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^{127}I, ^{130}Te, ^{138}Ba, ^{140}Ce, and ^{142}Ce

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A lithium-drift germanium γ-ray spectrometer has been used to make accurate intercomparisons of the ratio of resonance-integral to thermal-activation cross section by measuring cadmium ratios or relative activation rates in two different neutron spectra. The standard, gold, or secondary standard, indium, was mixed uniformly in the samples and the activities resolved with the spectrometer. Expressed as Westcott s_0 values, the results relative to $s_0 = 17.7$ for gold were as follows: ^{74}Se $= 10.3 \pm 0.1$, ^{78}Se $= 12.3 \pm 0.3$, ^{80}Se $= 2.65 \pm 0.02$, ^{81}Br $= 24.3 \pm 0.5$, ^{127}I $= 27.8 \pm 0.5$, ^{130}Te $= 2.10 \pm 0.07$, ^{138}Ba $= 0.649 \pm 0.004$, ^{140}Ce $= 0.476 \pm 0.003$, ^{142}Ce $= 0.865 \pm 0.005$.

Introduction

The accuracy of neutron activation cross section measurements has often been limited by the inability to completely separate the desired activity from other activities in the sample. These come from other isotopes of the same element or from impurities. The high resolution attainable with a lithium-drift germanium γ-ray spectrometer (Ewan and Tavendale 1964) gives sufficient discrimination so that the activity desired can often be measured in samples containing the element mixed with a comparison standard such as gold or indium. We have used this high resolution to make accurate measurements of the ratio of resonance neutron activation to thermal neutron activation or s_0 value for nine isotopes.

Method

Samples containing the same proportions of unknown element and standard were prepared from a solution. The proportions were adjusted to give approximately equal unknown and standard γ-ray intensities in the γ-ray spectrum. Pairs of samples were then irradiated bare and cadmium covered (cadmium ratio method) or in two

neutron spectra with widely different resonance neutron fractions (two spectrum method). The γ-ray spectra of the two samples were then measured and the relative number of counts in the photopeaks calculated. Both methods give the relative ratio of resonance-to-thermal activation for unknown and standard. Only ratios of ratios are measured, except for a measurement of the cadmium ratio for gold to obtain the epithermal spectral index of the neutron spectra.

Analysis

Cadmium ratios were measured with samples in which resonance self-shielding was small and thermal self-shielding negligible.

In the Westcott notation (Westcott *et al.* 1958; Walker and Copley 1966), if one assumes negligible thermal self-shielding, the cadmium ratio can be expressed as

$$[1] \quad R_{Cd} = [\{r\sqrt{(T/T_0)}\}^{-1} + G_r s_0/g]$$
$$\times [(F/g)(s_0 G_r - W) + 1/K]^{-1},$$

where $r\sqrt{(T/T_0)}$ is the epithermal index, g is the ratio of the detector activation in a Maxwellian flux to that of a $1/v$ detector having the same σ_0 or 2200 m/s cross section, F is the correction factor for the resonance neutrons shielded by the cadmium, G_r is the resonance self-shielding factor,

$1/K = 4\sqrt{E_0}/\sqrt{E_{Cd}}\pi$ and is proportional to the epicadmium $1/v$ activation,

$$W = (2/\sqrt{\pi})\Delta I'/\sigma_0,$$

$$\Delta I' = \int_{\mu kT}^{E_{Cd}} [\sigma(E) - g\sigma_0\sqrt{(E_0/E)}]\frac{dE}{E}.$$

The parameter measured in our experiments is

[2] $$s_0 = (2/\sqrt{\pi})I'/\sigma_0,$$

where I' is the reduced resonance integral defined as

[3] $$I' = \int_{\mu kT}^{\infty} [\sigma_a(E) - g\sigma_0\sqrt{(E_0/E)}]\frac{dE}{E},$$

σ_0 is the absorption cross section at energy $E_0 = 0.025$ eV, and μkT is the equivalent cutoff energy of the $1/E$ spectrum.

A measurement of $R_{Cd}(Au)$ gives $r\sqrt{(T/T_0)}$ in terms of the known s_0 for gold. A measurement of R_{Cd} for the unknown then gives s_0 for the unknown.

Eliminating $r\sqrt{(T/T_0)}$ from all but the correction terms gives

[4] $$\left(\frac{G_r s_0}{g}\right)_x = \frac{Z}{Q}\left[\frac{1}{g}(s_0 G_r - W) + \frac{1}{KF}\right]_s$$
$$- \left[\frac{1}{KF} - \frac{W}{g}\right]_x,$$

where $Q = (FR_{Cd} - 1)_x/(FR_{Cd} - 1)_s,$

$$Z = 1 + \frac{r\sqrt{(T/T_0)}}{Z'}\left[\left(\frac{W_x}{g_x} - \frac{W_s}{g_s}\right)\right.$$
$$\left. + \frac{1}{K}\left(\frac{1}{F_s} - \frac{1}{F_x}\right)\right],$$

$$Z' = 1 + r\sqrt{(T/T_0)}\left(\frac{W_s}{g_s} - \frac{1}{K}\frac{1}{F_s}\right).$$

The subscript x refers to the element and subscript s to the standard.

