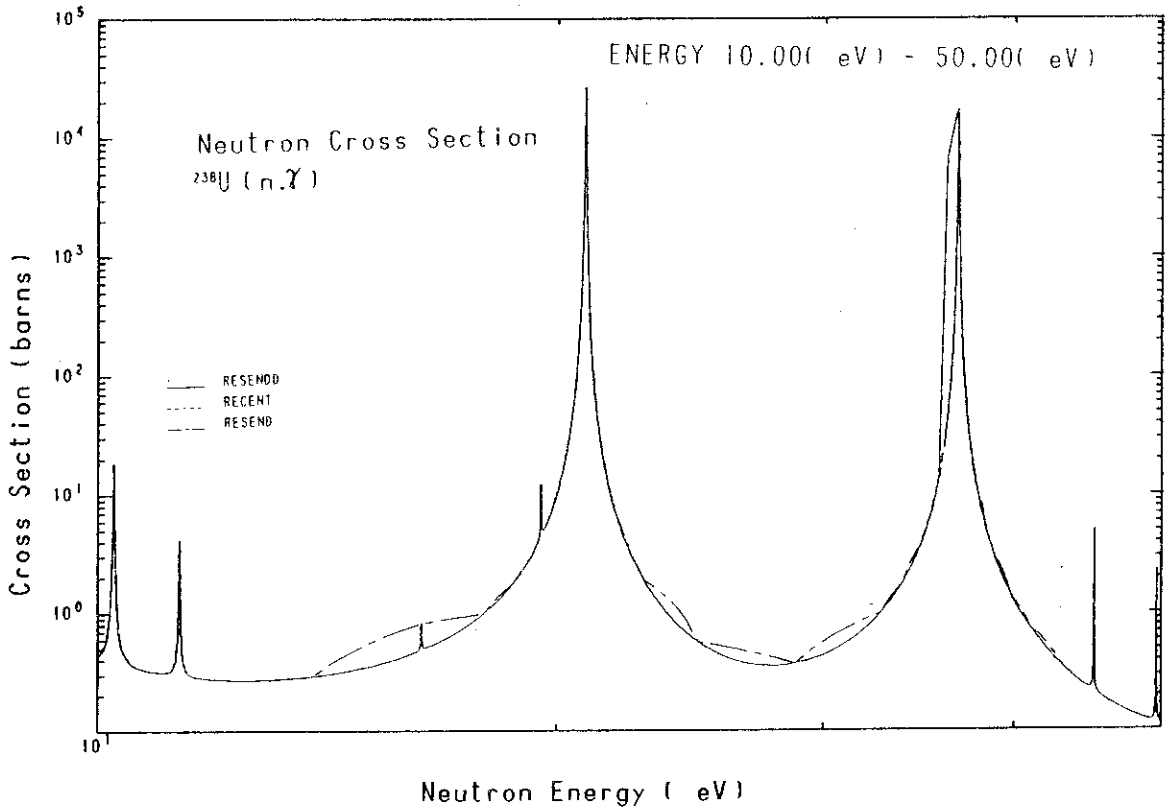

Fig.3.6.7 Neutron cross-section of U-238 (n, gamma) from 10 eV to 50 eV

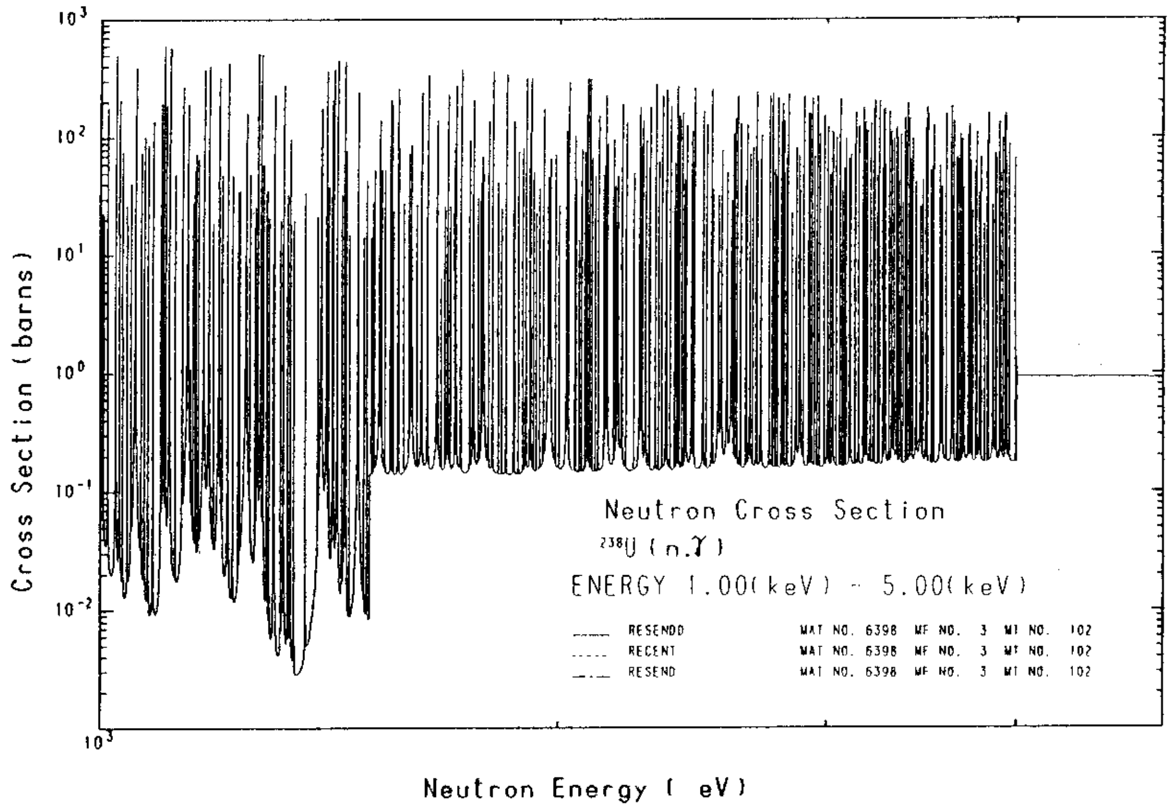

Fig.3.6.8 Neutron cross-section of U-238 (n, gamma) from 1 keV to 5 keV

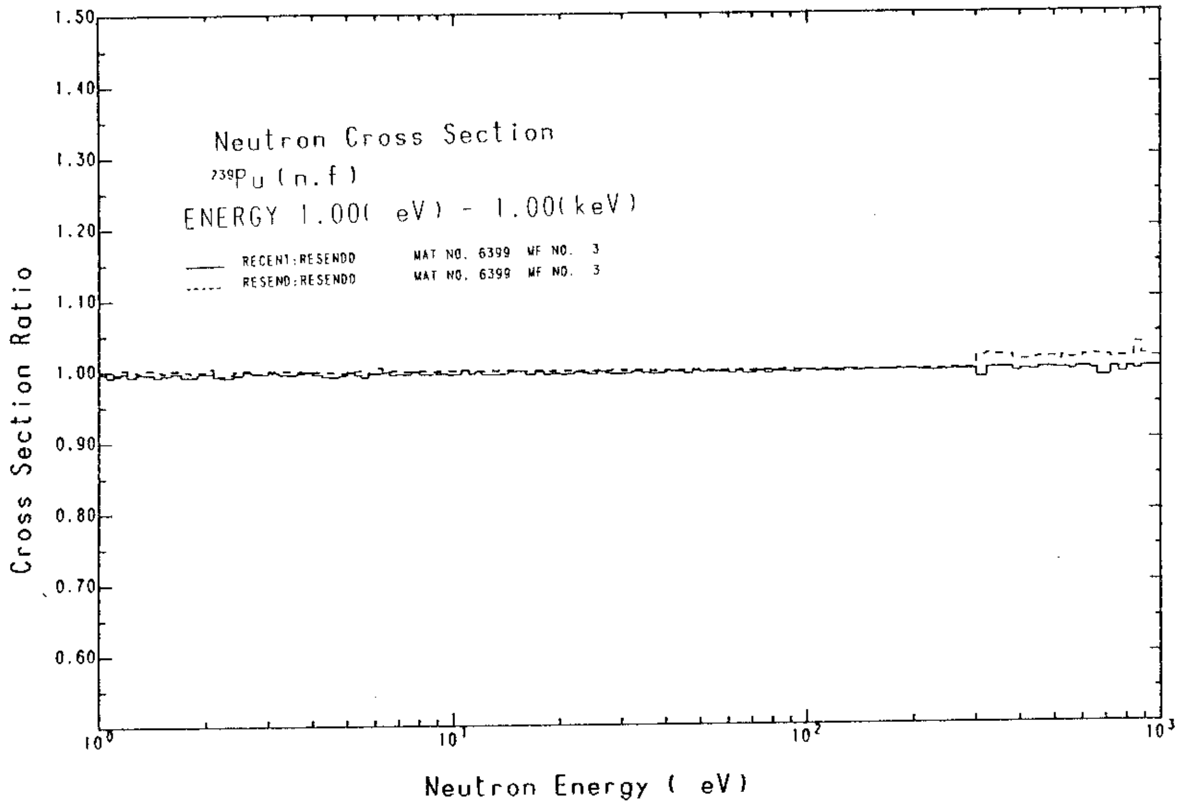

Fig.3.7.1 Cross-section ratio for Pu-239 (n, f) in SAND-II 620-group structure (1)

