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NEUTRON ACTIVATION RESONANCE INTEGRAL OF ^{74}GE AND ^{76}GE AND EVALUATION OF ^{74}GE KEV NEUTRON RADIATIVE CAPTURE CROSS SECTION AND RESONANCE INTEGRAL

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Neutron Activation Resonance Integral of ^{74}Ge and ^{76}Ge and Evaluation of ^{74}Ge keV Neutron Radiative Capture Cross Section and Resonance Integral

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Abstract

Values of the reduced activation resonance integral relative to the thermal cross section, I'/σ_0 of ^{74}Ge and ^{76}Ge were determined relative to gold by measuring cadmium ratios in a reactor spectrum.

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

The results for ^{74}Ge are $I'/\sigma_0 = 1.514 \pm 0.031$ and $I' = 0.681 \pm .123$ barn with an assumed $\sigma_0 = 0.45 \pm 0.08$ barn ; for ^{76}Ge $I'/\sigma_0 = 12.00 \pm 0.16$ and $I' = 1.992 \pm 0.359$ with an assumed $\sigma_0 = 0.166 \pm 0.030$ barn.

The values obtained for I' are in serious disagreement with the values calculated with neutron resonances parameters and confirm previous results obtained in similar keV average resonance spacing isotones.

Due to this fact a careful evaluation of keV neutron radiative capture cross section and resonance integral for ^{74}Ge was undertaken.

The evaluation and comparison with the experimental value of the resonance integral shows first that for nuclides with an average resonance spacing of keV the unresolved resonance integral has been seriously underestimated in many evaluations and second that between 10 keV and 100 keV resonance integrals calculated with smooth low resolution activation cross section give a better calculation of neutron captures than that obtained with neutron resonance parameters.

Introduction

Previous results (Ricabarra et al. 1968, 1969, 1970) showed that a consistent serious discrepancy existed between calculated and experimental values of the resonance integral for several isotopes in which the predominant resonances were in the keV energy region.

^{74}Ge and ^{76}Ge are elements with these characteristics, and it is interesting to see if these elements confirm our previous results.

Furthermore keV radiative capture cross sections in the Ge isotopes are particularly important for stellar nucleosynthesis (Fowler 1968) and the understanding of keV neutron captures by isotopes with wide average resonance spacing (~keV) is also of interest in fast reactor physics.

In addition one of the outstanding problems of neutron detection has been the detection of keV energy neutrons in presence of strong gamma radiation and thermal neutron fields.

Recently similar isotopes like ^{80}Se and ^{64}Zn have been proposed (Connolly et al. 1968) and used (Müller 1970) to determine neutron flux in the keV energy region of a fast critical assembly, but apparently the authors has not checked the radiative capture cross sections and neutron resonances parameters of these elements against experimental values of the resonance integral.

^{74}Ge and ^{76}Ge may be convenient detectors for this energy range but a comparison of the experimental resonance integral with the calculated one has to be made in order to know if resonances parameters may be trusted to calculate keV effective cross sections.

Recently a complete measurement of germanium neutron resonances parameters has been reported (Maletzki et al. 1968), and this measurement has been made by high resolution transmission and radiative capture technique applied to enriched germanium samples. The combination of these techniques is believed to give a reasonable accuracy for radiative width determination in resonances with large neutron widths, and a better information about weaker p-wave resonances.

In addition there are for ^{74}Ge a good number of differential neutron activation cross sections measurement in the keV and MeV energy region and semi-empirical statistical model calculation of the cross section.

Therefore ^{74}Ge is a suitable element to make critical comparisons of keV neutron captures calculated by different procedures and arrive at a meaningful understanding of the cause of discrepancies in this energy region.

Some provisional data about germanium isotopes together with previously published values were reported in a review of our work in this field in the Helsinki Conference (Ricabarra et al. 1970). In this paper is given a complete description of the technique, evaluation and results which supersedes previous provisional values.

Method

The cadmium ratio technique was applied to determine the ratio of the reduced resonance integral, I', to the thermal activation cross section, σ_0, as has been discussed in previous work (Ricabarra et al. 1968).

The ^{74}Ge cadmium ratio was determined by measuring the activity of ^{75}Ge (82 m.). An isomer is also produced, but it decays enterely to the ground state with a half-life of 48 s., so that for counts starting $\sim$ 1 hour after the end of the irradiation, the ^{75}Ge activity is proportional to the total ^{74}Ge cross section.

