Further Studies of the Neutron Shielding of Metals in Thermal Neutron Activation

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In thermal-neutron activation analysis, it is desirable to use samples which are smaller than those in which self-shielding effects are observed. Therefore, the permissible size in neutron irradiation in nuclear reactors is limited by the self-shielding in the sample. For elements with very large neutron absorption cross sections, this effect of shielding occurs when even small amounts of the sample are present; this may sometimes cause an error in the determination of such elements by neutron activation. In order to eliminate this error, the weight of a sample which has an appreciable self-shielding effect must be determined experimentally.

The authors have studied this problem in an attempt to ascertain the relationship between the neutron absorption cross section and the weight of each element which brings about an appreciable self-shielding effect, hoping thus to simplify the experimental process.

As a part of the results obtained, a rough relationship has been reported[1] for silver, gold, antimony, chromium and mercury metals. If this relationship is applicable to numerous other elements, it will be useful in estimating the most suitable amounts of sample to be used in neutron activation analysis.

Further studies will be reported on in this report in order to determine the applicability of this relationship to several other elements. In this investigation, the authors measured the self-shielding effects of gold, silver, copper, cobalt, indium, gallium, antimony, chromium, selenium and tin metals.

Experimental

Samples.—Samples were prepared from commercially-available G. R. metal particles or blocks as follows.

Selenium and Copper.—The method of preparing these samples consists of fusing particles of the metal, solidifying different amounts of fused metal on a quartz plate, making the product spherical with emery paper, and washing the surface in order to decontaminate it.

Indium, Silver, Cobalt, Tin, Gold, Gallium, Antimony and Chromium.—These samples were prepared by cutting them into smaller blocks from the original block, making them spherical with emery paper, and washing the surface in order to decontaminate them.

Each sample was wrapped with a parchment paper and sealed in a polyethylene pouch. As the

1) Y. Kamemoto and Y. Onoda, *J. Chem. Soc. Japan, Pure Chem. Sec.* (*Nippon Kagaku Zasshi*), **83**, 1164 (1962).

TABLE I. ACTIVATION AND MEASUREMENT OF SAMPLES

Sample	Irradiation period, hr.	Counted nuclide half life	γ-Ray energy MeV.	Time for calculation of specific activity hr. after irradiation
Se	2	^{81m}Se (57 min.) ^{75}Se (119.9 d)	0.103 0.269, 0.138, 0.077	6
In	0.5	^{116m}In (54.0 min.)	0.137, 0.406	6
Ag	2	^{110m}Ag (253 d)	0.676, 0.885, 1.389	53
Cu	2	^{64}Cu (12.8 h)	0.51	6
Co	2	^{60}Co (5.2 y)	1.173, 1.332	38
Sn	2	^{117m}Sn (14 d)	0.159, 0.162	32
Au	2	^{198}Au (2.72 d)	0.4118	28
Ga	2	^{72}Ga (14.2 h)	0.603, 0.834, 2.203, 2.508	7
Sb	2	^{112}Sb (2.75 d) ^{124}Sb (60 d)	0.57 0.603, 1.71, 2.11	25
Cr	2	^{51}Cr (27.8 d)	0.32	32

standard sample in which self-shielding does not occur, about 20 μg. of a sample was infiltrated into a filter paper (Toyo Roshi No. 5C) 2 cm. in diameter and sealed in a polyethylene pouch. The pouch containing the same element was packed in a capsule with soft paper and irradiated in the reactor.

Neutron Irradiation.—Samples were irradiated in the experimental hole No. 16 (pneumatic tube) of JRR-1 for 30 min.~2 hr. The thermal neutron flux was about 3×10^{11} n/cm^2/sec., and the cadmium ratio was 3~3.7.[2)]

Counting.—The irradiated sample was dissolved in mineral acid and diluted with water. A part of the resultant solution was pipetted into a polyethylene tube and diluted to 5 ml. with water. This sample for counting was mounted on a 3×3 inch NaI crystal attached to the RCL-256 channel pulse height analyzer, and the γ-ray spectrum was measured. By determining the γ-ray energy and the decay time of photopeaks of the γ-ray spectrum, the radiochemical purity of each sample was verified. Thereafter, the relative specific activity of each sample was calculated from the peak height of the γ-ray spectrum.