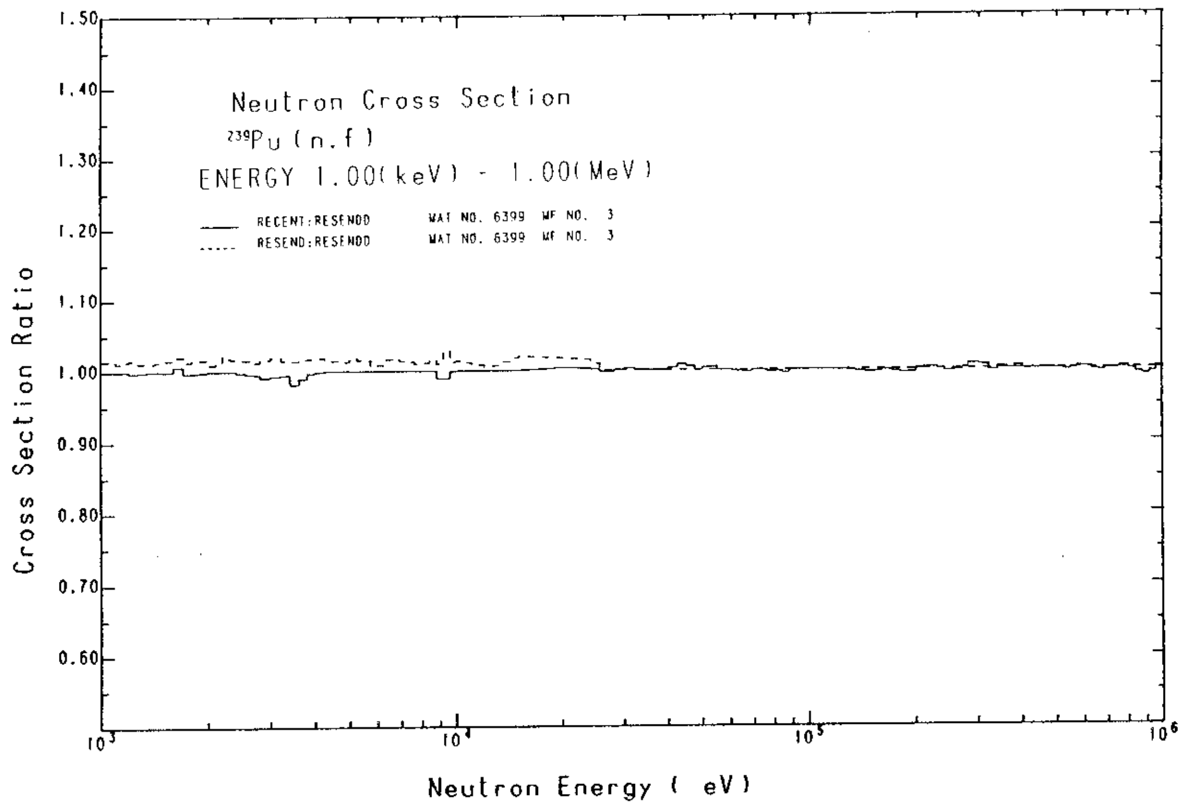

Fig.3.7.2 Cross-section ratio for Pu-239 (n, f) in SAND-II 620-group structure (2)

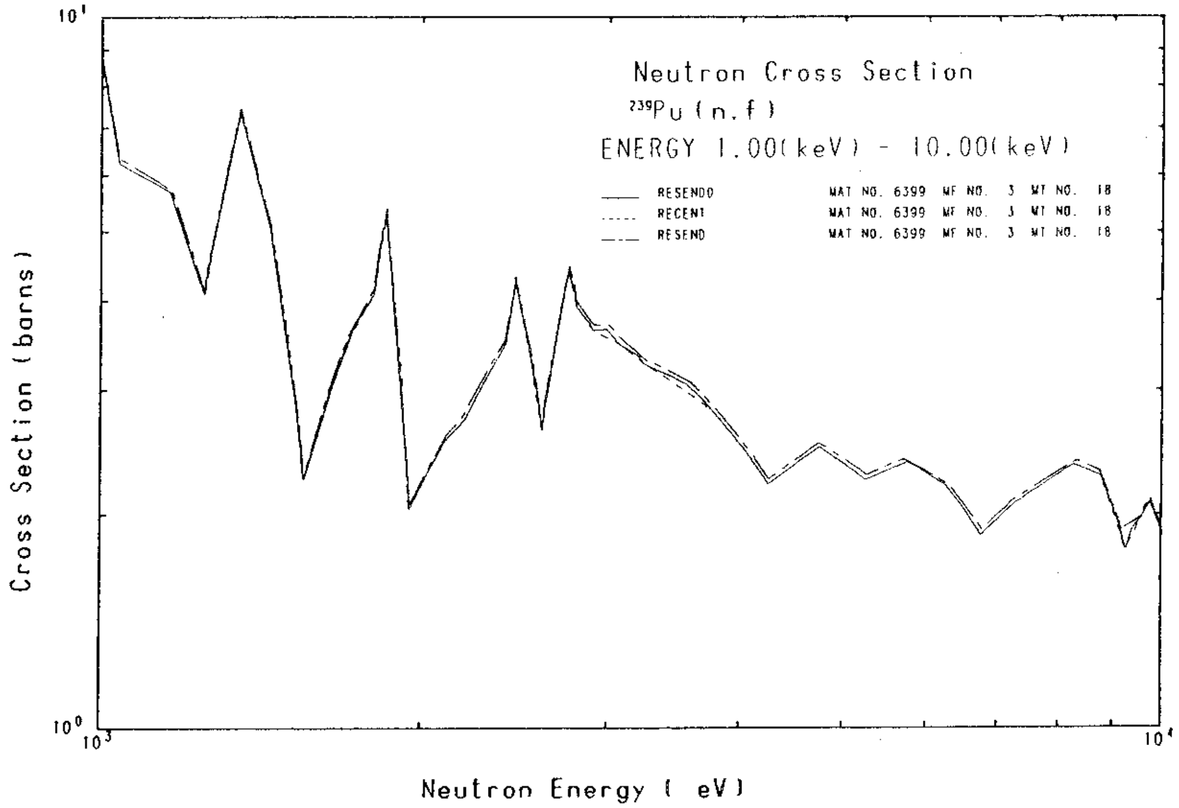

Fig.3.7.3 Neutron cross-section of Pu-239 (n, f) from 1 keV to 10 keV

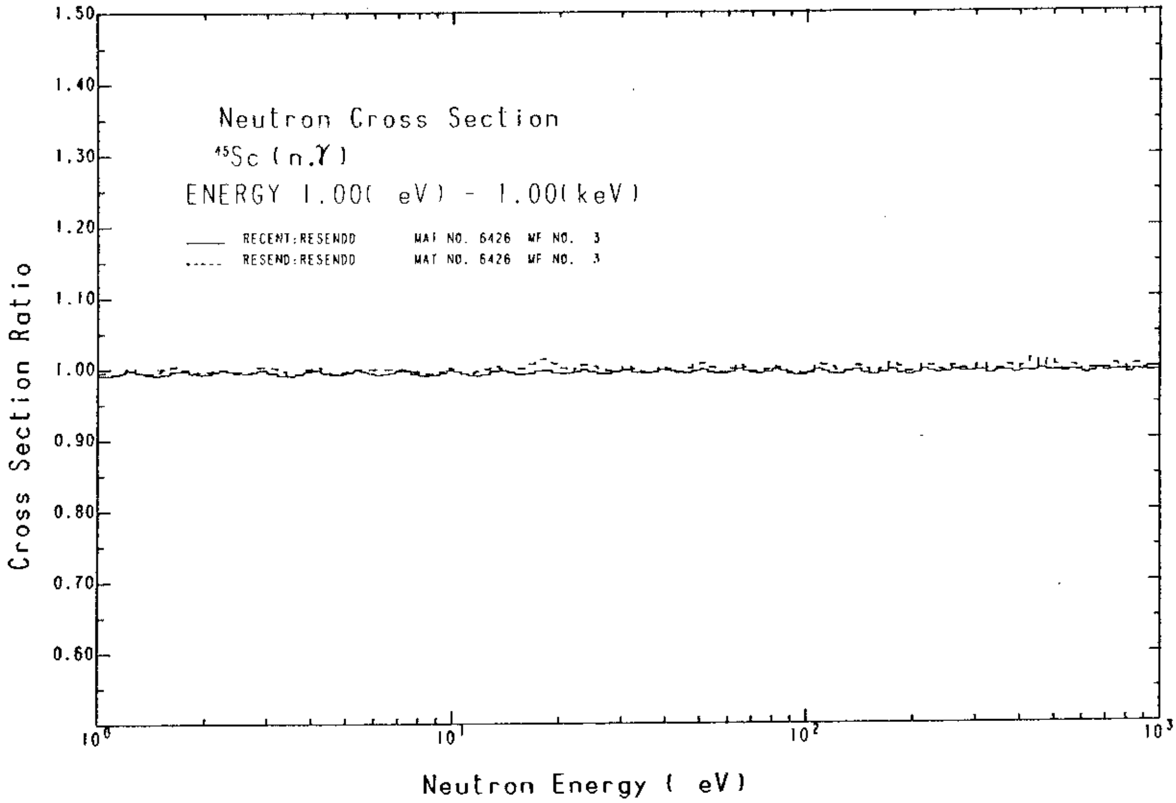

Fig.3.8.1 Cross-section ratio for Sc-45 (n, gamma) in SAND-II 620-group structure (1)

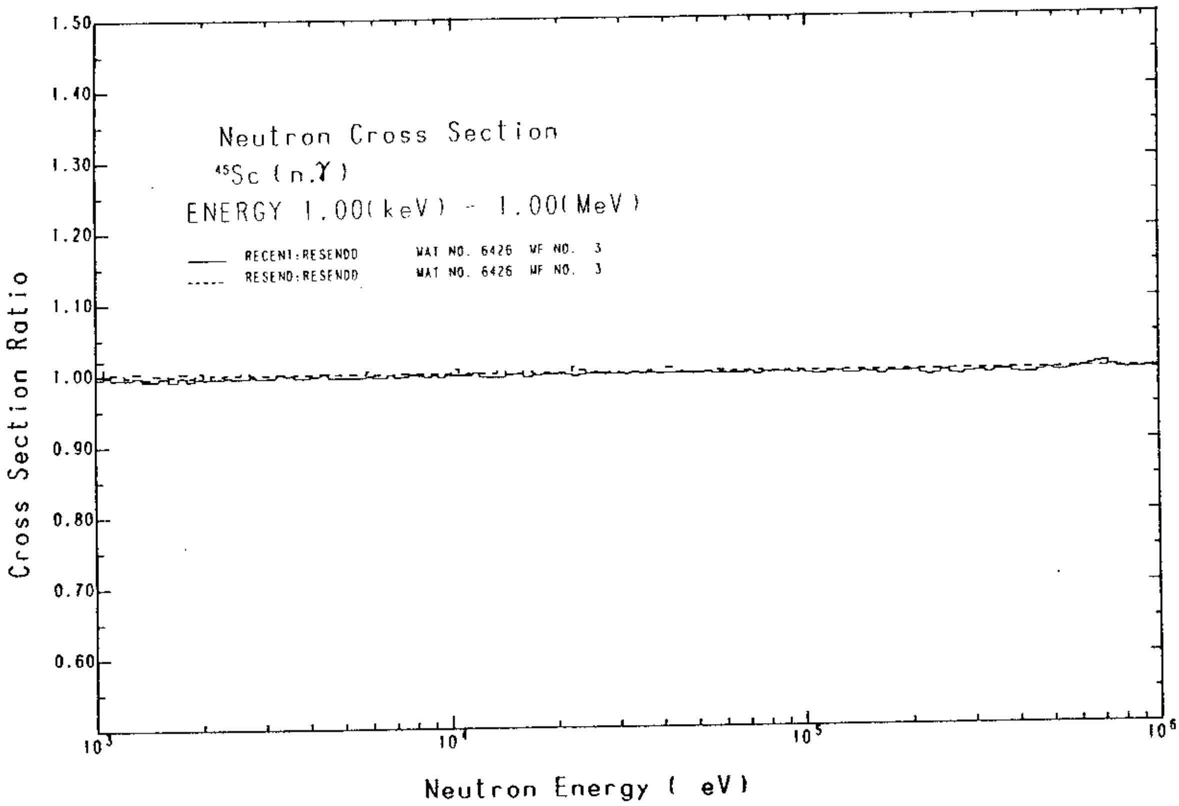

Fig.3.8.2 Cross-section ratio for Sc-45 (n, gamma) in SAND-II 620-group structure (2)

