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ENHANCEMENT OF THE EPITHERMAL NEUTRON BEAM AT THE BROOKHAVEN MEDICAL RESEARCH REACTOR

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INTRODUCTION

The Brookhaven Medical Research Reactor (BMRR)[1] became operational in 1959 to support Boron Neutron Capture Therapy (BNCT) research in the Medical Department of the Brookhaven National Laboratory (BNL). The research was interrupted in 1961 after the failure of initial BNCT trials to show efficacy.

In 1988, a moderator to produce an epithermal neutron beam was designed and installed in one of the shutters at the BMRR. The horizontal section of the BMRR extending from the core out to the epithermal port is depicted in Figure 1, including the reactor core, graphite reflector, inner bismuth shield, moderator tanks in C, A and B, beam shutter, outer bismuth shield, and Li_2CO_3 in polyethylene (Li-poly) shield at the irradiation port. The moderator region C consists of two empty spaces. The Al and Al_2O_3 which was identified by Brugger and Less[2] as a good moderator to produce an epithermal beam were selected by Fairchild and Wheeler[3] as the primary moderator. Plates of Al and Al_2O_3 were filled in the A and B regions of the existing shutter to

Figure 1. The Present BMRR Epithermal Beam.

Table 1. Comparisons of MCNP Calculations and Dosimetric Measurements After One Fuel Element in Place of the Graphite Stringer in June 1992.

	Comments	Difference
MCNP	1. Epithermal flux	+ 18%
	2. Beam neutron and gamma doses proportionally increased	
	3. No perceptible change in neutron spectrum	
Measure	1. Epithermal flux in air	+ 16%
	2. Thermal flux at different depths in the lucite phantom	+ 18%
	3. Neutron dose rate in air	+ 17%
	4. Gamma dose rate in air	+ 14%

produce the present epithermal neutron beam. A 38-mm-thick Li-poly shield was added in 1991 around the bismuth port to reduce the neutron flux coming from outside the port.

An irradiation point for future reference is labelled as the "X" point in Figure 1. There are now 30 partially spent fuel elements in the core. The reactor may be operated at 3 MW power. Since the moderator was assembled in 1988, dosimetric measurements and calculations in air and in phantoms have been made[4,5] at the epithermal port. The BMRR beam is the best available now to proceed with BNCT. The purpose of this study is to show how this beam can be further improved based on MCNP calculations which are confirmed by dosimetric measurements.

POSSIBLE CHANGES

To improve an epithermal beam, the major target is to increase the epithermal flux and to reduce the fast neutron dose in the beam. Possible changes of the BMRR beam are in the areas including the core, moderator assembly, and irradiation port. The graphite reflector and inner bismuth would be very difficult to modify at this time. MCNP calculations of the BMRR beam were made to predict improvements of the neutron beam at the epithermal port. After each change was made, the calculated results at the "X" point were normalized by the calculated values of the present design. Finally, optimized changes in each area were combined to predict an improved epithermal beam.

Reactor Core One way to increase the epithermal flux at the irradiation port is to shift the fuel elements in the core toward the port while still retaining a critical but controlled condition. In the present core, there are two spaces facing the epithermal port which are not fueled. One is a graphite stringer and the other is a tube for sample irradiation. In June 1992, the BMRR was operated with one fuel element replacing the graphite stringer. While the element was in position, flux and dose measurements at the epithermal port were made to compare to the previous measured values and MCNP calculations. The results are listed in Table 1. The MCNP calculation predicts increased fluxes and doses by 18% for such a change. Different dosimetric measurements in a lucite phantom and in air verified the calculated results. The thermal flux measured by bare and Cd-covered gold foil activation at different depths in the lucite phantom went up 18% on average while the neutron and gamma dose rates measured by paired ionization chambers went up no more than 18%.

These results indicate that most of the epithermal neutrons reaching the irradiation port come from fission neutrons produced in the front rows of fuel elements on the epithermal side of the core. By changing the core configuration while maintaining criticality and control, the beam intensity at the epithermal port can be effectively increased without reducing the beam quality. An alternative is to place new fuel elements in the first or even second rows facing the epithermal port to shift the power distributions in the core toward the epithermal port. Thus, the beam intensity at the epithermal port will be significantly increased. This part of proposed change is now being made at the BMRR. The increase of epithermal flux is predicted to be 40%.

