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MEASUREMENT AND EVALUATION OF THE ACTIVATION RESONANCE INTEGRAL OF ^{146}Nd, ^{148}Nd AND ^{150}Nd

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A B S T R A C T

Values of the ratio of the reduced activition resonance integral to the thermal cross section, I'/σ_0 of ^{146}Nd, ^{148}Nd and ^{150}Nd were determined relative to gold by measuring cadmium ratios.

A lithium-drifted germanium gamma ray spectrometer was used to resolve the activities of the irradiated samples.

The results are: for ^{146}Nd $I'/\sigma_0 = 1.42 \pm 0.10$ and with an assumed $\sigma_0 = 1.4$ barn, $I' = 1.99 \pm 0.20$; for ^{148}Nd $I'/\sigma_0 = 4.22 \pm 0.14$ and with an assumed $\sigma_0 = 2.5$ barn, $I' = 10.5 \pm 0.9$ barn, and for ^{150}Nd $I'/\sigma_0 = 13.7 \pm 0.8$ and with an assumed $\sigma_0 = 1.2$ barn, $I' = 16.4 \pm 2.8$.

The resolved and unresolved epithermal integrals of ^{146}Nd, ^{148}Nd and ^{150}Nd were calculated.

Values of the spectral correction factor were also calculated, so the resonance integral could be obtained from the epithermal integral data measured in our reactor spectrum in this experiment.

Epithermal integral and spectral correction factors are listed in the text.

The most important result of this investigation is that the ^{148}Nd activation reduced resonance integral is about half of previously recommended value and consequently the radiative width for ^{148}Nd is also about half of previously accepted value.

INTRODUCTION

Accurate neutron reactor effective cross section for ^{146}Nd, ^{148}Nd and ^{150}Nd have been requested by the last panel on burn-up physics (IAEA 1971).

In addition in spite of the effort made to study neutron resonance parameters of neodymium isotopes by time of flight technique (Alves et al. 1969; Migneco et al. 1969; Karzhavina et al. 1969; Tellier 1971) still there is a considerable uncertainty about the radiative widths for ^{148}Nd and ^{150}Nd needed for accurate estimation of keV and MeV neutron radiative captures for fast reactor burn-up and reactivity calculations.

Resonance integrals provide a reliable check of how confidently resonance parameters may be used to calculate neutron capture integral data and in this sense may be considered as an experimental technique of evaluation apart from its practical importance for thermal reactor physics.

In this work a measurement of the activation resonance integrals of ^{146}Nd, ^{148}Nd and ^{150}Nd was undertaken together with an evaluation of neutron resonance parameters, neutron capture cross section and related integral data.

M E T H O D

The cadmium ratio method used in this experiment gives the reduced resonance integral if it is assumed that the reactor spectrum is 1/E.

However what is really measured by this method is the epithermal reaction rate in a reactor spectrum minus the 1/v contribution normalized to the slowing down flux at the resonance energy of the standard.

We may call this magnitude epithermal integral, I_e', and by means of a calculated factor f, it would be possible to obtain the reduced resonance integral, I':

$$I' = f\, I_e' \qquad (1)$$

Most previous work either assumes $I' \cong I_e'$ or calculates f assuming a relatively small departure from the 1/E distribution of the slowing down flux in the low energy range of the neutron spectrum.

However there are a good number of isotopes in which the contribution of absorption produced by MeV neutrons in excess of the 1/E distribution is non-negligible (more than 1%). This implies first that in order to make a meaningful comparison of the epithermal integral with the calculated values, we must evaluate properly the unresolved epithermal integral and second, that the distribution of neutron captures in the whole range of energy to 10 MeV must be taken into account for the calculation of f. (See appendix I).

According to Westcott formalism (Westcott et al. 1958) we can deduce:

$$\frac{I_e' G_r}{\sigma_0} = \frac{\sqrt{\pi}}{2} \; \frac{1 - R_{cd}\left(r\sqrt{T/T_0}\right)\left(1/K\right)}{\left(R_{cd} - 1\right)\left(r\sqrt{T/T_0}\right)} \qquad (2)$$

where I_e' is the epithermal integral; R_{Cd} is the measured cadmium ratio: $(r\sqrt{T/T_0})$ is the epithermal neutron index; 1/K is proportional to the ratio of the 1/v resonance integral above the cadmium cut-off to the thermal cross section σ_0; Gr is the resonance self-shielding factor.