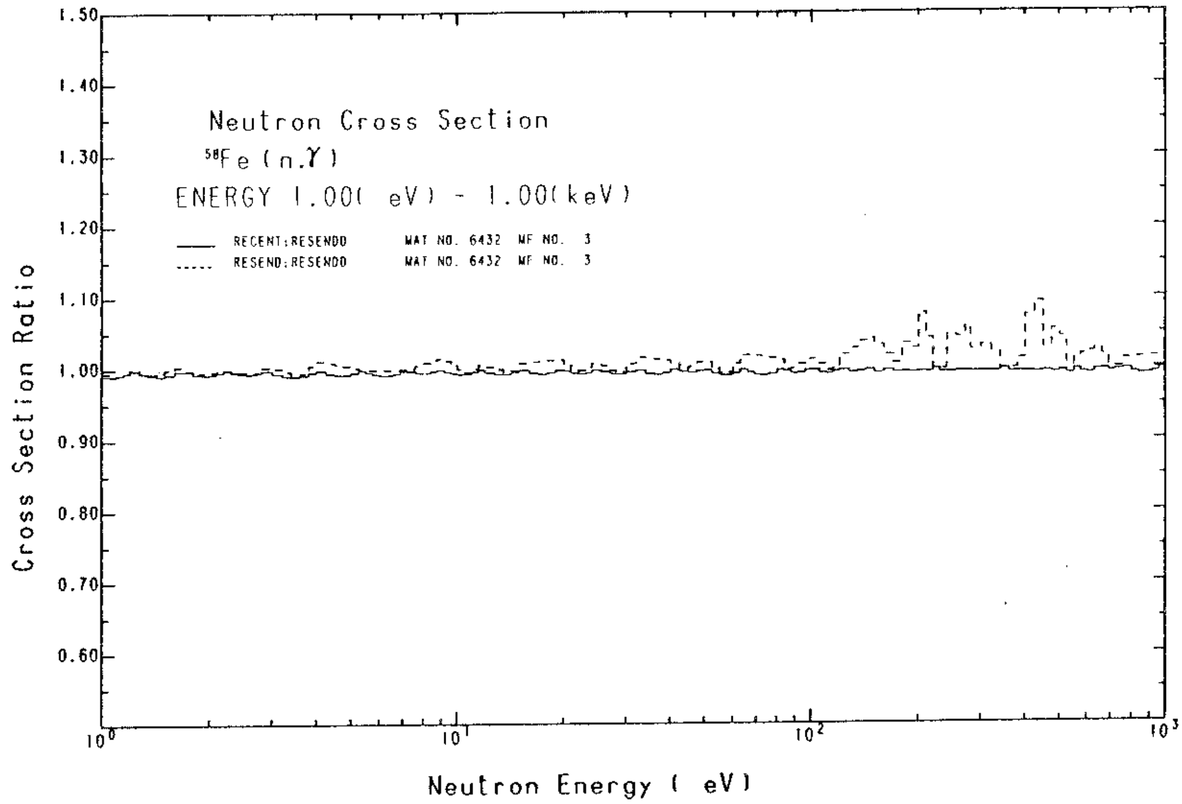

Fig.3.9.1 Cross-section ratio for Fe-58 (n, gamma) in SAND-II 620-group structure (1)

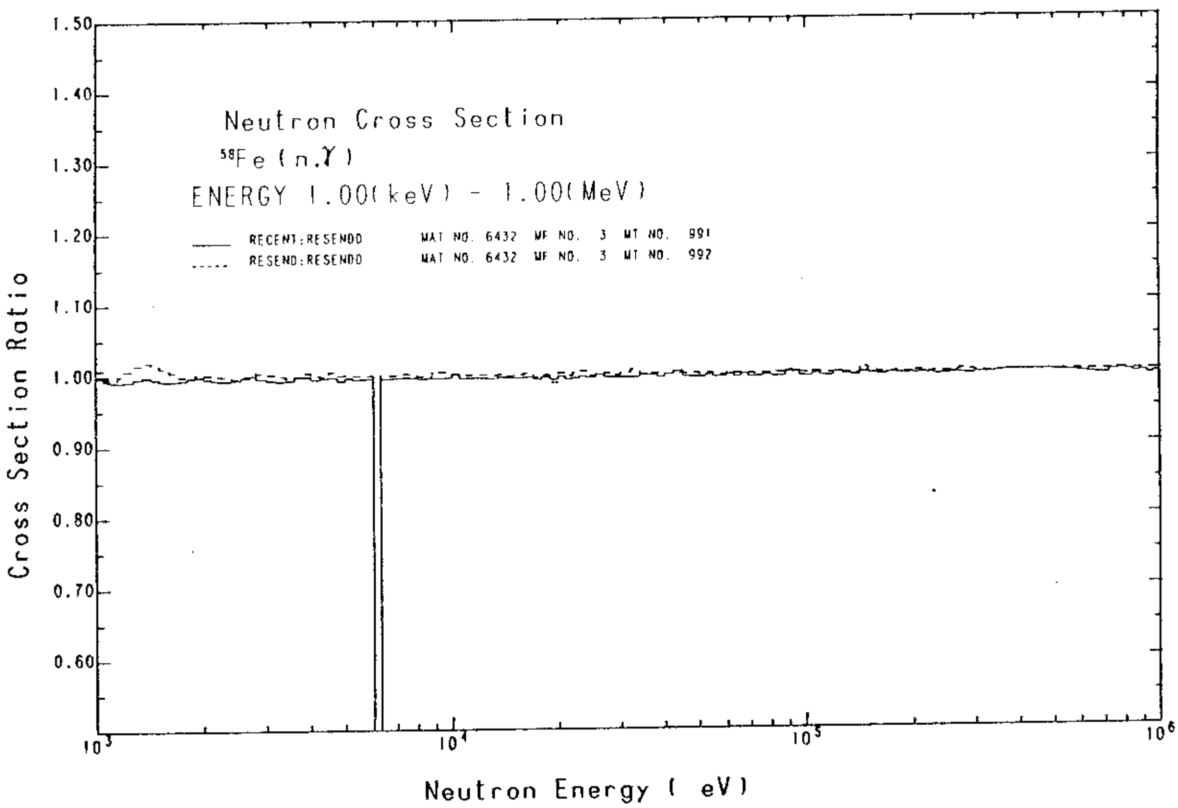

Fig.3.9.2 Cross-section ratio for Fe-58 (n, gamma) in SAND-II 620-group structure (2)