Table 2. Comparisons of Beam Parameters at the Irradiation Point "X".

	Power MW	Φ_{epi} x 10^9 n/cm²/s	D_n/n_{epi} x 10^{-11}cGy /(n/cm²)	D_γ/n_{epi} x10^{-11}cGy /(n/cm²)	J/Φ
BMRR*† May 1992	3	1.2	4.8	1.4	0.67
Stage 1A*† June 1992	3	1.4	4.8	1.4	0.67
Stage 1B* Oct. 1992	3	1.7	4.8	1.4	0.67
Stage 2* FY 1993	3	2.2	3.4	1.7	0.72

* Calculated by MCNP   † Measured

Moderator Tank C, A & B The two empty spaces in moderator tank C can be filled with aluminum pellets to move the moderator assembly toward the core. The packing density of aluminum pellets was assumed to be 60% in the MCNP calculation. Then, space left in the beam shutter can be designed to accommodate the outer bismuth (or lead plus ^{6}Li) shield and this will allow an air indentation at the irradiation port so that the beam is directed more toward the "X" point. MCNP calculations also indicate that the beam can be enhanced by optimizing the moderator configuration and thicknesses of Al and Al_2O_3 to increase the epithermal flux and reduce the fast neutron dose.

Bismuth Shields The outer bismuth blocks shield the patient from the neutron induced gamma rays from Al and construction material. An alternative is to use lead plus 0.05% atomic number density of ^{6}Li to replace bismuth. The ^{6}Li captures the thermal neutrons while the lead appears to be more effective to moderate fast neutrons than is bismuth.

Combined Changes With a combination of feasible changes, the calculated results of new design are compared to the calculated values of the present design and listed in Table 2. The

Figure 2. The New Design.

final design is seen in Figure 2. At stage 2, the major changes include: (1) Four new fuel elements are placed in the first row facing the epithermal port; (2) The C tank is filled with aluminum pellets; (3) A piece of 14.6-cm-thick Al followed by a piece of 41.2-cm-thick Al_2O_3 is filled in the A and B tanks; (4) Bismuth shield at the irradiation port is replaced by 13.4 cm of lead plus 0.05% atomic number density of ^6Li; (5) A 15.8 cm air indentation is created at the irradiation port from the face of lead shield to the "X" point.

The final result shows, with a relatively insignificant increase of the gamma dose per epithermal neutron, the neutron dose per epithermal neutron can be reduced by 30% and the epithermal flux can be increased by 80%. With the new design, the epithermal flux at the "X" point is 2.2×10^9 n/cm²/sec at 3 MW power and the neutron dose per epithermal neutron is 3.4×10^{-11} cGy/(n/cm²). The neutron current to flux ratio can also be increased by 7% from 0.67 to 0.72 to gain more penetration into the head.

CONCLUSIONS

Improvements for the BMRR epithermal neutron beam have been evaluated by MCNP calculations and measurements. Different dosimetric measurements have been made after one fuel element was in place of the graphite stringer in the core. Measurements show an 18% increase of beam intensity without reducing the beam quality. These results are consistent with the predictions of an MCNP calculation.

Major changes to enhance the beam include rearranging the fuel elements in the core, placing aluminum pellets in the moderator tank C, redesigning the moderator assembly, replacing the outer bismuth by lead plus 0.05% atomic number density of ^6Li, and modifying the irradiation port to accommodate an air indentation. The MCNP calculated values for the present and new designs were compared to demonstrate the improvements. The results show that the epithermal flux can be increased by 80% at the irradiation port. The neutron dose per epithermal neutron can be reduced by 30%. The beam directionality can be improved by 7%.

