BULLETIN OF THE INSTITUTE OF NUCLEAR SCIENCES „BORIS KIDRICH“
VOL. 10, № 195. — MARCH, 1960. LABORATORY OF PHYSICS

THE EXPERIMENTAL DETERMINATION OF THE BUCKLING IN THE BARE HEAVY WATER NATURAL URANIUM CRITICAL ASSEMBLY „RB“

by

Nenad M. Raišić, Dragoslav D. Popović, Stevan M. Takač and Magdalena M. Đorđević

The buckling of the heavy water natural uranium critical assembly was determined by measuring the thermal neutron flux distribution. The obtained value for the critical buckling at the temperature of 20° C is:

$$B^2 = (8.516 \pm 0.02)\ m^{-2}$$

The above error is a statistical one, obtained from several series of measurements. The possible systematic error was estimated as $0.1\ m^{-2}$.

The heavy water critical assembly „*RB*“ (1), of the Institute of Nuclear Sciences „Boris Kidrich“, was designed bare to allow for the exact determination of the buckling by measuring the geometrical characteristics of the system, and introducing only small corrections, due to the presence of the tank walls, the lid and the supporting platform, which act as neutron reflectors.

The studied core lattice was square with a 12 cm pitch. The fuel elements are cylindrical uranium rods with a diameter of 25 mm. The rods are canned in pure aluminium 1 mm thick. The mean density of uranium metal was 18.7 gr cm^3. Heavy water used during the experiments had a D_2O concentration of 99.76%.

Experiments

In this experiment the buckling was determined on the basis of the thermal neutron flux distribution in the core, measured by means of indium and dysprosium foils. Corrections to the geometrical parameters (extrapolated radius and height) due to the presence of the surrounding material were determined.

In earlier experiments with the reactor the dependence of the critical heavy water level on the temperature was determined by the approach to criticality method with a precision better than 1 mm. Therefore it was sufficient to measure the water temperature in order to know the critical level.

However during the irradiation of foils the reactor had some small excess reactivity, which produced a power rise with a period of the order of five minutes. Because of some supercriticality added and the poisoning effect of the foils and the foil holders, the actual heavy water level was higher than in normal critical conditions. For this reason it was necessary to correct the results obtained for the vertical neutron flux distribution, taking into account all mentioned effects.

Taking the thermal neutron flux in horizontal and vertical directions as mutually independent, the horizontal and the vertical distribution in the two group theory can be expressed by:

$$N(B_r r) = A_1 J_0(B_r r) + A_2 I_0(B_r r) \ldots . \quad (1)$$
$$N(B_h h) = A_1' \cos(B_h h) + A_2' \cosh(B_h h)$$

with the condition that the flux will vanish at the extrapolated boundaries of the reactor.

Far enough from the reactor boundaries, one can neglect the second expression in the equations above.

Using the experimentally determined thermal neutron flux distribution one can calculate the bucklings B_r^2 and B_h^2 using the equations (1), and determine the extrapolated radius R_{ex} and height H_{ex}. The total buckling will be:

$$B_2 = B_r^2 + B_h^2$$

To find the regions in the reactor where equation (1) holds, several measurements of the cadmium ratio for indium were made along the horizontal and vertical planes going trough the reactor centre. In the range of experimental error the measurements show the constant ratio up to approximately 15 cm from the boundaries. Owing to this fact it was sufficient to measure the total indium activity without subtracting the epithermal activity. For the buckling calculations few measured points near the boundaries were omitted.

