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CRITICALITY MEASUREMENTS AT VNIITF REVIEW

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ABSTRACT

A review of the criticality measurements at RFNC-VNIITF is presented in this report.

INTRODUCTION

Criticality measurements began in Chelyabinsk-70 in 1957 on a designed and manufactured vertical lift machine FKBN whose prototype was used in Arzamas-16 and was mentioned in A.D. Sakharov reminiscences. FKBN is Russian abbreviation for Physical Pile of Neutrons.

The machine was designed mainly for:

- criticality measurements to check and calibrate calculations, and to estimate and calibrate neutron constants;
- experimental investigations to estimate criticality safety of certain systems with highly enriched metal fissile materials;
- investigations of neutron and photon transport in different models which simulated the fragments of fission, fusion, and hybrid reactors, their shields and channels through shields (collimators).

In the interests of radiation material resistance investigation, Yu.A. Milovanov, L.B. Poretzky, V.N. Konnov brought the unit into operation in static regime with power 1÷5 kW, as well as in pulsed regime (1964) with energy release $7x10^{16}$ fissions and pulse duration 7÷200 mcs, this led to the building of EBR-type pulsed nuclear reactors. At present, a modification of the EBR-200 reactor is used to investigate nuclear pulsed lasers [1]. Later, having put into operation specialized nuclear reactors, FKBN unit was no longer used for irradiation.

In 1969-70 the unit was modernized when it was transported to a new building. Now it is installed in a hall having the dimensions 18x12x8 m^3. The walls are made of boric concrete.

SPHERICAL ASSEMBLIES

About 100 axially symmetrical critical assemblies (CA) with cores assembled of hemispherical layers of metallic ^{235}U(90%) and ^{239}Pu(88%), were researched experimentally until 1980. Above-mentioned critical assemblies with one- and multi-layer polyethylene, beryllium, beryllium oxide, borated polyethylene, aluminium, iron, copper, depleted uranium reflectors have rather simple geometry and are considered acceptable to use as benchmarks in criticality safety.

For example, let us consider a critical assembly containing a spherical core of highly enriched uranium and a reflector of 0.8 cm steel + 9.65 cm polyethylene.

The experiment is schematically shown in Figure 1. The assembly is a spherical unit divided into two parts separated with a gap. The upper (immovable) part is supported by a 0.2 cm thick steel diaphragm. The lower (movable) part is nested in a 0.15 cm thick copper cup supported by a steel cylinder.

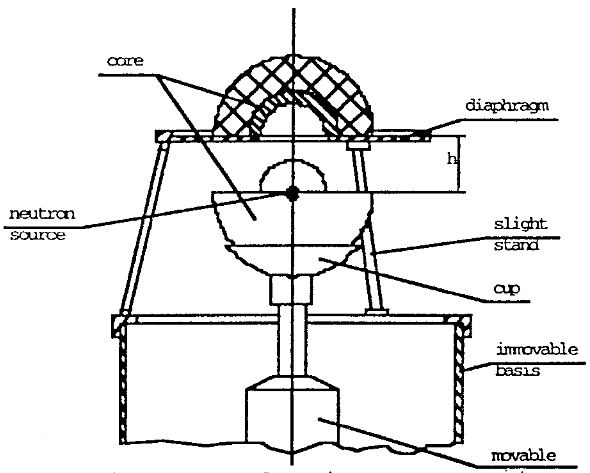

Fig.1. Geometry of experiments.

A central neutron source of ^{252}CF has the yield $2x10^6$ n/s and does not disturb the assembly criticality. The critical gap width (h_{cr}) was determinated by extrapolation of the function 1/M(h) to zero, through the points with M > 100.

The measurements of the gap width, h, were performed with 0.1 mm accuracy. The overall uncertainty in h_{cr}. depending also on accuracy of extrapolation of the value 1/M(h) to zero, was less than 0.2 mm. It yields 0.05% in K_{eff}.

The estimated influence of such reflectors as remote details of the construction, neutron detectors, the hall floor and walls increases the uncertainty in K_{eff} by a value less than 0.1%.

