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IRT-Sofia BNCT beam tube optimization study

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ABSTRACT

An optimization study of IRT-Sofia BNCT beam tube is presented. In the study we used the MIT/FCB experience. The enlarging of filter/moderator cross section dimensions and the decreasing of collimator length within the limits of the IRT-Sofia reactor design were analyzed. The influence of beam and reactor core axes non-coincidence on the beam properties was also evaluated. The irradiation resistance of polytetrafluoroethylene (Teflon®) was also evaluated. The results provide information for making decisions on the IRT-Sofia BNCT beam construction.

1. Introduction

The pool type research reactor IRT-Sofia is nowadays at the stage of reconstruction from the previous reactor design that operated until 1989 (IRT-2000). The new technical design of the reactor includes a BNCT facility. The preliminary IRT-Sofia BNCT beam tube design and properties were presented at the ICNCT-13 by Belousov et al. (2009). The BNCT tube outer dimensions in the preliminary design were suggested by ŠKODA (Fig. 1), and the filter/moderator followed the BNCT beam tube at the Massachusetts Institute of Technology Reactor (MITR) (Harling et al., 2002). Further IRT-Sofia BNCT beam tube studies to optimize the design based on the MITR experience have been performed. Additional details of the actual construction were included in the calculation model. Teflon® (as filter material) irradiation performance under the conditions required for IRT-Sofia operation was also evaluated.

2. Filter/moderator cross section area

In the ŠKODA (ŠKODA, 2003) design the outer dimensions of filter/moderator area are limited to 0.55 m width and 0.7 m height. The neutron source of the IRT-Sofia BNCT beam tube and the core fuel assemblies are limited by the beam entrance dimensions. The source area at the entrance of the beam is 0.6 m high and about 0.3 m wide according to the fuel meat distribution. Referring to Riley (2001) the epithermal neutron flux intensity of the beam could be rather efficiently increased without any significant loss of quality by increasing the filter/moderator (F/M) cross-sectional dimensions. A parametric study was performed for IRT-Sofia by varying the width of the neutron source of the BNCT beam line. The BNCT beam properties (averaged over 5 cm radius area) were compared at the beam exit (for conical collimator with L=0.9 m length and output area of 225 cm^2) for different square sided F/Ms. The shape of the preliminary design was described by a square with sides D=0.62 m. Additional calculations in this study were performed for D=0.8 and 1 m. The BNCT beam tube will be mounted at a position such that the previous IRT-2000 design was occupied by the thermal column. F/M side dimension of D=0.8 m with lead reflector of 0.1 m thickness gives a 1 m outer side dimension of the BNCT tube, which is the largest that could be accommodated by the hole in the biological shielding without heavy concrete cutting. F/M side dimension of 1 m gives a 1.2 m outer side dimension of the BNCT tube, that corresponds to available space for the BNCT tube installation but requires enlarging the hole in the biological shielding. The axis of the hole in the biological shielding is horizontally shifted by 10.5 cm relative to the reactor core (neutron source) axis. The impact of this latter shift (ΔS) on the BNCT beam properties was evaluated.

The MCNP code (Briesmeister, 2000) was used and calculations were performed in two stages. In the first stage, criticality core calculations provided the neutron surface source at the entrance of the BNCT tube for the next stage calculation of the beam tube properties at the collimator exit. The second stage calculation used mesh defined energy dependent weight windows for variance reduction.

The results of comparison for beam performance (for 200 kW reactor power level) including epithermal neutron flux—Φepi, beam collimation (current to flux ratio—$Jepi/\Phi epi$) and "in-air" soft tissue (ICRU 46, 1992) doses (fast neutron—D_{fn}, and photon doses—D_γ) are presented in the Table 1. Fig. 2 illustrates the dependence of the epithermal flux at the beam exit (for conical collimator with L=0.9 m length and output area of 225 cm^2) for F/M with square side dimension—D, m.

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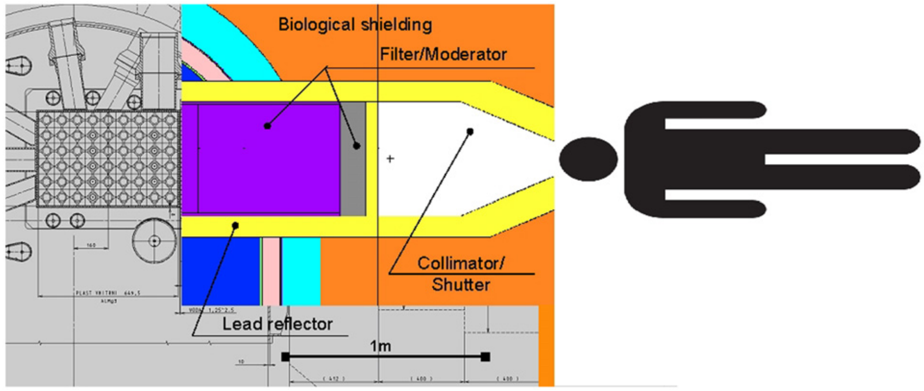

Fig. 1. IRT-Sofia reactor horizontal cross section with BNCT beam line, as evaluated in this paper.

