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NEUTRON RADIATIVE CAPTURE CROSS SECTION OF ^{232}Th

IN THE ENERGY RANGE 0.1 TO 1.2 MeV

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ABSTRACT

Recently reported neutron radiative capture cross section of Th-232 measurements in the energy range 0.1 to 1.2 MeV are compared with the calculations based on the statistical model Hauser-Feshbach theory using the spherical optical model transmission coefficients and simple Fermi gas level density formula. The calculations are in good agreement with the recent experimental data, reproducing both the absolute magnitude and the shape exhibited by the excitation function. The results of this comparative study can be used for improving the evaluation of the neutron radiative capture cross section of Th-232.

1. Introduction

Neutron capture cross section of Th-232 is important both from nuclear physics point of view to have a better understanding of nuclear reaction mechanism in the actinide nuclei where compound-nucleus (CN) direct-interaction (DI) and fission processes are involved, and reactor physics point of view to know the conversion ratio of the fertile nucleus Th-232 to the fissile nucleus U-233 which is required for the calculation of effective multiplication factor and breeding ratio in the ^{232}Th - ^{233}U fuel cycle. This cross section has been evaluated by Jain and Mehta[1], Vasiliu et.al[2], and there are other evaluated files ENDF-B/V, JENDL-2 etc. Integral validation of these evaluations was done by Ganesan[3] to compare the calculated and measured integral parameter alpha (i.e., the ratio of capture to fission cross section). The Indian evaluation gave the value of ratio of calculated to experimental alpha as $\simeq$ 1.1. To reduce this discrepancy Ganesan suggested that new and accurate measurements of the capture cross section are necessary. Moreover, the WRENDA 81/82 need the accuracy for this cross section as $\pm$ 3% for the energy range 0.1 - 1.2 MeV. In view of these findings we continued the cross section measurement as well as its theoretical calculation.

In evaluating neutron cross section data, it is often necessary to supplement the available experimental data with calculated one. For this, the best one can do is to calculate the cross section over the energy range of interest with a nuclear model, fit the calculated data to experimental results by adjusting the nuclear parameters involved, and then assume that the calculated data are accurate for the entire incident neutron energy range. The present report describe the theoretical calculations performed with the computer code FISPRO-II[4]. The computer code FISPRO-II is based on Hauser-Feshbach statistical model using the spherical optical model transmission coefficients and simple Fermi gas level density formulae. The input nuclear parameters (i.e. resonance, optical model and level density parameter) for these calculations were suitably chosen to get a good visual fit with the more recent measurements[5,6,7,8]. Similar analysis within the framework of the Hauser-Feshbach-Moldauer statistical model has also been reported in Ref.9.

2. Theoretical Formalism

The phenomenological theory of nuclear reactions at low energy is based on statistical compound nucleus (CN) formation and its subsequent decay taking into account the various competing processes and this (CN) process makes a major contribution to the total interaction cross section. The Hauser-Feshbach (H.F) theory is the most consistent method of calculating the CN cross section in terms of the statistical theory.

According to H-F theory when a fast neutron of kinetic energy E is absorbed by a target nucleus of ground state spin I to form a CN, then the radiative capture cross-section is given by the simple relation

$$\sigma_{n\gamma} = \sigma_C(E).G \qquad (1)$$

where σ_C = CN formation cross-section

and G = Branching ratio for gamma-decay

If the compound state de-excites by emitting neutrons and gamma rays only, then the Eq.(1) can be re-written in terms of transmission coefficients as

$$\sigma_{n\gamma}(E) = \pi \lambda^2 \sum_{J\Pi l j} \frac{(2J+1)}{2(2I+1)} \frac{T_{lj}^{J\Pi}(E)\, T_C^{J\Pi}(E+B_n)}{T^{J\Pi}(E)} \qquad (2)$$

where

J = Compound nucleus spin

Π = Parity of compound nucleus states.

l and l' = Orbital angular moments of the incoming and outgoing neutron

j = Total angular momentum of the incoming neutron

$T^{J\Pi}_{lj}(E)$ = Neutron transmission coefficient

$T^{J\Pi}_{c}(E+B_n)$ = Gamma-ray transmission coefficient for radiative capture event, i.e., gamma ray cascade ends up to bound levels (states below B_n)

$T^{J\Pi}(E)$ = Total transmission coefficient

E = Incident neutron energy in the center of mass system.