The two-spectrum measurement gives the ratio of the activation or effective cross sections in the two spectra, one the thermal column spectrum with small $r\sqrt{(T/T_0)}$ and the other the reactor spectrum with large $r\sqrt{(T/T_0)}$. We define

$$R = [\hat{\sigma}_x/\hat{\sigma}_s]_{rs}/[\hat{\sigma}_x/\hat{\sigma}_s]_{tc},$$

where $\hat{\sigma} = \sigma_0 g(1 + r\sqrt{(T/T_0)} \cdot (G_r s_0/g))$ is the effective absorption cross section and the sub-

scripts rs and tc refer to the reactor spectrum and thermal column spectrum respectively. Substituting and rearranging gives

[5] $$(G_r s_0/g)_x = Rf(G_r s_0/g)_s$$
$$+ (Rf - 1)/[r\sqrt{(T/T_0)}]_{rs},$$

where

$$f = \frac{1 + [r\sqrt{(T/T_0)}]_{tc}(G_r s_0/g)_x}{1 + [r\sqrt{(T/T_0)}]_{tc}(G_r s_0/g)_s}.$$

The spectral indices in the reactor spectrum $[r\sqrt{(T/T_0)}]_{rs}$ and thermal column spectrum $[r\sqrt{(T/T_0)}]_{tc}$ were found from cadmium ratio measurements.

In practice, f is near unity, so that [5] can be solved easily by iteration. This method is accurate only for large values of s_0.

The unknown cross sections were assumed to be $1/v$ below the cadmium cutoff, so that $g_x = 1$ and $W_x = 0$. For the 0.8-mm cadmium used here, $1/K = 0.462$ corresponding to an effective cutoff $E_{Cd} = 0.60$ eV (Maunders 1965). The parameters used for gold and indium are listed in Table I. The s_0 value for gold is the standard,

TABLE I
In and Au parameters

	In	Au
s_0	18.7*	17.7
g	1.028	1.0078
W	0.335	0.089
F	0.960†	0.998
$1/K$		0.462

*Experimental value determined by using Au as the standard.
†Experimental value determined by measuring indium-cadmium ratios with several thicknesses of cadmium.

the value for indium is a secondary standard based on gold.

For most of the measurements, the resonance self-shielding was small and was calculated using

[6] $$G_r = 1/\sqrt{[1 + 2\zeta f(\theta)]},$$

where $\zeta = N\sigma_r$, N is the number of atoms per cm^2, σ_r is the peak capture cross section of the resonance, and $f(\theta)$ is a factor correcting for Doppler broadening (Dresner 1960). For thicker samples, $(FR_{Cd} - 1)_\zeta \propto 1/G_r$ was extrapolated to zero thickness as a function of $\sqrt{[1 + 2\zeta f(\theta)]}$, giving

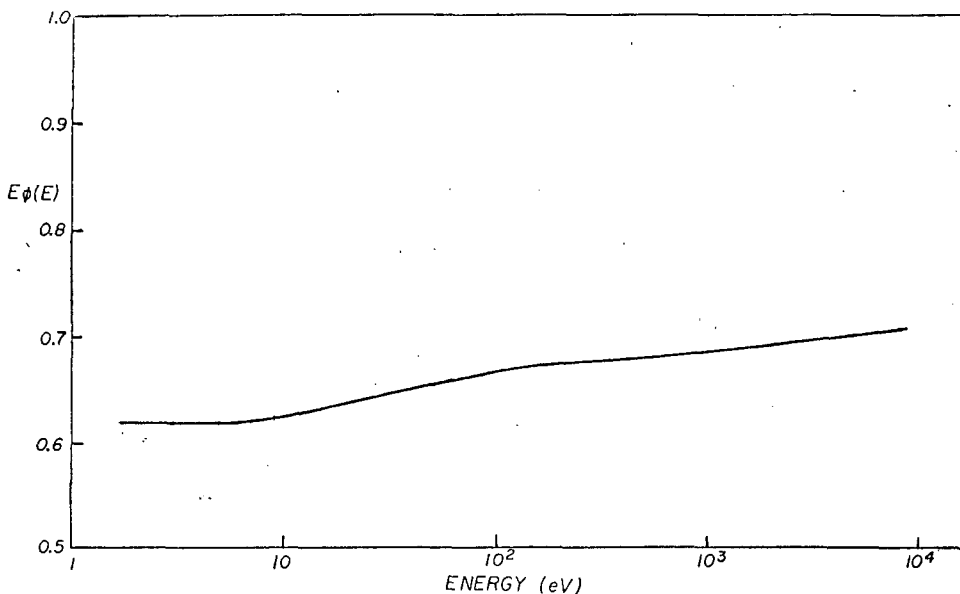[7] $$G_r = (FR_{Cd} - 1)_{\zeta=0}/(FR_{Cd} - 1)_\zeta.$$

FIG. 1. The reactor spectrum form function $\phi(u) = E\phi(E)$.

Some of the isotopes measured have no resonance parameters listed; for these G_r was assumed to be unity.

The transmission of the cadmium for resonance neutrons, F, was calculated with the infinite slab approximation, using the absorption cross section as a transmission cross section. Cross sections from Hughes and Schwartz (1958) and Chepkin et al. (1967) were used. F can also be obtained by comparing the results from cadmium ratio measurement and from a two-spectrum measurement, because F does not occur in [5] except in the measurement of $r\sqrt{(T/T_0)}$.

