The Physics Experimental Study for In-hospital Neutron Irradiator

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Abstract: $MNSR_S$(Miniature Neutron Source Reactor) are low power research reactors designed and manufactured by China Institute of Atomic Energy (CIAE). $MNSR_S$ are mainly used for NAA, training and teaching, testing of nuclear instrumentation. The first MNSR, the prototype MNSR, was put into operation in 1984, later, eight other $MNSR_S$ had been built both at home and abroad. For $MNSR_S$, highly enriched uranium(90%) is used as the fuel material.

The In-hospital neutron irradiator(IHNI) is designed for Boron Neutron Capture Therapy(BNCT) based on Miniature Neutron Source Reactor(MNSR).

On the both sides of the reactor core, there are two neutron beams, one is thermal neutron beam , and the other opposite to the thermal beam, is epithermal neutron beam. A small thermal neutron beam is specially designed for the measurement of blood boron concentration by the prompt gamma neutron activation analysis(PGNAA).

In this paper, the experimental results of critical mass，worth of the top Be reflectors，worth of the control rod, neutron flux distribution and other components worth were measured, the experiment was done on the Zero Power Experiment equipment of MNSR.

1 Description of equipment

The reactor with thermal power 30Kw is an undermoderated reactor of pool-tank type, and UO_2 with enrichment of 12.5% as fuel, light water as coolant and moderator, and metallic beryllium as reflector. The fission heat produced by the reactor is removed by the natural convection. Fig. 1 shows the figure of the experimental equipment.

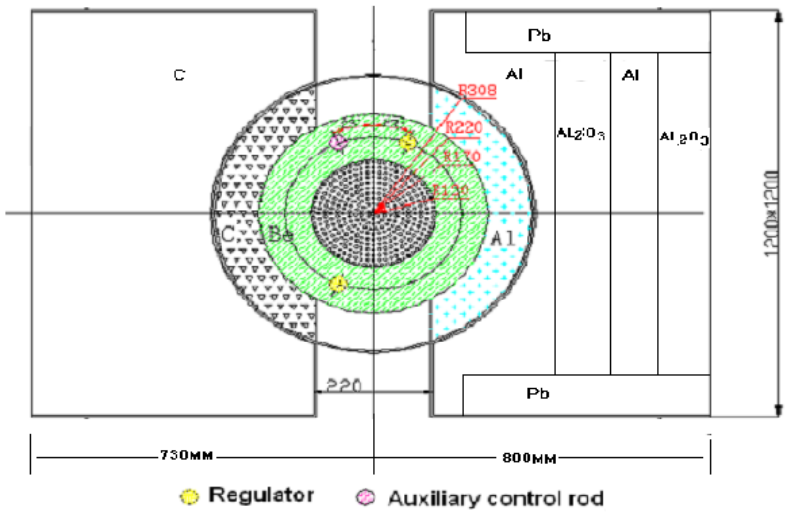
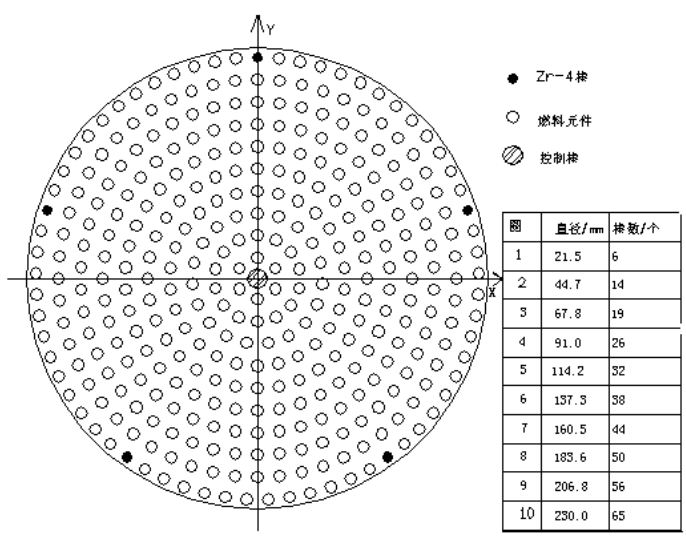


Fig.1 The diagram of the experimental equipment

One central control rod is in the center of reactor core, one auxiliary control rod and two reactivity regulators are in the side beryllium reflector.