B_n = Neutron binding energy in compound nucleus

The total transmission coefficient can be written as sum of transmission coefficient associated with neutron inelastic scattering (n,n') and total gamma ray transmission coefficient (T^{J}_{γ}) which correspond to gamma ray transition to all states below the excitation energy $U = E + B_n$.

$$T^{J\Pi}(E) = T^{J}(E) = \sum_{nj'l'} T^{J}_{j'l'}(E-E_n) + T^{J}_{\gamma}(E+B_n)$$

$$= \sum_{l'} \sum_{n} \varepsilon^{J}_{j_n l'} T_{l'}(E-E_n) + T^{J}_{\gamma}(E+B_n) \qquad (3)$$

$$T^{J\Pi}_{lj}(E) = T^{J}_{lj}(E) = \varepsilon_{Jl} T_{l}(E)$$

where

E_n = Energy of n^{th} discrete level of spin j_n in the residual target nuclei populated by outgoing neutron

$T_\ell(E)$ = Neutron transmission coefficient calculated with spherical optical model and assumed to be independent of J.

$\mathcal{E}^J_{j\ell}$ and $\mathcal{E}^J_{j_n\ell'}$ = Accessible reaction channel numbers i.e., degree of degeneracy of state

Summation is performed only over those discrete levels (n) and orbital moments (ℓ') which satisfy the conservation of energy, total angular momentum and parity.

From Eq.(2) and (3) we get

$$\sigma_{n\gamma}(E) = \frac{\pi \lambda^2}{2(2I+1)} \sum_J \frac{\sum_\ell T_\ell(E)\, \mathcal{E}^J_{j\ell}\,(2J+1)\, T^J_c(E+B_n)}{T^J_\gamma(E+B_n) + \sum_{\ell'} \sum_n \mathcal{E}^J_{j_n\ell'}\, T_{\ell'}(E-E_n)}$$

$$= \frac{\pi \lambda^2}{2(2I+1)} \sum_J \frac{\sum_\ell T_\ell(E)\, \mathcal{E}^J_{j\ell}\,(2J+1)\, \dfrac{T^J_c(E+B_n)}{T^J_\gamma(E+B_n)}}{1 + \dfrac{\sum_{\ell'} \sum_n \mathcal{E}^J_{j_n\ell'}\, T_{\ell'}(E-E_n)}{T^J_\gamma(E+B_n)}} \qquad (4)$$

The γ-ray transmission coefficients given in Eq.(4) are defined as follows:

$$T^J_c(B_n+E) = \frac{2\pi\, \bar{\Gamma}_c(J, B_n+E)}{D(J, B_n+E)}$$

and

$$T_\gamma^J(B_n+E) = \frac{2\pi\ \bar{\Gamma}_\gamma(J;B_n+E)}{D(J;B_n+E)}$$

where D = Level spacing

$\bar{\Gamma}_\gamma$ = Radiation width

$\bar{\Gamma}_C$ = Capture width

For gamma-ray calculation, as usual, only electric dipole transition is important. According to "Weisskopf estimates" the following energy dependence of the average radiation width $\bar{\Gamma}_\gamma$ and capture width $\bar{\Gamma}_C$ is assumed in FISPRO

$$\bar{\Gamma}_\gamma(J;B_n+E) \simeq G(J;B_n).D(J;B_n+E)\int_0^{B_n+E}\frac{\epsilon_\gamma^3\,d\epsilon_\gamma}{D(0;B_n+E-\epsilon_\gamma)}$$

$$\bar{\Gamma}_C(J;B_n+E) \simeq G(J;B_n).D(J;B_n+E)\int_E^{B_n+E}\frac{\epsilon_\gamma^3\,d\epsilon_\gamma}{D(0;B_n+E-\epsilon_\gamma)} \qquad (5b)$$

with

$$G(J;B_n) = \frac{\bar{\Gamma}_\gamma(J;B_n)}{\bar{D}(J;B_n)}\left[\int_0^{B_n}\frac{\epsilon_\gamma^3\,d\epsilon_\gamma}{D(0;B_n-\epsilon_\gamma)}\right]^{-1}$$

ϵ_γ = energy of gamma-ray emission by decay of a CN level with spin J.

