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A STUDY OF THE CONCEPT OF A FISSION-PLATE CONVERTER AS A SOURCE FOR AN EPITHERMAL NEUTRON BEAM

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1. ABSTRACT

It has been suggested that a Fission-Plate Converter (FPC) at a reactor can enhance the intensity of an epithermal neutron beam produced by the reactor. By computer modeling, this concept has been applied to two sets of reactors to study how effective a FPC might be. The first set of reactors contains high-powered research reactors and is represented by the Missouri University Research Reactor and the Georgia Institute of Technology Research Reactor. The second set combines the FPC into the core of a low-powered reactor, yielding a thin, large area, reactor that we call a slab reactor. For these reactors, epithermal fluxes above 1×10^9 n/cm².sec are predicted while the fast-neutron doses per epithermal neutron are $< 3 \times 10^{-11}$ cGy.cm²/n.

2. INTRODUCTION

It has been suggested that a Fission-Plate Converter (FPC) placed near the core of a reactor might enhance the intensity of a beam of epithermal neutrons that could be produced by the reactor¹. The FPC would allow the source of fission neutrons that are converted into epithermal neutrons to be moved closer to the patient irradiation position, thus increasing the epithermal flux. In addition, since the fission neutrons all start from the FPC, instead of the volume of the core, a lower dose from fast neutrons per epithermal neutron is predicted. With the MCNP code, different types and sizes of reactors were modeled to test this concept. Two different sets of reactors were tried. The first set includes high-powered research reactors with FPCs. The second set comprises a low-powered reactor in which the core has been rearranged to be thin, but with a large area, to resemble a FPC. This we call a slab reactor.

3. HIGH-POWERED REACTORS

In this study the Missouri University Research Reactor (MURR) and the Georgia Institute of Technology Research Reactor (GTRR) have been selected to represent high-powered research reactors. The Brookhaven Medical Research Reactor (BMRR) has been evaluated in another study².

3.1 MURR³

The MURR is a research reactor at the University of Missouri campus in Columbia, Missouri, USA. This reactor operates at 10 MW, 90% of the time to supply neutrons and other radiation for faculty and other users. It is typical of a high-powered, highly-enriched-fueled, H₂O-cooled-and-moderated research reactor. Figure 1 shows a horizontal section of the reactor. Starting at the center of the reactor with the flux trap, the trap is surrounded by the annulus of fuel and the fuel is encased in the pressure vessel. Just outside the pressure vessel is a H₂O filled space for the control blades followed by the Be reflector and the graphite reflector wedges. Still inside

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the tank, in the direction of the thermal column, is a Pb shield to stop gamma rays from the core. This is followed by the tank, or pool, wall. In the present study, the components inside the tank were not modified.

Outside the tank wall is the graphite of the present thermal column. These graphite blocks have been removed and rearranged in the past and they can be changed again to accommodate a new beam. Since the inner cavity of the thermal column is only 0.87 m wide and the outer cavity only 1.10 m wide, these are not large enough for a satisfactory treatment room. Therefore, the beam is extended 3.10 m from the core center to the irradiation point, X, which will be just outside the reactor biological shield.

A FPC was placed next to graphite blocks between the inner and outer cavities. The FPC (80 cm x 80 cm x 2 cm) is assumed to consist of 25 wt% of U enriched to 20% ^{235}U and 75 wt% of Al. The mass of ^{235}U in the FPC would be 4.4 kg. Downstream from the FPC comes 48 cm-thick Al and 24 cm-thick Al_2O_3 as the primary moderator. A 0.05 cm-thick sheet of Cd is used for filtering out thermal neutrons and then 12 cm of Pb shields for gamma rays. The beam path is a conical air space with a circular area tapering to 24 cm in diameter at the irradiation port.

3.2 GTRR⁴

The GTRR is a research reactor at the Georgia Institute of Technology campus in Atlanta, Georgia, USA. It is licensed to operate at 5 MW. It is typical of a high-powered, highly-enriched-fueled, D_2O -cooled-and-moderated research reactor. A horizontal section of the GTRR is shown in figure 2. The core of the reactor is a matrix of 19 fuel elements (inside the inner circle of figure 2) in a 1.81 m-diameter tank of D_2O . This D_2O serves to cool the fuel and to moderate the neutrons in the core to maintain criticality, and also to moderate the neutrons escaping from the core which feed the beam tubes, the thermal column, and the medical irradiation port. The medical irradiation facility (to the right in figure 2) was built at this reactor back in the days when it was thought that thermal neutrons would be used for NCT. The flux of thermal neutrons at the tank wall is high, 1.7×10^{13} n/cm².sec. In the direction of the medical irradiation facility, there is a Bi shield just outside the tank. At the edge of the reactor biological shield is a shielded treatment room.

For the GTRR, a curved FPC (about 80 cm x 80 cm x 1 cm, 2.4 kg of ^{235}U) fit to the shape of the tank wall was used for the study. The Bi shield outside the tank was not changed. After the Bi shield is a moderator section of 48 cm-thick Al and 24 cm-thick Al_2O_3 . A 0.05 cm-thick Cd sheet is used for filtering out thermal neutrons and then 12 cm-thick Pb for shielding the gamma rays. The beam path is a conical air space with a circular area tapering to 24 cm in diameter at the irradiation port.

