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NEUTRON AGE CALCULATIONS

(Homogeneous Systems)

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NEUTRON AGE CALCULATIONS

(Homogeneous Systems)

by

N. Ketzlach

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NEUTRON AGE CALCULATIONS

(Homogeneous Systems)

In an earlier study[1] on criticality conditions for homogeneous mixtures, 27 cm^2 was used as the neutron age for all mixtures of water and uranium. At the higher H/U ratios (low uranium concentrations), the calculated critical parameters were in good agreement with experimental data. At the low H/U ratios (high uranium concentrations) the calculated critical parameters were smaller than the experimental ones (more conservative from a nuclear safety point of view). These results indicated that using 27 cm^2 as the neutron age gives increasingly conservative results as the H/U ratio decreases.

A later study[2] indicated how much the calculated criticality parameters may be increased by taking into account the change in neutron age with concentration of moderator in the system. In this later study slowing down and transport cross sections were neglected. This reduced the neutron age formulation used as a model to the following:

$$\tau = \frac{\tau_{(H_2O)}}{(\rho_{H_2O})^2}$$

where τ = neutron age of system

$\tau_{(H_2O)}$ = neutron age in pure water

ρ_{H_2O} = density of water in the system.

However, at the high uranium concentrations the slowing down and transport cross section terms cannot be neglected. A more reasonable equation for the neutron age as a function of composition for homogeneous systems is the following:

$$\tau = \frac{\tau_{pM}}{\left[\frac{\rho_M}{\rho_{pM}} + \frac{\Sigma_{Sl}^F}{\Sigma_{Sl}^M}\right]\left[\frac{\rho_M}{\rho_{pM}} + \frac{\Sigma_{tr}^F}{\Sigma_{tr}^M}\right]}$$

where pM = pure moderator

M = moderator

F = fuel (U, UO_3, UO_2F_2, etc.)

