LETTERS TO THE EDITORS

A Note Concerning the Purely Proton Moderated Spectrum*

In the case of moderation in a nonabsorbing and infinite medium of hydrogen, the collision density is given by (*1*)

$$\Sigma(E)\phi(E) = S(E) + \frac{1}{E}\int_E^\infty S(E)\,dE \qquad (1)$$

The normalization in Fig. 2 is arbitrary and a better match could no doubt be achieved. However, the fact that above about 1 Mev the purely proton moderated spectrum is rather well represented simply by the fission spectrum is illustrated in Fig. 2.

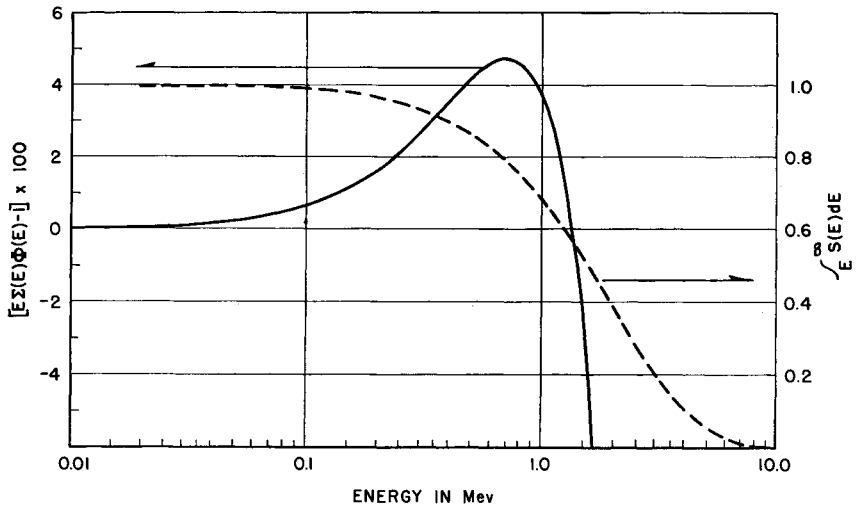

FIG. 1. Deviation of the hydrogen collision density from $1/E$ and the integral of the U^{235} fission spectrum as a function of energy.

where $\Sigma(E)$ is the hydrogen scattering cross section and $S(E)$ is the source distribution. If E is below the energy at which neutrons are produced, that is, when $S(E) = 0$ for $E < E^*$, then

$$\Sigma(E)\phi(E) = \frac{S}{E}, \qquad E < E^* \qquad (2)$$

where S is just the total source strength.

Equation (1) was evaluated using the U^{235} fission spectrum (*2*). The rather unexpected results are shown graphically in Fig. 1 where we plot $E\Sigma(E)\phi(E) - 1$ expressed in per cent. Also shown for purposes of orientation is the integral of the fission spectrum from E to infinity. It is amusing that *below 1.6 Mev, the hydrogen collision density is never more than 5% away from the value 1/E*. This deviation represents the contribution of the uncollided fission source neutrons to the collision density. Thus for purposes of spectrum weighting, for example, for weakly absorbing large systems, the purely proton moderated spectrum is adequately given simply by $1/E\Sigma(E)$ below 1.5 Mev or so.

Figure 2 shows $\phi(E)$ compared with the fission spectrum, $S(E)$. $\phi(E)$ was evaluated using the BNL-325, 2nd edition cross sections (*3*) for hydrogen. $S(E)$ has been normalized to $1/E\Sigma(E)$ at 1 Mev using the normalization factor 0.6780.

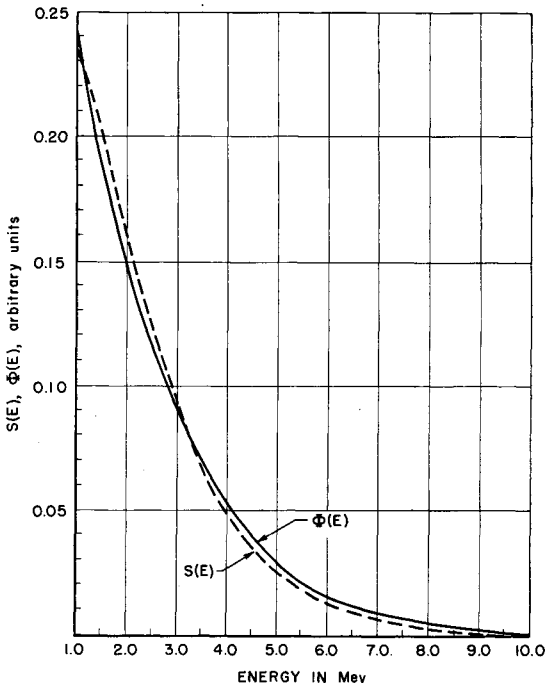

FIG. 2. Comparison of the hydrogen moderated spectrum and the U^{235} fission spectrum above 1 Mev.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

REFERENCES

1. A. M. Weinberg and E. P. Wigner, "The Physical Theory of Neutron Chain Reactors," p. 292. Univ. of Chicago Press, Chicago, Illinois, 1958.
2. "Reactor Physics Constants," ANL-5800 (1958).
3. "Neutron Cross Sections," BNL-325, 2nd ed. (1958).

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Calibration of Lutetium for Measurements of Effective Neutron Temperatures*

At the Hanford Laboratories, the determination of effective neutron temperatures is important for the study of re-thermalization cross sections. The ratio of the radioactivity from the fission products of Pu^{239} to that from the fission products of U^{235} is a sensitive indicator of this temperature for values between 400 and 1000°K (*1*). However, for temperatures below 400°K the ratio is a slowly varying function of the temperature.