This is not the case for ^{76}Ge, because the metastable isomer, ^{m77}Ge (54 s.) produced by neutron capture only partially (24%) decays to the ground state ^{77}Ge (11.3 h.) and 76% of ^{m77}Ge decays to ^{77}As (38.7 h.) (Lederer et al. 1968). See fig.1

The activity of ^{77}As does not represent the sum of the activity of the two isomers due to the fact that its half-life is of the same order as the ^{77}Ge half-life.

If $\hat{\sigma}$ (m) and $\hat{\sigma}$ (g) are the effective cross sections to the metastable and ground state isomers, the saturation activity of ^{77}Ge and ^{77}As at the end of the irradiation, per atom of ^{76}Ge and neutron flux equal to one, can be expressed (See Apendix II):

$$Q(^{77}Ge) = \hat{\sigma}(g) + f\,C_0\,\hat{\sigma}(m)$$

$$Q(^{77}As) = \hat{\sigma}(g) + B_0\,\hat{\sigma}(m)$$

where $B_0 = \dfrac{(1-f)C_1 + fC_3}{C_2}$

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Fig. 1

f is the isomeric transition fraction and C_0, C_1, C_2 and C_3 are terms which depends on the decays constants (λ_1, λ_2, λ_3) the irradiation time (T) and the time elapsed from the end of irradiation (t).

If one allows for complete decay of the 54 sec. activity, the coefficients C_0 and C_1 become constants: $C_0 = \lambda_1 / (\lambda_1 - \lambda_2)$ and $C_1 = \lambda_1 / (\lambda_1 - \lambda_3)$. Fig. 2 shows C_2, C_3 and B_0, calculated as a function of time.

The ^{76}Ge isomeric yield ratio is different for thermal and epicadmium capture, hence the cadmium ratio obtained by measuring ^{77}Ge gamma rays will be different from that obtained by measuring ^{77}As gamma rays.

The ratios of the bare to the cadmium covered activity obtained from ^{77}Ge, R_2 and ^{77}As, R_3, photopeaks can be expressed in terms of the cadmium ratio, R_{Cd} :

$$[1] \qquad R_2 - 1 = (R_{Cd} - 1) \frac{1 - \alpha (1 - Y)}{1 - \alpha (1 - Y_1)}$$

$$[2] \qquad R_3 - 1 = (R_{Cd} - 1) \frac{1 - \beta (1 - Y)}{1 - \beta (1 - Y_1)}$$

where $\alpha = 1 - C_0 f$ and $\beta = 1 - B_0$,

Y is the isomeric yield ratio below the cadmium cut-off and equals the thermal isomeric yield ratio; Y_1 is the epicadmium isomeric yield ratio.

From the experimental values R_2 and R_3 and expressions [1] and [2] the cadmium ratio, R_{Cd} , can be obtained.

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Fig. 2

Assuming that the transmission of resonance neutrons in cadmium is equal to one ($F=1$) and the cross section below the cadmium cut-off is $1/v$ ($g = 1$, $W=0$), the reduced resonance integral I' , can be deduced from the Westcott formalism (Westcott et al. 1958):

$$[3] \quad \frac{I' G_r}{\sigma_0} = \frac{\sqrt{\pi}}{2} \; \frac{1 - R_{cd}\,(1/K)\,(r\sqrt{T/T_0})}{(R_{cd} - 1)\;(r\sqrt{T/T_0})}$$

where G_r is the resonance self-shielding correction; $r\sqrt{T/T_0}$ is the epithermal neutron index; $1/K = .462$, for $E_0 = 0.025$ eV and $E_{cd} = 0.60$ eV. The definition of the experimental resonance integral and its dependence on the reactor spectrum are discussed in Appendix I.

Resonance self-shielding correction

The self-shielding correction, G_r, was calculated for every resonance using the parameters of Maletzki et al. 1968. The Doppler effect and resonance integral were calculated for every resonance. The narrow resonance approximation (Dresner 1960) was used to calculate self-shielding, because the neutron width was considerably narrower than the average decrement of the neutron energy per collision in the germanium resonances.

A experimental determination of the resonance self-shielding correction was made by measuring the cadmium ratio for two different sample thicknesses and $I' G_r$ was derived from them.

The infinite-dilution resonance integral was obtained by extrapolating the experimental values of $I' G_r$ to zero thickness using the calculated G_r as a parameter.

In cases where there is a serious disagreement between calculated and experimental value of self-shielding this procedure is somewhat involved and may produce a 1% systematic error in the experimental resonance integral.

Experimental details

In previous work (Ricabarra et al. 1968, 1970) most of the experimental details and analysis relevant to this kind of measure were given.