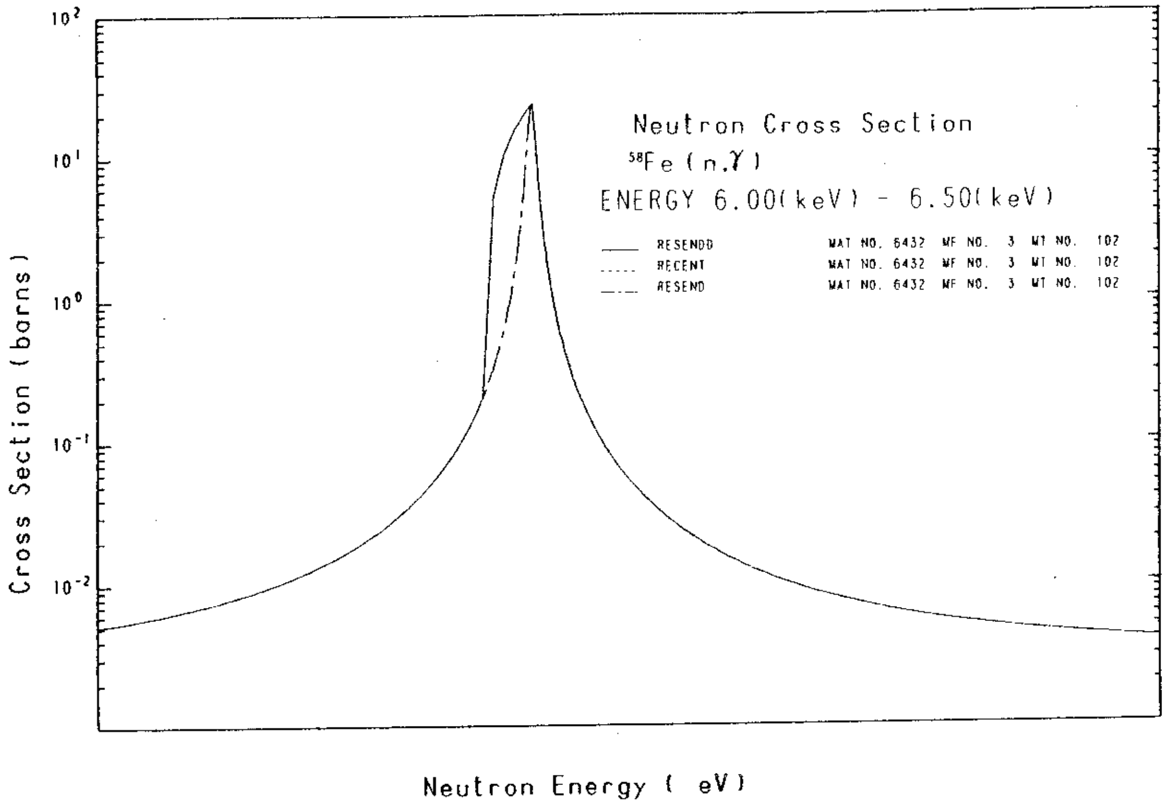

Fig.3.9.3 Neutron cross-section of Fe-58 (n, gamma) from 6 keV to 6.5 keV

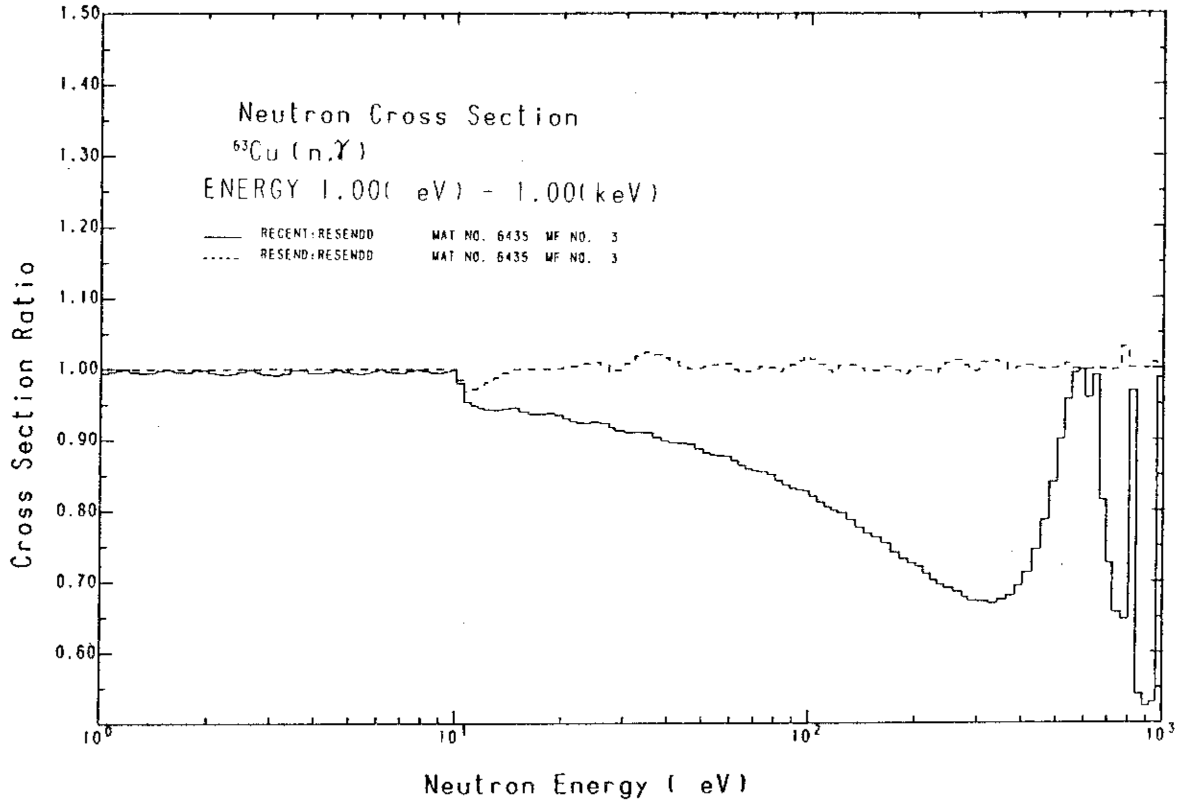

Fig.3.10.1 Cross-section ratio for Cu-63 (n, gamma) in SAND-II 620-group structure (1)

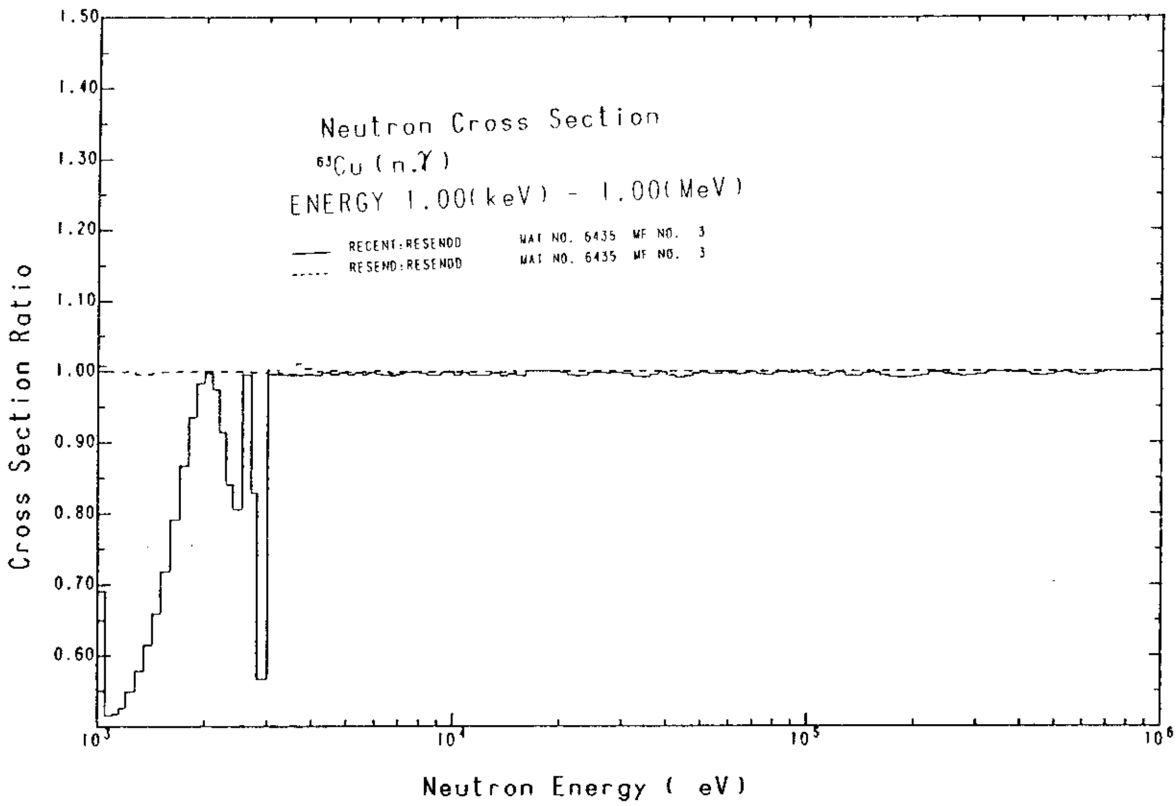

Fig.3.10.2 Cross-section ratio for Cu-63 (n, gamma) in SAND-II 620-group structure (2)