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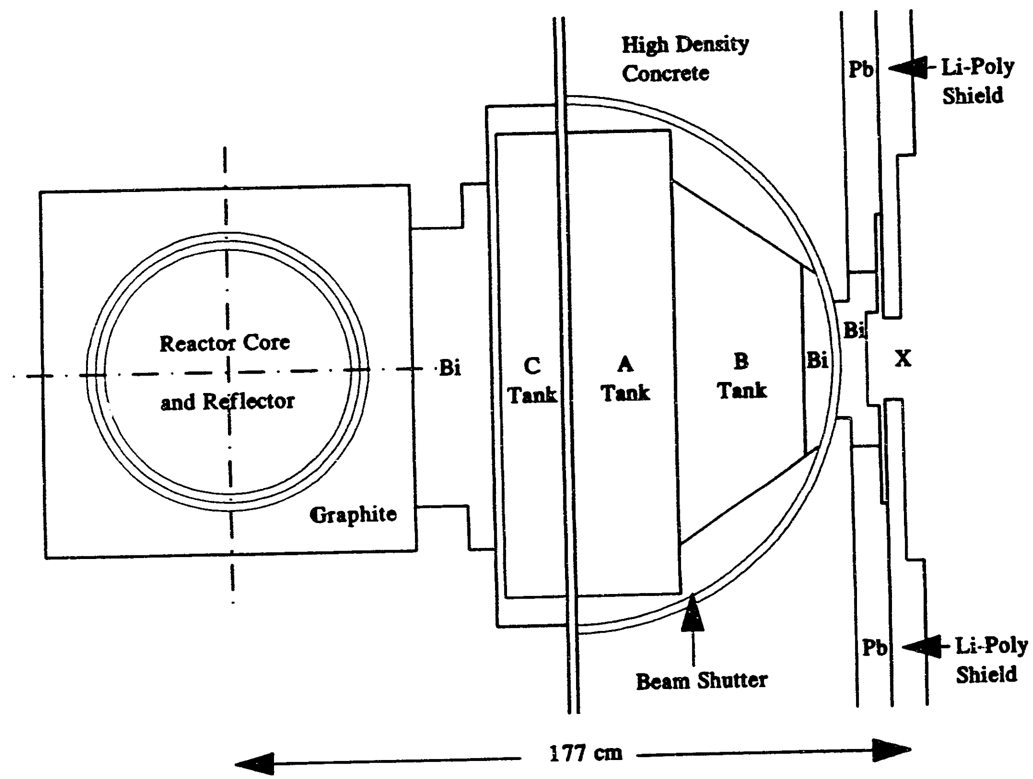
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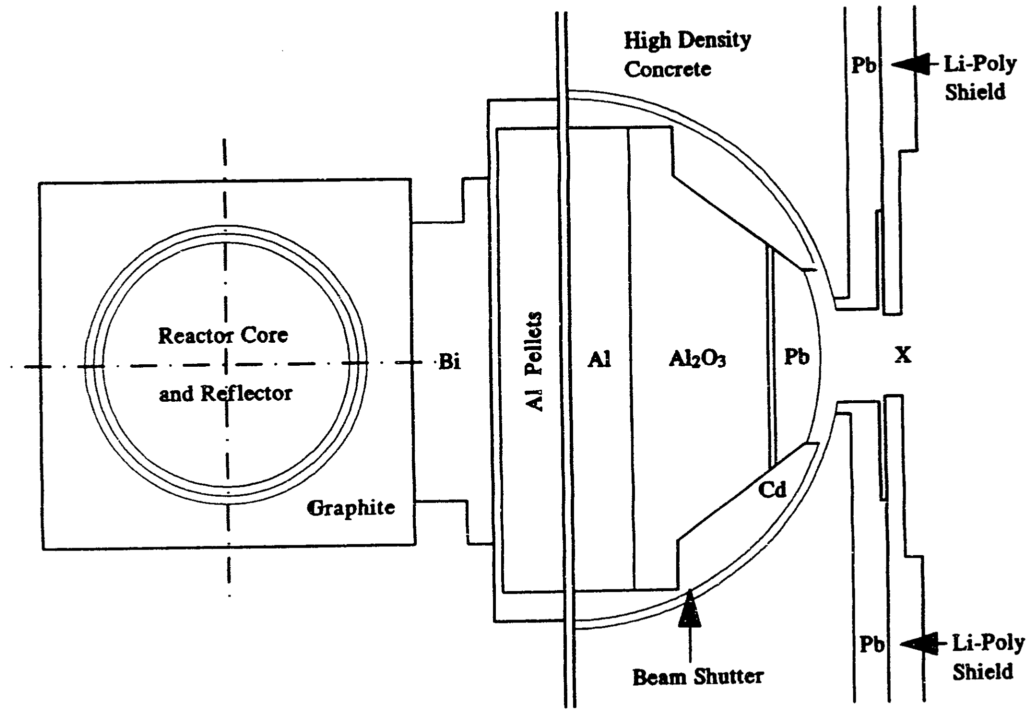

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