Combining Eq.(4), (5a) and (5b), one get

$$\sigma_{n\gamma}(E) = \frac{\pi\lambda^2}{2(2I+1)}\sum_l T_l(E)\sum_J\frac{\epsilon_{jl}^J(2J+1)f(E;E)}{1+\sum_J f(E;0)\sum_{l'}\sum_n \epsilon_{j_n l'}^J T_{l'}(E-E_n)} \qquad (5c)$$

where

$$f(E;\omega) = \frac{\int_{\omega}^{B_n+\omega} \epsilon_\gamma^{2\ell+1} \rho_{oc}(\bar{U}-\epsilon_\gamma)\, d\epsilon_\gamma}{\int_{0}^{B_n+E} \epsilon_\gamma^{2\ell+1} \rho_{oc}(\bar{U}-\epsilon_\gamma)\, d\epsilon_\gamma}$$

ϵ_γ = Energy of emitted gamma ray

$\bar{U}$ = Effective excitation energy of compound nucleus

= $U + \Delta = E + Bn + \Delta$

2ℓ = Multipole type of the radiation emitted in the gamma-decay of compound nucleus. For E1 electric dipole emission, which usually gives the largest contribution to the radiative decay process. $2\ell + 1 = 3$.

$\rho_{oc}(\bar{U}-\epsilon_\gamma)$ = Level density of normal states of compound nucleus at excitation energy $\bar{U}-\epsilon_\gamma$

The simple Fermi gas model is used for level density

$$\rho_o(\bar{U}) = C\left[A(\bar{U}+t)\right]^{-2} \exp\left[2(a\bar{U})^{\frac{1}{2}}\right]$$

where

A = Mass number of nucleus considered

C = 1 MeV

a = Level density parameter

$\bar{U}$ = Effective excitation energy, $\bar{U} = at^2 - t = U + \Delta$

t = Thermodynamic temperature

Δ = Pairing energy of the nuclei considered, given by

$$\Delta = \begin{cases} 0 & \text{for even-even nuclei} \\ \delta & \text{for odd-A nuclei} \\ 2\delta & \text{for odd-odd nuclei} \end{cases}$$

and is estimated by empirical relation[10]

$$\delta = 0.41(4 - \frac{A}{100}) \text{ MeV for } A > 40$$

$$\xi_J = D^J(B_n) / 2\pi \Gamma_\gamma^J(B_n)$$

Eq.(5c) is the basic expression adopted in FISPRO-II for theoretical calculation of neutron radiative capture cross section.

The "Axel estimate" can also be adopted by following substitution in the above formulae (5b)

$$\varepsilon_\gamma^3 \rightarrow \frac{\varepsilon_\gamma^4}{(\varepsilon_R^2 - \varepsilon_\gamma^2)^2 + \varepsilon_\gamma^2 \Gamma_R^2} \qquad (6)$$

where ε_R and Γ_R represent the appropriate giant resonance parameters given by[11].

$$\varepsilon_R \simeq 40.7\ A^{-0.2} \text{ MeV} \qquad (7)$$

and

$$\Gamma_R \simeq 2.5 + \beta\, \varepsilon_R \text{ MeV} \qquad (8)$$

with β is the nuclear deformation[12].

3. Cross Section Calculations

In the computer code FISPRO-II using the expression (5c) the CN formation cross section and its subsequent decay taking into account the competition between radiative capture event (where the compound state de-excite by gamma emission leading to bounds levels)and neutron emission populating the discrete levels of the residual target nuclei can be calculated. For doing this a set of values are needed for the following parameters :

i) Resonance parameter $\bar{\Gamma}_\gamma$, $\bar{D}_{obs}$ and S at the neutron separation energy Bn

ii) Spherical optical model parameter for calculating the transmission coefficients T_ℓ (E)

iii) Level density parameter a and Δ

iv) Discrete energies levels and spins of target nuclei.

The computation of radiative capture cross section for Th-232 has been carried out using the resolved resonance analysis parameters[2] $\bar{\Gamma}_\gamma$, $\bar{D}_{obs}$ as a first estimate.

$\bar{\Gamma}_\gamma$ = Average radiation width as an input = 20 meV

$\bar{D}_{obs}$ = Average level spacing = 17 eV

S = Capture strength-function = $\frac{\bar{\Gamma}_\gamma \text{ (meV)}}{\bar{D}_{obs} \text{ (eV)}}$ =1.176 as an input

The adjusted Madland-Young parameters[13] for the spherical optical model potential have been used in the calculation of the neutron transmission coefficients.