The irradiation place was the central graphite reflector of the Reactor Argentino 1 (RA1). The flux distribution and slowing down spectra in the site of irradiation were given in the papers mentioned above.

The Westcott epithermal index, $r\sqrt{T/T_0}$, was 0.0794 ± 0.0003 based on a gold cadmium ratio of 1.674 ± 0.003 and a value of I'/σ_0 of 15.69.

Cadmium ratios were made for two foil thickness; foils of metallic germanium 406 mg/cm^2 thick and thin foils of 25 mg/cm^2 or 40 mg/cm^2 of germanium oxide deposited in plastic paper.

An activation analysis was made of the irradiated plastic paper to be sure that no undesirable activities were present in the gamma energy region of interest. The reproducibility of our germanium oxide deposits was checked and was found to be better than 10%.

To avoid problems of weight intercalibration each run was repeated for each pair of foils reversing the position of bare and cadmium covered foils.

The foil activities were counted alternately in a Li-drifted Ge gamma ray spectrometer to total around 10^6 counts. Dead time correction in the spectrometer multichannel analyzer system was controlled to be less than 0.5% and the multichannel analyzer was operated in the live-time mode.

^{74}Ge

Metallic germanium foils (406 mg/cm^2) were irradiated in the central graphite refledtor.

The 190 keV gamma ray of ^{75}Ge (82 m.) was measured two hours after irradiation and the activity followed for about one and half hours.

The average result from three experiments is:

$$R_{Cd}\,(^{74}Ge) = 7.00 \pm 0.09$$

$$I'\,G_r / \sigma_o = 1.383 \pm 0.021$$

Thin foils (40 mg/cm^2) of germanium oxide were irradiated bare and cadmium covered for 5 minutes and the 190 keV gamma ray activity measured one hour after irradiation. Eight runs were made with four pair of foils, reversing the cadmium box position for each pair.

The average result is:

$$R_{Cd}(^{74}Ge) = 6.64 \pm 0.10$$

$$I'G_r/\sigma_o = 1.497 \pm 0.027$$

By extrapolation of $I'\,G_r/\sigma_o$ as a function of the calculated G_r, as described before, the value of the ratio of the resonance integral to the thermal cross section for infinite dilution is obtained:

$$I'/\sigma_o = 1.514 \pm 0.031$$

In table I are summarized the results of the experiments and the experimental resonance self-shielding.

The thermal cross section adopted for ^{74}Ge is the value recommended

by Goldberg et al. 1966, $\sigma_o = 0.45 \pm 0.08$ barn.

From the experimental value of I'/σ_o and $\sigma_o = .45 \pm 0.08$ b, $I' = 0.681 \pm .123$ barn is obtained. The calculated value is $I'_{calc} = 0.217$ and disagrees by a factor of three. This calculation was made with the resonances parameters of Maletzki et al (1968) from 2 keV to 60 keV and Dresner treatment of the unresolved resonance integral

This discrepancy is considered further in a separate section.

Similarly the experimental G_r in table I disagrees with the calculated G_r. If one assumes that this discrepancy is due to a non-shielded contribution, P , to the resonance integral, then :

$$G_r(\text{exp.}) = \frac{(\sum G_{ri} I_i)^{calc} + P}{(\sum I_i)^{calc} + P}$$

and P is about 0.5 barn, which gives $I' = 0.72$ barn in better agreement with our experimental value of the resonance integral.

^{76}Ge

Thick foils of 406 mg/cm^2 of metallic germanium were irradiated for three hours and measurement of the ^{77}Ge photopeaks started 24 hours after irradiation to allow for complete decay of ^{75}Ge (82 m.).

The bare and cadmium covered samples were counted alternately and the decay of the 210, 215 and 263 keV of ^{77}Ge photopeaks (11.3 h.) was followed for about two days.

Three irradiation were performed and the average result is:

$$R_2 = 1.897 \pm 0.001$$

To obtain R_3 the activity of the ^{77}As (38.7 h.) 239 keV gamma ray was counted. This is the strongest activity available because 97% of the decays go directly to the ground state. This activity was counted

when the ^{77}Ge photopeaks activity had decayed to be of the same order. Three irradiations were made and the foils activity was counted for about ten hours, from 117 to 127 hours after the end of irradiation. The average result is :

$$R_3 = 2.041 \pm 0.010$$

During the time of the counting B_o in expression (2) varies very slowly (.12% in 10 hours) and can be considered constant during the measurement, $B_o = 0.7792$ at 122 hours.