$\Sigma_{Sl} = \Sigma_{IN} + \xi\,\Sigma_S$

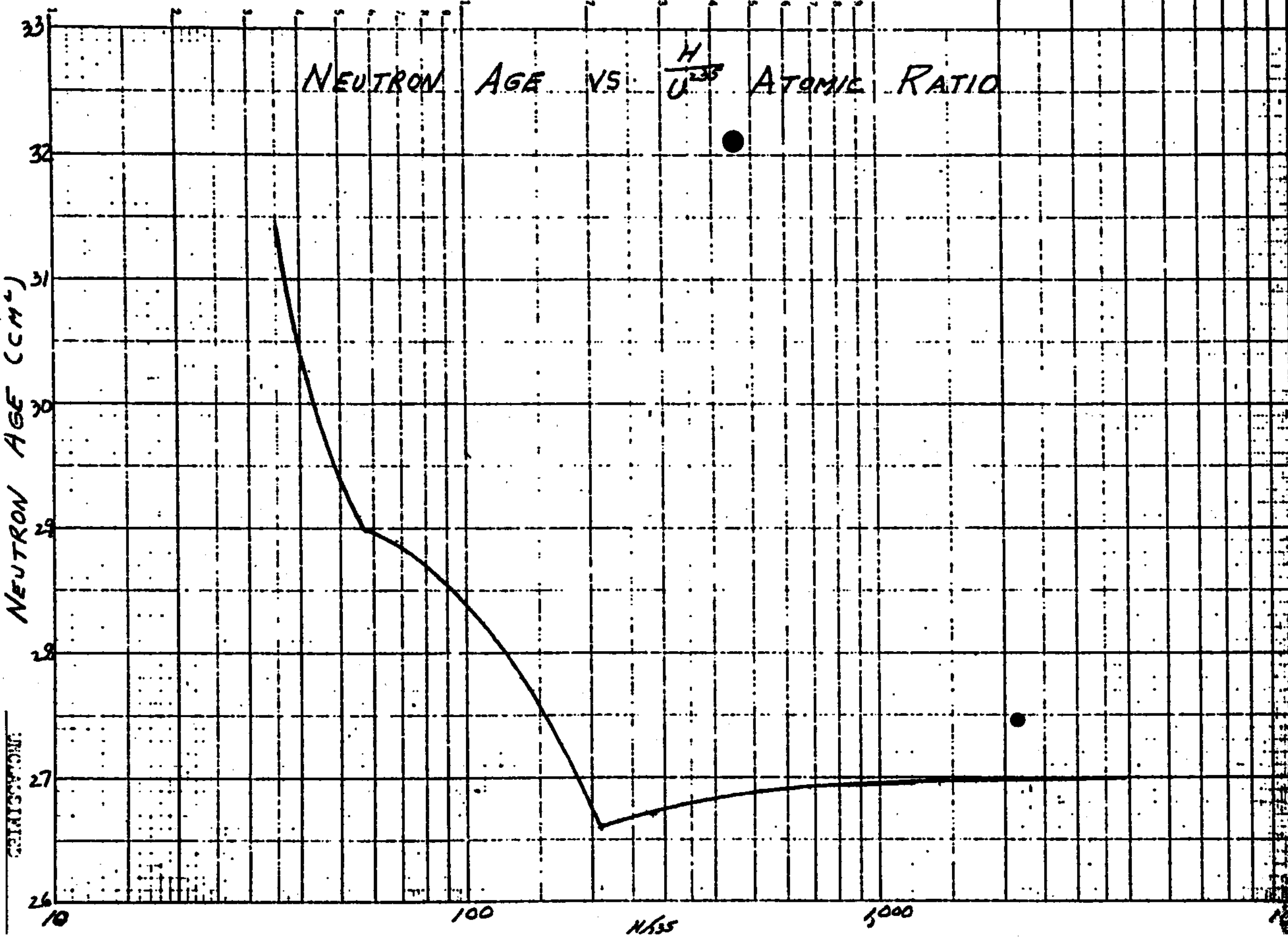
The neutron age for highly enriched uranyl fluoride (~90% U-235) in water was calculated by this formulation as a function of H/U-235 using 27 cm^2 as the neutron age in pure water. The results are plotted in Figure 1. It appears that there are three distinct regions. For H/U-235 values > 200 there is essentially no water displacement. The slight decrease in neutron age is due to the increase in uranium concentration. In the intermediate range, the rate of increase in neutron age due to decreased water moderation is slowed down by the increase in uranium concentration. For H/U-235 values < 55 the rate of increase in neutron age is controlled by the rapid displacement of water by fuel (rapid decrease in water concentration).

It is indicated, from Figure 1, that the neutron age is about 29.8 cm^2 at an H/U-235 of 45 (concentration for maximum material buckling). Good agreement between experiment and theory had been obtained[1] using 27 cm^2 as the extrapolation length for solutions of UO_2F_2 in water for H/U-235 ratios as low as 45. This does not mean that the method presented here for neutron age is not any good. There is a compensating factor in the formulation used to calculate critical parameters for high concentrations of highly enriched solutions. For an H/U-235 ratio of 200 the probability of capture during slowing down in water is about 5 or 10 percent and proportionally larger for smaller H/U-235 ratios(3).

For such H/U-235 ratios, it is not clear whether the effect of these epi-thermal captures is to increase or decrease the reactivity. If the average number of fission neutrons produced per capture were independent of the energy of the captured neutrons, then epi-thermal captures would increase the reactivity. However, the ratio of radiative capture to fission in U-235 is known to be substantially larger for epi-thermal neutrons than for thermal ones(3). This effect would tend to reduce the reactivity. It is not known whether the combination of these two effects increases or decreases the reactivity. A study should be made of the effect on the reactivity of the capture of neutrons while slowing down in reactors of relatively low H/U-235 ratios. This study would have to take into account the resonance structure of U-235, allowing for self-shielding and for the variation of the capture to fission ratio as a function of energy. The results of such a study may throw some light on the validity of using the above formulation for neutron age in homogeneous systems as well as the use of 27 cm^2 for pure water as used in the above formula.

N Ketzlach/bg

FIGURE 1


NEUTRON AGE VS $\frac{H}{U^{235}}$ ATOMIC RATIO
NEUTRON AGE (CM²)
33
32
31
30
29
28
27
26
10
100
$H/_{235}$
1000

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3. Bell, George I., "A Simple Method of Calculating Critical Masses of Proton Moderated Assemblies," LA-1548, May 1953.