INCREASING THE NEUTRON FLUX DENSITY OF EPITHERMAL BEAM BY OPTIMIZE SIDE BERYLLIUM REFLECTOR

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Abstract:

MNSR for BNCT has been built and operated since 2009. But the neutron flux density of epi-thermal neutron beam is not high enough, by measured and calculated. A method of increasing the neutron flux density of epi-thermal beam in MNSR is studied by optimize the side beryllium reflector in the direction of epi-thermal beam.Remove part of the side beryllium reflector and refill same size aluminum back. Different thickness of aluminum plans were calculated by MCNP code for optimality.

The fuel cage of MNSR with size of φ240×256mm in the reactor core, there are ten rows concentrically arranged 356 lattices ,the central lattice is for central control rod, and five tie rods link the upper and lower grid plates are uniformly arranged at the tenth row , the rest 350 fuel lattices are for fuel pins or dummies . The diameter of the fuel meat is 4.2mm, the height is 240mm, with Uranium enrichment is 12.43%; the diameter of the fuel element is 5.1mm, the height is 256mm.The frame design of the epi-thermal neutron beam is: Al_2O_3 and Al material used as neutron moderation layer with its thickness is 68cm ; Cd with thickness of 0.1cm used as thermal neutron absorption layer, Bismuth with thickness of 10cm used as gamma ray shielding layer. And the neutron collimator parts is a composition of graphite, Cd and polythene with boron.The total length of the beam is 149cm, and the distance from the exit of the beam to the core is 160cm. The results show that optimize the side beryllium will increase the epi-thermal neutron flux density at the exit from $3.5\times10^8 n\cdot cm^{-2}\cdot s^{-1}$ to $5.9\times10^8 n\cdot cm^{-2}\cdot s^{-1}$ at full power of 30kW. The fast neutron contamination and gamma dose contamination has no marked change.

This method could supply data for future reference.

Key words: MNSR; increase neutron flux density; optimization of side beryllium;

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1. Introduction

MNSR for BNCT built in 2009 is arranged with thermal and epithermal neutron beam devices horizontally and symmetrically, and mainly used for boron neutron capture therapy (BNCT) of cancer. Its epithermal neutron beam flux density is $3.5\times10^{8}n\cdot cm^{-2}\cdot s^{-1}$, it shall take about 8 h to reach $1\times10^{13}n\cdot cm^{-2}$ required for treatment, but it can only operate for 2.5 h each time at full power, so it is significant to increase its epithermal beam neutron flux. Epithermal neutron beam flux density is increased by optimizing side beryllium structure in this paper. This method may provide reference for horizontal neutron beam design based on MNSR.

2. Calculation thought and method

Remove part of side beryllium in the direction of epithermal beam, reduce neutron reflection in this direction, increase leaked neutrons, and increase neutron flux density of epithermal neutron beam.

2.1 Calculation procedure and input parameter

This paper adopts MCNP procedure for neutron flux calculation and reactor excess reactivity. MCNP procedure is a large multifunctional Monte Carlo neutron - photon transport procedure developed by Los Alamos Laboratory in America, which is used to calculate neutron transport and eigenvalue problem, etc., and is highly universal. Initial geometrical model and materials for simulation calculation are all based on real MNSR for BNCT structure and materials, materials and layout of it are shown in the following figure:

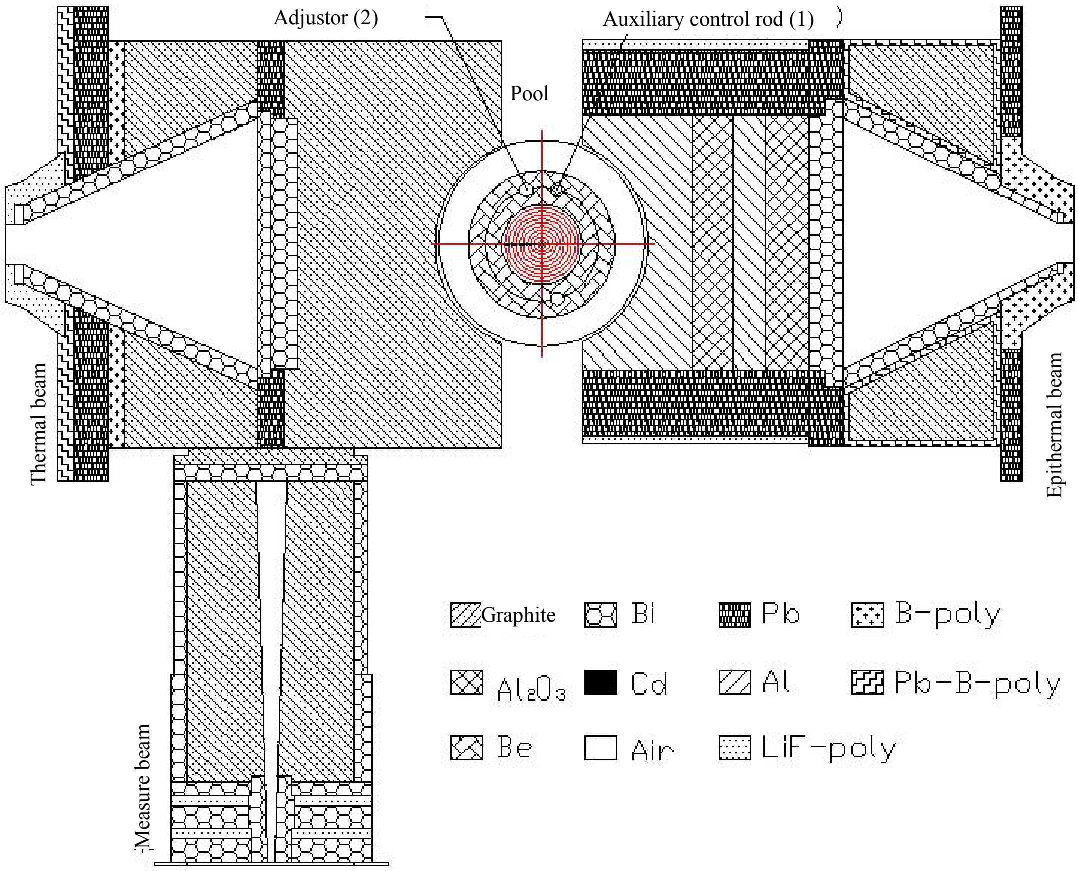

Fig.1 The Material and Arrangement of MNSR for BNCT

Reactor core fuel is UO_2 rod with ^{235}U enrichment of 12.43% and Zr-4 cladding, including 302 fuel elements, 38 deplated uranium elements, 5 aluminum dummy rod, and 5 Zr-4 tie rods. After adjustment by reactivity adjuster, excess reactivity is 4.2 mk, efficiency of central control rod is 6.4 mk. When the central control rod is at the position of 165mm, the reactor is at critical state. In the actual calculation, make the control rod at the position of 165mm, calculate the epithermal neutron flux density of epithermal neutron beam when approaching the critical state. and improve the side beryllium in the direction of epithermal neutron beam by removing part. In order to offset the reactivity reduction caused by removing part on side beryllium, replace all the deplated uranium elements and water displacer rod to be fuel elements, make the control rod remain at the same position. If calculation result shows that the reactor fails to reach critical state, the improvement mode will reduce its excess reactivity, therefore, only the scheme in which the critical state can be reached is considered.

2.2 Remove parts of side beryllium and refill mode

Thermal and epithermal neutron beams share one axle wire which is across the center of reactor core. With the reactor core center as the origin, the specified axle wire is x-axis, and the direction to epithermal beam is positive, horizontal direction vertical to x-axis is y-axis, vertical direction is z-axis.

Two modes for removing part of side beryllium:

Cylindrical: with x-axis as the axis, open cylindrical notches with radius of 1-12cm on side beryllium.

Conoid: with the origin as the vertex, x-axis as the axis, draw a cone with the vertex angle of 5-60° in the positive direction of x-axis, the opening part is taken from the intersection between the cone and side beryllium, as shown in the following figure:

In order to ensure unchanged thermal engineering flow channel, refill the opening part on side beryllium with the same shape of aluminum block or aluminum shell.

Three refill modes: aluminum: refill the notch on side beryllium with the aluminum block with the same shape and size as the beryllium cut off; He: refill the notch on side beryllium with the aluminum shell with the same shape and size as the beryllium cut off, the shell is 1mm thick, and refilled with He in the center; water: refill the notch on side beryllium with the aluminum shell with the same shape and size as the beryllium cut off, the shell is 1mm thick, and refilled with water in the center.