In the measurement of the γ-ray spectrum, the amount of sample pipetted is adjusted so that the counting rate is similar in each sample, thus reducing error from the difference in counting efficiency between the samples.

The experimental conditions adapted are shown in Table I.

2) T. Kurusu, Y. Saruta and T. Aburai, private communication.

Results and Discussion

The specific activity calculated from the peak height of photopeaks is plotted against the weight of sample. The curves thus obtained are shown in Figs. 1—10.

In the previous report, the weight of a sample (W g.) which has a specific activity 10 per cent smaller than that of "Zero" weight was determined graphically. This weight, W g., was assumed to represent the sample weight at which the self-shielding effect becomes appreciable. As a result of the above assumption, the following rough relationship between W and the neutron absorption cross section of the element (σ_{abs} barn) was found in the case of silver, gold, antimony, chromium and mercury metals. $W\times\sigma_{abs}$/atomic weight of sample = 0.02~0.04.

For the present report, the authors calculated the values of $\sigma_{abs}\times w$/atomic weight of sample (E), where w is the weight of a sample particle and σ_{abs} is the neutron absorption cross section of the sample (the ratio is hereafter shown as E). The relative specific activities were then plotted against E. When E is small, the specific activity is independent of E. Therefore, it is possible to normalize all the curves by bringing together their constant parts. If the neutron absorption cross section is large and if the independent part is not observed, the curves

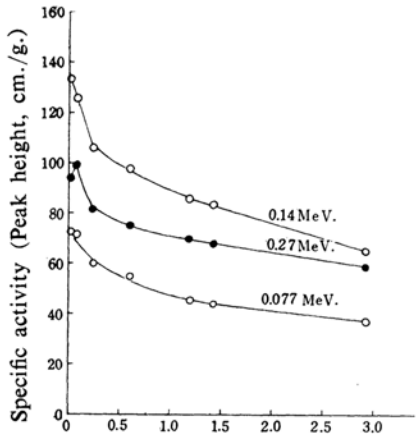

Fig. 1. Neutron shielding of selenium.

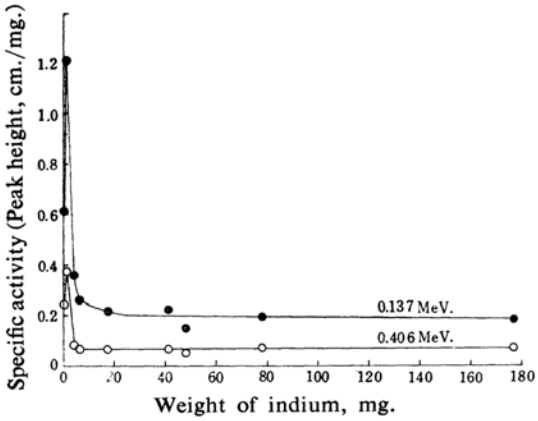

Fig. 2. Neutron shielding of indium.

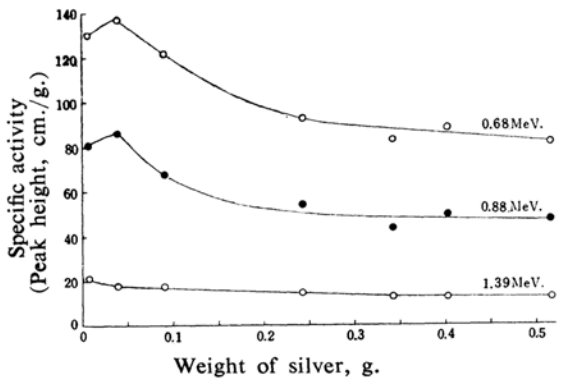

Fig. 3. Neutron shielding of silver.