Results

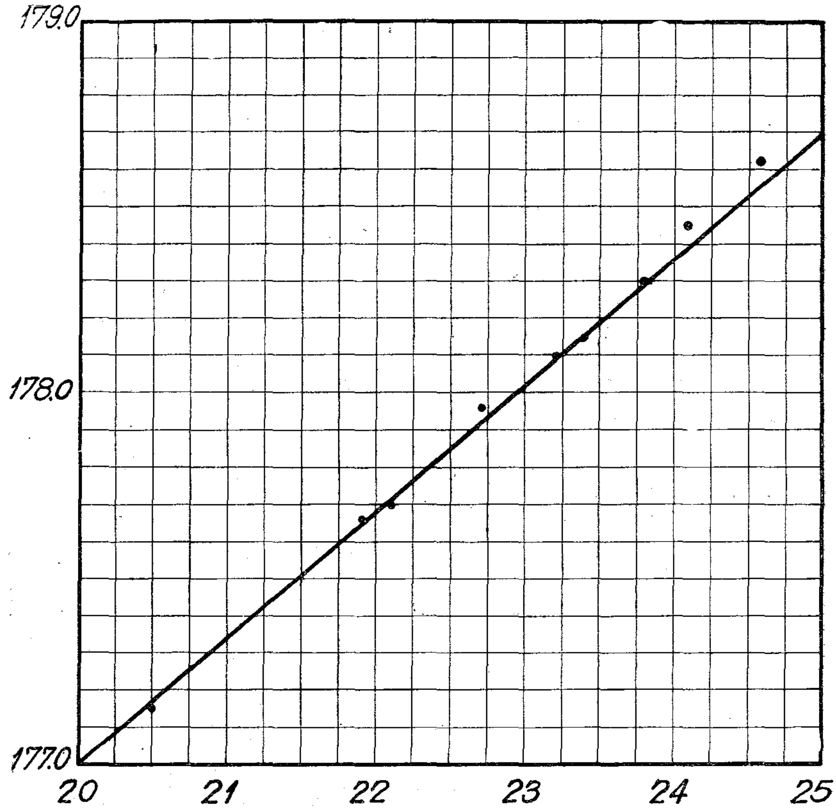
Diagram 1. represents the measured temperature dependence of the critical heavy water height. Since there was no artifical moderator heating the measured curve only goes to 25° C. In that small interval one has:

$$dh/dt = 0.34 \text{ cm}/°\,\text{C}$$

and from the measured value (2) of $d\rho/dh$ one can find the temperature coefficient for the moderator:

$$d\rho/dt = (2.4 \pm 0.1)\ 10^{-4}$$

These values were used as corrections, to obtain the geometrical parameters of the critical D_2O level at 20° C.



Diagr. 1. — The temperature dependence of the critical heavy water height.

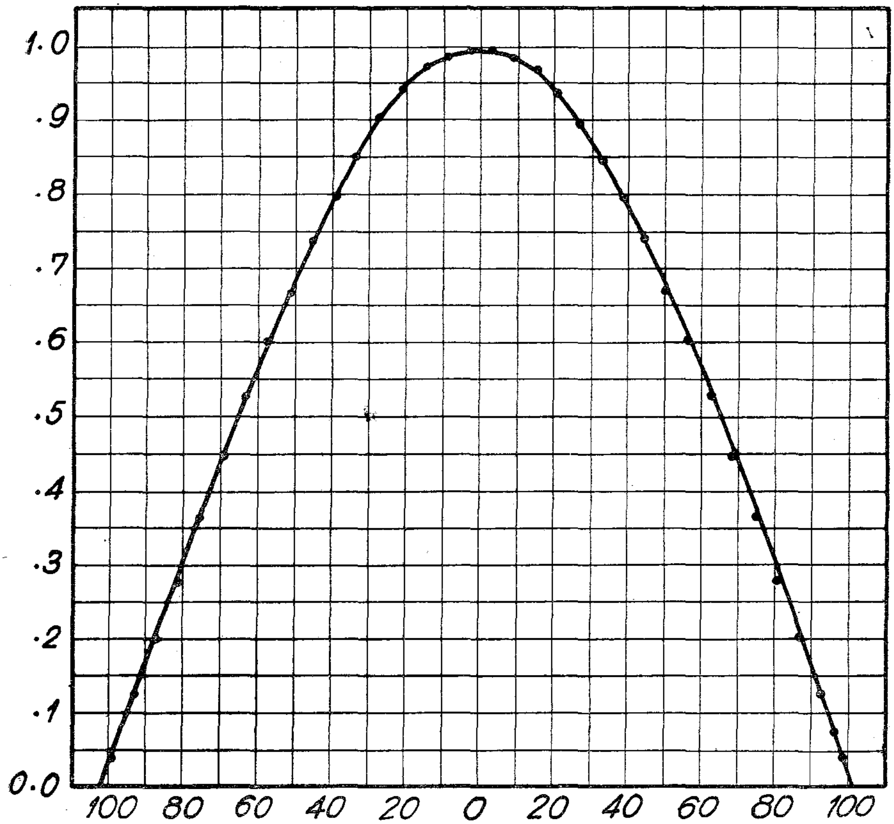
Diagram 2. represents the curve for the horizontal thermal neutron flux distribution. Every point on the curve represents a mean value of 15 measurements. The calculated horizontal buckling is:

$$B_r^2 = (5.576 \pm 0.016)\ \mathrm{m}^{-2}$$

From that value the extrapolated radius of the reactor core was found to be:

$$R_{ex} = 101.84 \pm 0.21\ \mathrm{cm}$$

If one takes for the core radius $R = \left(\frac{N}{\pi} \times b^2\right)^{1/2}$ where N is the total number of elementary cells in the core, and b the lattice pitch, one has the boundary condition that the neutron flux will vanish at $\lambda_{extr.} = 4.14$ cm from the core. One can compare this value with the theoretical one. The real radius of the tank is 99.93 cm and the aluminium wall thickness 10 mm, which means that the core is surrounded with a double reflector. The first



Diagr. 2. — The horizontal thermal neutron flux distribution.

is the heavy water reflector, 2,2 cm thick, and second the aluminium reflector. That makes the theoretical extrapolated length:

$$\lambda_{extr.} = 0.71\ \lambda_{tr.} + D_c/D_w \times l_w + D_c/D_a \times l_a$$

where the D_c, D_w and D_a are the diffusion constants for the core, heavy water and aluminium, and l the respective reflector thickness. If one calculates λ_{tr}, the transport mean free path for thermal neutrons in the core, with the nuclear constants taken from the literature (3), one obtains for the extrapolated distance:

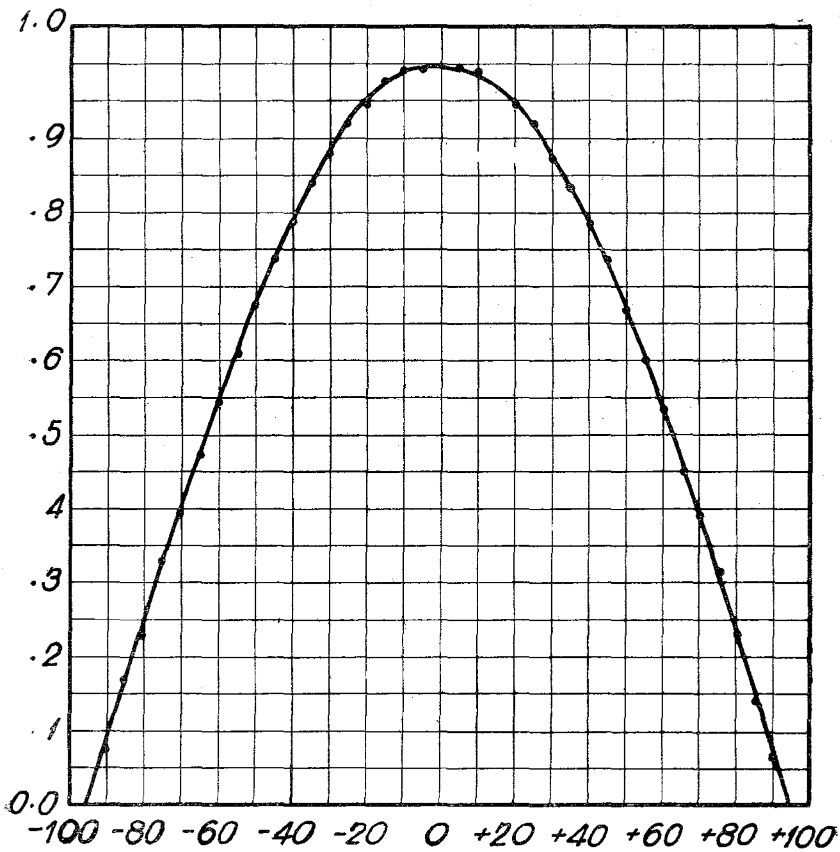
$$\lambda_{extr.} = 4.19\ \text{cm}$$

what is close to the experimental result. But, if one takes the extrapolated distances for thermal and fast neutrons weighted with the corresponding contributions of the slow and fast neutron diffusion lengths to the migration length, one obtains a higher value for the extrapolated distance. The difference is of the order of 0.5 cm and does not match the experimental results

The vertical distribution corresponds to the cosine law but one obtains an asymmetrical curve. The reason for this asymmetry obviously comes from unequal extrapolated lengths at the two boundaries since the construction of the bottom and top of the reactor tank differ.