A multigroup diffusion theory calculation (Boix and Solanilla 1967) showed that the resonance neutron spectrum deviated from the $1/E$ form by as much as 13% (see Fig. 1). Corrections were made using

$$\frac{I_x'(1/E)}{I_s'(1/E)} = \frac{I_x'}{I_s'}\frac{l_s}{l_x},$$

[8]

$$l_x = \frac{\sum_{i=1}^{n} \phi(E_i^r)I_{ix}}{\sum_{i=1}^{n} I_{ix}},$$

where $I_x'(1/E)$ is the reduced resonance integral in the $1/E$ spectrum, I_x' is the reduced resonance integral in the reactor spectrum, I_{ix} is the calculated self-shielded resonance integral in a $1/E$ spectrum for one isolated resonance, and $\phi(E_i^r)$ is

the slowing down flux at the resonance energy E_i^r from Fig. 1. The small non-resolved part of the resonance integral was not included since it would have negligible effects on the correction. The tellurium, barium, and cerium results were not corrected because the resonance parameters have not been measured.

Neutron Spectra

The cadmium ratios were measured in the central reflector of the Reactor Argentino 1 (R.A.1) (Ricabarra and Ricabarra 1960). The 17-cm radius graphite reflector is surrounded by an 8-cm-thick annular core which is fuelled with 20% enriched uranium and moderated and cooled with water. An external graphite reflector surrounding the core is enlarged to form a thermal column on one side.

Pneumatic "rabbit" systems carry samples in and out of positions in the internal reflector and in the thermal column. Aluminium capsules were used for most irradiations and nylon capsules only for short-lived isotopes which required removal of the samples for counting before the aluminium activity had decayed to a safe biological level. The sample position in the internal reflector was at the mid-plane of the reactor and 2 cm from the core. At the usual operating power of 80 kW, the flux in the reflector position was 2×10^{12} n/cm^2 s and in the thermal column

TABLE II

Cadmium ratios and spectral indices

Position	$R_{Cd}(Au)$	$R_{Cd}(In)$	$r\sqrt{(T/T_0)}$
Internal reflector			
Aluminium capsule	1.674 ± 0.003	1.739 ± 0.003	0.0805 ± 0.0002
Nylon capsule	—	1.782 ± 0.006	0.0758 ± 0.0005
Thermal column			
Aluminium capsule	20.2 ± 0.2	—	0.0028 ± 0.0001

1×10^{11} n/cm² s. The gold and indium cadmium ratios and spectral indices for the irradiation positions are summarized in Table II.

Cadmium ratio measurements (see Fig. 2) show that $r\sqrt{(T/T_0)}$ is constant along the vertical axis of the reflector and the cadmium covered
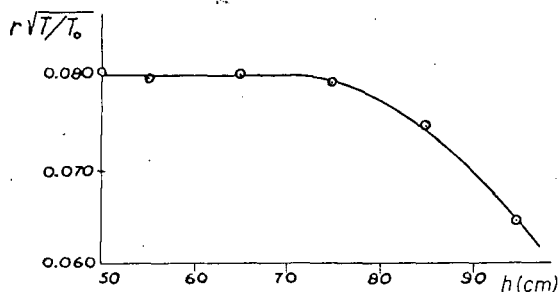

FIG. 2. Vertical variation of $r\sqrt{(T/T_0)}$ in the central graphite reflector of "RA1" ($h = 50$ cm corresponds to the middle plane of the core).

manganese activity (see Fig. 3) is constant across the reflector. Multigroup diffusion theory shows that, if the distribution is flat for 337-eV Mn resonance neutrons, it must also be flat for neutron energies down to 2 eV, except for possible depressions at the 6.8 eV U-238 resonances. The multigroup diffusion theory calculations (Boix and Solanilla 1967) show that the flux depression in the core at the 6.8-eV resonance has disappeared 2 cm into the graphite and that the flux at the 4.9-eV gold resonance will not be depressed. There is, however, a significant deviation from $1/E$, as shown in Fig. 1.

Samples

The measurements depend on the samples containing the same ratio of unknown to standard; the absolute amounts are required only for estimation of self-shielding effects, which were kept small by using thin samples.

A solution containing standard and unknown

in the desired proportions was prepared. Aliquots of 0.1 ml were dried on small pieces of filter paper and sealed into small plastic bags. The diameter over all was less than 1 cm.

Subsidiary measurements showed that the proportions in samples made this way were the same to better than $\pm 0.2\%$ and the absolute amounts the same to better than $\pm 10\%$.

High-purity compounds of natural elements (not separated isotopes) were used. Activation analyses were used to check for impurities before making up the solutions. The cadmium boxes used for the cadmium ratio measurements were 10 mm in diameter, 1 mm high, and had 0.8-mm-thick walls. The samples were mounted 4 cm apart in the rabbit capsules, one in the cadmium box and one wrapped in aluminium foil.

For two-spectrum measurements, the samples were mounted in separate capsules and irradiated for the same period in the two positions. Very accurate timing was important only if standard and unknown had very different half-lives.

The γ-Ray Spectrometer

An encapsulated lithium-drift germanium diode (manufactured by the RCA Co., Montreal) with an effective volume of 5 cm³ was maintained at liquid nitrogen temperature in the cryostat shown in Fig. 4. After initial pumping, the vacuum was held by molecular sieve. The diode was connected through a Kovar seal to a low-noise charge-sensitive preamplifier consisting of a vacuum tube (E810F) input stage followed by a transistor amplifier. The pulses were shaped to 1 μs differentiation and integration time constants in the main amplifier and sorted in a 256-channel TMC pulse-height analyzer. Resolution of 2.5 keV FWHM was obtained for ^{153}Gd γ rays at 96.7 and 103.4 keV.