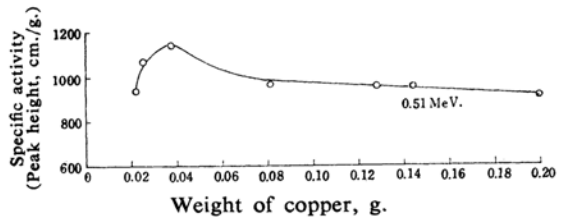

Fig. 4. Neutron shielding of copper.

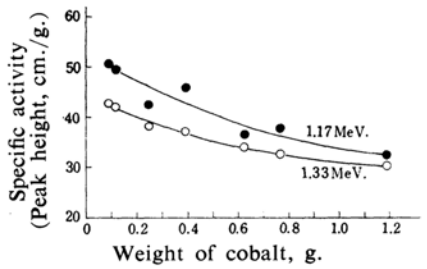

Fig. 5. Neutron shielding of cobalt.

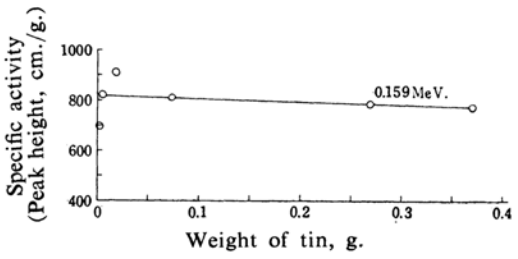

Fig. 6. Neutron shielding of tin.

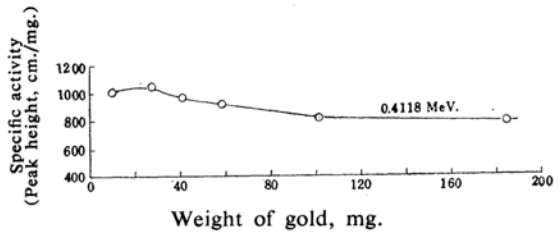

Fig. 7. Neutron shielding of gold.

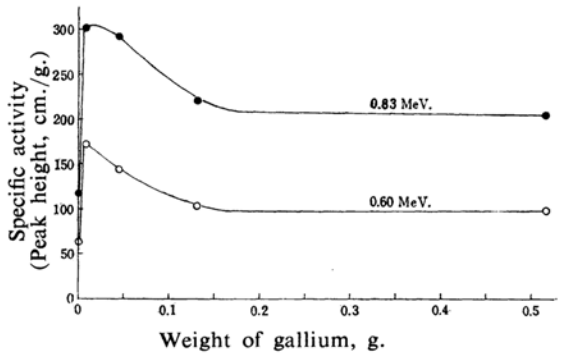

Fig. 8. Neutron shielding of gallium.

are normalized by using the specific activity of the standard samples, which are 20 μg. of the same element, assuming that no self-shieldind effect occurs in the standard. The normalized plots thus obtained are shown in Fig. 11, together with the optimum curve for the combined data.

From Fig. 11 the following relationship is obtained between the neutron absorption cross section in barns, σ_{abs}, and the weight in grams of a element corresponding to a 10 per cent self-shielding effect, W:

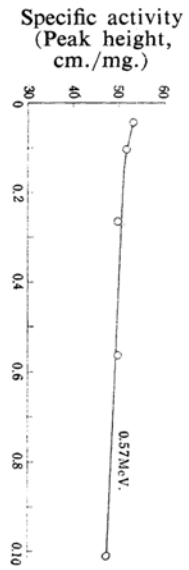

Fig. 9. Neutron shielding of antimony.

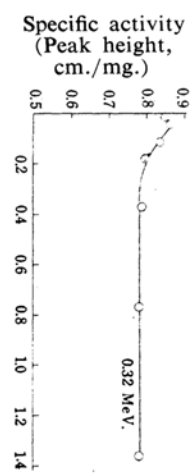

Fig. 10. Neutron shielding of chromium.