1.1 Reactor

The upper and lower grid plates are linked by five tie rods, ten rows of 351 lattices are concentrically arranged, the central lattice is reserved for central control rod. While the five tie rods are uniformly arranged at the tenth row. The rest lattices are for fuel element and dummy elements(see fig.2).



圈	直径/mm	棒数/个
1	21.5	6
2	44.7	14
3	67.8	19
4	91.0	26
5	114.2	32
6	137.3	38
7	160.5	44
8	183.6	50
9	206.8	56
10	230.0	65

Fig.2 The fuel arrangement

The UO_2 is used as the fuel meat with density 10.6g/cm^3, ^{235}U enrichment is 12.5%, the dimension is 4.2mm×240mm. The cladding material is Zr-4 alloy with wall thickness 0.4mm and 256mm in length（8mm end plug at up end,7mm end plug at lower end, 1mm Helium gas between the up end and fuel meat ）

The central control rod : 1）Guide tube：inner dia. 9mm，outer dia. 12mm，length：258mm；2）Meat：Cd tube outer dia. 4.0mm，inner dia. 2.0mm, length 280mm；inside Cd tube：Al rod Φ2.0×280（mm）; 3) Outside Cd tube S.S tube outer dia. 5mm，wall thickness：0.5mm , total length：450mm。

The fuel Cage：1）Dia：240mm，heiqht：240mm; 2）Top core plate：Zr-4 alloy thickness：2mm, lower core plate：Zr-4 alloy thickness：4mm.

1.2 Side Be reflector

The dimension：inner dia. 240mm，outer dia. 440mm, height：246mm

1.3 Bottom Be reflector

The dimension：dia. 350mm，thickness：100mm，central hole of 20mm in diameter.

1.4 Top Be reflector

The Al alloy tray for Top Be reflector：inner dia.：266mm, outer dia.：270mm， height：140mm，bottom thickness：2mm.

The dimension of top Be reflectors：dia.: 264mm, hole dia.: 20mm，total thickness：111mm（1.5，3.0，6.0 and 12.0mm）.

1.5 Auxiliary control rod

The auxiliary control rod is arranged at the radius of 170mm in the side Be, it consists of three parts, the up part: Cd tube outer dia.25.0mm，inner dia.23.0mm; Inside Cd tube: Al rod Φ23.0×250（mm）; the middle part: Al rod dia. 25mm; the lower part: Be rod dia. 25. The outside tube : Al tube outer Φ28.0×534mm.

1.6 Reactivity regulator

The two reactivity regulators are arranged inside Beryllium. The dimension of regulator：Cd tube outer dia.30.0mm，inner dia.28.0mm, height 250mm; Inside Cd tube: Al rod Φ28.0×250（mm）; Outside Cd tube: Al tube Φ33.0×260（mm）.

1.7 Neutron beam equipment

For thermal neutron beam equipment, the graphite is adopted as moderator, and aluminum, Lead and Al_2O_3 are adopted in epithermal neutron beam equipment.

2 Zero power experimental results

The experiment was done in the MNSR zero power equipment, some parameters were measured.

2.1 Critical mass

Two ways of extrapolation and insertion were used for the measurement of critical mass. The results are 296.8 fuel elements, the fuel elements in the outermost circle are not uniformly arranged.

3.2 Worth of the central control rod

The worth was measured by the period method. Insert a part of the rod in the reactor, measured the worth by the same method again. Do it Alternately, the total worth of the rod was measured finally(see Fig.3). The total worths of the central control rod of calculation and experiment are 6.0mk and 6.4mk respectively.