The cross section of the lutetium isotope of mass 176 contains a resonance at 0.142 ev. One would, therefore, expect the radioactivity of Lu^{177}, which is produced by neutron irradiation of Lu^{176}, to be more sensitive than Pu^{239} to low values of the effective neutron temperature. Moreover, there are only two naturally occurring isotopes of lutetium and both can be made radioactive by neutron irradiation. If the second isotope (Lu^{175}) has a cross section which varies as "$1/v$" for neutrons with thermal energies, it would be possible to obtain with a single foil a ratio of activities which is very sensitive to low values of the effective neutron temperature, i.e., the ratio of the activity of Lu^{177} to that of Lu^{176m} (A^{177}/A^{176m}).

Experiments have been conducted to determine the feasibility of using such a method to measure the effective neutron temperature. The experimental results include (*a*) the half-life of each activity, (*b*) cadmium ratios for each isotope, and (*c*) the ratio of the two activities for various neutron temperatures.

The half-lives have been measured as 6.74 ± 0.04 days and 3.69 ± 0.04 hr for Lu^{177} and Lu^{176m}, respectively. These values agree very well with those reported by Betts *et al.* (*2*).

Cadmium ratios of the lutetium isotopes were obtained with cadmium covers which were 40 mil thick. The irradiations were made on a graphite cylinder which was rotating in the Thermal Test Reactor (TTR). The rotating cylinder made it possible to irradiate both the bare and the cadmium covered foils simultaneously in an identical flux. The gamma-ray activity of the foils was counted with a scintillation spectrometer shortly after the irradiation and 4 days later when the 4-hr lutetium had decayed. Analysis of the data yielded cadmium ratios of 1.45 ± 0.02 and 69 ± 1 for Lu^{175} and Lu^{176}, respectively. The cadmium ratio of a thin "$1/v$" detector in the same position was 33 ± 1.

Lutetium foils were also irradiated without cadmium in a 4 × 4 ft graphite thermal column where the cadmium ratio for a $1/v$ detector is $\sim 10^3$. The irradiations were made at selected thermal-column temperatures which ranged between 23 and 581°C. The activity from each foil was counted as before. Ratios of the activity of Lu^{177} to that of Lu^{176m} were calculated from the data. These ratios are shown in Fig. 1 as a function of the temperature of the thermal column.

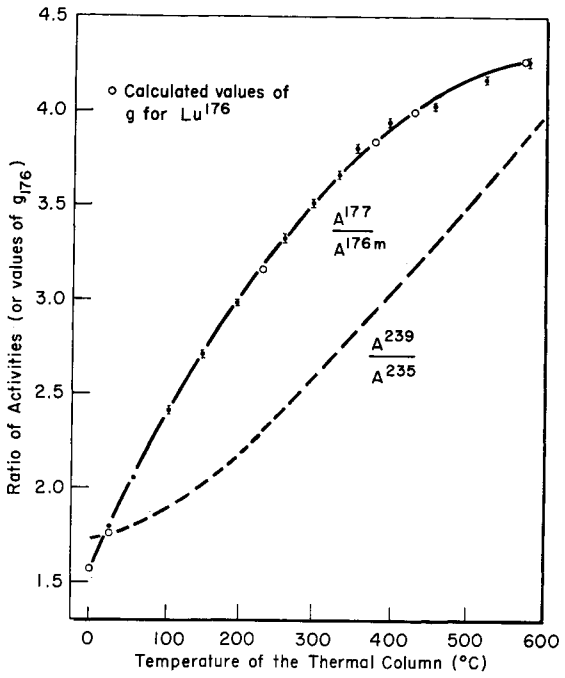

Fig. 1. The ratio of the activity of Lu^{177} to that of Lu^{176m} as a function of the temperature of the thermal column. The curve (solid line) is normalized at 577°C to a calculated curve of the g factors for Lu^{176}. The errors on the experimental points are those due to counting statistics. A curve (dashed lines) which shows the ratio of the fission activity of a Pu^{239} foil to that of a U^{235} foil is included for comparison. The Pu^{239}–U^{235} curve is normalized to the Lu curve at 20°C.

A copper foil was also irradiated along with each lutetium foil. A comparison of the activities resulting from neutron capture in Lu^{175} with that from the copper shows that the cross section of Lu^{175} for thermal neutrons varies as a function of neutron energy in the same manner as the cross section of copper, i.e., the cross section of Lu^{175} does not have an observable non-$1/v$ component for the neutron energies which were investigated. Thus the non-$1/v$ parameter g which has been defined by Westcott (*3*) can be taken as 1 for Lu^{175}. As a consequence of this value for Lu^{175}, the activity ratios are proportional to the g factors for Lu^{176}.

The experimental ratios in Fig. 1 have been normalized to g values which were calculated for Lu^{176} for six different Maxwellian distributions of neutron velocities. The calculations were made assuming: (*a*) that all the non-$1/v$ contribution to the cross section comes from the 0.142-ev resonance (the other resonances contribute ~0.5%), (*b*) that the resonance has the Breit-Wigner form

$$\sigma(E)\sqrt{E} = \frac{4.90 \times 10^3}{1 + 1108(E - 0.142)^2}$$

and (*c*) that the 2200-m/sec value for the cross section, $\sigma_{2200} = 1.92 \times 10^3$ barns, is that obtained from the Breit-Wigner formula. The calculated values of g are plotted in

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