CONF-9609293--8

BNCT Filter Design Studies for the ORNL Tower Shielding Facility*

D. T. Ingersoll
Charles O. Slater
L. R. Williams
Oak Ridge National Laboratory**
Oak Ridge, Tennessee 37831-6363

To be included in the proceedings of the
Seventh International Symposium on Neutron Capture Therapy for Cancer
Zurich, Switzerland
September 4-7, 1996

* Research sponsored by the U.S. Department of Energy.
**Managed by Lockheed Martin Energy Research Corp. for the U. S. Department of Energy under Contract DE-AC05-96OR22464.

DISCLAIMER

BNCT Filter Design Studies for the ORNL Tower Shielding Facility

Daniel T. Ingersoll, Charles O. Slater, and Larry R. Williams
Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA

Introduction

Boron Neutron Capture Therapy (BNCT) in the United States has entered into a new phase with the initiation of clinical trials using neutron sources at the Brookhaven National Laboratory[1] and the Massachusetts Institute of Technology.[2] If these trials are successful at demonstrating the efficacy of BNCT as a viable treatment for glioblastoma multiforme, then there will be an immediate demand for several additional neutron sources in order to treat the several thousand patients currently diagnosed with glioblastomas in the U.S. each year. However, the requirements for an acceptable neutron source for BNCT are rather severe in terms of the need to provide a sufficient number of epithermal neutrons to a patient-accessible location in a reasonable time with minimal thermal-neutron, fast-neutron, and gamma-ray background. A few reactor facilities in the United States have been studied for potential conversion to BNCT applications, most notably the Idaho Power Burst Facility (PBF)[1] and the Georgia Institute of Technology Research Reactor (GTRR).[3] A recent study of potential neutron sources at Oak Ridge National Laboratory (ORNL) has been completed, which concludes that another available source, the Tower Shielding Facility (TSF), also appears very well suited for BNCT.

Facility Description

The TSF was built in 1954 to support the shielding design for the Aircraft Nuclear Propulsion Project. The current reactor, the TSR-II, was put into operation in 1960 and is configured in a unique above-ground, partially shielded environment. The reactor core is made of aluminum-uranium alloy plates, which are assembled to form a spherical annulus surrounding a central control "ball" mechanism. The light-water-cooled reactor is contained in an aluminum pressure vessel and located in a large concrete "bunker" referred to as the Big Beam Shield (BBS). The BBS contains a 77-cm-diameter beam collimator, which permits access to a broad beam neutron flux exceeding 4×10^{11} $cm^{-2}s^{-1}$ at the operational power of 1 MW. A plan view of the BBS is given in Figure 1.

The collimated beam emerges horizontally onto an unenclosed test pad area on which shield mockups were assembled. Conversion of the reactor to BNCT application is straightforward, since no modifications to the existing reactor pressure vessel system are needed. The appropriate beam filter and collimator system can be easily constructed in the expansive area previously used for the large shield mockups. Additional engineering of the beam shutter mechanism and the construction of treatment support facilities will be needed but can be easily accommodated on the remote dedicated site.

Filter Design Analysis

Several preliminary one- and two-dimensional analyses have been performed to determine if the TSR-II is a viable source, i.e. one that can produce a suitable epithermal beam while maintaining sufficient flux to treat patients in a reasonable exposure time (less than one hour). Calculations were performed using the ANISN[4] and DORT[5] discrete ordinates codes and using well characterized boundary source data generated for analyses of previous shielding benchmark experiments. The initial calculations assumed that the filter materials would be placed adjacent to the current beam shutter and

Address for correspondence: Daniel T. Ingersoll, Oak Ridge National Laboratory, P. O. Box 2008, Oak Ridge, TN 37830-6363, USA.