In expressions [1] , [2] and [3] , $Y = 0.339$ (Mannhart and Vonach 1968), $f = 0.24$ (Lederer et al. 1968). The results are:

$$(R_{Cd} - 1) = 1.076 \pm 0.013$$

$$I' G_r / \sigma_o = 9.58 \pm 0.12$$

Thin foils of 25 mg/cm^2 of germanium oxide were irradiated 30 minutes. Three pairs of foils were used reversing the cadmium position for each pair, six runs in total were made.

The ^{77}Ge photopeaks were counted 24 hours after the end of irradiation an the average is:

$$R_2 = 1.731 \pm 0.007$$

Self-shielding which depends only on the total cross section at the resonances will affect equally both isomeric states and $R_2 - 1 / R_3 - 1$ will not depend on the thickness. This ratio could be determined with better statistics for thick samples than for thin samples. Then for thin samples only R_2 was determined and R_3 was obtained using the ratio of $R_2 - 1 / R_3 - 1$ determined for thick samples.

A direct measurement of R_3 made on thin samples only in one run agreed within 1% with the value obtained by this method.

The values of R_{Cd} and $I' G_r/\sigma_o$ for thin foils are:

$$(R_{Cd} - 1) = 0.877 \pm 0.011$$

$$I' G_r/\sigma_o = 11.860 \pm 0.158$$

From $I' Gr/\sigma_o$ for two thickness, I'/σ_o can be extrapolated as described in the Method Section and the results are shown in table II. We then obtain:

$$I'/\sigma_o = 12.00 \pm 0.16$$

Using the thermal activation cross section for ^{77m}Ge (54 s.) recommended by Goldberg et al (1966) $\sigma_o(m) = 0.11 \pm 0.02$ barn and the thermal isomeric yield ratio $Y = 0.339 \pm 0.020$ (Mannhart and Vonach 1968) one obtains $\sigma_o = .166 \pm 0.030$ barn.

With $I'/\sigma_o = 12.00 \pm 0.16$ and $\sigma_o = 0.166 \pm 0.030$ b we obtain:

$$I' = 1.992 \pm 0.359$$

Using the neutron resonances parameters gives by Maletzki et al (1968), the calculated value is $I' = 1.20$ barn which seriously disagrees with the experimental value.

Evaluation of ^{74}Ge keV neutron radiative capture cross section and Resonance Integral

Early measurements of ^{74}Ge neutron activation cross sections were made by Macklin et al. (1957) and Lyon and Macklin (1959) at 24 keV and 197 keV. New activation cross section measurements at 24 keV were made by Chaubey and Sehgal (1966) and Lakshmana Rao et al. (1970).

Tolstikov et al. (1967) and Dovbenko et al. (1969) made a differential activation cross section measurement from 10 keV to 3 MeV and obtained a good fit with their calculated statistical model curve and a reasonable agreement with Macklin measurements.

There are also measurements in the MeV energy region by Hughes et al. (1953) and Pasechnik et al. (1958).

In addition to these low resolution measurements there are the previously quoted neutron resonances and resonances parameters measurement from 2 keV to 60 keV, made by transmission and capture technique with enriched ^{74}Ge samples (Maletzki et al. 1968).

Furthermore there are two semi-empirical statistical model calculation for ^{74}Ge by Benzi and Reffo (1969) and Musgrove (1969).

We estimated from Maletzki neutron resonances parameters the average activation cross section at 24 keV with energy dispersion of $\pm$ 1 keV ($\Delta E = 2$ keV) as recommended for Sb-Be sources (Pauw 1970) and of $\pm$ 5 keV ($\Delta E = 10$ keV) as quoted by Dovbenko et al. (1969).

Examination of Table III shows that Maletzki neutron resonance parameters seriously underestimate neutron captures at 24 keV.

This discrepancy may be due to neglect of p-and d- wave neutron captures according to the statistical model calculations of Dovbenko et al (1969) and Musgrove (1969).

We may now proceed to evaluate the neutron radiative capture resonance integral from the ^{74}Ge cross sections quoted previously.

The unresolved part of the reduced resonance integral from 60 keV to 10 MeV was evaluated : by Dresner treatment (Dresner 1960) using Maletzki et al. (1968) average resonance parameters; by numerical integration of the resonance integral using the statistical model calculated cross section (Benzi and Reffo 1969); and finally using differential activation cross sections (Tolstikov et al. 1967; Dovbenko et al. 1969). These numerical integrations were made both for a 1/E spectrum and a reactor spectrum obtained from a 54 group diffusion code (Boix and Solanilla 1967). The results are shown in Table IV.