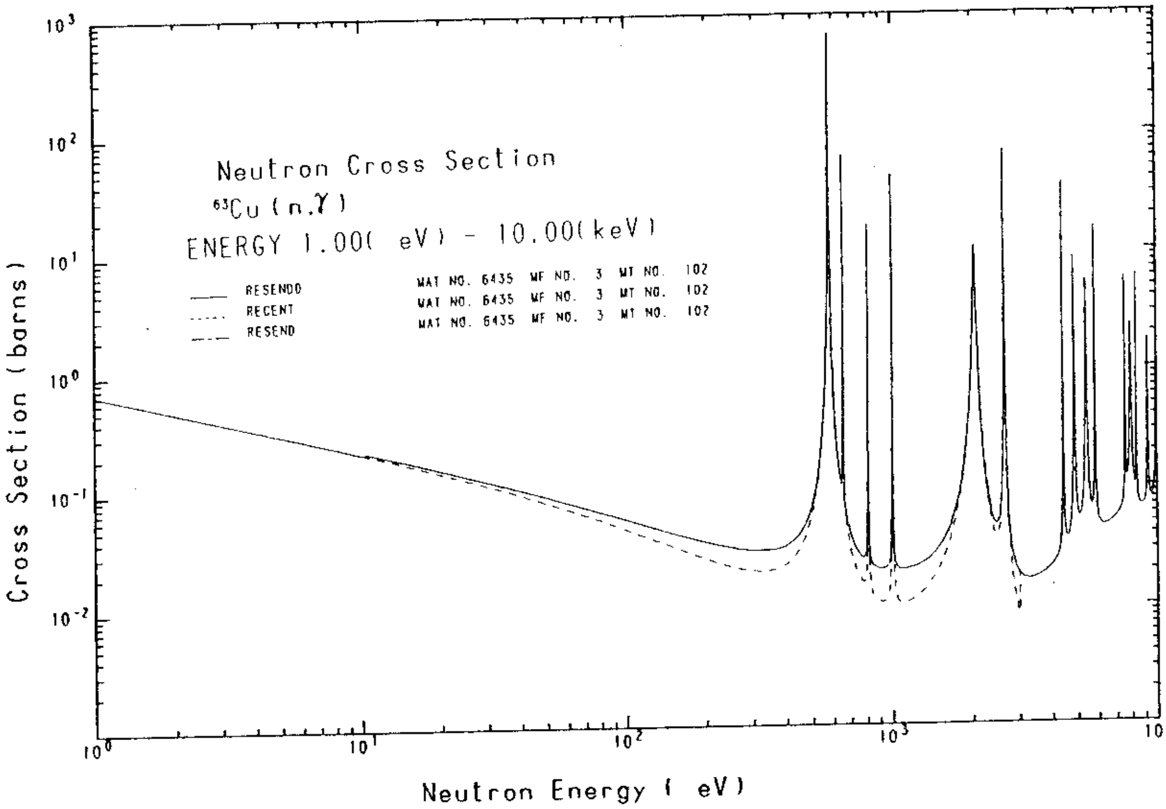

Fig.3.10.3 Neutron cross-section of Cu-63 (n, gamma) from 1 keV to 10 keV

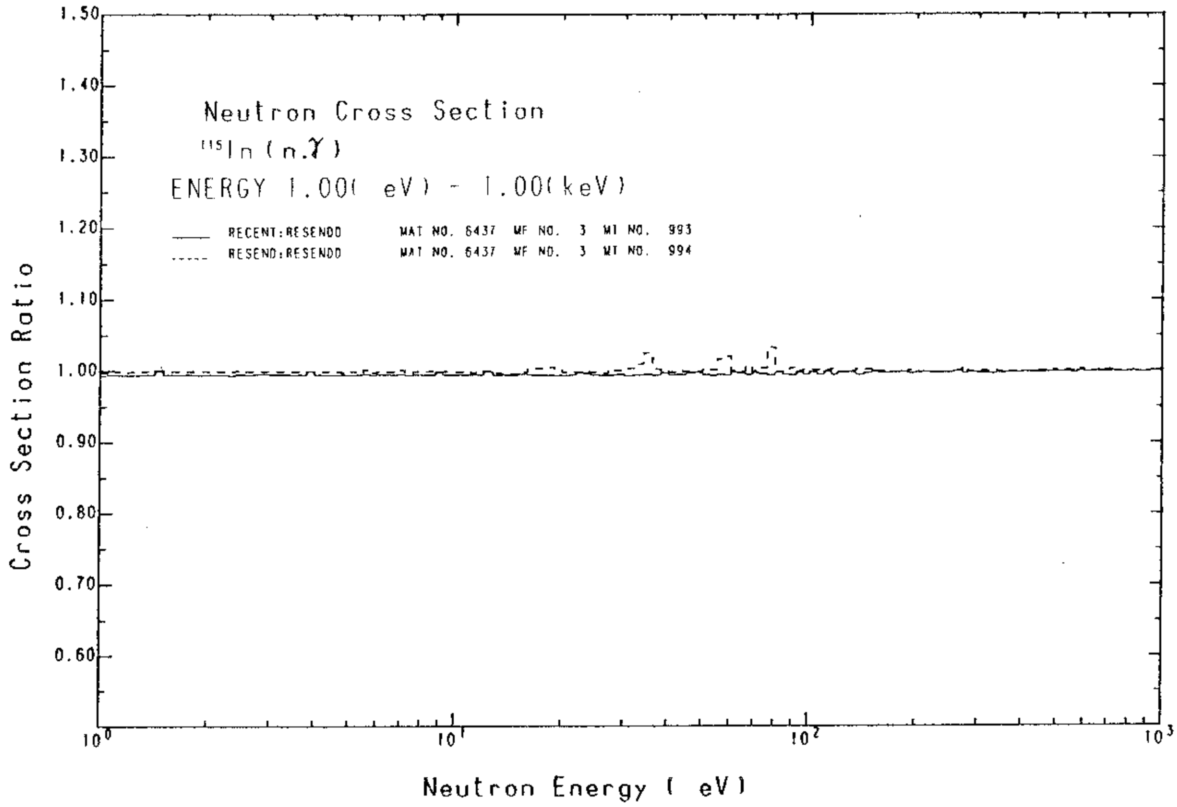

Fig.3.11.1 Cross-section ratio for Cu-63 (n, gamma) in SAND-II 620-group structure (1)

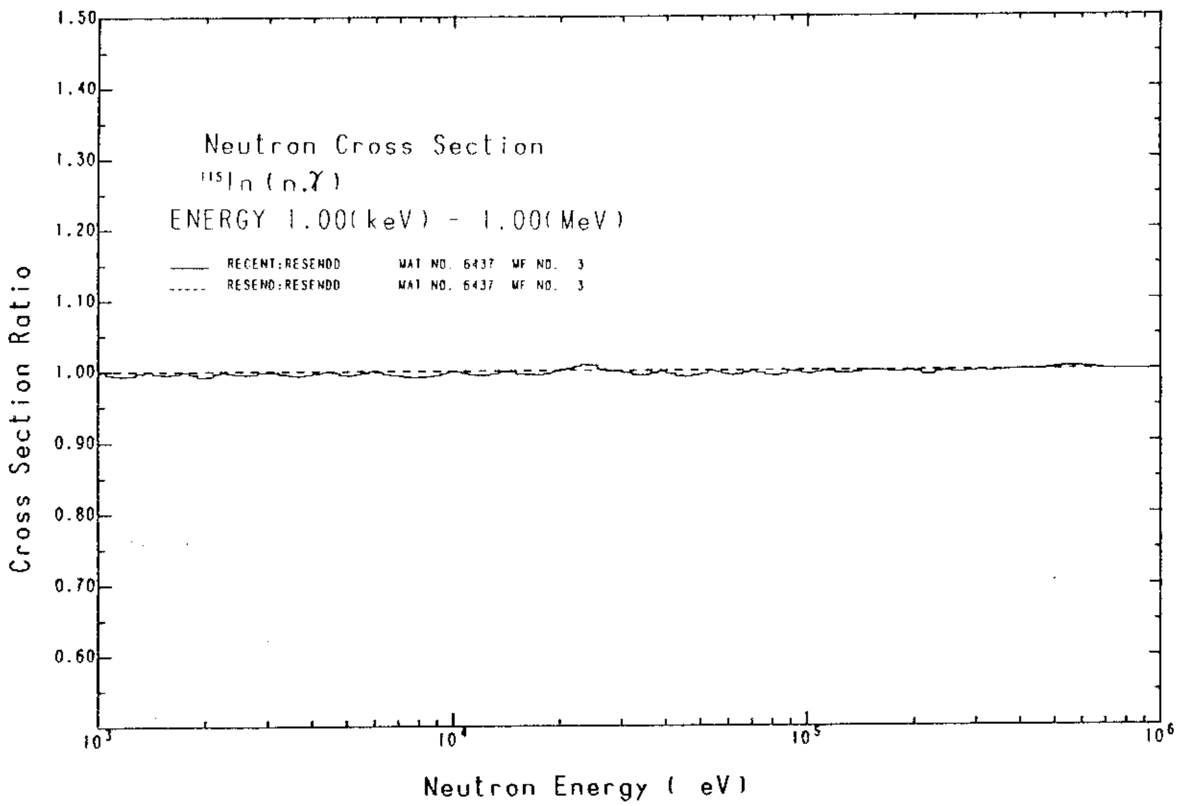

Fig.3.11.2 Cross-section ratio for Cu-63 (n, gamma) in SAND-II 620-group structure (2)

4. Conclusion

In general, agreement between RESENDD and RECENT code is well except the following three points: i.e.

i). Process error for RESENDD code in treatment of constant back-ground cross-section in file-3. If back ground cross-sections in file 3 are given in interpolation scheme 1 , RESENDD code gives erroneous results. The same error is detected in RESEND code.

ii). In unresolved resonance region, both RESENDD and RESEND codes seems violating the process criteria for the unresolved region cross-section. In this energy region, cross-section should be interpolated ,not for the resonance parameters. RESENDD and RESEND codes interpolate the resonance parameters for the energy grids other than the given energies by the resonance parameters.

iii).Insufficient data points generation is seen in RESENDD code especially for the very narrow resonance cross sections. Even if the error criteria of 0.1 % is specified in the RESENDD code, generated cross-sections are different more than 50 % from the exact ones in the case of very narrow resonances. This error occurred often in this benchmark test, as already seen in the previous section, then this error is a common error for the RESENDD code. Because this error is a damageful one for the users, we should correct the process flow to eliminate it.

As to the original code RESEND, it is revealed that the code generates rather erroneous point-cross-sections systematically. And when we use this RESEND code, we cannot design the reactors precisely,even with the best evaluated nuclear data library. The official version of RESEND code should be changed in the process flow so as to take the error decision for all reaction cross-sections rather than TOTAL reaction only. And also for this RESEND code, some errors are detected in unresolved resonance region as typically seen in the Pu-239 (n,f) case.

From the above discussions, at present stage, we recommend to use RECENT code among the tested three codes to generate energy dependent point-wise cross-sections.

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(4) Cullen,D.E. : "Program RECENT(Version 79-1): Reconstruction of Energy-Dependent Neutron Cross Sections from Resonance Parameters in the ENDF/B Format",Lawrence Livermore Laboratory , Livermore, CA, UCRL-50400, vol.17, Part C (1979).
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(6) Oster,C.A.,McElroy,W.M. and Marr,J.M. : "A Monte Carlo Program for SAND-II Error Analysis", HEDL-TME-73-20 (1973).
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The author is indebted to Dr. S.Igarashi for his great support to this work.

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(2) Nakagawa,T. : RESENDD private communication.
(3) Ozar,O. : "RESEND: A Program to Preprocess ENDF/B Materials with Resonance Files into a Pointwise Form", Brookhaven National Laboratory, Upton, NY, BNL-17134 (1973).
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(6) Oster,C.A.,McElroy,W.M. and Marr,J.M. : "A Monte Carlo Program for SAND-II Error Analysis", HEDL-TME-73-20 (1973).
(7) Cullen,D.E. : "Program GROUPIE(Version 79-1): Calculate Bondarenko Self-Shielded Cross Sections and Multiband Parameters from Evaluated Data in the Evaluated Nuclear Data File/Version B (ENDF/B) Format",Lawrence Livermore Laboratory , Livermore, CA, UCRL-50400, vol.17, Part D (1979).

Acknowledgments

The author is indebted to Dr. S.Igarashi for his great support to this work.