In expression (2) the epithermal neutron depression in cadmium is negligible and the cross section below the cadmium cut-off is 1/v.

Resonance self-shielding was calculated using the neutron resonance parameters of Karzhavina et al. (1969) in a rational approximation with Doppler broadening correction (Dresner 1960). For the sample thickness used the resonance self-shielding is negligible.

The cadmium ratios were measured relative to gold using very thin neodymium-gold samples. These samples were prepared from a solution and contained the same proportions of neodymium and the standard (^{197}Au).

The proportions were adjusted to give approximately equal neodymium and gold gamma rays intensities in the gamma ray spectrum.

The gamma ray spectra of the bare and cadmium covered samples were then measured and the relative number of counts in the photopeak calculated. Thus only ratio of ratios are determine minimizing most of the systematic errors inherent in this kind of measurement.

The gold cadmium ratio $R_{Cd}(Au)$, at the irradiation place is 1.684 ± 0.003 and with $I'/\sigma_0 = 15.7$ (Ricabarra et al 1968), the epithermal neutron index is $r\sqrt{T/T_0} = .0794 \pm .0003$.

The experimental results are compared with the calculated values as described in the evaluation section. A multigroup diffusion code was used to calculate the neutron spectrum at the irradiation site (Boix and Solanilla 1967).

The conditions fulfilled by the present determination of resonance integrals that permit a meaningful comparison with calculated values are:

1) High γ-ray resolution in order to be sure that the desired activity is measured.
2) Reproducibility of irradiation and counting positions.
3) Negligible correction of neutron flux and epithermal index differences between bare and cadmium covered samples.
4) Negligible epithermal self-shielding in the samples.
5) A well defined spectrum in a region where the spatial distribution of thermal and epithermal neutron flux is as flat as possible.
6) An estimation of the slowing down spectra (by multigroup calculation or other suitable method). Estimation of 1MeV neutron flux is as important as the knowledge of the small deviation over the 1/E spectrum between 1 eV and 10 keV.

For ^{146}Nd, ^{148}Nd and ^{150}Nd the first condition is the important due to the complex gamma ray spectrum obtained by neutron activation of these isotopes. Additional details on this technique are described in previous work (Ricabarra et al. 1968).

EXPERIMENTAL

Neutron capture in neodymium yields ^{147}Nd (11 days), ^{149}Nd (1.8 hours) and ^{151}Nd (12 minutes). ^{149}Nd and ^{150}Nd decay to ^{149}Pm (53.1 hours) and ^{151}Pm (28 hours) respectively. Because the ^{151}Pm gamma spectrum is complex (Ewan and Tavendale 1964; Lederer et al. 1968), a careful analysis of the gamma spectrum was made to check that no impurities were present and to select well resolved photopeaks.

A pure neodymium sample was irradiated four hours and gamma counted after decay of ^{149}Nd and ^{151}Nd. The photopeaks energies were checked in the range from 80 Kev to 600 keV.

Activities were also checked to prove that they were decaying with the expected half-lives.

From this measurement the 91 keV and 531 keV photopeaks of ^{147}Nd, the 285keV photopeak of ^{149}Pm and the 340keV photopeak of ^{151}Pm were selected to measure the cadmium ratio.

The ^{147}Nd 413 keV gamma ray slightly affects the determination of the 412 keV ^{198}Au gamma ray activity in the neodymium-gold samples. To correct for this contamination the ratio of the 413 keV photopeak activity relative to the 91 keV and 531 keV ^{147}Nd photopeaks activities in a pure neodymium sample was used. The effect of this correction in the cadmium ratio of the neodymium isotopes relative to the gold cadmium ratio is negligible at the end of the irradiation and it is less than 1.5% five days later.

Neodymium-gold samples 3 mg/cm^2 thick containing 3 parts of gold per 10 000parts of neodymium were prepared. Bare and cadmium covered samples were placed four cm apart in the central graphite reflector of the Reactor Argentino 1 (10^{12}n/cm^2 sec thermal neutron flux) where the neutron epithermal index and thermal flux distribution are flat in an ample region (Ricabarra et al. 1970).