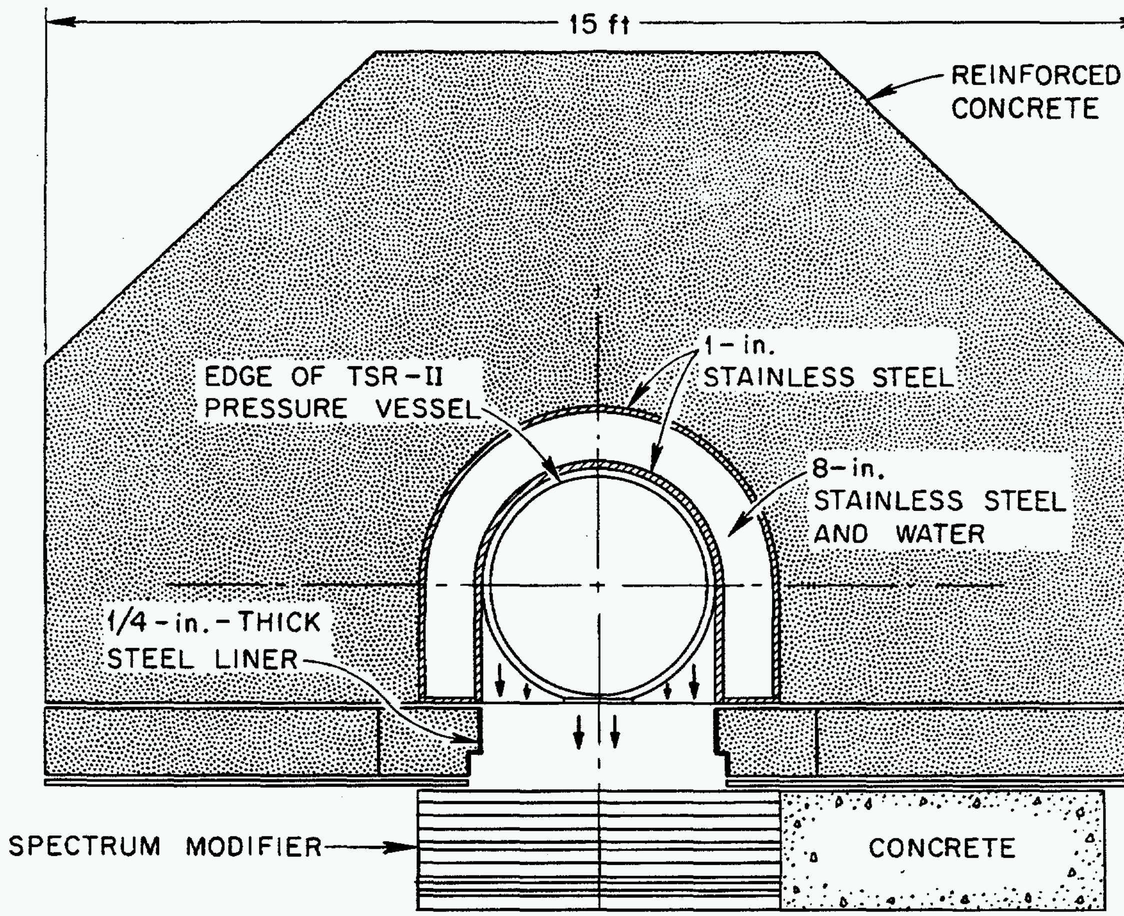

Fig. 1. Plan view schematic of the Big Beam Shield at the Tower Shielding Facility.

collimator mechanism, which is approximately 90 cm from the center of the reactor core or approximately 50 cm from the outer surface of the core.

Numerous filter designs were investigated using an assortment of materials commonly considered in other BNCT filter design studies. These include aluminum, heavy water, sulfur, bismuth, lead, cadmium, boral, and lithiated polyethylene. The best balance between beam intensity and energy spectrum was achieved using an aluminum/aluminum fluoride material developed for BNCT applications in Finland[6]. Several designs achieved a patient-incident epithermal flux of equal or greater strength than that of the Brookhaven Medical Research Reactor (BMRR) and provided a comparable or better neutron energy spectrum.

The preferred beam filter design selected from these preliminary calculations contains 80 cm of Al/AlF_3 (in a 1:1 mixture), followed by 9.2 cm sulfur, 0.02 cm cadmium, and 10 cm bismuth. Two-dimensional calculations indicated that a 10-cm-thick lithiated polyethylene collimator provides acceptable beam definition while minimizing beam loss. The reference configuration yields an epithermal flux of 2.4×10^9 $cm^{-2}s^{-1}$ with a non-epithermal neutron kerma of 1.4×10^{-11} $cGy \cdot cm^2$ and a gamma-ray kerma of 8.5×10^{-12} $cGy \cdot cm^2$. Figure 2 compares the flux spectrum of the TSR-II unfiltered beam with the flux spectrum on the patient side of the reference beam filter. Although the epithermal flux is attenuated by a factor of 40 across the filter, the thermal and fast fluxes are attenuated substantially more. In the filtered spectrum, approximately 98% of the total neutron flux is in the epithermal energy range of 0.5 eV to 10 keV.