Appendix A.1 SAND-II 620 Group Structure

NO.	GROUP-EV	NO.	GROUP-EV	NO.	GROUP-EV	NO.	GROUP-EV
1	1.0000- 4	54	1.5000- 3	107	2.3000- 2	160	3.6000- 1
2	1.0500- 4	55	1.6000- 3	108	2.4000- 2	161	3.8000- 1
3	1.1000- 4	56	1.7000- 3	109	2.5500- 2	162	4.0000- 1
4	1.1500- 4	57	1.8000- 3	110	2.7000- 2	163	4.2500- 1
5	1.2000- 4	58	1.9000- 3	111	2.8000- 2	164	4.5000- 1
6	1.2750- 4	59	2.0000- 3	112	3.0000- 2	165	4.7500- 1
7	1.3500- 4	60	2.1000- 3	113	3.2000- 2	166	5.0000- 1
8	1.4250- 4	61	2.2000- 3	114	3.4000- 2	167	5.2500- 1
9	1.5000- 4	62	2.3000- 3	115	3.6000- 2	168	5.5000- 1
10	1.6000- 4	63	2.4000- 3	116	3.8000- 2	169	5.7500- 1
11	1.7000- 4	64	2.5500- 3	117	4.0000- 2	170	6.0000- 1
12	1.8000- 4	65	2.7000- 3	118	4.2500- 2	171	6.3000- 1
13	1.9000- 4	66	2.8000- 3	119	4.5000- 2	172	6.6000- 1
14	2.0000- 4	67	3.0000- 3	120	4.7500- 2	173	6.9000- 1
15	2.1000- 4	68	3.2000- 3	121	5.0000- 2	174	7.2000- 1
16	2.2000- 4	69	3.4000- 3	122	5.2500- 2	175	7.6000- 1
17	2.3000- 4	70	3.6000- 3	123	5.5000- 2	176	8.0000- 1
18	2.4000- 4	71	3.8000- 3	124	5.7500- 2	177	8.4000- 1
19	2.5500- 4	72	4.0000- 3	125	6.0000- 2	178	8.8000- 1
20	2.7000- 4	73	4.2500- 3	126	6.3000- 2	179	9.2000- 1
21	2.8000- 4	74	4.5000- 3	127	6.6000- 2	180	9.6000- 1
22	3.0000- 4	75	4.7500- 3	128	6.9000- 2	181	1.0000+ 0
23	3.2000- 4	76	5.0000- 3	129	7.2000- 2	182	1.0500+ 0
24	3.4000- 4	77	5.2500- 3	130	7.6000- 2	183	1.1000+ 0
25	3.6000- 4	78	5.5000- 3	131	8.0000- 2	184	1.1500+ 0
26	3.8000- 4	79	5.7500- 3	132	8.4000- 2	185	1.2000+ 0
27	4.0000- 4	80	6.0000- 3	133	8.8000- 2	186	1.2750+ 0
28	4.2500- 4	81	6.3000- 3	134	9.2000- 2	187	1.3500+ 0
29	4.5000- 4	82	6.6000- 3	135	9.6000- 2	188	1.4250+ 0
30	4.7500- 4	83	6.9000- 3	136	1.0000- 1	189	1.5000+ 0
31	5.0000- 4	84	7.2000- 3	137	1.0500- 1	190	1.6000+ 0
32	5.2500- 4	85	7.6000- 3	138	1.1000- 1	191	1.7000+ 0
33	5.5000- 4	86	8.0000- 3	139	1.1500- 1	192	1.8000+ 0
34	5.7500- 4	87	8.4000- 3	140	1.2000- 1	193	1.9000+ 0
35	6.0000- 4	88	8.8000- 3	141	1.2750- 1	194	2.0000+ 0
36	6.3000- 4	89	9.2000- 3	142	1.3500- 1	195	2.1000+ 0
37	6.6000- 4	90	9.6000- 3	143	1.4250- 1	196	2.2000+ 0
38	6.9000- 4	91	1.0000- 2	144	1.5000- 1	197	2.3000+ 0
39	7.2000- 4	92	1.0500- 2	145	1.6000- 1	198	2.4000+ 0
40	7.6000- 4	93	1.1000- 2	146	1.7000- 1	199	2.5500+ 0
41	8.0000- 4	94	1.1500- 2	147	1.8000- 1	200	2.7000+ 0
42	8.4000- 4	95	1.2000- 2	148	1.9000- 1	201	2.8000+ 0
43	8.8000- 4	96	1.2750- 2	149	2.0000- 1	202	3.0000+ 0
44	9.2000- 4	97	1.3500- 2	150	2.1000- 1	203	3.2000+ 0
45	9.6000- 4	98	1.4250- 2	151	2.2000- 1	204	3.4000+ 0
46	1.0000- 3	99	1.5000- 2	152	2.3000- 1	205	3.6000+ 0
47	1.0500- 3	100	1.6000- 2	153	2.4000- 1	206	3.8000+ 0
48	1.1000- 3	101	1.7000- 2	154	2.5500- 1	207	4.0000+ 0
49	1.1500- 3	102	1.8000- 2	155	2.7000- 1	208	4.2500+ 0
50	1.2000- 3	103	1.9000- 2	156	2.8000- 1	209	4.5000+ 0
51	1.2750- 3	104	2.0000- 2	157	3.0000- 1	210	4.7500+ 0
52	1.3500- 3	105	2.1000- 2	158	3.2000- 1	211	5.0000+ 0
53	1.4250- 3	106	2.2000- 2	159	3.4000- 1	212	5.2500+ 0

NO.	GROUP-E	NO.	GROUP-EV	NO.	GROUP-EV	NO.	GROUP-EV
213	5.5000+	266	8.0000+ 1	319	1.1500+ 3	372	1.8000+ 4
214	5.7500+	267	8.4000+ 1	320	1.2000+ 3	373	1.9000+ 4
215	6.0000+	268	8.8000+ 1	321	1.2750+ 3	374	2.0000+ 4
216	6.3000+	269	9.2000+ 1	322	1.3500+ 3	375	2.1000+ 4
217	6.6000+	270	9.6000+ 1	323	1.4250+ 3	376	2.2000+ 4
218	6.9000+	271	1.0000+ 2	324	1.5000+ 3	377	2.3000+ 4
219	7.2000+	272	1.0500+ 2	325	1.6000+ 3	378	2.4000+ 4
220	7.6000+	273	1.1000+ 2	326	1.7000+ 3	379	2.5500+ 4
221	8.0000+	274	1.1500+ 2	327	1.8000+ 3	380	2.7000+ 4
222	8.4000+	275	1.2000+ 2	328	1.9000+ 3	381	2.8000+ 4
223	8.8000+	276	1.2750+ 2	329	2.0000+ 3	382	3.0000+ 4
224	9.2000+	277	1.3500+ 2	330	2.1000+ 3	383	3.2000+ 4
225	9.6000+	278	1.4250+ 2	331	2.2000+ 3	384	3.4000+ 4
226	1.0000+	279	1.5000+ 2	332	2.3000+ 3	385	3.6000+ 4
227	1.0500+	280	1.6000+ 2	333	2.4000+ 3	386	3.8000+ 4
228	1.1000+	281	1.7000+ 2	334	2.5500+ 3	387	4.0000+ 4
229	1.1500+	282	1.8000+ 2	335	2.7000+ 3	388	4.2500+ 4
230	1.2000+	283	1.9000+ 2	336	2.8000+ 3	389	4.5000+ 4
231	1.2750+	284	2.0000+ 2	337	3.0000+ 3	390	4.7500+ 4
232	1.3500+	285	2.1000+ 2	338	3.2000+ 3	391	5.0000+ 4
233	1.4250+	286	2.2000+ 2	339	3.4000+ 3	392	5.2500+ 4
234	1.5000+	287	2.3000+ 2	340	3.6000+ 3	393	5.5000+ 4
235	1.6000+	288	2.4000+ 2	341	3.8000+ 3	394	5.7500+ 4
236	1.7000+	289	2.5500+ 2	342	4.0000+ 3	395	6.0000+ 4
237	1.8000+	290	2.7000+ 2	343	4.2500+ 3	396	6.3000+ 4
238	1.9000+	291	2.8000+ 2	344	4.5000+ 3	397	6.6000+ 4
239	2.0000+	292	3.0000+ 2	345	4.7500+ 3	398	6.9000+ 4
240	2.1000+	293	3.2000+ 2	346	5.0000+ 3	399	7.2000+ 4
241	2.2000+	294	3.4000+ 2	347	5.2500+ 3	400	7.6000+ 4
242	2.3000+	295	3.6000+ 2	348	5.5000+ 3	401	8.0000+ 4
243	2.4000+	296	3.8000+ 2	349	5.7500+ 3	402	8.4000+ 4
244	2.5500+	297	4.0000+ 2	350	6.0000+ 3	403	8.8000+ 4
245	2.7000+	298	4.2500+ 2	351	6.3000+ 3	404	9.2000+ 4
246	2.8000+	299	4.5000+ 2	352	6.6000+ 3	405	9.6000+ 4
247	3.0000+	300	4.7500+ 2	353	6.9000+ 3	406	1.0000+ 5
248	3.2000+	301	5.0000+ 2	354	7.2000+ 3	407	1.0500+ 5
249	3.4000+	302	5.2500+ 2	355	7.6000+ 3	408	1.1000+ 5
250	3.6000+	303	5.5000+ 2	356	8.0000+ 3	409	1.1500+ 5
251	3.8000+	304	5.7500+ 2	357	8.4000+ 3	410	1.2000+ 5
252	4.0000+	305	6.0000+ 2	358	8.8000+ 3	411	1.2750+ 5
253	4.2500+	306	6.3000+ 2	359	9.2000+ 3	412	1.3500+ 5
254	4.5000+	307	6.6000+ 2	360	9.6000+ 3	413	1.4250+ 5
255	4.7500+	308	6.9000+ 2	361	1.0000+ 4	414	1.5000+ 5
256	5.0000+	309	7.2000+ 2	362	1.0500+ 4	415	1.6000+ 5
257	5.2500+	310	7.6000+ 2	363	1.1000+ 4	416	1.7000+ 5
258	5.5000+	311	8.0000+ 2	364	1.1500+ 4	417	1.8000+ 5
259	5.7500+	312	8.4000+ 2	365	1.2000+ 4	418	1.9000+ 5
260	6.0000+	313	8.8000+ 2	366	1.2750+ 4	419	2.0000+ 5
261	6.3000+	314	9.2000+ 2	367	1.3500+ 4	420	2.1000+ 5
262	6.6000+	315	9.6000+ 2	368	1.4250+ 4	421	2.2000+ 5
263	6.9000+	316	1.0000+ 3	369	1.5000+ 4	422	2.3000+ 5
264	7.2000+	317	1.0500+ 3	370	1.6000+ 4	423	2.4000+ 5
265	7.6000+	318	1.1000+ 3	371	1.7000+ 4	424	2.5500+ 5