One may observe in this table that the Dresner formalism which assumes equally spaced s-wave neutron resonances underestimates by a factor of 70 the unresolved resonance integral of ^{74}Ge.

This underestimation is significant for isotopes with wide average level spacing ($\sim$ keV), where the unresolved resonance integral is comparable with the contribution of the first or second keV main s-wave resonances, then some unresolved resonance integrals may have been uncorrectly calculated in previous evaluation (Persiani 1963; Schmidt 1966; Connolly et al.1968; Walker 1969; Müller 1970).

In addition it can be observed that about half of the unresolved resonance integral comes from the 1 MeV region where the slowing down spectrum of a thermal reactor is not 1/E.

This fraction is about 10% of the experimental resonance integral ($I' \cong 0.68$) and may be enhanced (by a factor of two or three) in partial resonance integrals for the production of high-spin isomers.

This shows that high-spin isomers may not be adequate indicators of keV neutron flux.

In Table V an evaluation of the reduced resonance integral of ^{74}Ge is made by different procedures.

It can be seen that Maletzki et al. (1968) neutron resonance parameters seriously underestimate captures between 10 keV and 60 keV and this is consistent with our evaluation of ^{74}Ge neutron capture cross section at 24 keV and the unresolved resonance integral.

A second observation is that the disagreement between the ^{74}Ge experimental activation resonance integral and that calculated with neutron resonance parameters will be reduced if the data from differential activation cross section of Dovbenko et al. (1969) are used to calculate the resonance integral from 10 keV to 10 MeV.

Therefore the present evaluation of the ^{74}Ge resonance integral suggests that about one third of the activation resonance integral comes from neutron captures in the main s-wave neutron resonances, another one third comes from energies higher than 60 keV and the remaining part can be ascribed to "p" and "d" wave neutron resonances which has not been resolved between 3 keV and 60 keV.

A comment may be added about the discrepancy in ^{76}Ge. The calculated resonance integral for the 550 eV. resonance of ^{76}Ge is around 1 barn and the contribution of keV energy resonances is 200 milibarns.

If the discrepancy of 800 milibarns between experimental and calculated ^{76}Ge resonance integral is assigned to the keV energy region, the calculated contribution of 200 milibarns in this energy region would be in error by a factor of 4 , in qualitative agreement with the results of ^{74}Ge.

Final remarks

This measurement of ^{74}Ge and ^{76}Ge activation resonance integrals confirms previous results which showed that neutron captures in the keV energy region by isotopes with wide average resonance spacing, were seriously underestimated by Breit-Wigner resonance integral calculation.

A critical analysis and evaluation of neutron radiative capture cross sections showed that an important fraction of neutron captures comes from energies higher than 10 keV.

This makes ^{74}Ge and ^{76}Ge and similar detectors like ^{80}Se and ^{64}Zn studied in our previous work (Ricabarra et al. 1968,1969) unsuitable for neutron detection in the keV energy region because only a minor fraction of the activity comes from neutron captures in the lowest keV energy resonances, and shows that there is still much work and investigation to be done in order to find a convenient foil detector for neutron flux in the keV energy region.

Finally, previous evaluation suggests that for isotopes with wide average resonance spacing ($\sim$ keV), differential activation or semi-empirical statistical model neutron cross sections may give a better description of neutron captures in the range of 10 keV to 100 keV than that obtained from resolved resonance parameters.

Appendix I

We may remind the reader that the value of the experimental resonance integral given in this paper may be defined as the integral reaction rate above the cadmium cut-off normalized to the slowing down flux at the standard resonance energy.

In previous work (M.D. Ricabarra et al., 1968, 1969, 1970) a correction for the small deviation of the reactor spectrum relative to the 1/E spectrum has been applied to our experimental value and this correction is accurate if it is assumed that activation comes mainly from one or two low energy resonances. In this case the spectral correction will not be dependent on the assumed resonance parameters.

In this paper our experimental data has not being corrected as in previous ones, because to do this correction would imply to know the distribution of neutron captures in function of energy which was "a priori" not known and is one of the results of this investigation.

However only 10% of the activation experimental resonance integral of ^{74}Ge comes from neutron captures in the MeV region, where the flux in the reactor is not "nearly" 1/E, and only this fraction would significantly change for a cadmium covered sample irradiated in a more thermalized spectrum. This fraction may be easily estimated with the knowledge of the fast flux and activation cross section of ^{74}Ge at 1 MeV.