The samples were irradiated 4 hours and measured alternativaly during 100 hours starting 24 hours after irradiation.

The samples were gamma counted in a lithium-drifted germanium gamma ray spectrometer, the amplifier output was connected to a 100 megacycles ADC interfaced to a 8 K Hewlett -Packard 5406 B computer and the gamma spectrum accumulated in a memory region. Background substraction, integration under the photopeaks, time extrapolation and normalization to the gold photopeak were performed on line. The quoted results are the average values from five irradiations.

^{146}Nd

The ratio of cadmium ratios obtained from the 91 keV and 531 keV ^{147}Nd gamma rays is:

$$R_{Cd}(^{146}Nd)/R_{Cd}(^{197}Au) = 3.43 \pm 0.05$$

or

$$R_{Cd}(^{146}Nd) = 5.78 \pm 0.08$$

and $I_e'/\sigma_o = 1.84 \pm 0.03$

with σ_o = 1.4 barn (Walker 1969), I_e' = 2.58 ± 0.20b.

^{148}Nd

The average result obtained by measuring the 285 keV ^{149}Pm photopeak is:

$$R_{Cd}(^{148}Nd) / R_{Cd}(^{197}Au) = 1.85 \pm 0.03$$

or $$R_{Cd}(^{148}Nd) = 3.11 \pm 0.05$$

and $$I'_e / \sigma_o = 4.69 \pm 0.11$$

and with σ_o = 2.5 barn (Walker 1969) $I'_e = 11.7 \pm 1.0$ barn

^{150}Nd

The result from the 340 keV ^{151}Pm gamma ray is:

$$R_{Cd}(^{150}Nd) / R_{Cd}(^{197}Au) = 0.99 \pm 0.02$$

or $$R_{Cd}(^{150}Nd) = 1.67 \pm 0.03$$

and $$I'_e / \sigma_o = 15.6 \pm 0.8$$

with σ_o = 1.2 barn (Walker 1969) $I'_e = 18.7 \pm 3.2$ b.

EVALUATION OF THE ACTIVATION RESONANCE INTEGRAL OF ^{146}Nd , ^{148}Nd AND ^{150}Nd.

General considerations about basic neutron cross section and related integral data.

There are several time of flight measurements of ^{146}Nd, ^{148}Nd and ^{150}Nd neutron resonance parameters from various laboratories. Measurements from Dubna (Karzhavina 1969) has been made by transmission and capture technique on enriched neodymium samples.

Measurements from Saclay has been made by transmission on natural neodymium (Alves 1969) and on enriched neodymium samples (Tellier 1971).

There are also measurements on natural neodymium samples using transmission and capture technique reported from Geel (Migneco et al. 1969).

The time of flight measurement of Tellier(1971) has better energy resolution and a more extended energy range (up to 20 keV).However since he measured only transmission, radiative widths are poorly determined for resonance with large neutron widths.

Some observation may be made on neutron resonance parameters determined by these time of flight experiments which are relevant for neutron capture integral data calculation.

For instance it may be seen in table II that for the two main neutron capture resonances of ^{148}Nd the radiative width obtained by different laboratories is strongly discrepant.

On the other hand for ^{150}Nd the main capture resonance integral is not as dependent on Γ_γ and although Γ_γ is discrepant by a factor of two between Tellier and Karzhavina, $(\Gamma_n \Gamma_\gamma)/\Gamma$ is in excellent agreement among different labora-

tories (See table III).

Similar considerations may be applied to the first resonance of ^{146}Nd in which there is a basically good agreement between Karzhavina and Tellier (Table I).

Thus examination of available results on radiative widths shows that there is an uncertainty about the radiative width for ^{148}Nd and ^{150}Nd which is important for the calculation of neutron captures in the unresolved high energy region of these isotopes.

This is related to the evaluation of the unresolved part of the epithermal and resonance integral which was previously estimated with an s-wave approximation. This may not be an adequate choice because the unresolved epithermal and resonance integral has to be calculated above 10 keV for neodymium isotopes and it has been shown that above this energy s-wave approximation like Dresner treatment may seriously underestimate the unresolved neutron captures (Ricabarra et al. 1972). (See Appendix I).