NO.	GROUP-EV	NO.	GROUP-EV	NO.	GROUP-EV	NO.	GROUP-EV
425	2.7000+ 5	478	3.7000+ 6	531	9.0000+ 6	584	1.4300+ 7
426	2.8000+ 5	479	3.8000+ 6	532	9.1000+ 6	585	1.4400+ 7
427	3.0000+ 5	480	3.9000+ 6	533	9.2000+ 6	586	1.4500+ 7
428	3.2000+ 5	481	4.0000+ 6	534	9.3000+ 6	587	1.4600+ 7
429	3.4000+ 5	482	4.1000+ 6	535	9.4000+ 6	588	1.4700+ 7
430	3.6000+ 5	483	4.2000+ 6	536	9.5000+ 6	589	1.4800+ 7
431	3.8000+ 5	484	4.3000+ 6	537	9.6000+ 6	590	1.4900+ 7
432	4.0000+ 5	485	4.4000+ 6	538	9.7000+ 6	591	1.5000+ 7
433	4.2500+ 5	486	4.5000+ 6	539	9.8000+ 6	592	1.5100+ 7
434	4.5000+ 5	487	4.6000+ 6	540	9.9000+ 6	593	1.5200+ 7
435	4.7500+ 5	488	4.7000+ 6	541	1.0000+ 7	594	1.5300+ 7
436	5.0000+ 5	489	4.8000+ 6	542	1.0100+ 7	595	1.5400+ 7
437	5.2500+ 5	490	4.9000+ 6	543	1.0200+ 7	596	1.5500+ 7
438	5.5000+ 5	491	5.0000+ 6	544	1.0300+ 7	597	1.5600+ 7
439	5.7500+ 5	492	5.1000+ 6	545	1.0400+ 7	598	1.5700+ 7
440	6.0000+ 5	493	5.2000+ 6	546	1.0500+ 7	599	1.5800+ 7
441	6.3000+ 5	494	5.3000+ 6	547	1.0600+ 7	600	1.5900+ 7
442	6.6000+ 5	495	5.4000+ 6	548	1.0700+ 7	601	1.6000+ 7
443	6.9000+ 5	496	5.5000+ 6	549	1.0800+ 7	602	1.6100+ 7
444	7.2000+ 5	497	5.6000+ 6	550	1.0900+ 7	603	1.6200+ 7
445	7.6000+ 5	498	5.7000+ 6	551	1.1000+ 7	604	1.6300+ 7
446	8.0000+ 5	499	5.8000+ 6	552	1.1100+ 7	605	1.6400+ 7
447	8.4000+ 5	500	5.9000+ 6	553	1.1200+ 7	606	1.6500+ 7
448	8.8000+ 5	501	6.0000+ 6	554	1.1300+ 7	607	1.6600+ 7
449	9.2000+ 5	502	6.1000+ 6	555	1.1400+ 7	608	1.6700+ 7
450	9.6000+ 5	503	6.2000+ 6	556	1.1500+ 7	609	1.6800+ 7
451	1.0000+ 6	504	6.3000+ 6	557	1.1600+ 7	610	1.6900+ 7
452	1.1000+ 6	505	6.4000+ 6	558	1.1700+ 7	611	1.7000+ 7
453	1.2000+ 6	506	6.5000+ 6	559	1.1800+ 7	612	1.7100+ 7
454	1.3000+ 6	507	6.6000+ 6	560	1.1900+ 7	613	1.7200+ 7
455	1.4000+ 6	508	6.7000+ 6	561	1.2000+ 7	614	1.7300+ 7
456	1.5000+ 6	509	6.8000+ 6	562	1.2100+ 7	615	1.7400+ 7
457	1.6000+ 6	510	6.9000+ 6	563	1.2200+ 7	616	1.7500+ 7
458	1.7000+ 6	511	7.0000+ 6	564	1.2300+ 7	617	1.7600+ 7
459	1.8000+ 6	512	7.1000+ 6	565	1.2400+ 7	618	1.7700+ 7
460	1.9000+ 6	513	7.2000+ 6	566	1.2500+ 7	619	1.7800+ 7
461	2.0000+ 6	514	7.3000+ 6	567	1.2600+ 7	620	1.7900+ 7
462	2.1000+ 6	515	7.4000+ 6	568	1.2700+ 7	621	1.8000+ 7
463	2.2000+ 6	516	7.5000+ 6	569	1.2800+ 7		
464	2.3000+ 6	517	7.6000+ 6	570	1.2900+ 7		
465	2.4000+ 6	518	7.7000+ 6	571	1.3000+ 7		
466	2.5000+ 6	519	7.8000+ 6	572	1.3100+ 7		
467	2.6000+ 6	520	7.9000+ 6	573	1.3200+ 7		
468	2.7000+ 6	521	8.0000+ 6	574	1.3300+ 7		
469	2.8000+ 6	522	8.1000+ 6	575	1.3400+ 7		
470	2.9000+ 6	523	8.2000+ 6	576	1.3500+ 7		
471	3.0000+ 6	524	8.3000+ 6	577	1.3600+ 7		
472	3.1000+ 6	525	8.4000+ 6	578	1.3700+ 7		
473	3.2000+ 6	526	8.5000+ 6	579	1.3800+ 7		
474	3.3000+ 6	527	8.6000+ 6	580	1.3900+ 7		
475	3.4000+ 6	528	8.7000+ 6	581	1.4000+ 7		
476	3.5000+ 6	529	8.8000+ 6	582	1.4100+ 7		
477	3.6000+ 6	530	8.9000+ 6	583	1.4200+ 7		

Appendix A.2 Detailed Analysis for Erroneously Generated Cross Sections of RESENDD for Very Narrow Resonances

Clear differences in 620-group averaged cross-sections between RECENT results and RESENDD results are found in Th-232(n,f), Th-232(n,gamma), U-238(n,f), U-238(n,gamma), and Fe-58(n,gamma) cross sections. And the differences between these codes are usually less than 10 %, but occasionally they exceed 50 times(e.g. U-238(n,gamma) case) between the codes.

After the recognizing the gap in the results between the codes, we immediately start the investigation for the error sources. As seen in Fig.3.4.6 for the Th-232(n,gamma), it is impossible to find out the differences of the cross-section shape from the plotted output such a wide scale sheets.

We choose the following two nuclides here for detailed analysis;

a. Fe-58 (n,gamma) at 6.2 keV resonance: an example for very large difference case(from Table A.2.1, more than 2.4 times difference is found in average cross-section between RECENT and RESENDD).
b. Th-232 (n,f) from 3.4 to 3.6 keV: an example for the moderate difference case(from Table A.2.1, about 20 % difference in average cross-section is found between RECENT and RESENDD).

We investigated here following two possible error sources for this discrepancy ; i.e.

i). effect of truncation error in 11 characters-representation for the energy field in ENDF/B format. This problem was arised from the fact that on one side RESENDD uses the 1PE11.5 format (i.e. 6 digits representation. see Fig.A.2.1) in the output file of point-wise data, and on the other side RECENT uses variable 9 digits representation for the energy fields (see Fig.A.2.2) . Because for the very narrow resonance case (for example Γ f =1.3E-7 eV, Γ =2.6E-2) at relatively high energy (i.e 3.4keV), in such cases , the representation in 6 digits might cause serious lack of informations in the most significant digits for such a small widths. To clarify such effects, we perform the accuracy check for the averaging of the cross-sections to a) and b) cases by making small program to integrate the cross-sections in single precision and double precision.

The results are shown in Table A.2.1. From this Table, for both cases there are no effect to the integrated results arising from the difference in effective digits for the representation of the energy field.

ii). Generated cross-section error for such a narrow resonance case.

This is a rather clear one, if we carefully check the output cross-section shape from the codes. We take following way to visualize from where this difference comes;we plot the integrated cross-section in the same sheet of the cross-section curve. From Fig.A.2.3 and Fig.A.2.4, for both Fe-58(n,gamma) and Th-232(n,f) cases, the same behaviours are shown. The integrated cross sections are displayed in step function for both codes. This error is always occur in the lower side of very narrow resonances. And when we plot the cross-section curve in enlarged scale, as seen in Fig.3.9.3 , it is revealed that insufficient data points generation is attributed to this error. Clearly the generated cross-sections by RESENDD are erroneous. From the listing of output data for Fe-58(n,gamma) case, as seen in Fig.A.2.1 and A.2.2, for RESENDD code from 6.17618 keV to 6.19900 keV only 2 data points are generated, but for RECENT, it generate 87 data points in the same energy range(in the Table A.2.2 '*' mark is inserted for this energy range). It is necessary for RESENDD to generate more data points between these sparce energy grid. Because this error found in the RESENDD is a damageful one for the users, we should correct the process flow to eliminate this error. In any way, for the users of these codes ,resonance integrals calculated from the generated cross-section curve should be exactly the same as originally evaluated one. Then, it is very important to generate cross-section curve to asure the resonance integrals calculated from those curve are correct ones.

Table A.2.1 Effect of effective digits in RECENT and RESENDD codes to the integrated results.

a. Fe-58(n,gamma) average cross-section from 6.0 to 6.3 keV

code	eff-digit	SINGLE precision (barns)	DOUBLE precision (barns)	SINGLE/DOUBLE (ratio)
RECENT	9	0.53103	0.53104	1.0000
RESENDD	6	1.2032	1.2033	0.9999

b. Th-232(n,f) average cross-section from 3.4 to 3.6 keV

code	eff-digit	SINGLE precision (barns)	DOUBLE precision (barns)	SINGLE/DOUBLE (ratio)
RECENT	9	2.5463E-4	2.5471E-4	0.9997
RESENDD	6	3.0965E-4	3.0711E-4	0.9995

where SINGLE precision: single precision calculation for the integration of cross-section.
DOUBLE precision: double precision calculation for the integration of cross-section.