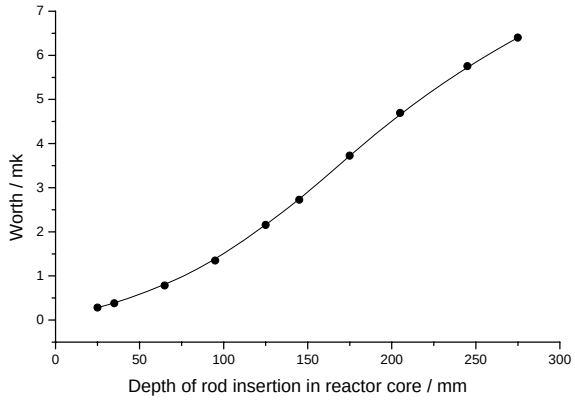


Fig.3 Central control rod worth

2.3 Worth of the top Beryllium reflectors

By the period method, the worth was also measured. Add the piece of top Be, measured the worth; and then, take out the fuel element from the reactor core, add the top Be, measured the worth again; Do it Alternately, the total worth of the rod was measured finally(see Fig.4). The total worths of the top Be reflectors calculation and experiment are 17.6mk and 16.11mk respectively**.**

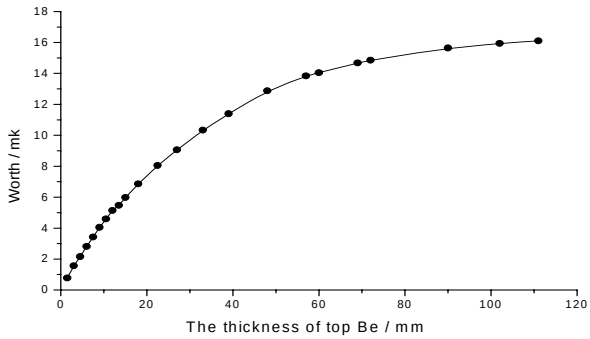


Fig.4 Top Be worth

2.4 Relative neutron flux distribution

Using the Mn activation method, the neutron flux distribution in the reactor core was measured.

The Mn foils were put in the height of 120mm from the up surface of the lower plate at the different position in the radial direction, the Mn foils were put between the 4th circle and 5th circle at different position for the measurement of axis neutron flux. the activity was measured by γ spectrum equipment. See fig.5.

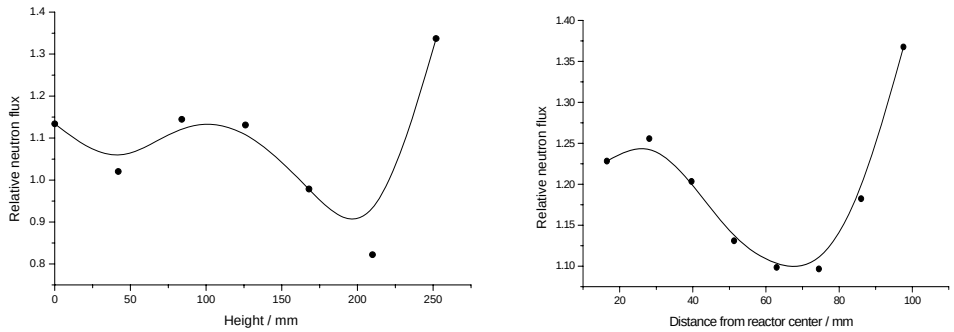


Fig.5 Neutron flux distribution in the reactor core

2.5 Worth of auxiliary control rod(ACR), reactivity regulator(RR) and neutron beam equipment(NBE), see Table 1.

Table 1 The Worth of auxiliary control rod, reactivity regulator and neutron beam equipment

ACR/mk		RR /mk		NBE/mk	
Experiment	Calculation	Experiment	Calculation	Experiment	Calculation
-3.78	-5.8	-8.07	-6.4	-0.17(-6.7)*	-0.45(-7.8)*

*: epithermal neutron beam equipment

3 Conclusion

At the initial loading, there are the lower part of auxiliary control rod, one reactivity regulator in the reactor, and the excess reactivity of the reactor is 4.5mk. Consideration of the worth of the ACR, one RR and 4.5mk of excess reactivity, the final loading at the initial state of reactor is 302 fuel elements, the rest lattices will be filled by fuel elements of ^{238}U.