In table IV may be seen the unresolved epithermal and resonance integral calculated with a semi-empirical statistical model radiative neutron cross section (Benzi and Reffo 1969).

The semi-empirical calculation of Benzi has probably been fit to the data of Johnsrud et al (1958) as normalized by Goldberg et al (1966) for ^{148}Nd and ^{150}Nd. This measurement is for energies higher than 100 keV and were normalized by Goldberg et al. (1966) to their recommended absorption thermal neutron cross section σ_0 (^{148}Nd) = 2.9 $\pm$ 0.6 barn and σ_0 (^{150}Nd) = 1.8 $\pm$ 0.3b.

Since these values are too high according to the recent evaluation of Walker (1969) we have renormalized the Johnsrud data and the Benzi semi-empirical fit to Walker's recommended neutron activation thermal cross section for ^{148}Nd and ^{150}Nd.

It is difficult to estimate the error which may be assigned to a semi-empirical calculation or low resolution differential activation measurements. We assume rather arbitrarily that the calculated unresolved resonance integral may be in a error by 50%.

DISCUSSION AND COMPARISON OF EXPERIMENTAL AND CALCULATED EPITHERMAL INTEGRALS FOR ^{146}Nd, ^{148}Nd and ^{150}Nd

One may examine results shown in table V for ^{146}Nd in which is shown a good agreement between I_e'/σ_0 measured by us and that of Alstad(1967).

However Alstad spectrum(heavy water, natural uranium lattice) may be softer in the high energy region than our spectrum (enriched uranium, light water reactor), in consequence a better comparison in the light of the comments made in the appendix needs a knowledge of the fast flux in the irradiation facility of Alstad.

The reduced resonance or epithermal integral calculated with the resonance parameters of Karzhavina (1969) is lower by about 1 barn than that obtained with our experimental results and this figure is comparable with the resolved resonance integral and cannot be explained by discrepant resonance parameters of ^{146}Nd or spectrum corrections in the low energy resonances.

The disagreement would be reduced if our calculated unresolved epithermal integral were added to the resolved one. This suggests that at least for ^{146}Nd neutron captures above 10 keV are comparable to that below 10 keV in the spectrum of a light water, enriched uranium reactor.

The activation epithermal integral of ^{148}Nd measured by us agrees with that measured by Alstad (1967) and both measurements disagree with the experimental determination of Rider et al.(1964) (see table VI). The same comment made above about spectrum differences in our reactor and that of Alstad and Rider is valid here, however the difference in the experimental epithermal integrals are well within the quoted errors.

Calculation with resonance parameters of Karzhavina et al (1969) is higher than the experimental results by a factor of two. However as has been pointed out before, radiative width which is the relevant parameter for the calculation of resonance integral of ^{148}Nd is strongly discrepant among different time of flight measurements.

In principle one may be inclined to give preference to the radiative width obtained by Karzhavina time of flight experiment because of the use of transmission and capture technique on enriched samples (conditions not fulfilled completely by the other experiments), however good agreement between ourselves and Alstad strongly suggests that radiative width for ^{148}Nd may be half of the value determined by Karzhavina and similar to the radiative width of ^{146}Nd.

Also the neutron activation thermal cross section of ^{148}Nd is significantly lower than that calculated with Karzhavina neutron resonance parameters when one would expect the opposite due to the contribution of virtual levels that in ^{146}Nd and ^{150}Nd contributes to the activation thermal cross section with about 1 barn.

Results shown in table VII for ^{150}Nd show a difference of 15% between our value of I_e/σ_0 and that of Alstad et al. (1967), although they agree within their quoted errors. The epithermal integral calculated with the Karzhavina resonance parameters is lower by around 30% and this disagreement would be reduced significantly if the unresolved epithermal integral calculated in our reactor spectrum is added to the resolved one.

FINAL RESULTS: EPITHERMAL AND RESONANCE INTEGRAL FOR ^{146}Nd, ^{148}Nd AND ^{150}Nd

One may discuss which data may be useful to quote. The first problem arises when we compare our results with the results from other papers where there is not other information about their spectrum than a "nearly" 1/E spectrum, in the low energy range.

