Nuclear measurement

7 copies - Ch to Young

DECLASSIFIED
CLASSIFICATION CHANGED TO:
BY AUTHORITY OF: E. F. Murphy 1-9-63
BY: R. Smith 6-6-63

MUC-E PW-143 [redacted]
This document consists of 5 pages and 0 figures
No. 7 of 9 copies, Series A
Young-Weinberg

Memorandum

January 9, 1945

ORNL Technical Information Division
Y-12 Technical Library
Document Reference Section
Bldg. 9711-1

A few days ago we received the information that the plutonium absorption at thermal energies is caused only partly by the .3 eV resonance and partly by a much broader resonance. This very broad resonance gives a 1/V distribution which has a value of about 300 B at thermal energies and which is connected with very little if any capture. On the other hand the capture to fission ratio of the resonance level is .8. It is expected that the capture to fission ratio again decreases at higher energies so that ~~it~~ α rises from the value of .45 at thermal energies to .8 at .3 eV and then drops again to practically 0. If the ν, that is the number of neutrons per fission, is the same for all levels, the η will behave in the opposite way. It will begin to drop from its thermal value of about 2.05 to 1.65 at .3 eV and then may rise again to a value as high as 3. If this is the case and if 40 is either not fissionable or does not have a large cross section, it is evidently disadvantageous to have the neutrons absorbed by the .3 eV resonance. One must either absorb them at thermal energies or, what is even better if the above picture is correct, before they reach .3 eV.

Although the behavior of η as function of ~~with~~ energy ~~es~~ is far from being well established it seems worth while to sketch briefly the consequences of the above picture as far as a converter or breeder is concerned.

Thermal Breeder

The first possibility is to have practically all neutrons absorbed at thermal energies. As a matter of fact η is reasonably well known for

[redacted]

[redacted]

[redacted]

thermal energies and what will be said next is reasonably well established although it may not be the most advantageous thing to run the pile on thermal neutrons. If the number of neutrons absorbed at resonance is small, their number is given by $\frac{4500}{N \sigma_s \xi}$. In this, N is the number of moderator atoms per plutonium atom, σ_s is their scattering cross section, and ξ is the logarithmic energy loss upon collision with these atoms. 4500 is the estimated $\int \sigma \, dE/E$ for the .3 eV resonance. Since η is assumed to be only 1.65 for the resonance neutrons, one has a loss of efficiency of 35% for all of the above neutrons. In addition to that, the absorption of the moderator gives a further loss of ~~Na/1060~~ Na/1060. In this a is the absorption cross section of the moderator atoms and 1060 is the cross section of plutonium. Thus the total loss of efficiency is

$$.35 \frac{4500}{N \sigma_s \xi} + \frac{Na}{1060}$$

This expression assumes its smallest value for $N = \frac{1300}{\sqrt{a \sigma_s \xi}}$ and the minimum loss is $2.4\sqrt{\frac{a}{\sigma_s \xi}}$. Inserting numerical values, one obtains that the minimum loss in efficiency is 29% if water is the moderator, 18½% if graphite is used as a moderator, and 5.75% for heavy water. This shows that only heavy water can be used as moderator with any efficiency under the above conditions, i.e., if one wants to run the pile essentially on thermal neutrons, if η drops considerably in the resonance at .3 eV and if 40 does not have favorable fission characteristics. The optimal values for N are 265 in the case of water, 17,000 in case of graphite, and 10,300 in case of heavy water. This latter

[redacted]

[redacted]

figure corresponds to a solution of 1 gm plutonium and 770 cm^3 of water.