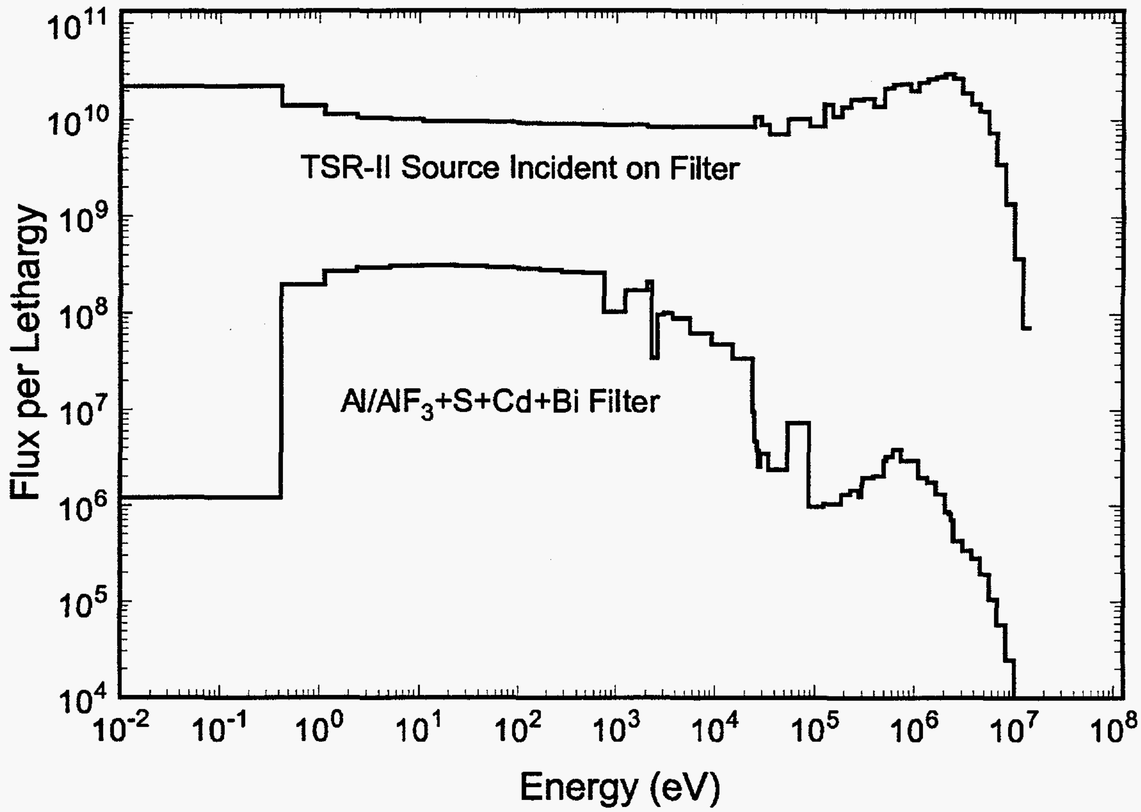

Fig. 2. Comparison of unfiltered and filtered neutron spectra at the Tower Shielding Facility.

A assessment of how the TSF source compares to other actual or proposed BNCT facilities is shown in Figure 3. The patient-incident epithermal flux is plotted against a figure-of-merit parameter called "beam purity".[7] The beam purity parameter is defined to be larger (better) for beams with good collimation and low background radiations (thermal neutrons, fast neutrons, and gamma rays). The reference filter design described above yields a beam purity of 9.1×10^9 $cGy^{-1}cm^{-2}$. The results plotted in Figure 3 show the sensitivity of the beam intensity and purity to changes in the thickness of some of the key filter materials. In particular, the Al/AlF_3 was varied from 50 to 80 cm and the sulfur was varied from 5 to 12.5 cm. The different series of data show clearly the classic trade-off between beam intensity and beam quality. The superior performance of the proposed PBF treatment facility is due to the relatively high power level of that reactor (10 MW).

Conclusions

Our analyses have shown that a beam which meets or exceeds the magnitude and spectral quality of the BMRR beam can be achieved using the TSR-II. Other attractive features of the TSF site include its close proximity to key medical and research facilities, especially at ORNL and at the University of Tennessee, its relative separation from the main ORNL site, and the unconstrained space surrounding the reactor system. Hence, it appears that this facility is very well suited for potential dedication to BNCT research and clinical treatments. Future analyses are planned to further optimize the filter and collimator design.

