REFERENCE 186

J. T. MIHALCZO, "PROMPT-NEUTRON DECAY IN A TWO COMPONENT ENRICHED-URANIUM-METAL CRITICAL ASSEMBLY," TRANS. AM. NUCL. SOC. 6:60-61 (1963).

Transactions

Volume 6 Number 1 June 1963

1963 ANNUAL MEETING

Salt Lake City, Utah, June 17-19, 1963

AMERICAN NUCLEAR SOCIETY
Hinsdale, Illinois, U. S. A.

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Prompt-Neutron Decay in a Two-Component Enriched-Uranium-Metal Critical Assembly,

J. T. Mihalczo (ORNL)

The variation of the prompt-neutron decay constant with separation of parts of a two-component unreflected and unmoderated U(93.2)* metal critical assembly has been measured by the Rossi-α technique.[1] Since the neutron flight time across the gap is a significant part of the prompt-neutron lifetime (ℓ) in these assemblies, the prompt-neutron decay constant (which for delayed-critical assemblies equals β_{eff}/ℓ) depends on the distance between components and the number of neutrons traveling from one component to the other.

Consider a two-component critical assembly of fissionable material in which the two parts are separated a distance x. It is required that the shape of each component be such that all neutrons leaving the exterior surface escape. Defining

F_a = average fraction of neutrons born in part a,
P_{ab} = probability that a neutron born in part a leaks into part b,
R_{ab} = probability that a neutron will be reflected by part a into part b,
t_{ab} = average neutron flight time from part a to part b,
ℓ_s = prompt-neutron lifetime in the assembly if the neutron flight time across the gap were zero,

and similarly defining F, P, R, and t for component b, the mean neutron lifetime can be written as

$$\ell = \ell_s + t_{ab} F_a P_{ab} [1 + R_{ba} + R_{ab} R_{ba} + R_{ab} R_{ba}^2 + \ldots] + t_{ba} F_b P_{ba} [1 + R_{ab} + R_{ba} R_{ab} + R_{ba} R_{ab}^2 + \ldots]$$

or

$$\ell = \ell_s + t_{ab} F_a P_{ab} \frac{(1 + R_{ba})}{(1 - R_{ab} R_{ba})} + t_{ba} F_b P_{ba} \frac{(1 + R_{ab})}{(1 - R_{ab} R_{ba})}.$$

If the components of the system are identical rectangular parallelepipeds, each located a distance x/2 from their plane of symmetry,

$$F_a = F_b = 0.5, \qquad R_{ab} = R_{ba} = R(x),$$
$$P_{ab} = P_{ba} = P(x), \qquad t_{ab} = t_{ba} = t(x),$$

and the above expression is

$$\ell = \ell_s + t(x) \left[\frac{P(x)}{1 - R(x)}\right].$$

In general, t, P, and R will also depend very strongly on the energy and angular distribution of the neutrons and can be calculated by using Monte Carlo methods and in some special cases by using transport theory. The term (1 - R) in the denominator accounts for multiple reflections of neutrons back and forth across the gap. For a system with no gap, t is zero and the lifetime is that in a single-component critical assembly. As the space between the halves becomes infinite, P approaches zero faster than t approaches infinity, and the lifetime again approaches that in a single-component assembly.

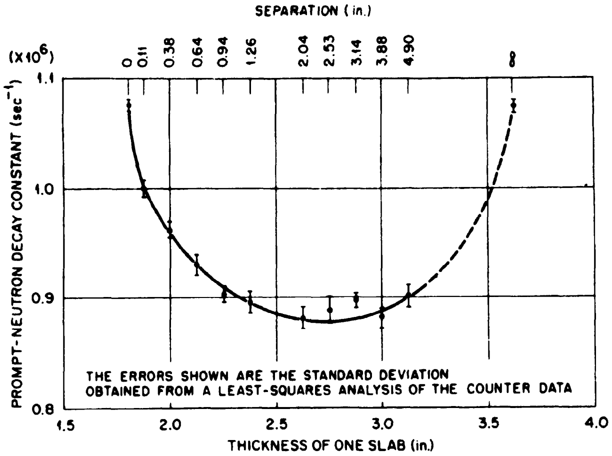

Fig. 1. Prompt-Neutron Decay Constant for Two Interacting 8 by 10 in. Uranium Metal Slabs as a Function of Slab Thickness.

Although these equations were developed for a two-component critical system, they can be generalized to hold for any array of components by adding additional terms of the same form.

The prompt-neutron decay constant for two 8 × 10 in. slabs of equal thicknesses, with critical spacings from 0 to 5 in., was measured by detecting leakage neutrons and is shown in Figure 1. The two slabs were parallel to each other so that neutrons were exchanged by the facing 8 × 10 in. surfaces. Figure 1 also shows the dependence of slab thickness on the separation distance.

Although the decay constant in rectangular geometry has not been calculated, a similar experiment in cylindrical geometry has been calculated by transport theory; a comparison of the results is given in Table I.

TABLE I. Results of an Experiment and Calculations in Cylindrical Geometry

Disc diameter	11 in.
Disc thickness	2.378 in.
Disc separation	1.99 in.

Neutrons exchanged by facing plane surfaces only.

	Calculated[a]	Experimental
k_{eff}	0.9929	1.0000
β_{eff}, 10^{-4}	66.7[b]	
ℓ, 10^{-9} sec		7.88[c]
$\frac{t(x)\,P(x)}{1 - R(x)}$, 10^{-9}sec	1.54[d]	
Prompt-Neutron Decay Constant, 10^6 sec^{-1}	- 0.901	-0.846 ± 0.007

[a] S_8 calculation[2] using Hansen and Roach cross sections.[3]

[b] Decrease in k_{eff} calculated by subtracting the delayed neutrons from the fission spectrum using the delayed-neutron-energy distribution of Batchelor and Hyder[4] and yields of Keepin et al.[5]

[c] Inferred from prompt-neutron decay constant.

[d] $t(x) = 6.47 \times 10^{-9}$ sec; $P(x) = 0.226$; $R(x) = 0.0478$.

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*This designates uranium of 93.2 wt% U-235 content.

No correction for room-return effects on the critical spacing or on the prompt-neutron decay constant has been made.

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