An elementary sample changer operated from the analyzer allowed the two samples to be counted one after the other automatically for a
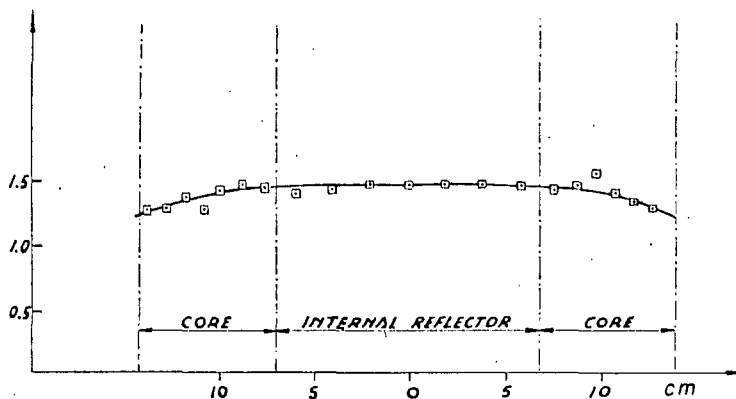
FIG. 3. Radial distribution of epithermal neutron flux in the central graphite reflector and core.
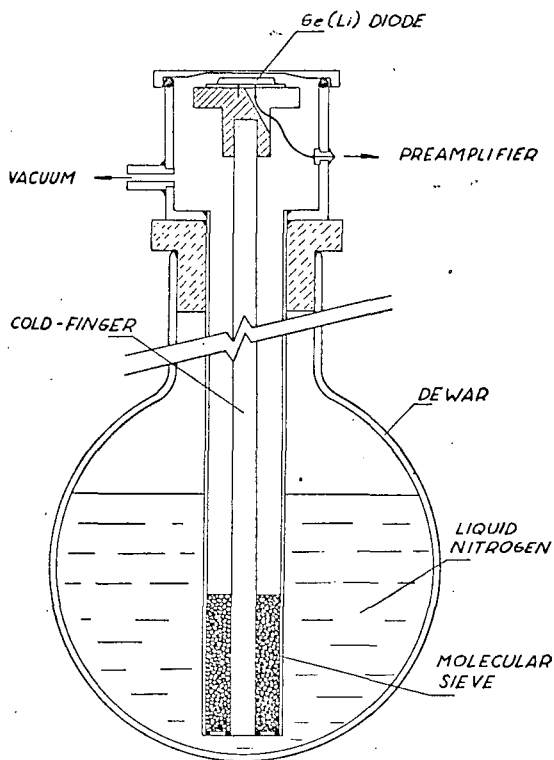

FIG. 4. The cryostat for the lithium-drift germanium diode. After the initial pumping, the vacuum was maintained by the molecular sieve.

suitable period after the irradiation. The spectra were recorded on punched paper tape and read into a computer for summing over peaks.

Data Reduction

The number of counts in the photopeak was calculated by summing regions of the spectrum as illustrated in Fig. 5. The sum of B_1 and B_2,

normalized to the same number of channels as in P_x, was subtracted from P_x to correct for the continuum and counter background. This assumes that both background and continuum are linear under the peak. Measurements were made only on well-resolved and well-separated peaks to reduce the uncertainties in this procedure.

The double ratio of corrected activities gives

$$\frac{R_{Cd}(x)}{R_{Cd}(s)} = \frac{(A_x/A_s) \text{ bare}}{(A_x/A_s) \text{ cadmium}}$$

or in the two-spectrum measurement

$$R = \frac{(A_x/A_s) \text{ reactor spectrum}}{(A_x/A_s) \text{ thermal column}}.$$

If the activities decayed significantly between counts, results from the two spectra taken before
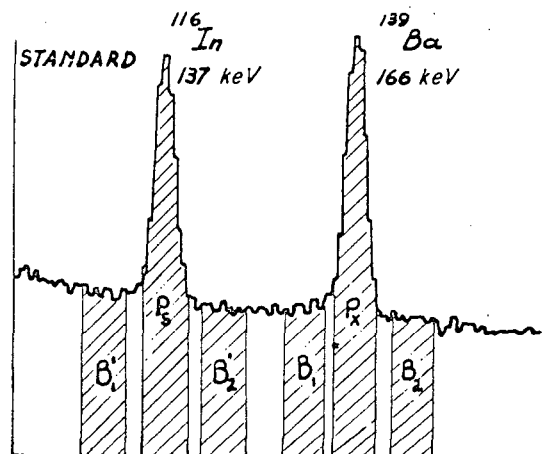

FIG. 5. Example of the procedure used to obtain the activity under the photopeak $(A_x = P_x - (B_1 + B_2)/2$; $A_s = P_s - (B_1' + B_2')/2)$.

and after a given count were averaged in calculating the ratio; this assumes a linear decay. If the half-life was shorter than about 10 times the counting period, exponential decay corrections were made. Usually the results from a number of pairs of spectra with a total of about 10^6 counts were used in each ratio measured.