Appendix II

The activity of ^{77}Ge and ^{77}As per atom, in a germanium sample that has been exposed to a flux equal to one, during a time, T, and measured at a time, t, after the end of the irradiation is:

$$A(^{77}Ge) = a_o \hat{\sigma}(g) + f\, a_1 \hat{\sigma}(m)$$
$$A(^{77}As) = (1 - f)\, b_o \hat{\sigma}(m) + b_1 \hat{\sigma}(g) + f\, b_2 \hat{\sigma}(m)$$

where $\hat{\sigma}(g)$ and $\hat{\sigma}(m)$ are the effective cross sections for the production of the ground and metastable isomers, and the coefficients a_o, a_1, b_o, b_1, b_2, depend on the decay constants λ_1, λ_2, λ_3 of ^{77m}Ge, ^{77}Ge and ^{77}As, the irradiation time and the time of the measurement.

Extrapolating to the end of the irradiation and dividing by $(1 - \exp(-\lambda T))$, we have the saturation activities:

$$Q(^{77}Ge) = \frac{A(^{77}Ge)\; e^{\lambda_2 t}}{1 - e^{-\lambda_2 T}}$$

$$Q(^{77}As) = \frac{A(^{77}As)\; e^{\lambda_3 t}}{1 - e^{-\lambda_3 T}}$$

which can be expressed:

$$Q(^{77}Ge) = \hat{\sigma}(g) + f\, C_o \hat{\sigma}(m)$$
$$Q(^{77}As) = (1 - f)\, C_1 \hat{\sigma}(m) + C_2 \hat{\sigma}(g) + f\, C_3 \hat{\sigma}(m)$$

or

$$Q(^{77}As) = \hat{\sigma}(g) + B_o \hat{\sigma}(m)$$

$$B_o = \frac{(1 - f)\, C_1 + fC_3}{C_2}$$

From well known expressions for radioactive decay we have:

$$C_0 = \frac{e^{\lambda_2 t}}{1 - e^{-\lambda_2 T}} \left[\frac{\lambda_2}{\lambda_2 - \lambda_1} \left(1 - e^{-\lambda_2 T}\right) e^{-\lambda_1 t} - \frac{\lambda_1}{\lambda_2 - \lambda_1} \left(1 - e^{-\lambda_1 T}\right) e^{-\lambda_2 t} \right]$$

C_1 has the same form, with λ_3 instead of λ_2, and C_2 is similar, replacing λ_2 with λ_3 and λ_1 with λ_2.

$$C_3 = \frac{e^{\lambda_3 t}}{1 - e^{-\lambda_3 T}} \left[\frac{\lambda_3}{\lambda_3 - \lambda_2} \left(1 - \frac{\lambda_2}{\lambda_2 - \lambda_1} e^{-\lambda_1 T} + \frac{\lambda_1}{\lambda_2 - \lambda_1} e^{-\lambda_2 T}\right) e^{-\lambda_2 t} \right.$$

$$\left. - \frac{\lambda_2}{\lambda_3 - \lambda_2} \left(1 - \frac{\lambda_3}{\lambda_3 - \lambda_1} e^{-\lambda_1 T} - \frac{\lambda_1}{\lambda_3 - \lambda_1} e^{-\lambda_3 T}\right) e^{-\lambda_3 t} \right]$$

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List of tables

TABLE I

Resonance Integral and Resonance Self-shielding of ^{74}Ge

δ	G_r	$I'G_r/\sigma_0$	G_r
(mg Ge/cm^2)	calculated	measured	experimental
406	.7042	1.383	.9135
28	.9622	1.497	.9888
0	1	1.514	1

TABLE II

Resonance Integral and Resonance Selfshielding for ^{76}Ge

δ	G_r	$I' G_r/\sigma_o$	G_r
(mg Ge/cm^2)	calculated	measured	experimental
406	.782	9.584	.798
17	.987	11.860	.988
0	1	12.004	1

TABLE III

^{74}Ge Cross Section at 24[a] keV

REFERENCES	Cross Section (barn) calculated	measured
Macklin et al.1957		.057
Chaubey and Sehg al 1966		.020
Lakshmana Rao et al. 1970		.0896
Benzi 1969	.049	
Musgrove 1969	.033	
Dovbenko et al. 1969	.044	.044
Average	.042	.053
Estimated cross section at 24 keV with Maletzki et al. (1968) parameters, with dispersion:		
Δ E=±1 keV	.016 [b]	
ΔE=±5 keV	.011 [c]	

a-Nominal Sb-Be source neutron energy.
b-Estimated cross section varies 10% if calculated at 22keV.
c-Calculated cross section does not vary if calculated at 22 keV instead of 24 keV.