The other possibility is not to permit the neutrons to reach .3 eV but absorb them above that energy. What will be said about this is more questionable than what has been said above because there are only indications that radiative capture may be very small above, about .5 eV. According to Anderson the $\int \sigma dE/E$ for plutonium above the cadmium limit is 450. From this about 150 must be subtracted as the tail of the .3 eV resonance. This leaves a useful $\int \sigma dE/E$ of 300 B. We shall denote with p the fraction of all the neutrons which reach the energy .5 volts. We shall denote then

$$I = (\ln \frac{1}{p})^{-1} \int_{.5}^{\infty} \frac{\sigma_{Pu} dE}{E}$$

The number of plutonium atoms per cm^3, N_{Pu}, is then given by the equation $\xi / \lambda = I N_{Pu}$, where λ is the mean free path of neutrons. If we assume that this mean free path is independent of the energy, an assumption which is only crudely valid, the age of neutrons will be given by the equation

$$\tau = \frac{\lambda^2}{3\xi} \ln(E_f/E_r)$$

In this E_f/E_r is the ratio of fission to resonance energies and has been estimated to be 2×10^4, giving

$$\tau = 3.3 \lambda / N_{Pu} I$$

with the aid of the above equation.

The usual pile equations give for the radius of the critical sphere the equation

[redacted]

[redacted]

$$R^2 N_{Pu} = \frac{\pi^2 3.3\,\lambda}{(\ln k) I}$$

The total number of plutonium atoms is then given by

$$V N_{Pu} = \frac{136 \lambda R}{I \ln k}$$

and its weight expressed in kg is $\frac{54.5\,\lambda R}{I(\ln k)}$. The logarithmic energy ~~dropped~~ loss on collision, ξ, on the other hand is given by $\xi = \frac{33\,\lambda^2}{R^2 \ln k}$.

One sees that the larger a chain reacting unit one makes the more plutonium is needed. However, the amount of plutonium increases only at the first power of the radius so that its concentration will decrease. If one assumes that the power output is crudely proportional to the volume of the unit it appears advantageous to make the unit as large as possible because the production per unit amount of plutonium will increase. At the same time ξ decreases so that the moderator will be composed of increasingly heavier elements. However, one cannot go too far in this direction because the resonance absorption of the moderator will eventually interfere with the efficiency of the system. Denoting with N_m the number of moderator atoms per cm^3, with I_m the $\int \sigma dE/E$ for the moderator, the loss is

$$\frac{N_m I_m}{N_{Pu} I \ln \frac{1}{p}} = \frac{\ln k}{\ln \frac{1}{p}} \frac{R^2}{33\lambda^2} \frac{I_m}{\sigma_{ms}}$$

In this σ_{ms} is the scattering cross section of the moderator. Evidently as R increases the loss will increase partly because of the second factor above and partly because on the whole I_m will be increasing. The follow-

[redacted]

[redacted]

[redacted]

ing table gives a few numerical results. It was assumed that ln k = 1 ?

and for the last two rows λ = 5 cm and I = 300 B were used, which corresponds to p = 1/e = .37. M in the table is the mass number of the moderator atom, w the weight of the Pu in kg.

R/λ	6	10	15	20
ξ	1	.33	.147	.0825
M ~~Mass~~ number of moderator	1	5.4	13	23.5
w ~~weight of Pu~~	27.5	45.5	68	91 kg
R	30	50	75	100 cm

The above calculation is of course schematic inasmuch as a constant, energy independent λ was used. It seems worth while to remark that those elements are in the more favorable position ~~if~~ for which λ is ~~small~~ large in the resonance region and ~~large~~ small at higher energies--the opposite of the usual behavior. For instance, Al would be very suited as moderator from this point of view because the low Al cross section at low energies will give great efficiency to the plutonium resonances and the higher Al cross section at fission energies makes the critical sphere relatively small. Hydrogen or water, on the other hand, are ~~pure~~ poor from this point of view. On the other hand, water has probably practically no resonance absorption itself, $I_m \sim 0$, while for Al this quantity may ~~be~~ possibly be as large as .4. This would give, of course, a very considerable less which can be decreased only moderately by making p very small.

[redacted]

RECEIVED
MAY 27 1948
OAK RIDGE NATIONAL
LABORATORIES
CENTRAL FILES