The error quoted is the standard error of the average value of the ratio of ratios obtained from several irradiations, which is not only an indication of counting statistics but also of the small systematic differences that may arise from slightly different irradiation and counting positions.

Significant ($\sim 5\%$) resolving time losses were sometimes found early in the counting period, but these do not affect the results because the same correction applies to both peaks in the spectrum. Usually the counting rate was limited by pile-up effects that destroyed the resolution rather than by excessive resolving time losses.

Selenium

The cadmium ratio for capture in ^{74}Se leading to ^{75}Se (120 d) was measured relative to gold, using a mixed sample irradiated for four hours. The cadmium ratio for capture in ^{80}Se, giving the 62-minute isomeric state in ^{81}Se, was measured relative to ^{74}Se by irradiating pure selenium samples for one hour, and finally, the cadmium ratio for capture in ^{78}Se leading to the 3.9-minute isomeric state in ^{79}Se was measured relative to ^{80}Se by irradiating pure selenium samples for two minutes.

^{74}Se

Mixed samples containing 5 mg/cm^2 of selenium and 0.001 mg/cm^2 of gold were irradiated bare and cadmium covered for four hours. One or two days later the ^{75}Se 265-keV and 280-keV γ rays were measured relative to the 412-keV gold γ ray (Fig. 6). About 6 days later, when the gold γ ray had decayed to the same level as the 405-keV γ ray, these were also compared. The three cadmium ratios agreed to within 0.5%. The averaged result from three irradiations gave

$$R_{Cd}(^{74}\text{Se})/R_{Cd}(^{197}\text{Au}) = 1.322 \pm 0.006,$$

or with $R_{Cd}(^{197}\text{Au}) = 1.674 \pm 0.003,$

$$R_{Cd}(^{74}\text{Se}) = 2.213 \pm 0.011.$$

The ^{74}Se resonance at 27.0 ± 0.2 eV is shielded slightly by the ^{111}Cd resonance at 27.7 ± 0.3 eV

(Hughes and Schwartz 1958). A value for $F = 0.94$ was estimated from the curves. Self-shielding was negligible. Including a -3% spectrum correction, we get

$$s_0(^{74}\text{Se}) = 10.3 \pm 0.1.$$

The resonance integral calculated from the parameters given by Goldberg et al. (1966), $I' = 530$ b and the thermal cross section $\sigma_0 = 50 \pm 7$ b (Hughes and Schwartz 1958) give $s_0 = 12$ in reasonable agreement.

^{80}Se

Bare and cadmium-covered samples of selenium, 5 mg/cm^2 thick, were irradiated for one hour and the 103-keV γ ray from ^{81}Se (62 minutes) measured relative to the 136-keV γ ray from ^{75}Se. The averaged result from two irradiations was

$$R_{Cd}{}^m(^{80}\text{Se})/R_{Cd}(^{74}\text{Se}) = 1.585 \pm 0.003$$

or $R_{Cd}{}^m(^{80}\text{Se}) = 3.508 \pm 0.016.$

The cadmium cross section given by Block et al. (1961) was used to estimate $F = 0.99$ for the ^{80}Se resonances at 1.9, 4.1, and 4.8 keV. Including a spectrum correction of -13% gives

$$s_0{}^m = 3.870 \pm 0.022$$

for formation of the isomeric state.

The isomeric yield ratios for thermal and resonance capture are different because there is a significant contribution for p capture in these high energy resonances. Using the yields measured by Bishop et al. (1964) for the fraction of the 62-minute isomer,

$$s_0(^{80}\text{Se}) = 3.870 \times 0.115/0.168 = 2.65 \pm 0.02,$$

neglecting any uncertainty in the ratio of the two-yield ratios.

The measured thermal cross section $\sigma_0 = 0.61 \pm 0.05$ b (Goldberg et al. 1966) and $I' = 1.58$ b, calculated from the resonance parameters assuming equal s and p strength functions (Weinberg and Wigner 1958; Moldauer 1961), gives $s_0 = 2.9$. This is excellent agreement and shows that p capture in these resonances is comparable with s capture.