V = Real part of the optical potential = 44 MeV

W = Imaginary part of the optical potential = 6.2 MeV

d_{ws} = Diffuseness of the Woods-Saxon optical potential = 0.6 fm

r_o = Radius constant (1.26 fm)

The standard Woods-Saxon form has been chosen for both the real and imaginary parts and the T_l (E) were computed for maximum value of ℓ as 9.

Initially the level density parameter a given by the linear relation $a = \frac{A}{10}$ MeV^{-1} was used and later on a estimated by the relation[14] $a \approx \frac{A}{11}$ MeV^{-1} was employed. The

Table - I

The Excitation Energy of the Discrete Levels of ^{232}Th with Natural Parity

Sr.No.	Energy (MeV)	Spin/Parity J^{π}
0	0.0000	0^+
1	0.0494	2^+
2	0.1621	4^+
3	0.3332	6^+
4	0.7142	1^-
5	0.7303	0^+
6	0.7741	2^+
7	0.7744	3^-
8	0.7853	2^+
9	0.8730	4^+
10	0.8836	5^-
11	0.8901	4^+
12	1.0729	2^+
13	1.0777	1^-
14	1.0788	0^+
15	1.1057	3^-
16	1.1228	2^+
17	1.1483	4^+
18	1.1825	3^-
19	1.2089	5^-

Table -2

Present Adopted Parameters for ^{232}Th Radiative Capture Cross Section Calculations

B_n	= 4.786	MeV
ε_R	= 13.692	MeV
Γ_R	= 6.156	MeV
$\overline{\Gamma}_\gamma$	= 25.5	meV
S	= 1.47	
a_c	= 21.7	MeV^{-1}
a_t	= 21.6	MeV^{-1}
Δ_c	= 0.685	MeV
Δ_t	= 0.0	
V	= 44.0	MeV
W	= 6.2	MeV
d	= 0.60	fm
r_o	= 1.26	fm
β	= 0.267	

Fig.2 of Ref.[14] shows that the experimentally deduced values of Fermi gas level density parameter a for the actinide region agree well with $a = \frac{A}{11}$ MeV^{-1} relation.

Using the above mentioned formulae both

$a_t = a$ - value for the compound nucleus level density

and

$a_c = a$ - value for the target nucleus level density

were estimated. The paring energy Δ_c for the target and compound nucleus were obtained as shown in Section 2. These estimated values for a_c, a_t, Δ_c and Δ_t parameter were used for performing $\sigma_{n\gamma}$ calculations. (Final values used $a_c = 21.7$ MeV^{-1}, $a_t = 21.6$ MeV^{-1} $\Delta_c = 0.685$ MeV and $\Delta_t = 0$).

The discrete energy levels and spins[15] of the residual nucleus (i.e., Th.232, 19 in all) included in the analysis are listed in Table-1. The states of unnatural parity and those with spins greater than $6\hbar$ were excluded from the main analysis.

The results of the computation were than compared with the experimental values of $\sigma_{n\gamma}$ and the resonance parameters ($\bar{\Gamma}_\gamma$ and S) were adjusted until a reasonably good visual fit between theory and experiment was achieved. (Final[16] values used $\bar{\Gamma}_\gamma = 25.5 \pm 1.2$ meV, $S = 1.470 \pm 0.5$).

Table-2 gives the values of various parameters adopted for the present theoretical calculation of $\sigma_{n\gamma}$. Table-3 gives the recent "normalised" experimental data for $\sigma_{n\gamma}$ with quoted uncertainty and the corresponding calculated values.

Table -3

Recent Normalised Measured and Calculated ^{232}Th Radiative Capture Cross Section