TABLE IV

Calculation of ^{74}Ge Unresolved Resonance Integral ($60keV < E \leqslant 10MeV$)

REFERENCES	Resonance Integral (barn)	
	1/E Spectrum	Reactor Spectrum [a]
Dresner formalism [b]	.002	
Benzi (1969)	.058	.161
Tolstikov et al. 1967 and Dovbenko et al. 1969	.055	.150

a- 54 group diffusion reactor spectrum calculation.
b-With Maletzki et al.(1968) parameters.

TABLE V

Evaluation of ^{74}Ge Resonance Integral in the Reactor Spectrum.[a]

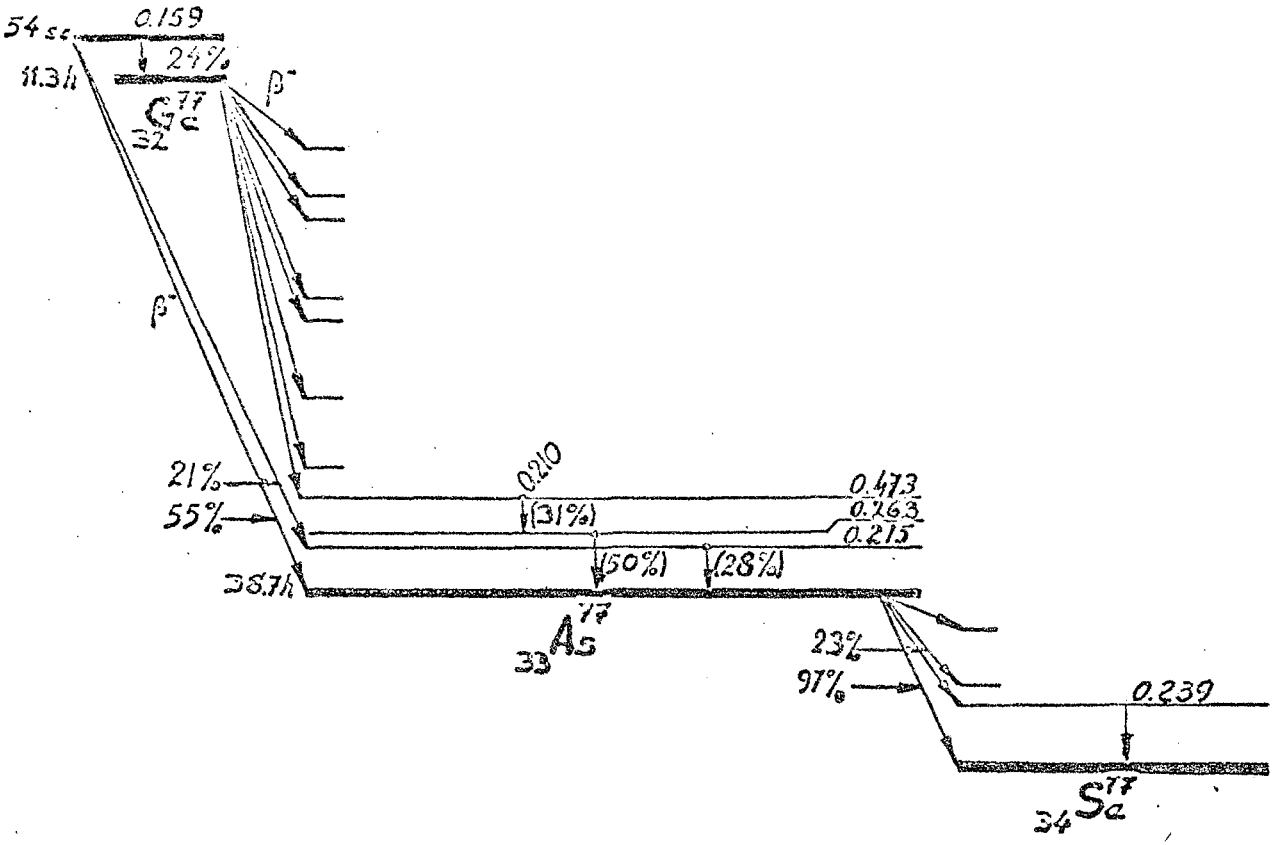
REFERENCES	I' (barn)		
	2-10 keV	10-60 keV	60 keV-10 MeV
Maletzki et al. 1968 [b]	.231	.013	.005
Tolstikov et al. 1967 [c] and Dovbenko et al. 1969		.116	.150
Benzi 1969 [d]		.126	.161