Evaluation has always been made with a 1/E spectrum, which is reasonable; however in some cases these data may significantly differ from the reactor data due to the importance of high energy neutron captures.

We calculate a spectrum correction factor, f , as the ratio of epithermal neutron captures in a 1/E spectrum to the epithermal neutron captures in our reactor spectrum:

$$f = \frac{\int_{E_c} \sigma_{n,\gamma}(E) \; 1/E \, dE}{\int_{E_c} \sigma_{n,\gamma}(E) \; \phi_R(E) \, dE}$$

is the neutron capture cross section which has been calculated using Karzhavina neutron resonance parameters in the resolved energy range and with the semi-empirical statistical model calculation of neutron capture cross section (Benzi and Reffo 1969) in the unresolved region and $_R(E)$ is the reactor spectrum calculated with 54 group diffusion code.

The unresolved epithermal and resonance integral of ^{146}Nd is comparable to the resolved one, then a 6% systematic error in f must be expected due to 50% error atributed to our calculation of the unresolved epithermal integral.This systematic error is less than

2% for the other neodymium isotopes. Final results are shown in table VIII.

CONCLUDING REMARKS

We have finally arrived at a meaningful comparison of experimental and calculated activation integral data for ^{146}Nd, ^{148}Nd and ^{150}Nd. This has permitted us to calculate a spectral correction factor to get the resonance integrals from our measured epithermal integrals for these isotopes.

The result of this investigation is that for ^{146}Nd and ^{150}Nd the calculated epithermal integral agrees reasonable well with our experimental result. However for ^{146}Nd, captures above 10KeV are quite significant, then a better knowledge of the neutron radiative capture cross section at high energies would improve the evaluation of the resonance integral.

The most important conclusion is that for ^{148}Nd our activation resonance integral is about half of the value recommended by Walker(1969) and that the corresponding average radiative width is also about half of the previously accepted value (Karzhavina et al. 1969).

APPENDIX I

The inadequacy of a s-wave statistical model calculated neutron radiative cross section for the estimation of neutron captures above 10 keV has been shown for keV average resonance spacing isotopes where this inadequate calculation produced an apparent discrepancy of a factor of three between calculated and experimental activation integral data (Ricabarra et al. 1972).

In our previous work is was also shown that the s-wave approximation produced a significant error not only in the value of the unresolved epithermal and resonance integral, but also in the distribution of neutron captures in function of energy, underestimating seriously neutron captures at 1MeV where the neutron reactor spectrum deviates strongly from the 1/E assumption and has a nearly fission spectrum shape.

This may be easily shown for ^{146}Nd. The measurement of the activation cross section made by Hughes (1953) at 1 MeV gives 40 milibarns (cross section at the same energy measured by Johnsrud et al (1959) or calculated by Benzi and Reffo (1969) for ^{148}Nd and ^{150}Nd are within 50% of this value).

Assuming that the fast reactor spectrum has a nearly fission shape the contribution of MeV neutron captures to the epithermal integral may be easily estimated with values of fast flux (measured with threshold detectors) and epithermal flux (measured with gold). Our estimation gives for this fraction ($\phi_{fast}/\phi_{epi} \cdot \sigma_{n\gamma}$ (1MeV)) the value of .38 barns.

The same fraction estimated by numerical integration, using 54 group calculated reactor spectrum and the radiative captures cross section calculated with a semi-empirical statistical model by Benzi and Reffo (1969) gives .47 barn.

This fraction is in between 10 and 20% of the total epithermal integral ($I_e' = 2.6$ barn) and is about half of the estimation of the unresolved epithermal integral which takes into account all neutron captures above 7keV.

An s-wave approximation would have given a cross section at 1MeV more than one order of magnitude smaller (0.7 milibarn) than that measured by Hughes (1953) and the calculated contribution to the epithermal integral would have been entirely negligible.

This simple example shows that a better statistical model description of the capture cross section above 10 keV than that provided for an s-wave approximation, is needed to make a meaningful comparison of calculated values with experimental integral data.

As far as the relative influence of neutron p-captures for ^{146}Nd, ^{148}Nd and ^{150}Nd at the relatively low energy range (10 keV $\leq E \leq$ 50 keV) we may refer to the work of Thirumala Rao et al. (1970), that has shown that at 25 keV for these isotopes a p-contribution larger than 50% is present.

