and Kaplan have presented a method for performing such an analysis together with the experimental comparison (6).

REFERENCES

ROBERT W. Deutsch
General Nuclear Engineering Corporation
Dunedin, Florida
Received March 17, 1961

Measurements of Relative Pu Fission Rates in Slightly Enriched Uranium-Water Lattices

The fission activation of Pu$^{239}$ relative to Pu$^{238}$ and Pu$^{241}$ has been measured for the TRX facility, a slightly enriched uranium-light water moderated reactor. The lattices in which the experiments were performed were composed of 1.3 wt% enriched uranium metal fuel rods, 0.387 in. in diameter, with a water to uranium volume ratio of either 2.35:1 or 1:1. The experiments described here are an extension of previously reported measurements for these lattices (1, 2).

The Pu was in the form of 1 mg/cm$^3$ deposits on highly pure nickel foils 0.010 in. thick. The isotopic concentrations of the deposits are given in Table I.

The presence of approximately 19% Pu$^{239}$ in the "Pu$^{239}$" deposit introduced the problem that the Pu$^{249}$ isotope contributes only of the order of 3-4% to the total fission activation of this deposit irradiated in these lattices. This relative contribution was increased to roughly 50% by irradiating this deposit Cd covered, thereby suppressing the thermal activation contribution of the Pu$^{239}$.

The ratio of the measured total fission product activity of a Cd covered "Pu$^{239}$" deposit to a bare "Pu$^{239}$" deposit is given by:

$$\gamma(t)_{40} = \frac{u(t)^{40} N_{40} I_{40}^{P} + u(t)^{41} N_{41} I_{41}^{P} + u(t)^{43} N_{43} I_{43}^{P}}{u(t)^{40} N_{40} I_{40}^{P}}$$

where $\gamma(t)^{40}$ is the relative activity at time $t$ after irradiation, $N_i$ is the number of atoms of isotope $i$ in deposit $k$ and $u(t)^{40}$ is a time function which reflects the gross fission product decay rate of isotope $i$. The $u(t)^{41}$ and hence the $\gamma(t)$ are functions of the time of irradiation and the time $t$ at which the deposits are counted. It is implicitly assumed that $u(t)^{40}$ and $u(t)^{41}$ are independent of the incident neutron energy initiating fission. No time dependence was detected in the Cd ratio measurements. The various fission activation integrals are denoted by the symbol $I$; i.e.,

$$I^x = \int_0^\infty \sigma_j(E) \phi(E) \, dE$$

where $\epsilon$ is the Cd cutoff energy (~0.45 ev). The Pu$^{249}$ contribution was neglected.

If the above expression is solved for the ratio of the Pu$^{239}$ to Pu$^{238}$ fission integrals, the result is the following:

$$\frac{\int_0^\infty \sigma_j^{40}(E) \phi(E) \, dE}{\int_0^\infty \sigma_j^{41}(E) \phi(E) \, dE} = P(t)^{49} \left[ \frac{N_{49}^{49} \gamma(t)^{49} - N_{49}^{49} \gamma(t)^{41}}{N_{49}^{49} \gamma(t)^{49} - N_{49}^{49} \gamma(t)^{41}} \right]$$

where $R^1$ is the measured Cd ratio of the $i$th isotope and $P(t)^{49}$ is the ratio $u(t)^{49}/u(t)^{41}$ and accounts for the relative gross fission product decay rates of isotopes $i$ and $m$.

In a similar manner, the following is obtained:

$$\gamma(t)^{41} = \frac{u(t)^{40} N_{40}^{41} I_{41}^{P} + u(t)^{41} N_{41}^{41} \gamma(t)^{41} + u(t)^{43} N_{43}^{41} \gamma(t)^{43}}{u(t)^{40} N_{40}^{41} I_{41}^{P} + u(t)^{41} N_{41}^{41} \gamma(t)^{41} + u(t)^{43} N_{43}^{41} \gamma(t)^{43}}$$

$$\int_0^\infty \sigma_j^{40}(E) \phi(E) \, dE = P(t)^{41} \frac{\int_0^\infty \sigma_j^{41}(E) \phi(E) \, dE}{\int_0^\infty \sigma_j^{41}(E) \phi(E) \, dE}$$

$$\left[ \frac{N_{41}^{40} \gamma(t)^{40} - N_{41}^{41} \gamma(t)^{41}}{N_{41}^{40} \gamma(t)^{40} - N_{41}^{41} \gamma(t)^{41}} \right]$$

TABLE I

<table>
<thead>
<tr>
<th>Deposit</th>
<th>Pu$^{239}$%</th>
<th>Pu$^{238}$%</th>
<th>Pu$^{240}$%</th>
<th>Pu$^{241}$%</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Pu$^{239}$&quot;</td>
<td>99.36</td>
<td>0.63</td>
<td>0.01</td>
<td>-</td>
</tr>
<tr>
<td>&quot;Pu$^{238}$&quot;</td>
<td>18.64</td>
<td>90.08</td>
<td>1.14</td>
<td>0.14</td>
</tr>
<tr>
<td>&quot;Pu$^{240}$&quot;</td>
<td>9.02</td>
<td>31.01</td>
<td>57.96</td>
<td>2.01</td>
</tr>
</tbody>
</table>

The experimental procedure is similar to the previously reported measurements (1, 2). The quantity $\gamma(t)$ was obtained by irradiating the deposits in a split fuel rod and counting the resultant fission product activity with a scintillation counter biased to reject pulses having equivalent energies less than 400 kev. The quantities designated as $P(t)$ were obtained from a separate experiment utilizing a double fission chamber technique (2).