Table 1
Comparison of calculated IRT-Sofia BNCT beam performance for different F/M widths (D) and beam shift relative to the reactor core (ΔS) (Θ—collimator cone tapering angle).

D (m) (ΔS, (cm))	Θ (deg.)	Φ_{epi} (cm^{-2} s^{-1})	J_{epi}/Φ_{epi}	D_{fn} (Gy s^{-1})	D_{fn}/Φ_{epi} (cGy cm^2)	D^{γ} (Gy s^{-1})	D_{γ}/Φ_{epi} (cGy cm^2)
0.62 (0)	22	4.63+9 0.27%	0.704	1.48–3 1.92%	3.20–11	2.55–4 3.15%	0.552–11
0.80 (10.5)	28	6.58+9 0.48%	0.683	1.91–3 2.64%	2.90–11	3.57–4 2.64%	0.543–11
0.8 (0)	28	6.79+9 0.23%	0.682	1.94–3 1.88%	2.91–11	3.73–4 0.77%	0.549–11
1.0 (10.5)	35	8.12+9 0.27%	0.662	2.15–3 2.36%	2.65–11	4.32–4 0.98%	0.532–11
1.0 (0)	35	8.25+9 0.27%	0.664	2.15–3 2.15%	2.65–11	4.30–4 0.97%	0.521–11

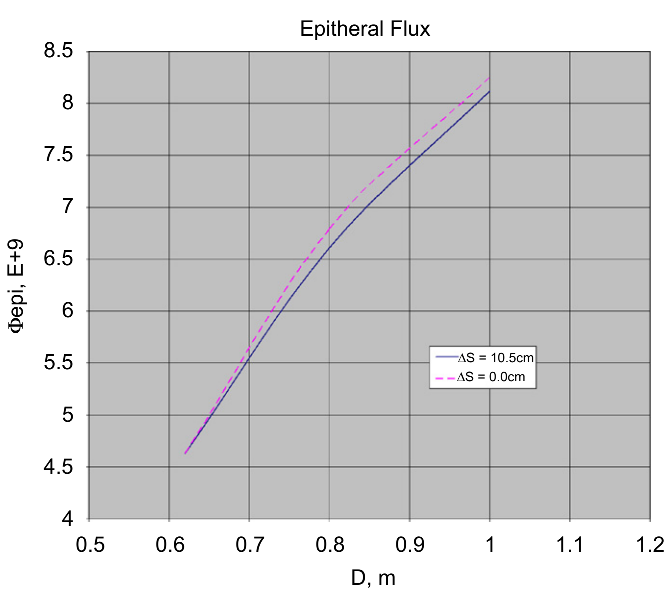

Fig. 2. Φ_{epi} dependence on F/M side dimension.

3. Collimator length

It is clear that increase in the collimator length will decrease the epithermal beam intensity at the exit of the BNCT tube. This was demonstrated in our preliminary study (Belousov and Ilieva, 2009). The preliminary collimator length L=0.9 m selection was not completely optimized. In this optimizing study we analyzed the dependence of the collimator length on the IRT-Sofia BNCT beam properties more carefully taking into account dimensional constraints after the thermal column dismantling.

Evaluation of the impact of the conical collimator length on the BNCT beam properties was performed to study the impact of lengthening the beam line to incorporate shutters and improving access by extending into the reactor hall. These calculations used the hole in the biological shielding left after dismantling of the thermal column, which could be installed without cutting of the heavy concrete. It corresponds to F/M side dimension equal to 0.8 m and a 10.5 cm horizontal shift of the BNCT tube axis against the core axis. Again as in the F/M area analysis the collimator output aperture was 225 cm^2 for all considered lengths of the collimator. A set of collimator lengths L, was used for calculation: (1) 0.9 m; (2) 0.72 m; (3) 0.8 m; (4) 1.24 m; (5) 1.50 m and (6) 1.64 m. The first dimension is the base one used in the previous calculations. The second one corresponds to the shortest collimator that could be realized by incorporating a shutter inside the thermal column. The third one is intermediate. The fourth dimension corresponds to a longer collimator for which a shutter could be used outside the biological shield so that no cutting of heavy concrete is needed. The sixth dimension models an extension of the fourth case by 0.4 m (including the shutter thickness) and the fifth is again an intermediate one.

The calculation results of the IRT-Sofia BNCT beam properties at the collimator exit obtained from the considered set of collimator length L, are presented in Table 2. Fig. 3 illustrates the strong dependence of the epithermal flux, at the beam exit, on the collimator length.

4. Teflon irradiation performance

To evaluate the irradiation performance of Teflon® in the F/M of the IRT-Sofia BNCT tube, the neutron fluence (with energy above 1 MeV) and gamma dose (Hubbell and Seltzer, 2009) over the Teflon® were calculated. The expected lifetime exposure for Teflon® in F/M of the IRT-Sofia BNCT tube is shown by the rectangular shaded region in