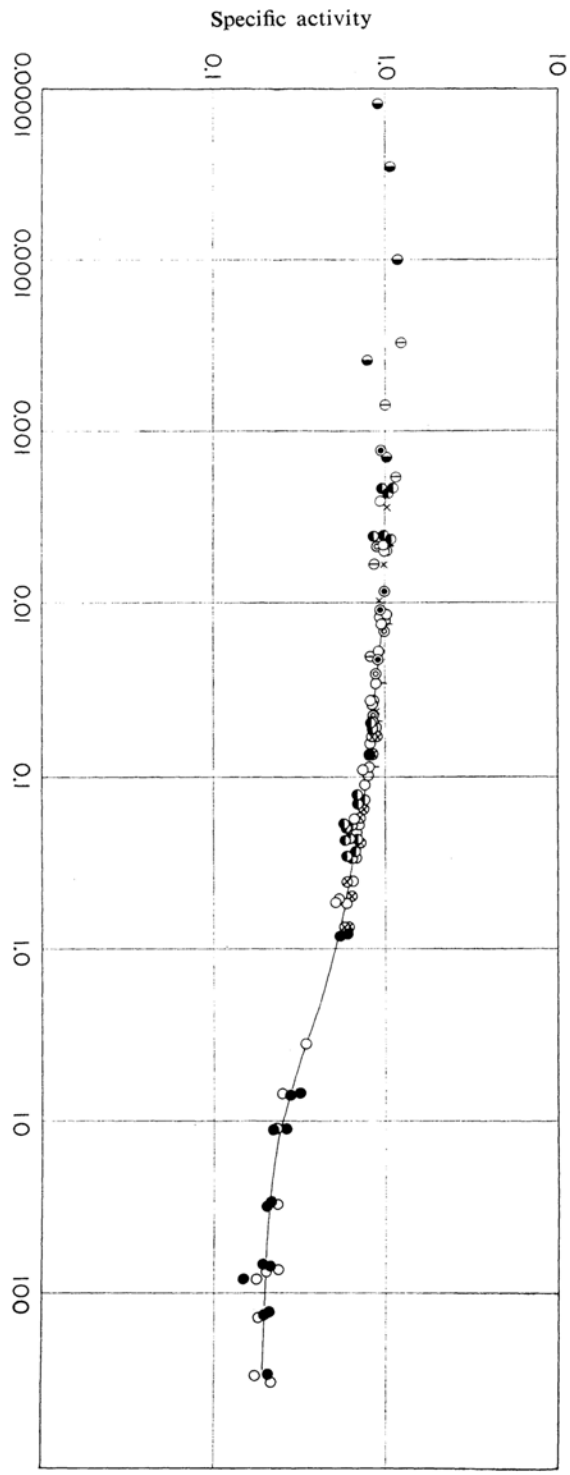

Fig. 11. Normalized plots of specific activity vs. $\sigma_{abs} \times w$/atomic weight.

○ Se ◐ Ag ⊗ Co ◍ Ga ◎ Sb ● In ⊙ Cu ◑ Sn ◇ Au ×Cr

$$\frac{\sigma_{abs} \times W}{\text{Atomic weight of sample}} \simeq 0.03^{3)} \quad (1)$$

In a similar experiment using indium metal, Okada reported the value of 0.06.[4] However, it was found from our experiments that Eq. 1 was applicable to numerous elements, including indium.

The weight of stainless steel corresponding to a 10 per cent self-shielding effect has been calculated. This value agrees with the value obtained experimentally using an in-pile loop plug in a JRR-3 reactor. The results obtained appear to confirm that this equation is useful in estimating the most suitable amounts of a sample to be used in neutron activation analysis.

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3) Y. Kamemoto, *Inst. J. appl. Rad. Isotopes, in press.*
4) M. Okada, ibid., **13**, 53 (1962).