The distribution was measured 15 times and the numerical analysis was applied separately for the upper and the lower part of the distribution curve.

Diagram 3. represents the measured vertical neutron flux distribution for the actual heavy water level at 182 cm. The extrapolated lengths calculated as mean values from all measurements are:



Diagr. 3. — The vertical thermal neutron flux distribution.

$$\lambda_{ex,\ bottom} = (3.51 \pm 0.4)\ \mathrm{cm}$$
$$\lambda_{ex,\ up} = (2.69 \pm 0.36)\ \mathrm{cm}$$

The total vertical buckling corrected for the temperature of 20° C is:

$$B_h^2 = 2.940 \pm 0.012)\ \mathrm{m}^{-2}$$

The extrapolated lengths in vertical direction are longer than those obtained in the horizontal direction. The long extrapolated length in the bottom direction comes from the double bottom and the platform which makes more than 35 mm of aluminium reflector with additional gaps between individual aluminium plates. Somewhat longer extrapolated length in the top direction of the core can be explaned with the reflecting effects of the lid and the uranium bars sticking out of the water by nearly 30 cm.

These results confirm that the assembly can not be taken as exactly bare. The constructive elements influence the boundary conditions and act as reflectors. The influence is rather small in this case and does not influence the total height of the heavy water by more than 10 mm.

The total buckling will be the sum of horizontal and vertical bucklings:

$$B^2 = B_h^2 + B_r^2 = (8.516 \pm 0.02)\ \mathrm{m}^{-2}$$

where the error includes the statistical error only. Since the measured extrapolated length in the horizontal direction is smaller than the theoretical one, one might expect a systematic error not higher than 0.1 m^{-2}.

Comparison with other published results

There is a number of published data on the buckling of heavy water natural uranium assemblies (4), (5), (6), (7). It is known that all these measurements do not agree well with one another, except the Canadian and the French one. The American values are in general higher then the Canadian and French by approximately 0.3 m^{-2}, while Swedish values are still higher. The American value for the buckling of the lattice with 1″ diameter uranium rods and a pitch of 4.5″ is 8.47 m^{-2}. For the lattice of 2.54 cm diameter rods and 12 cm pitch the Swedish exponential experiment gave 8.66 m^{-2}. The French results from the critical measurements, extrapolated from the values obtained with 2.6 cm uranium rods and various lattice pitch, should give for our case the buckling in the region of 8.3 m^{-2}. Our value for the lattice of 2.5 cm rods and 12 cm lattice spacing are practically the same as the American one but in discrepancy with the others.

REFERENCES:

1) D. Popović, S. Takač, H. Marković, N. Raišić, Z. Zdravković, Lj. Radanović: Bulletin of the Institute of Nuclear Sciences „Boris Kidrich", Vol. **9**, (1958).
2) D. Popović, N. Raišić, S. Takač, H. Marković, Z. Zdravković, B. Lolić: Bulletin of the Institute of Nuclear Sciences „Boris Kidrich", Vol. **9** (1958).
3) C. H. Westcott, CRRP-680.
4) Cohen E. R. A/CONF. 8/P/605 (Geneva 1955).
5) Ibid.
6) R. Persson, E. Blomsjö, M. Bustraan, R. Meier: J. Nuclear Energy I. (1956) Vol. **3**, 188.
7) Y. Girard, J. Koechlin, J. Moreau, R. Naudet: A/CONF Vol. **12** P/336 (Geneva 1958).

December, 1959.

Institute of Nuclear Sciences
„Boris Kidrich"
Laboratory of Physics