Sr.No.	Neutron Energy E_{lab} (MeV)	Normalised Measured Cross Section (mb)	Calculated Cross Section (mb)	χ_i^2	Reference
1	0.121	197 ± 4	239	110	5
		204 ± 2		306	
2	0.154	184 ± 3	198	22	
		187 ± 1		121	
3	0.198	164 ± 3	171	5	
4	0.217	156 ± 1	164	64	
5	0.264	147 ± 3	153	4	
6	0.300	160 ± 6	149	3	
7	0.324	140 ± 1	147	49	
8	0.398	137 ± 2	145	16	
9	0.484	143 ± 1	147	16	
10	0.525	152 ± 4	149	1	
11	0.580	159 ± 2	153	9	
12	0.600	193 ± 2	155	361	
13	0.681	180 ± 2	164	64	
14	0.720	165 ± 2	166	1	
15	0.779	162 ± 2	158	4	
16	0.800	150 ± 4	148	1	
17	0.824	156 ± 1	141	225	
18	0.935	133 ± 1	128	25	
19	1.010	125 ± 14	124	1	
20	1.070	124 ± 2	124	1	
21	1.24	111 ± 7	110	1	
22	0.110	194 ± 4	261	28	6
23	0.135	183 ± 5	218	49	
24	0.165	175 ± 5	189	8	
25	0.195	164 ± 6	172	2	
26	0.230	156 ± 6	160	1	
27	0.275	154 ± 6	152	1	
28	0.325	145 ± 6	147	1	
29	0.375	144 ± 6	145	1	
30	0.425	147 ± 6	145	1	
31	0.475	153 ± 6	147	1	
32	0.525	152 ± 6	149	1	
33	0.575	158 ± 7	153	1	
34	0.625	163 ± 7	157	1	
35	0.675	173 ± 7	163	2	
36	0.105	216 ± 18	273	10	7
37	0.121	211 ± 17	239	3	
38	0.141	200 ± 16	211	1	
39	0.167	192 ± 16	188	1	
40	0.200	172 ± 14	170	1	
41	0.244	147 ± 6	157	3	
		142 ± 12		2	
42	0.305	152 ± 12	148	1	

Table -3 (contd.)

Sr.No.	Neutron Energy E_{lab} (MeV)	Normalised Measured Cross Section (mb)	Calculated Cross Section (mb)	χ_i^2	Reference
43	0.500	149 ± 6	148	1	
44	0.600	162 ± 12	155	1	
45	0.622	173 ± 8	157	4	
46	0.700	170 ± 12	166	1	
47	0.850	160 ± 12	137	4	
48	1.013	132 ± 6	124	2	
49	0.350	138 ± 12	146	1	8
50	0.400	136 ± 10	145	1	
51	0.455	134 ± 10	146	2	
52	0.510	155 ± 9	148	1	
53	0.565	147 ± 7	152	1	
54	0.620	149 ± 10	157	1	
55	0.675	153 ± 8	163	2	
56	0.725	158 ± 8	165	1	
57	0.830	166 ± 8	140	10	
58	0.935	156 ± 8	128	10	

Note. The normalised measured cross sections have been obtained by normalising the published cross section values to the ENDF-B/V standards

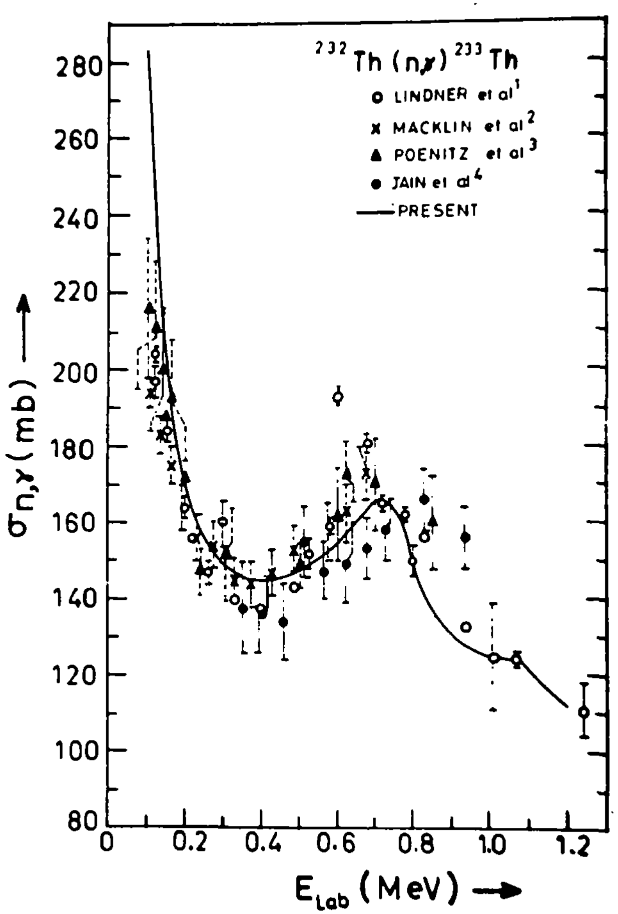

Fig.1 Comparison of Statistical Model Calculations (Solid Curve) with Recently Measured Data for ^{232}Th Neutron Radiative Capture Cross Sections.