CYLINDRICAL ASSEMBLIES: ROMB

Further development of critical measurements began at VNIITF after research into the cylindrical geometry of measurements with the creation of the removable blanket (ROMB), an experimental model of which was built at VNIITF in 1981 in order to perform investigations for correction of neutron data in energy range up to 14 MeV. ROMB is a cylinder (practically with no clearances) of depleted uranium (0.5% of ^{235}U HxD=90x70 cm^2, 6.5 ton in weight, average density is 18.75 g/ cm^3). It consists of external zone rings with diameter 70/40 cm, intermediate zone rings with diameter 40/20 cm and central zone disks with diameter 20 cm. The cylinder has vertical and horizontal channels for introducing neutron sources (E_n=14 MeV) and detectors. There are additional sets of disks made of ^{235}U (diameter - 20 cm, thickness - 0.4 and 1.0 cm), Pu (12 cm in diameter, 0.45-cm thick) and various structural and moderating materials (CH_2, Be, BeO, Al, Ti, Fe, Mo, Ni, Pb, W) what produced numerous variants in assemblies with different neutron spectra from thermal up to fast.

In addition, there are polyethylene rings 70/40 cm and 40/20 cm in diameter as well as lead rings 40/20 cm in diameter.

Cylindrical heterogeneuos assemblies make it possible to realize a greater number of various combinations than critical assemblies with spherical layers. The calculational accuracy for cylindrical geometry is higher if compared with spherical, where the calculation of crescent-shaped clearances presents difficulties.

More than 250 critical assemblies have been studied, using the ROMB facility including one- and multi-component assemblies both without side reflector and within side reflectors of polyethylene, lead and depleted uranium [2].

For example, a schematic of critical experiments in cylindrical geometry is shown in Figure2.

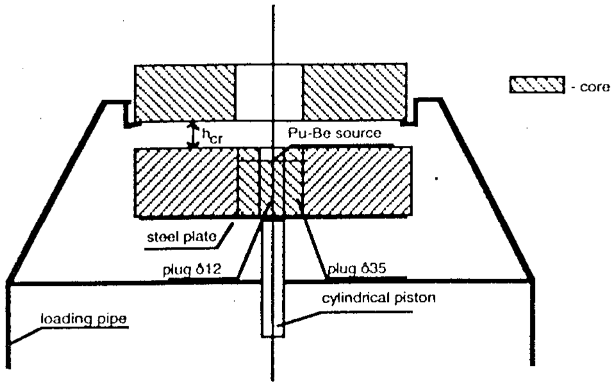

Fig. 2 Critical assembly scheme

OTHER MEASUREMENTS

A series of critical mass measurements investigating criticality of one-dimensional lattices modelling metallic fissile materials in protective containers [3] is considered to be important in practical aspect. The results obtained enable one to evaluate constant errors of such calculations of 2...3% as unfavourable in tterms of the calculated evaluation of criticality safety.

The most complicated and labour-consuming critical mass investigations performed in the end of 1994 are those of experimental modelling of neutron transport in uranium - hydrogen systems with the ratio $n_H/n_{238}\approx10$ on the basis of the following existing set of components:

- a massive side reflector is created of alternating layers of polyethylene and depleted uranium 70/40/20 cm in diameter with average by its volume ratio $n_H/n_{238}\approx2$ (Figure 3);
- internal part 20 cm in diameter consists of cells with alternating disks of highly enriched uranium, depleted uranium and polyethylene, and its upper part is installed on a diaphragm (Figure 3) and the lower part is on a mobile rod of the piston.

Tables 1...3 show lower (mobile) and upper (located on diaphragm) cylindrical parts 20 cm in diameter consisting of alternating disks of ^{235}U, ^{238}U, and CH_2, forming critical assemblies 1-3 while being located in a cavity of massive composite reflector (Figure 3). The order of the component numeration is sequential from the bottom to the top. The disk thicknesses, in cm, are pointed out in parentheses. The multipliers after the brackets show the number of similar translations. h_{cr} is the gap between the end of the system mobile part and the diaphragm.