Numerical details of our reactor spectrum and 1/E neutron captures calculation in the unresolved region of ^{146}Nd are given in Table IX. This integration has been made above 7 keV using neutron radiative capture cross section of Benzi and Reffo (1969) and a calculation of our reactor spectrum with a 54 group code. Dresner approximation gives in this region $I' = 0.09$ barn.

$\Delta I'$ and $\Delta I_e'$ are the neutron captures per energy interval in a 1/E spectrum and in our reactor spectrum normalized to the slowing down flux at low energy.

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LIST OF TABLES

TABLE I

Neutron resonance parameters of ^{146}Nd first resonance (361eV)

Reference	Γ_γ (meV)	Γ_n (meV)	$\frac{\Gamma_\gamma \Gamma_n}{\Gamma}$
Karzhavina et al. (1969)	55 ± 8	43 ± 7	24.1
Tellier (1971)	65.5 ± 20.1	44.5 ± 2.5	26.5

TABLE II

Neutron resonance parameters of ^{148}Nd main resonances.

Reference	E_r (eV)	Γ_γ (meV)	Γ_n (meV)	Γ (meV)
Karzhavina et al. (1969)	155	100 ± 15	1610 ± 240	1710
Migneco et al. (1969)		70 ± 8	2000	2070
Alves et al. (1969)		(40)[a]	2460 ± 200	2500±200
Tellier (1971)		(250 ± 283)[a]	1850 ± 200	2100±200
Karzhavina et al. (1969)	285	96 ± 14	2600 ± 200	2696
Migneco et al (1969)		58 ± 6	1980 ± 100	2038
Alves et al. (1969)		—	3700 ± 370	
Tellier (1971)		(50 ±224)[a]	3130 ± 100	3180±200

a.- Obtained only by transmission. The radiative width has a very large error because was obtained by difference of large quantities.

TABLE III

Neutron resonance parameters of ^{150}Nd first resonance (78.9 eV).

Reference	Γ_γ (meV)	Γ_n (meV)	$\frac{\Gamma_n \Gamma_\gamma}{\Gamma}$
Karzhavina et al. (1969)	115 ± 20	15.1 ± 1.6	13.3
Migneco et al. (1969)	70 ± 20	18 ± 2,5	14.4
Tellier (1971)	51.1 ± 10	18.9 ± 0.5	13.9

TABLE IV

Calculted unresolved epithermal and resonance integral of ^{146}Nd, ^{148}Nd and ^{150}Nd.

Isotope	Unresolved Resonance Integral (barn) (1/E Spectrum)	Unresolved Epithermal Integral (barn) (Reactor Spectrum)
^{146}Nd	0.64	1.16
^{148}Nd	0.56	1.03
^{150}Nd	1.21	1.91

TABLE V

^{146}Nd activation epithermal integral.

References	σ_0 (barn)	I'_e/σ_0	I'_e (barn)
Alstad et al. (1967)	1.3 ± 0.1	1.9 ± 0.24	2.5 ± 0.25
This paper	1.4 [a]	1.84 ± 0.03	2.58 ± 0.20 [d]
Breit Wigner calculation [b]			1.76 [b]
Unresolved epithermal integral (reactor spectrum) [c]			1.16

a.- Walker (1969) recommended value

b.- From Karzhavina et al. (1969) neutron resonance parameters and increased, by a 10% to account for the reactor spectrum deviation (in a 1/E spectrum I' = 1.6).

c.- Cross section from Benzi and Reffo (1969) statistical semiempirical calculation.

d.- Thermal cross section error quoted by Alstad et al. (1967).

TABLE VI

^{148}Nd activation epithermal integral

References	σ_0 (barn)	I_e'/σ_0	I_e' (barn)
Rider et al. (1964)	2.54 ± 0.18	6.97 ± 0.74	17.7 ± 1.4
Alstad et al. (1967)	2.5 ± 0.2	5.2 ± 0.9	13 ± 2
This paper	2.5[a]	4.69 ± 0.11	11.7 ± 1.0
Breit Wigner calculation[b]	3.27	7.2	27.7[b]
Unresolved epithermal integral (the reactor spectrum)[c]			1.03

a.- Walker (1969) recommended value

b.- From Karzhavina et al. (1969) neutron resonance parameters and increased by a 10% to account for the reactor spectrum deviation (in a 1/E spectrum I' = 25.2)

c.- Cross section from Benzi and Reffo (1969) statistical semiempirical calculation.