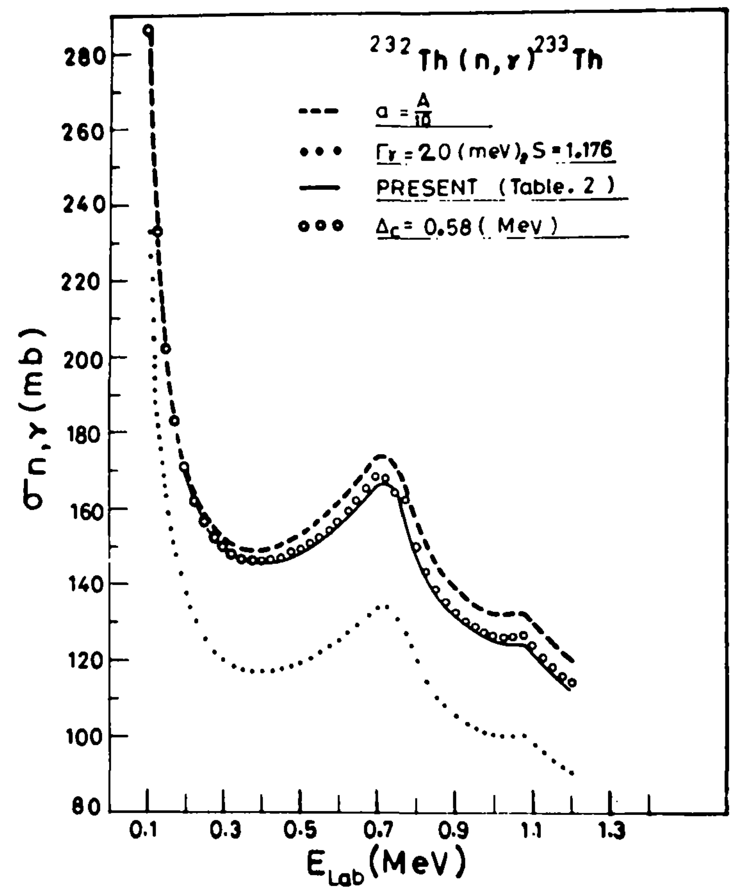

Fig.2. Effect of Variation of Level Density Parameter a, Paring Energy Δ, Resonance Parameters $\overline{\Gamma_\gamma}$ and S on Statistical Model Calculations for ^{232}Th Neutron Radiative Capture Cross Sections.

4. Discussion

In Fig.1 the recent experimental data for $\sigma_{n\gamma}$ are compared with the present calculations made using the parameters listed in Table-2. For the calculation of the energy dependence of $\bar{\Gamma}_{\gamma}$ and $\bar{\Gamma}_{c}$ the procedure of Axel was used. In the neutron energy region from $E \sim 200$ to 1200 keV, there is reasonable agreement between the experimental data and the theoretical prediction both in absolute magnitude and in the overall shape of the excitation function. As we have not incorporated in the present calculations the neutron level width fluctuations corrections which become increasingly important for low energy region, the agreement between the data and the prediction is not very good for neutron energy $E < 200$ keV. Also we have not taken into account the direct & $(n, 2\gamma)$ cascade processes which are important in the high energy region. In making these calculations we have tried to study the sensitivity of the results to various parameters given in (Table 2). In Fig.2 we have shown the effects due to variation of the level density parameter a and Δ. Both the magnitude and the shape of the excitation function are affected by the variation of these parameters In the same figure the change in the $\sigma_{n\gamma}$ values predicted due to variation of $\bar{\Gamma}_{\gamma}$ and S are also shown. It is seen from the figure that there is an overall increase of $\sigma_{n\gamma}$ values in the whole energy region with the increase of $\bar{\Gamma}_{\gamma}$ and S values. In the program the effect of change in $\bar{\Gamma}_{\gamma}$ over the calculated values of $\sigma_{n\gamma}$ comes through the $S = \frac{\bar{\Gamma}_{\gamma}}{D_{obs}}$ parameter only and not through $\bar{\Gamma}_{\gamma}$ directly. In Fig.3 we have shown the changes in the $\sigma_{n\gamma}$ values due to variation of the optical model parameters, V, W and d. It is clear from the figure, that the