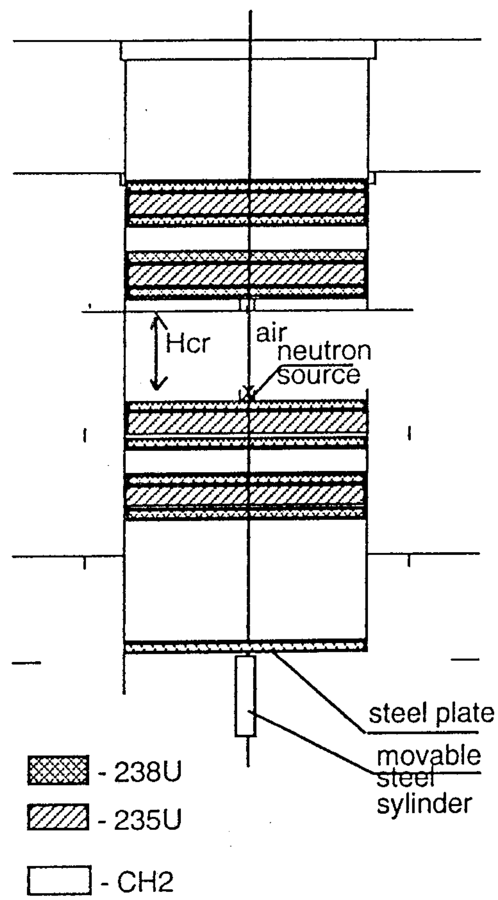

Figure 3. Geterogeneous Critical Assembly on ROMB-Facility

Table 1. Critical Assembly 1, h_{cr}=0.06 cm

Bottom	$^{238}U(5)+CH_2(1)+[CH_2(1)+ {}^{238}U(2)+{}^{235}U(1)+{}^{238}U(2)+ CH_2(1)]x4$
Top	$[CH_2(1)+{}^{238}U(2)+{}^{235}U(1)+ {}^{238}U(2)+CH_2(1)]x1+[CH_2(1)+ {}^{238}U(2)+{}^{235}U(2)+{}^{238}U(2)+ CH_2(1)]x2+[CH_2(1)+{}^{238}U(2)+ {}^{235}U(1)+{}^{238}U(2)+CH_2(1)]x1+ CH_2(1)+{}^{238}U(10)$

Table 2. Critical Assembly 2, h_{cr}=1.13 cm

Bottom	$^{238}U(10)+[CH_2(5)+{}^{238}U(1)+ {}^{235}U(1)+{}^{238}U(1)]x4+CH_2(2.5)$
Top	$CH_2(2.5)+{}^{238}U(1)+{}^{235}U(1)+ {}^{238}U(1)+CH_2(5)+{}^{238}U(1)+ {}^{235}U(2)+{}^{238}U(1)+CH_2(5)+ {}^{238}U(1)+{}^{235}U(1.2)+{}^{238}U(1)+ CH_2(5)+{}^{238}U(1)+{}^{235}U(1)+ {}^{238}U(1.5)+CH_2(5)+{}^{238}U(10)$

Table 3. Crutical Assembly 3, h_{cr}=0.24 cm

Bottom	$^{238}U(10)+[{}^{235}U(1)+{}^{238}U(3)]x4 + {}^{235}U(1)+ {}^{238}U(1.5)$
Top	$^{238}U(1.5)+[{}^{235}U(1)+{}^{238}U(3)]x 5+ {}^{235}U(1)+{}^{238}U(10)$

The critical assemblies presented are of benchmark class; detailed data on geometry and the content of the parts used are carefully documented.

Preliminary calculations (by Yuri Chernukhin) using currently used programs and nuclear data showed a significant underestimation of K_{eff} calculated values (up to 3%) in comparison with the experiment.

CONCLUSION

The further development of work using FKBN-M unit [4] is connected with the need to expand the existing set of cylindrical parts of highly-enriched fuel and structural materials with compatible sets of parts of low enriched uranium (5...20%) as well as energetic plutonium. This will improve the potential for this unit to perform benchmark critical experiments on various problems of the nuclear-fuel cycle of power engineering (including investigations of emergency situations on nuclear reactors, storage, transport and retreatment of reactor fuel, development of active target for electronuclear reactor etc.).

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