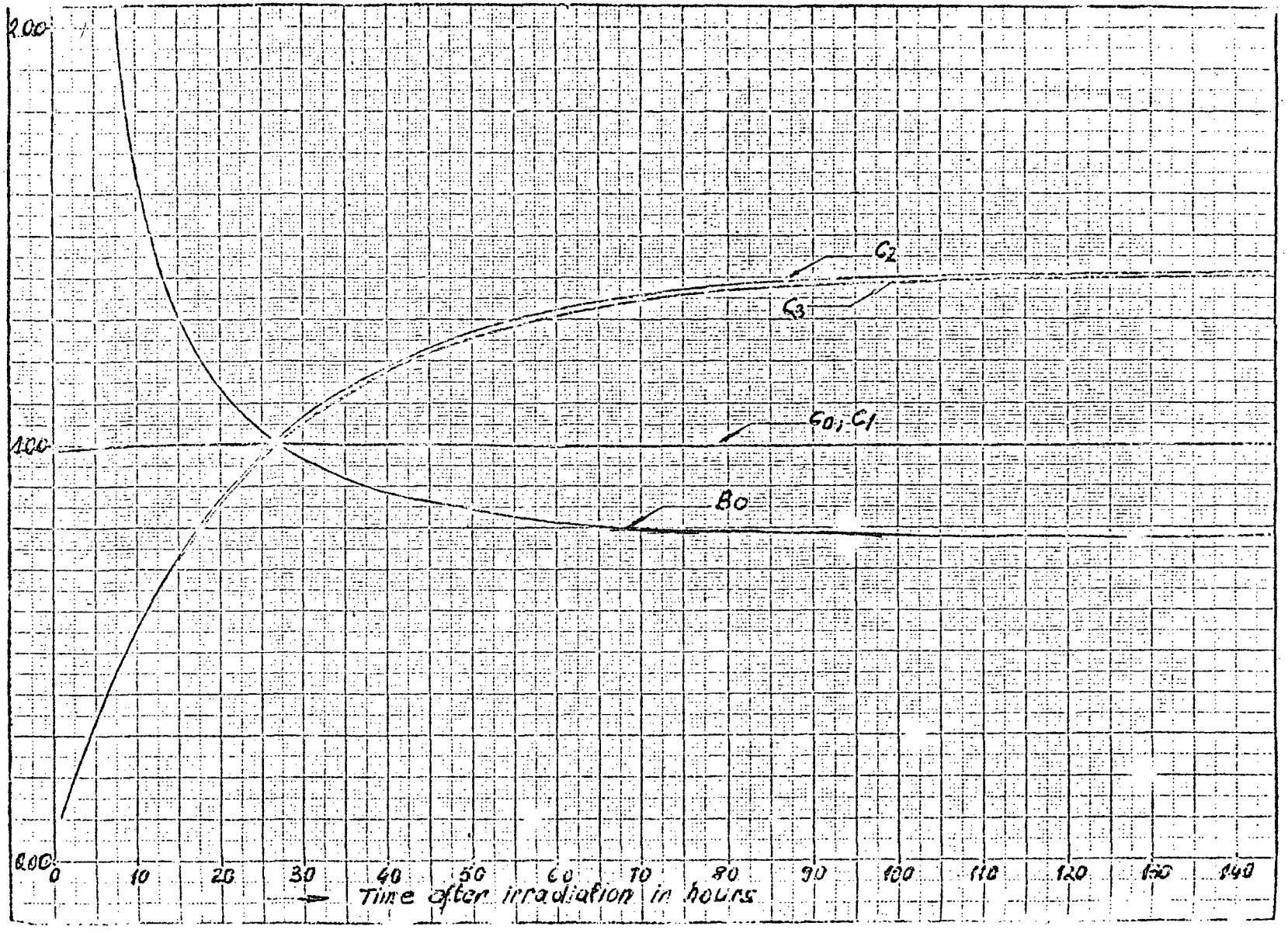
Experimental value I'=.68±.12

a-Multigroup diffusion calculation.
b-Breit-Wigner calculation and Dresner formalism for non resolved resonance integral.
c-Low resolution differential activation cross section measurement.
d-Semi-empirical statistical model cross section.

List of figures

FIG. 1


54 sec
0.159
24%
11.3 h
$^{77}_{32}Ge$
β⁻
β⁻
21%
55%
0.210
(31%)
0.473
0.263
0.215
(50%)
(28%)
38.7 h
$^{77}_{33}As$
23%
97%
0.239
$^{77}_{34}Se$


200
100
0.00
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Time after irradiation in hours
C2
C3
C0; C1
B0