TABLE VII

^{150}Nd activation epithermal integral

References	σ_o (barn)	I_e'/σ_o	I_e' (barn)
Alstad et al. (1967)	1.0 ± 0.2	13.6 ± 4.7	13.6 ± 3.9
This paper	1.2[a]	15.6 ± 0.8	18.7 ± 3.2[b]
Breit Wigner calculation[b]			15.3
Unresolved epithermal integral (reactor spectrum)[c]			1.91

a.- Walker (1969) recommended value.

b.- From Karzhavina et al. (1969) neutron resonance parameters are ~~and~~ increased by ~~a~~ 10% to account for the reactor spectrum deviation (in a 1/E spectrum I' = 13.9).

c.- Cross section from Benzi and Reffo (1969) statistical semiempirical calculation.

c.- Thermal cross section error quoted by Alstad et al. (1967).

TABLE VIII

Final results for ^{146}Nd, ^{148}Nd and ^{150}Nd.

	Previous Evaluation[a]	Calculated Data		f	Experimental Data	
	I'	I'_e	I'		I'_e	I'
	(barn)	(barn)			(barn)	
^{146}Nd	2.0	2.92	2.24	0.77 ± 0.05	2.58 ± 0.20	1.99 ± 0.20
^{148}Nd	20	28.73	25.76	0.90 ± 0.02	11.7 ± 1.0	10.5 ± 0.9
^{150}Nd	14	17.21	15.11	0.88 ± 0.02	18.7 ± 3.2	16.4 ± 2.8

a.- Walker (1969).

TABLE IX

CALCULATION OF HIGH ENERGY NEUTRON CAPTURES OF ^{146}Nd.

LETARGY	E	E $\phi(E)$ [a]	$\sigma_{n,\gamma}(E)$ [b]	$\Delta I'$	$\Delta I'_e$
	keV	Norm.	mbarn	mbarn	mbarn
7.264	7	1.139	291.5	—	—
7.131	8	1.142	277	38.1	43.4
7.013	9	1.142	264.3	32.0	36.5
6.908	10	1.142	252.9	27.3	31.2
6.215	20	1.186	177.5	170.8	197.0
5.809	30	1.322	138.3	67.4	83.1
5.521	40	1.405	115.8	37.5	50.8
5.298	50	1.473	102.0	24.7	35.3
5.116	60	1.541	93.4	18.0	27.0
4.961	70	1.587	87.7	14.0	21.9
4.828	80	1.662	83.9	11.5	18.6
4.710	90	1.715	81.4	9.8	16.4
4.605	100	1.813	79.7	8.5	14.9
3.912	200	2.282	73.7	58.3	114.4
3.506	300	2.871	71.8	30.4	76.4
3.218	400	3.953	78.3	21.1	70.6
2.995	500	3.627	36.6	12.8	49.5
2.813	600	4.262	28.5	6.0	23.4
2.659	700	4.776	27.1	4.3	19.4
2.525	800	4.776	27.5	3.6	17.4
2.407	900	4.776	28.8	3.3	15.8
2.302	1000	4.927	30.9	3.1	15.2
1.897	1500	5.652	35.7	13.6	71.7
1.609	2000	5.720	32.0	10.0	56.5
1.386	2500	5.667	21.0	6.1	34.7
1.203	3000	4.761	14.2	3.3	17.6
1.049	3500	3.778	9.0	1.8	8.0
0.916	4000	3.113	5.8	1.0	3.5
0.693	5000	2.085	2.5	1.0	2.7
0.510	6000	1.307	1.2	0.3	0.6
0.356	7000	0.891	0.6	0.14	0.16
0.223	8000	0.453	0.45	0.07	0.05
0.105	9000	0.181	0.78	0.07	0.02
0	10000	0	1.91	0.13	0.07

a- Normalized to low energy slowing down flux (4.5 eV)

b- Cross sections from Benzi and Reffo (1969)