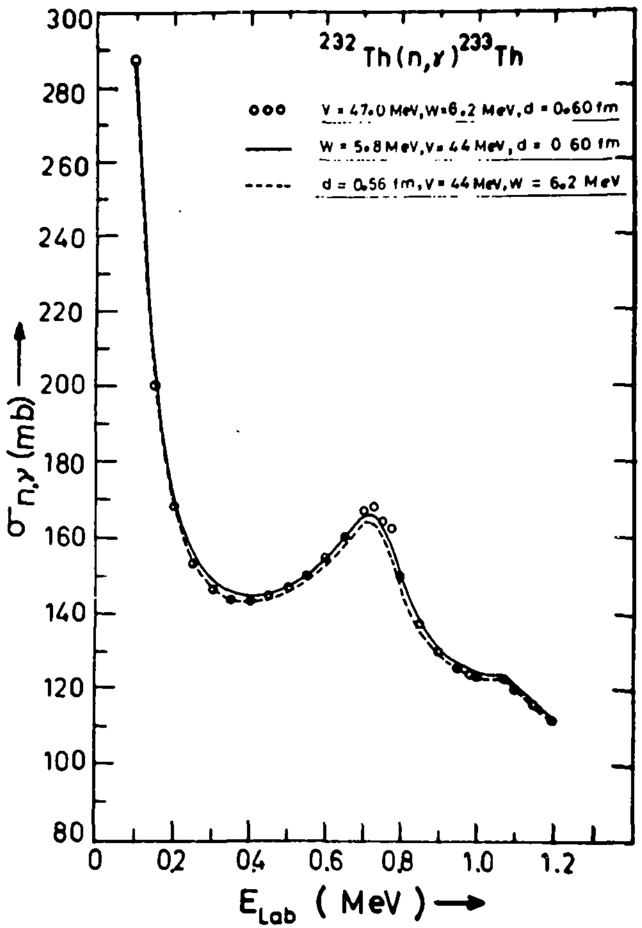

Fig.3. Effect of Variation of Optical Model Parameters V, W and d on Statistical Model Calculations for ^{232}Th Neutron Radiative Capture Cross Sections.

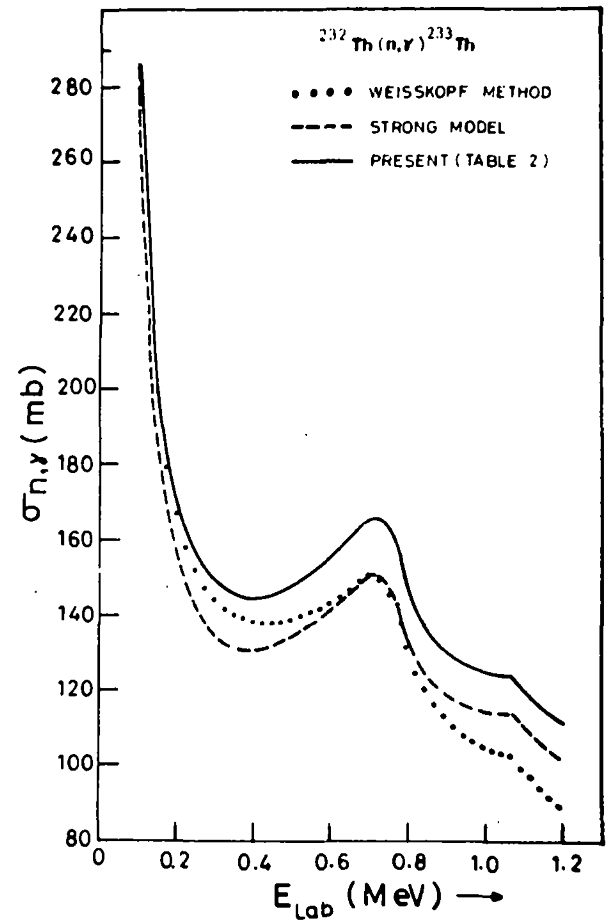

Fig.4. Comparison of ^{232}Th Neutron Radiative Capture Cross Sections Calculated using Axel Method (Solid Curve), Weisskopf Method for $\overline{\Gamma_\gamma}$ and $\overline{\Gamma_c}$ (●●● Curve) and Strong Absorption Model (--- Curve).