^{78}Se

Neutron-capture γ rays populate a 3.9-minute low-spin isomeric state in ^{79}Se which decays to a long-lived high-spin state by emitting a 96-keV γ ray. The intensity of this γ ray was measured relative to that of the 103-keV γ ray from ^{81m}Se.
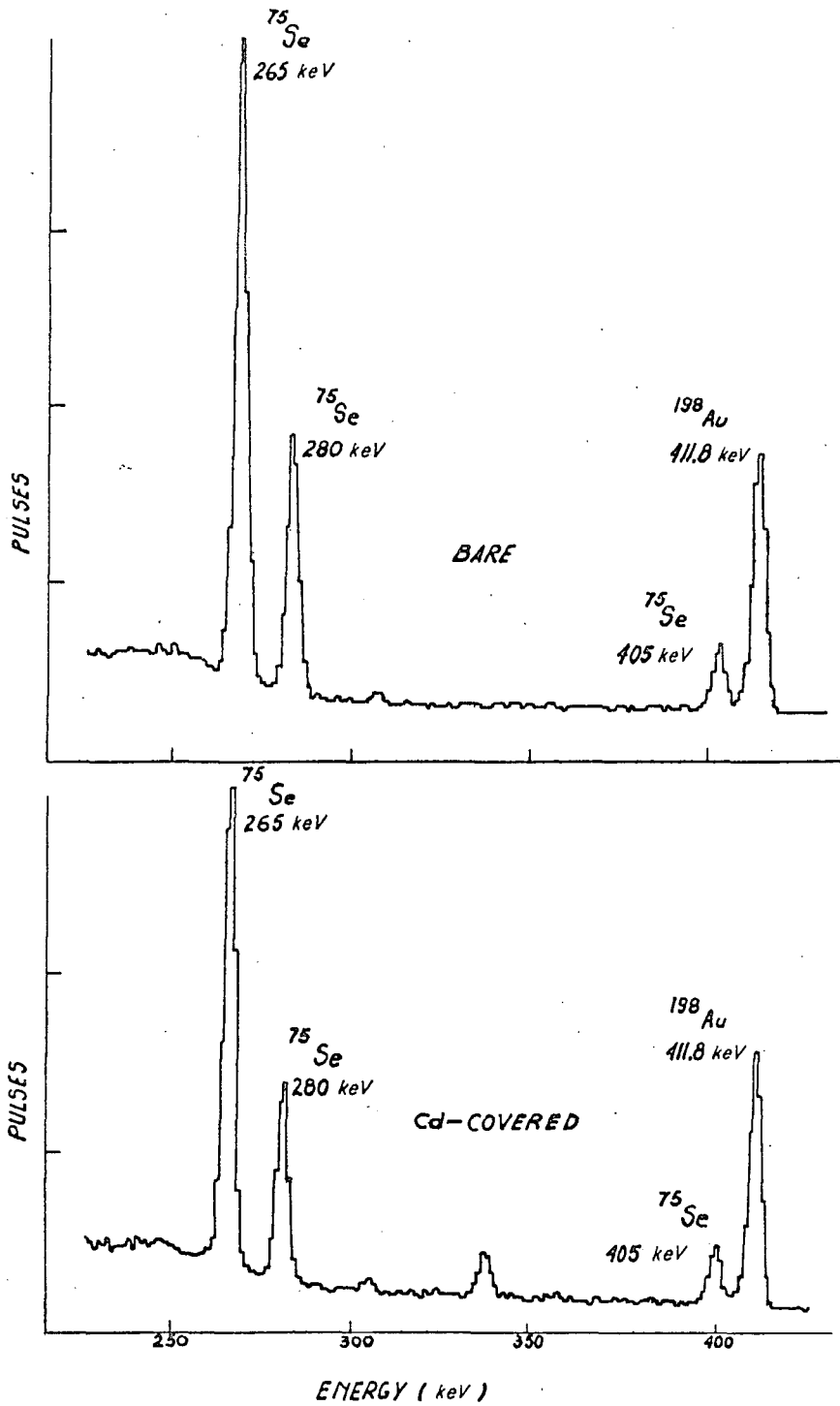
FIG. 6. γ-ray spectra of bare and cadmium-covered selenium–gold samples one day after the irradiation. These spectra gave the 265- and 280-keV γ-ray intensities relative to the gold. The 405-keV γ ray was measured 5 days later when the gold had decayed to about the same intensity.

Samples containing 5 mg/cm^2 of selenium were irradiated for 2 minutes in a nylon capsule. Activation of the nylon was low enough to allow immediate removal of the samples. The γ-ray spectra were measured, starting 3 minutes after the irradiation. The averaged result from three measurements was

$$R_{Cd}{}^m({}^{78}Se)/R_{Cd}{}^m({}^{80}Se) = 0.544 \pm 0.007,$$

Using the ratio of spectral indices given for the aluminium and nylon capsules in Table II and the cadmium ratio for ^{80}Se given above, we get

$$R_{Cd}{}^m({}^{78}Se) = 1.936 \pm 0.032,$$

relative to gold in the aluminium capsule. With $F = 1$, negligible self-shielding, and a spectrum correction of -10%, we obtain

$$s_0{}^m({}^{78}Se) = 12.3 \pm 0.3$$

for formation of the 3.9-minute isomeric state.

For comparison, the resonance integral calculated from the resonance parameters (Goldberg et al. 1966), $I' = 5.78$ b, reduced by 10% to correct for direct formation of the long-lived state, and the measured thermal cross section 0.38 ± 0.04 b (Goldberg et al. 1966), give

$$s_0{}^m = 16.$$

The calculated value for the resonance integral has been obtained with $\Gamma = 800 \pm 200$, $\Gamma_n = 400 \pm 150$, and $\Gamma_\gamma = 400$. Le Blanc et al. (1959) give Γ_γ as 250, Coté et al. (1964) as 500. The measured s_0 supports the evidence from the systematics (Huynh et al. 1967), suggesting that Γ_γ is lower than the value recommended (Goldberg et al. 1966). Kramer and Wahl (1965) have measured the activation cross section for ^{78}Se (n, γ) ^{79m}Se and their quoted cadmium ratios for ^{78}Se and ^{197}Au give

$$[R_{Cd}({}^{78m}Se) - 1]/[R_{Cd}(Au) - 1] = 1.385.$$

We obtained 1.389, in good agreement. If their experimental conditions were the same as ours, this agreement also indicates agreement in s_0 values.