A significant effect in the measurements with plutonium deposits that was not important in the previous uranium work was the large $\alpha$ particle emission rate which tends to produce poor plateaus in the fission chamber. In order to decrease the contribution of the $\alpha$ background relative to the fission product ionization, the anode to cathode spacing was varied to give the maximum fission to $\alpha$ ratio consistent with a reasonable gain in the system. The rise time of the system was also improved by using a transistorized pre-amp feeding a nonoverloading amplifier. The fission chamber
fission integrals are an indication of the difficulty encountered in detecting the Pu\textsuperscript{239} activity with these particular "Pu\textsuperscript{240}" deposits. The results for the Pu\textsuperscript{241} fission integral relative to the Pu\textsuperscript{239} fission integral agree with the previously measured values, within experimental error, although the experimental uncertainties are large in the present measurements.

A comparison with calculated results is shown in Table II in the case of Pu\textsuperscript{239} relative to Pu\textsuperscript{238}. The fission cross sections utilized were obtained from BNL-325, 2nd ed., and the energy dependent flux constructed for these lattices in refs. 1 and 5. It is seen that the calculated values are at least 30-40% lower than the measured results. A large portion of this difference is probably due to the lack of adequate cross section data for Pu\textsuperscript{239}, particularly in view of the relatively good agreement between calculated and measured results given in ref. 1. Calculations were also performed using the Pu\textsuperscript{241} cross section data of Nesterov and Smirenkin (6) in which the threshold was determined experimentally to extend to 0.15 Mev in contrast to the value of approximately 0.26 Mev shown in BNL-325. However, only a 1% increase results in the calculated values using this data.

An important conclusion can be drawn by noting the difference between the measured Pu results of this work and those of previous experiments for U, as listed in Table II for these lattices. It is seen that, for the neutron energy spectrum generated in the slightly enriched uranium-water moderated systems investigated, the Pu\textsuperscript{241} fission activation integral contribution relative to Pu\textsuperscript{239} appears to be of the order of 3-4 times as important as the corresponding U\textsuperscript{238} fission activation integral contribution relative to U\textsuperscript{235}.

REFERENCES

1. D. Klein, Measurements of Pu and U\textsuperscript{235} fission rates in water-uranium reactor spectra, Nuclear Sci. and Eng. 8, 405-409 (1960).


J. J. Volpe

D. Klein

Bettis Atomic Power Laboratory*
Westinghouse Electric Corporation
Pittsburgh, Pennsylvania
Received March 29, 1961


---

### Table II

**Relative Fission Activation Integrals**

<table>
<thead>
<tr>
<th>Lattice</th>
<th>Experimental</th>
<th>Calculated</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) 2.35:1 Lattice</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\int_0^\infty \sigma_{\nu}^0(E)\phi(E) , dE$</td>
<td>0.0053 ± 0.0007</td>
<td>0.0052 ± 0.0003</td>
</tr>
<tr>
<td>$\int_0^\infty \sigma_{\nu}^1(E)\phi(E) , dE$</td>
<td>0.0038 ± 0.0007</td>
<td></td>
</tr>
<tr>
<td>$\int_0^\infty \sigma_{\nu}^{12}(E)\phi(E) , dE$</td>
<td>0.0031 ± 0.00006</td>
<td></td>
</tr>
<tr>
<td>(B) 1:1 Lattice</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\int_0^\infty \sigma_{\nu}^0(E)\phi(E) , dE$</td>
<td>0.0096 ± 0.0010</td>
<td>0.0052 ± 0.0003</td>
</tr>
<tr>
<td>$\int_0^\infty \sigma_{\nu}^1(E)\phi(E) , dE$</td>
<td>0.0096 ± 0.0013</td>
<td></td>
</tr>
<tr>
<td>$\int_0^\infty \sigma_{\nu}^{12}(E)\phi(E) , dE$</td>
<td>0.00238 ± 0.00012</td>
<td></td>
</tr>
<tr>
<td>(C) $P(t)^{\text{Pu}}_{\text{U}} = 0.98$</td>
<td>$P(t)^{\text{Pu}}_{\text{U}} = 1.11$</td>
<td>$P(t)^{\text{Pu}}_{\text{U}} = 1.13$</td>
</tr>
<tr>
<td>± 0.05</td>
<td>± 0.04</td>
<td>± 0.07</td>
</tr>
</tbody>
</table>