predictions are not very sensitive to these parameters. In Fig.4, we have shown the calculation using the Weisskopf method for $\overline{\Gamma_\gamma}$ and $\overline{\Gamma_c}$ energy dependance and these are compared with the results from Axels method. The former predictions are considerably lower as compared to the latter results and hence will not fit the data well. The use of strong absorptions as against the optical model also leads to still smaller values. Hence, in order to get reasonable fits to the experimental data using either the Weisskopf method or the strong absorption model (Axel method) one will have to use fairly large $\overline{\Gamma_\gamma}$ and S values which may be unrealistic.

The χ^2 value at each data point is also calculated and listed in Table-3. In the energy region above E_n = 200 keV but below E_n = 1.20 MeV the χ^2/N obtained from measured data sets of Poenitz et.al.[7], Macklin et.al.[6] and Jain et.al.[8], are approximately 1,2 and 3 respectively. The corresponding value for the data set of Lindner et.al.[5], is $\simeq$ 47. From Fig.1 it is clear that the measured data point of Lindner at 600 keV is quite discrepent in comparison to both theory and other measured data sets. After rejecting this point the $\chi^2/N \sim 29$. In our earlier[1] $\sigma_{n\gamma}$ evaluation for ^{232}Th the Lindner data set was used full as reported. Since the quoted errors are relatively smaller than the other measured data sets which resulted in more weightage to these data in evaluation. In view of these finding, a reevaluation of this cross-section has become necessary after rejecting this 600 keV measured point from Lindner data set and including the Jain et.al.[8], full data set.

When the present work was nearly complete we came across a paper[9] on the Hauser-Feshbach calculation for Th-232 (n,γ)

reaction in the energy region 1-1000 keV. The two works are similar in many aspects. The important differences are as follows:

1. They have used 15 discrete levels of ^{232}Th (0.0 to 0.890 MeV) taken from Nuclear Data Sheets, 1977, while we have used the 19 levels (0 to 1.2 MeV) from the recent compilation[15]. In their calculations the levels $0.8297, 3^+$ and $0.8901, 4^-$ of unnatural parity are included. We have considered the levels with natural parity only. The inclusion of $0.8297, 3^+$ level in our calculation lowered the $\sigma_{n\gamma}$ values from 0.850 MeV onwards and it becomes less by $\simeq$ 5% at 1 MeV and the assignment of parity 4^- or 4^+ to level 0.8901 MeV makes negligible change.

2. They have used the energy dependent deformed optical potential while we have used the spherical one and independent of neutron energy valid for small energy range involved.

3. They have taken into account the neutron width fluctuation.

4. Their calculations give a somewhat larger $\sigma_{n\gamma}$ values as shown below:

Neutron Energy MeV	$\sigma_{n,\gamma}$ (mb) Ref[14]	Present
0.3	152	149
0.7	180	166
1.0	138	125

5. They have used Fermi gas level density formulae with corrections for collective phenomena in the highly excited nucleus (both rotational and vibrational). We have used simple Fermi gas model without any correction for collective phenomena and $a \simeq \frac{A}{11}$ MeV^{-1}.

6. We have also extended the calculation to neutron energy 1200 keV. In comparing their calculations with the experimental data, they have not used the more recent data. Our present work remove this deficiency as well.

5. Conclusion

The neutron radiative capture cross sections for Th-232 have been calculated in the neutron energy region 100 to 1200 keV using the statistical Hauser-Feshbach formalism. The present calculations reproduce fairly well the experimental trend, both in magnitude and shape. It has been found that using the optical model for the calculation of the neutron transmission coefficients, following the Axel model for the energy variation of $\overline{\Gamma_\gamma}$ and $\overline{\Gamma_c}$, the relation $a = A/11\ \mathrm{MeV}^{-1}$ for the level density parameter a and the values for the parameters $\overline{\Gamma_\gamma} = 25.5$ meV and $\overline{D}_{obs} = 17.0$ eV, a satisfactory visual fit to the experimental data has been achieved. Based on the results of the present work, it is proposed to reevaluate the $\sigma_{n\gamma}$ cross section data for ^{232}Th by including the latest data, assigning more realistic errors to Lindner data set after removing the 600 keV point, and also make use of the theoretical prediction for proper weighting of data sets.

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