Bromine

Cadmium ratio and two-spectrum ratio measurements were made with bromine–gold samples of several thicknesses. The ^{81}Br 554- and 620-keV γ rays were measured relative to the 412-keV gold γ ray. Samples containing 1.0, 2.0, and 20.4 mg/ cm^2 of ^{81}Br were prepared from a solution with a bromine–gold ratio of 156 to 1. Two cadmium ratio measurements were made with each sample thickness. Three two-spectrum measurements were made with 20.4 mg/cm^2 samples and one with a 1.0 mg/cm^2 sample.

The results obtained by the two methods with the 20.4 mg/cm^2 samples were used to obtain a value of F. There is a possibility that the 101.0 ± 0.1 eV resonance in ^{81}Br is shielded by the 99.6 ± 0.2 eV resonance in ^{111}Cd. The value of $F = 0.946 \pm 0.015$ obtained from the comparison is in good agreement with 0.95 estimated from the cadmium cross section.

The cadmium ratio measurements were then used to evaluate the resonance self-shielding. The results are summarized in Table III. Calculated values for gold are also given. Using $F = 0.946$ and the G_r values listed in Table III, the s_0 values listed in Table IV were obtained. The result for the 20.4 mg/cm^2 sample was not used here because it was used in checking the self-shielding. The agreement is good and, including a -9% spectrum correction, the weighted average is

$$s_0({}^{81}Br) = 24.3 \pm 0.4.$$

Only 2.2% of the disintegrations by-pass the ground state, so this s_0 should be very close to that for total capture.

The resonance integral calculated from the resonance parameters $I' = 63.1$ b and $\sigma_0 = 3.1 \pm 0.4$ b (Goldberg et al. 1966) gives $s_0 = 23$, in reasonable agreement with our value. The experimental value of $I_{Cd} = 41$ b given by Emery (1965) would give a much lower s_0 value. This may perhaps have been caused by a large resonance self-shielding effect in Emery's samples.

Iodine

Two-spectrum measurements were made relative to indium. The 442-keV γ ray of 25-minute ^{128}I was compared with the 416-keV γ ray of 54-minute ^{116}In.

Samples containing 2.25 mg/cm^2 of iodine and 0.025 mg/cm^2 of indium were irradiated for 10 minutes in the thermal column and central reflector. The γ-ray intensities were compared over three half-lives, beginning 30 minutes after the irradiation. The averaged result from three irradiations is

$$R({}^{127}I/{}^{115}In) = 1.306 \pm 0.014,$$

TABLE III

Summary of experimental and calculated G_r values for ^{81}Br

	^{81}Br				^{197}Au	
	Experimental G_r determination		Calc.		Thickness	Calc.
Thickness (mg/cm²)	$(FR_{Cd} - 1)$	G_r	G_r		(mg/cm²)	G_r
20.4	0.479 ± 0.003	0.918 ± 0.015	0.928		0.13	0.986
2.0	0.445 ± 0.003	0.989 ± 0.010	0.990		0.01	0.999
0	0.440 ± 0.007	—	1			

TABLE IV

Summary of results for ^{81}Br

Thickness (mg/cm²)	Two-spectrum ratio		Cadmium ratio	
	R	s_0	$R_{Cd}(^{81}Br)/R_{Cd}(^{197}Au)$	s_0
20.4	1.216 ± 0.014	26.5 ± 0.5	0.929 ± 0.003	—
2.0	—	—	0.912 ± 0.003	26.4 ± 0.6
1.0	1.30 ± 0.05	27.2 ± 1.2	0.905 ± 0.003	27.3 ± 0.6

which, with $G_r = 0.982$ for iodine and $G_r = 0.996$ for indium and a spectrum correction of -4%, gives

$$s_0(^{127}I) = 27.8 \pm 0.5.$$

A comparison with other results, in terms of resonance integrals, is given in Table V.

Tellurium

Capture in ^{130}Te leads to 25-minute ^{131}Te which decays to 8-day ^{131}I. A contaminant γ ray at 410 keV made it difficult to measure the 360-keV ^{131}I γ ray relative to the 412-keV gold γ ray. Instead, the 150-keV γ ray of ^{131}Te was measured relative to the 137-keV γ ray of 54-minute ^{116}In.

Bare and cadmium-covered samples containing 8.8 mg/cm² of tellurium and 0.0025 mg/cm² of indium were irradiated for 2 minutes and counted, beginning 20 minutes after the irradiation. The ^{131}Te 150-keV γ ray was followed for about three half-lives. The average of five measurements was.

$$R_{Cd}(^{130}Te)/R_{Cd}(^{115}In) = 3.26 \pm 0.11$$

or

$$R_{Cd}(^{130}Te) = 5.67 \pm 0.19.$$

Self-shielding in both tellurium and indium was negligible. Assuming that $F = 1.0$, and with no spectrum correction, we obtain

$$s_0(^{130}Te) = 2.10 \pm 0.07.$$

The isomeric yield is the same for resonance and thermal neutron capture (Namboodiri et al. 1966), so that this value also applies for the total capture cross section.

The listed parameters (Bilpuch et al. 1961) give a very low s_0 value. The main contribution is from the 1.5-keV resonance. This suggests that some of the unassigned resonances in tellurium at lower energies (Goldberg et al. 1966) are in ^{130}Te.