Fig.A.2.1 Output from RESENDD for Fe-58(n,gamma)
6-digits representation for energy field

```
energy        cross-sec     energy        cross-sec     energy        cross-sec
6.16548+ 3 9.79850- 2 6.16619+ 3 1.02142- 1 6.16690+ 3 1.06600- 16432
6.16762+ 3 1.11391- 1 6.16833+ 3 1.16490- 1 6.16904+ 3 1.21956- 16432
6.17047+ 3 1.34168- 1*6.17618+ 3 2.07784- 1*6.19900+ 3 2.40762+ 16432
6.19912+ 3 2.39973+ 1 6.19925+ 3 2.37455+ 1 6.19937+ 3 2.33607+ 16432
6.19951+ 3 2.27527+ 1 6.19963+ 3 2.21105+ 1 6.19976+ 3 2.13298+ 16432
6.20002+ 3 1.95096+ 1 6.20053+ 3 1.58152+ 1 6.20065+ 3 1.49733+ 16432
6.20078+ 3 1.41111+ 1 6.20091+ 3 1.32886+ 1 6.20104+ 3 1.24858+ 16432
6.20116+ 3 1.17945+ 1 6.20129+ 3 1.10812+ 1 6.20142+ 3 1.04329+ 16432
6.20155+ 3 9.82675+ 0 6.20167+ 3 9.29407+ 0 6.20180+ 3 8.76423+ 06432
6.20193+ 3 8.27063+ 0 6.20206+ 3 7.79758+ 0 6.20218+ 3 7.39563+ 06432
```

Fig.A.2.2 Output from RECENT for Fe-58(n,gamma)
9-digits representation for energy field

```
energy     cross-sec     energy     cross-sec     energy     cross-sec
6170.31250 1.32709- 1 6171.37500 1.42873- 1 6172.43750 1.54270- 16432
6172.96875 1.60519- 1 6173.50000 1.67110- 1 6174.03125 1.74174- 16432
6174.56250 1.81645- 1 6175.09375 1.89613- 1 6175.62500 1.98187- 16432
6176.15625 2.07293- 1*6176.68750 2.17121- 1 6177.21875 2.27672- 16432
6177.75000 2.38931- 1 6178.28125 2.51053- 1 6178.81250 2.64227- 16432
6179.34375 2.78364- 1 6179.87500 2.93789- 1 6180.40625 3.10412- 16432
6180.93750 3.28492- 1 6181.46875 3.48355- 1 6182.00000 3.70078- 16432
6182.53125 3.93721- 1 6183.06250 4.19704- 1 6183.59375 4.48567- 16432
6184.12500 4.80263- 1 6184.39062 4.97385- 1 6184.92187 5.34772- 16432
6185.18750 5.54909- 1 6185.45312 5.76201- 1 6185.98437 6.22977- 16432
6186.25000 6.48326- 1 6186.78125 7.04299- 1 6187.04687 7.34792- 16432
6187.31250 7.67294- 1 6187.57812 8.01983- 1 6187.84375 8.39618- 16432
6188.10937 8.79336- 1 6188.37500 9.21908- 1 6188.64062 9.67613- 16432
6188.90625 1.01676+ 0 6189.17187 1.07050+ 0 6189.43750 1.12768+ 06432
6189.70312 1.18950+ 0 6189.96875 1.25645+ 0 6190.23437 1.32912+ 06432
6190.50000 1.40937+ 0 6190.76562 1.49562+ 0 6190.89844 1.54168+ 06432
6191.29687 1.69466+ 0 6191.56250 1.80814+ 0 6191.82812 1.93308+ 06432
6192.09375 2.07101+ 0 6192.22656 2.14541+ 0 6192.35937 2.22611+ 06432
6192.62500 2.39600+ 0 6192.75781 2.48805+ 0 6192.89062 2.58529+ 06432
6193.02344 2.68811+ 0 6193.15625 2.79691+ 0 6193.28906 2.91215+ 06432
6193.42187 3.03431+ 0 6193.55469 3.16392+ 0 6193.82031 3.45234+ 06432
6193.95312 3.60831+ 0 6194.08594 3.77443+ 0 6194.21875 3.95152+ 06432
6194.35156 4.14048+ 0 6194.48437 4.34231+ 0 6194.61719 4.55809+ 06432
6194.75000 4.78899+ 0 6194.94922 5.16654+ 0 6195.14844 5.59455+ 06432
6195.28125 5.90064+ 0 6195.41406 6.22956+ 0 6195.54687 6.58323+ 06432
6195.61328 6.76999+ 0 6195.81250 7.38572+ 0 6195.94531 7.82750+ 06432
```

6196.07812	8.30307+	0	6196.21094	8.81489+	0	6196.34375	9.36543+	06432
6196.47656	9.95705+	0	6196.60937	1.05919+	1	6196.74219	1.12719+	16432
6196.87500	1.19984+	1	6197.14062	1.36162+	1	6197.27344	1.44815+	16432
6197.40625	1.53870+	1	6197.67187	1.72903+	1	6198.07031	2.01863+	16432
6198.20312	2.10874+	1	6198.33594	2.19387+	1	6198.46875	2.26637+	16432
6198.60156	2.32613+	1	6198.73437	2.37075+	1	6198.86719	2.39831+	16432
*6199.00000	2.40756+	1	6199.12891	2.39862+	1	6199.26172	2.37136+	16432
6199.39453	2.32701+	1	6199.52734	2.26749+	1	6199.59375	2.23277+	16432
6199.79297	2.11022+	1	6199.92578	2.02023+	1	6200.05859	1.92550+	16432
6200.32422	1.72791+	1	6200.58984	1.53767+	1	6200.72266	1.44719+	16432
6200.85547	1.36073+	1	6200.98828	1.27870+	1	6201.12109	1.20130+	16432
6201.25391	1.12859+	1	6201.38672	1.06052+	1	6201.51953	9.96966+	06432

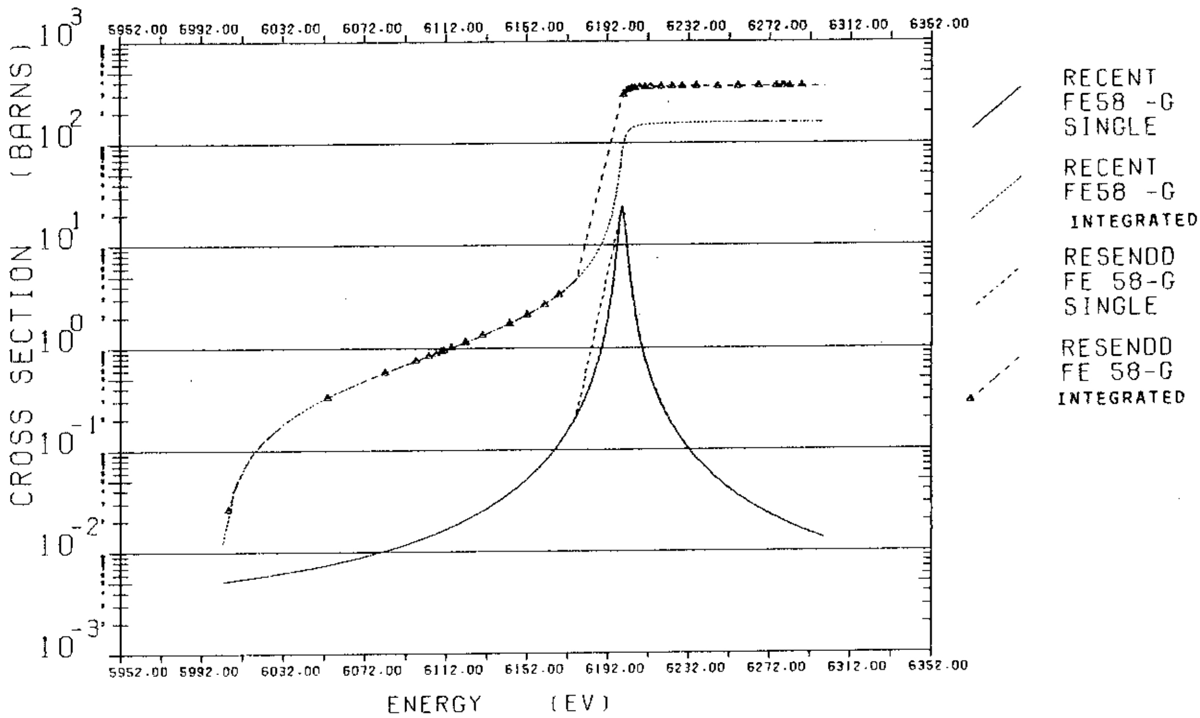

Fig.A.2.3 Fe-58 (n, gamma) cross-section curve and integrated one for RECENT and RESENDD codes

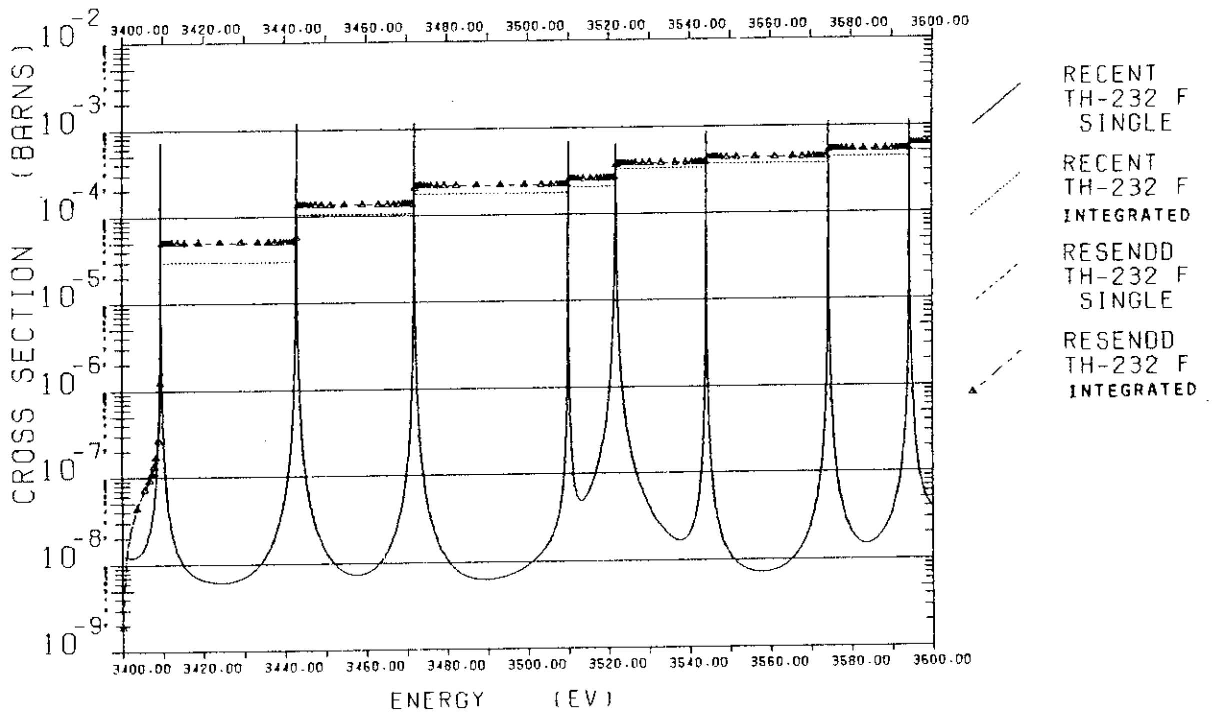

Fig.A.2.4 Th-232 (n, f) cross-section curve and integrated one for RECENT and RESENDD codes