2.3 Calculation result and discussion

Calculate the epithermal neutron flux at the outlet of epithermal neutron beam by MCNP procedure when not removing part of side beryllium, at full load, and when the removing part is conoid, refill mode is aluminum shell filled with water, opening angle is 5-60°. When not removing part, reactor keff is 1.03672, neutron fluxes of thermal and epithermal bundles are $1.617\times10^{9}n\cdot cm^{-2}\cdot s^{-1}$ and $3.5\times10^{8}n\cdot cm^{-2}\cdot s^{-1}$. Calculation result for removing part of side beryllium is shown in the following table:

Table 1 The Neutron Flux Changes with Different Angles

Refill material	Opening angle	keff	Φ_{th} of thermal beam	Φ_{ep} of Epithermal beam
Aluminum shell filled with water	5	1.03633	1.573E+09	3.700E+08
	10	1.03338	1.660E+09	3.821E+08
	15	1.02802	1.663E+09	3.671E+08
	20	1.02310	1.722E+09	3.881E+08
	25	1.01484	1.814E+09	4.203E+08
	30	1.00791	1.740E+09	4.898E+08
	35	1.00096	1.853E+09	5.797E+08
	40	0.99403	1.755E+09	5.819E+08
	45	0.98719	1.865E+09	6.173E+08
	50	0.98104	1.903E+09	6.742E+08
	55	0.97529	1.817E+09	6.371E+08
	60	0.96841	1.957E+09	6.654E+08

We can see from the above table that removing part of side beryllium in the direction of epithermal beam has relatively small effect (basically positive) on thermal neutron beam:

$$\frac{(\phi_{th\max}-\phi_{th\min})}{\overline{\phi}_{th}}\times100\%=22\%\,.$$

Therefore, this method's effect on thermal beam is not considered in this paper.

The epithermal neutron changes with different angles are shown in the following figure:

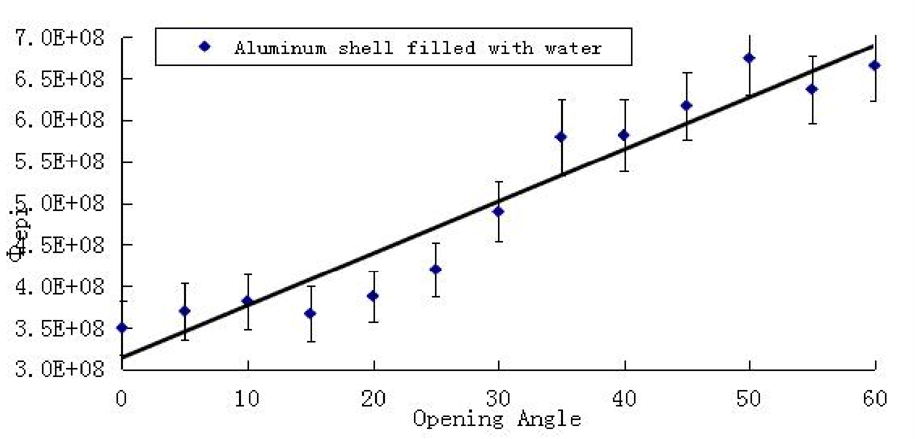

Fig.2 The Epithermal Neutron Changes with Different Angles

We can see from the above figure and table that the epithermal neutron flux increases with the increase of opening angle on side beryllium, however, when the opening angel reaches 40°, critical state will not be reached even at full load. Therefore, at critical condition, the epithermal neutron flux may reach $5.797\times10^{8}n\cdot cm^{-2}\cdot s^{-1}$ when the opening vertex angle is 35°, and may be increased by 87% compared with the original design.

Calculate the action of the other modes (the removing part is cylindrical or conoid; refill mode is aluminum block, aluminum shell filled with He, aluminum shell filled with water) on increasing the epithermal neutron flux density in the same mode. The result is shown in the following table:

Table.2 The Epithermal Neutron Flux Increases Depend on the Material Refilled

Optimize mode	Refill material	Maximum opening angle/size	Reactivity	$\Phi_{epi\text{-}Max}$	Increase ratio
Conoid	Aluminum block	35°	1.00092	5.896E+08	90%
	Aluminum shell filled with He	35°	1.00085	5.648E+08	82%
	Aluminum shell filled with water	35°	1.00096	5.797E+08	87%
Cylindrical	Aluminum block	11cm	1.00496	4.635E+08	50%
	Aluminum shell filled with He	9cm	1.00448	4.535E+08	47%

3. Conclusion

Removing part of side beryllium in the direction of epithermal neutron beam may increase the epithermal neutron flux density, especially that in conoid shape, which is up to 90%, but this method can't increase the epithermal neutron flux density to a larger degree. If it is necessary to increase the epithermal neutron flux density to a larger degree, other parameters of the reactor, e.g. fuel uranium enrichment, arrangement of fuel elements in the reactor core, shall be changed, or materials and arrangement of neutron beam itself shall be improved, which is the future research direction.