Barium

The cadmium ratio for capture in ^{138}Ba leading to 85-minute ^{139}Ba was measured relative to 54-minute ^{116}In. Samples containing 3.6 mg/cm² of barium and 0.004 mg/cm² of indium were

TABLE V

Summary of resonance integral values for ^{127}I

	I_{Cd} (barns)[a]
Integral measurements	
Macklin and Pomerance (1955)	130–140
Klimentov and Griazev (1957)	106 ± 13
Tattersall et al. (1960)	183 ± 30
This measurement with $\sigma_0 = 6.2 \pm 0.2$	156 ± 6
From resonance parameters	
Parameters listed by Goldberg et al. (1966)[b]	158.4

[a] $I_{Cd} = \int_{E_{Cd}}^{\infty} \sigma(E)dE/E$.

[b] In calculating the resonance integral from the resonance parameters, it was assumed that $J = 3$ for the three main resonances at 31.3, 37.8, and 45.5 eV and the statistical weight factor $g = 1/2$ for the others.

TABLE VI

Summary of results

Nuclide	Measured s_0	σ_0 (barns)	I' (barns)		
			This experiment	Resonance parameters	Other measurements
^{74}Se	10.3 ±0.1	50 ±7	456	530	—
^{78}Se	12.3 ±0.3	0.42±0.05	4.58±0.6	5.78	—
^{80}Se	2.65 ±0.02	0.61±0.05	1.43±0.16	1.58	—
^{81}Br	24.3 ±0.4	3.1 ±0.4	67 ±10	63	41
^{127}I	27.8 ±0.5	6.2 ±0.2	153 ±6	156	180±30[b]
^{130}Te	2.10 ±0.07[a]	0.26±0.08	0.48±0.14	—	—
^{138}Ba	0.649±0.004[a]	0.35±0.15	0.20±0.09	—	—
^{140}Ce	0.476±0.003[a]	0.60±0.06	0.25±0.03	—	0.255
^{142}Ce	0.865±0.005[a]	0.95±0.05	0.73±0.04	—	—
Standard					
^{197}Au	17.7	98.8 ±0.3	—	1551	—
Secondary standard					
^{115}In	18.7 ±0.1	—	—	—	—

[a]No neutron spectrum corrections have been made because the resonance parameters have not been measured.
[b]See Table V.

irradiated for 5 minutes. The relative intensities of the 166-keV γ ray of ^{139}Ba and the 137-keV γ ray of ^{116}In were measured over two ^{139}Ba half-lives. The average result from four irradiations was

$$R_{Cd}(^{138}\text{Ba})/R_{Cd}(^{115}\text{In}) = 7.23 \pm 0.03$$

or

$$R_{Cd}(^{138}\text{Ba}) = 12.57 \pm 0.05.$$

Assuming that $F = 1$ and $G_r = 1$ for barium,

$$s_0(^{138}\text{Ba}) = 0.649 \pm 0.004.$$

The only identified resonance in ^{138}Ba is at 31.7 keV, but some unassigned lower resonances may also be in ^{138}Ba. This s_0 value and $\sigma_0 = 0.35 \pm 0.15$ (Goldberg et al. 1966) gives $I' = 0.20 \pm 0.09$ b.

Cerium

The cadmium ratios for capture in ^{140}Ce and ^{142}Ce were measured relative to gold. Samples containing 5.66 mg/cm² of cerium and 0.0015mg/cm² of gold were irradiated for 4 hours. The 145.6-keV γ ray of 32.5-day ^{141}Ce and the 294-keV γ ray of 33-hour ^{143}Ce were measured relative to the 412-keV gold γ ray. Three irradiations were made.

^{140}Ce

The averaged result was

$$R_{Cd}(^{140}\text{Ce})/R_{Cd}(^{197}\text{Au}) = 8.21 \pm 0.03$$

or

$$R_{Cd}(^{140}\text{Ce}) = 13.74 \pm 0.05.$$

Assuming that $F = 1$ and $G_r = 1$,

$$s_0(^{140}\text{Ce}) = 0.476 \pm 0.003.$$

The value $I_{Cd} = 0.486$ b and the thermal cross section of 0.58 b given by Lantz et al. (1964) give $s_0 = 0.48$, in good agreement.

^{142}Ce

The averaged result was

$$R_{Cd}(^{142}\text{Ce})/R_{Cd}(^{197}\text{Au}) = 5.98 \pm 0.02$$

or

$$R_{Cd}(^{142}\text{Ce}) = 10.01 \pm 0.04.$$

Assuming that $F = 1$ and $G_r = 1$,

$$s_0(^{142}\text{Ce}) = 0.865 \pm 0.005.$$

This value of s_0 with $\sigma_0 = 0.95 \pm 0.05$ b (Goldberg et al. 1966) gives $I' = 0.73$ b.

Conclusions

In Table VI the experimental and calculated s_0 values and results from previous investigations are listed. The agreement with the calculated values is satisfactory considering the systematic errors assigned to resonance parameters.

There have been no previously published values for ^{74}Se, ^{78}Se, ^{80}Se, ^{130}Te, ^{138}Ba, and ^{142}Ce. Our value for ^{81}Br and ^{127}I is in better agreement

with the calculated resonance integral than previously reported values.

This determination has also shown the importance of p capture in the activation resonance integral of ^{80}Se. Other isotopes of similar characteristics are now currently being examined. The preliminary results show that p capture is not negligible and must be taken into account in the calculation of the resonance integral.

Acknowledgments

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