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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.

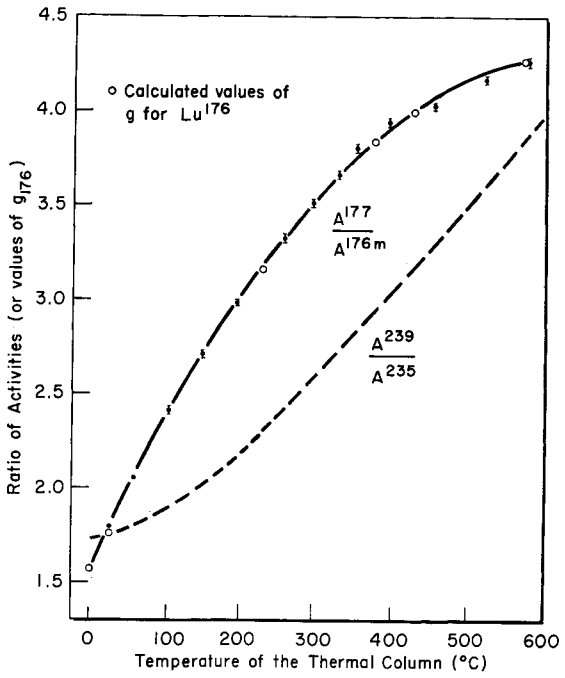

Fig. 1. The ratio of the activity of Lu^{177} to that of Lu^{176m} as a function of the temperature of the thermal column. The curve (solid line) is normalized at 577°C to a calculated curve of the g factors for Lu^{176}. The errors on the experimental points are those due to counting statistics. A curve (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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Fig. 1 assuming the neutron temperature to be the same as the thermal-column temperature. The experimental curve is normalized to the calculated value at 577°C.

Also appearing in Fig. 1 is a curve which is to be compared to the activity ratios obtained with the lutetium foils. This curve appears as a broken line and shows the changes in the ratio of the fission product activities of Pu^{239} to those of U^{235} as a function of neutron temperature. These ratios were obtained (*1*) from plutonium and uranium foils which were irradiated in the same manner as the lutetium foils. For the comparison the values obtained with the fission foils have been normalized at 20°C to the curve for the lutetium foils. From a comparison of the slopes of the curves in Fig. 1, it is evident that the lutetium "thermometer" is ~ 7 times more sensitive at room temperature than the Pu^{239}–U^{235} "thermometer" and remains more sensitive up to ~ 400°C.

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Void Coefficient Measurement

A quantity which has proven somewhat difficult to measure for tank type reactors with plate spacing of the order of $\frac{1}{8}$ in. is the void coefficient for voids in the moderator between the plates. It is difficult to simulate the voids properly. Methods have been used which depended on a knowledge of the compositions of plastics such as polyethylene and involved calculation of the reduction in hydrogen density when the material was inserted between fuel plates (*1*). Use has also been made of Styrofoam. In the first case a large amount of foreign material must be inserted in the core per unit of equivalent void; in the second case the variations in effective void fraction with pressure, time under water, and surface-to-volume ratio of the Styrofoam are unknown and enters the calculations directly if the effective void is calculated from physical dimensions.

If, however, the void equivalent of Styrofoam is measured by measuring the buoyant force on a submerged fuel element loaded with it, considerably greater precision can be obtained. It can be shown that

$$\Delta V = \frac{\Delta W}{\rho_{H_2O}} \left(\frac{1 - k_H \delta}{1 - k\delta} \right)$$

where ΔV is the equivalent void introduced, ΔW is the buoyant force, k_H is the relative hydrogen atom density of polystyrene with respect to water, k is its relative weight density, and δ is the volume fraction of Styrofoam which is solid material. It will be found that this expression has only a slow and indirect dependence on δ for Styrofoam of the usual characteristics. One can construct a simple balance and measure ΔW *in situ*, using a long wire to suspend the fuel element under water near the grid plate of the reactor. As a counterweight one can use a second fuel element. A simple measurement of the weight required to rebalance the two when Styrofoam is added to one of them gives the void equivalent directly to an approximation sufficiently good for most purposes.

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Dejacketing Pellets Using RF Heat

Pellets of Be_3N_2 are irradiated in aluminum cans to produce C^{14}. Removing these pellets from the cans is difficult because they swell against the wall, the characteristics of aluminum are changed by radiation, and radiation from cobalt impurity in the target material is high, 5 to 10 r/hr per can at 1-ft gamma activity.

The pellets cannot be dejacketed by chemical methods because of the danger of introducing normal carbon. Therefore several mechanical methods were tried. One involved sawing the cans lengthwise and then sawing the ends off.

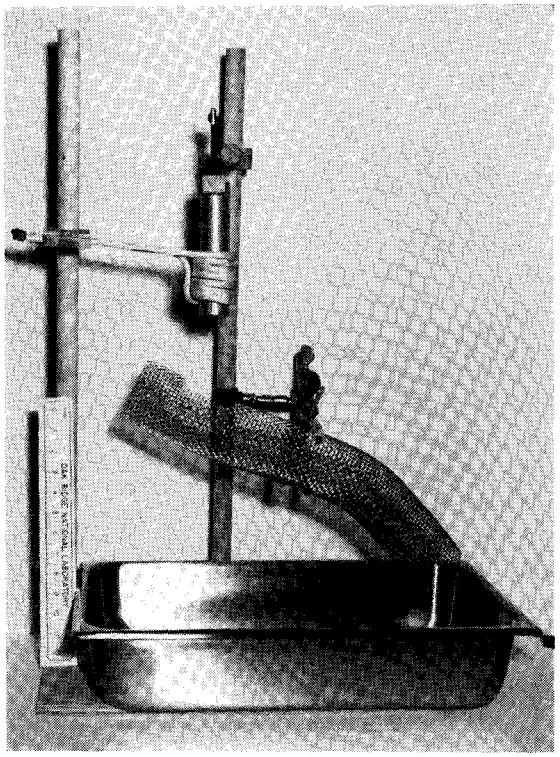

Fig 1. In cell set-up.