4. SLAB REACTOR^{5,6}

As an example for this set, Figure 3 shows the mid-plane horizontal section of an epithermal neutron beam facility based on a 300 kW slab reactor using TRIGA fuel⁷. The core volume is 20 cm x 80 cm x 80 cm, with 100 locations to place 86 fuel elements (filled circles), four control rods (open triangles), and 10 fuel-element locations left vacant (open circles). The core

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contains 3.4 kg of ^{235}U and is H_2O cooled. The slab core is surrounded by a reflector at least 40 cm-thick. To the right, in the direction of the epithermal neutron beam, aluminum serves as part of the reflector and also as part of an epithermal neutron filter.

Next to the Al reflector-filter is a neutron beam shutter. This shutter can move up and down to control beam delivery. Forty cm of Al_2O_3 is placed in the beam shutter for the second stage of moderation to slow neutrons leaking through the Al filter. After the Al_2O_3 block, there is a 15 cm-thick Pb shield for absorbing gamma rays from the core and also those induced by captured neutrons in the materials in the beam. A 0.05 cm-thick Cd sheet is attached to the face of the Pb shield on the irradiation-port side to eliminate thermal neutrons in the beam. The remaining spaces in the shutter are filled with high-density concrete. The patient irradiation port is designed to have an area of 20 cm in diameter with a beam path 26 cm long. The irradiation point is labelled X and is 132 cm away from the center of the core. Lead of 15 cm thickness is used as the final shield around the irradiation port to absorb core- and induced-gamma rays in the beam. Finally, a 5.1 cm-thick Li-poly block is placed next to the Pb shield to further reduce the number of stray neutrons outside the irradiation port.

5. RESULTS and DISCUSSIONS

Table 1 lists the beam parameters calculated for the reactors considered in the two sets plus a set of parameters for the BMRR. For the BMRR and GTRR, one notes that epithermal fluxes above $1 \times 10^{10} \text{ n/cm}^2\cdot\text{sec}$ are predicted. This would allow a full-dose treatment of NCT to be completed in a few minutes. The MURR, even though it is higher powered than the other two does not deliver as much flux. This is because, in the design chosen, no changes were made inside the tank which reduced the thermal neutron flux that would reach the FPC. Also, in H_2O -cooled-and-moderated reactors, the thermal neutron flux drops rapidly as the distance from the core increases. For the GTRR, the very high beam flux is realized because of the large flux of thermal neutrons reaching the tank wall where the FPC is located. For the GTRR the heat in the FPC is about 600 kW which is large. Since the FPC is in the tank and cooled by D_2O , this high heat rate may be acceptable. The fast-neutron dose per epithermal neutron predicted for the GTRR is the lowest of these reactors.

The slab reactor concept combines the reactor core and the FPC into a single volume. The thickness of the reactor should be kept as thin as possible since fission neutrons coming from deeper inside the fissioning volume add more to the fast-neutron dose rate than to the epithermal neutron flux. However, some compromise on thickness must be struck to reach criticality at a reasonable ^{235}U loading. The design selected for this study is such a compromise. At 300 kW core power, fluxes of epithermal neutrons above $1 \times 10^9 \text{ n/cm}^2\cdot\text{sec}$ and a fast-neutron dose per epithermal neutron below $3 \times 10^{-11} \text{ cGy}\cdot\text{cm}^2/\text{n}$ are predicted which would be satisfactory for NCT.

This study indicates that the proposed use of FPCs in different types of reactors has promise. If tests of the concept confirm the predictions, a greater number of the presently operating reactors may be made available to provide epithermal neutrons for NCT.

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FIGURE CAPTIONS

Figure 1. A horizontal section at the mid plane of the Missouri University Research Reactor. The epithermal neutron beam exits at the right and the irradiation point is X.

Figure 2. A horizontal section at the mid plane of the Georgia Institute of Technology Research Reactor. The epithermal neutron beam exits at the right and the irradiation point is X.

Figure 3. A horizontal section of a design for a slab reactor. The epithermal neutron beam exits at the right and the irradiation position is X.

Table 1. Comparisons of beam parameters in air for designs based on different reactors.

	BMRR ²	MURR	GTRR	Slab ^{5,6}
Reactor power (MW)	3	10	5	0.3
Distance (core-to-FPC) (cm)	90	95	90	---
Distance (FPC-to-X) (cm)	105	215	170	---
Thermal flux at FPC location w/o FPC (10^{13} n/cm ² .sec)	0.08	0.07	1.7	---
²³⁵ U in FPC (kg)	8.0	4.4	2.4	---
Fission heat in FPC (kW)	72	32	600	---
Epithermal flux (X) (10^{10} n/cm ² .sec)	1.2	0.25	3.4	0.18
Fast dose per epi-neutron (X) (10^{-11} cGy.cm ² /n)	2.8	1.8	1.0	2.6
Neutron current-to-flux ratio (J/ Φ)	0.78	0.85	0.82	0.80

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Figure 1

W: 38 H: 20

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Figure 2

W: 35 1/2 H: 20

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Figure 3

W: 241/2 H: 23