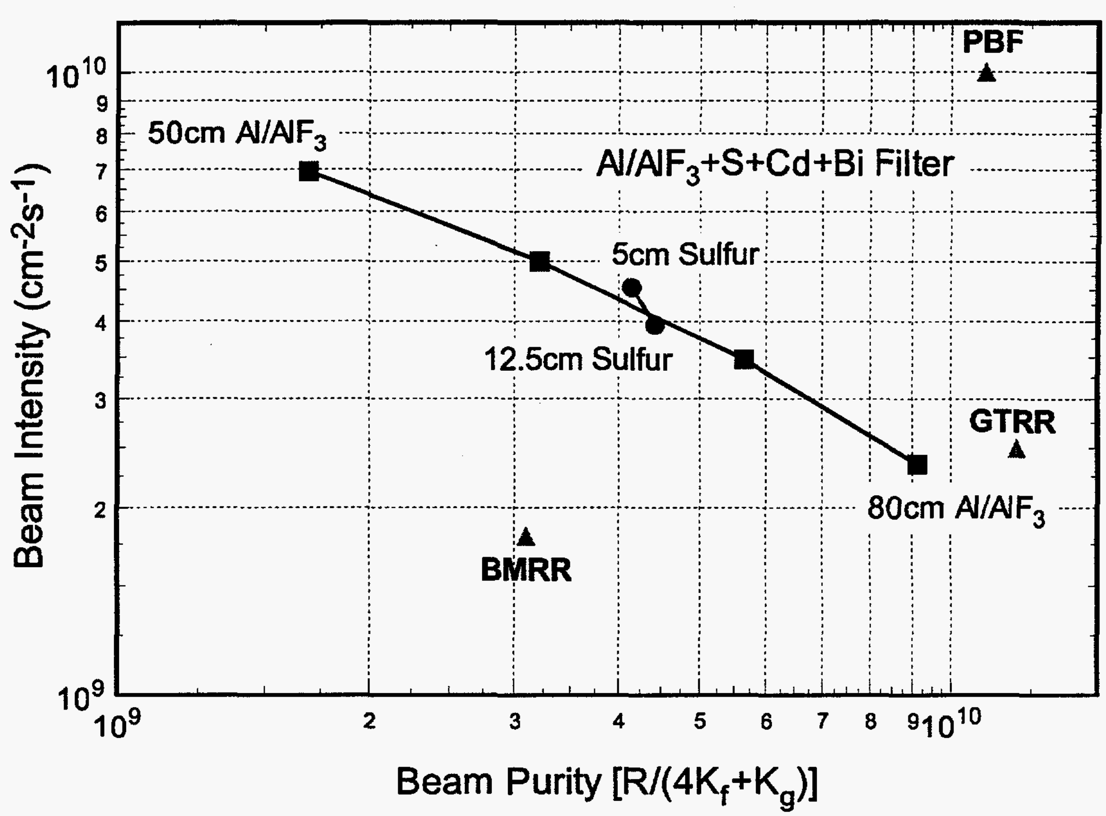

Fig. 3. Performance of various TSF filter options compared to other BNCT facilities.

References

1. F. J. Wheeler, D. K. Parsons, B. L. Rushton, and D. W. Nigg, "Epithermal Neutron Beam Design for Neutron Capture Therapy at the PBF and BMRR Reactor Facilities," *Nucl. Technology,* **92**, 106-117 (1990).
2. J. R. Choi, S. D. Clement, O. K. Harling, and R. G. Zamenhof, "Neutron Capture Therapy Beams at the MIT Research Reactor," *Neutron Beam Design, Development, and Performance for Neutron Capture Therapy*, O. K. Harling, Ed., Plenum Press, New York (1990).
3. K. A. Klee, D. W. Nigg, F. J. Wheeler, and R. A. Karam, "Conceptual Design for an Advanced Epithermal-Neutron Beam for Boron Neutron Capture Therapy at the Georgia Institute of Technology Research Reactor," Proceedings of the 1994 Topical Meeting on Advances in Reactor Physics, Knoxville, TN, Vol. III, 72-82 (1994).
4. W. W. Engle, Jr., "ANISN, A One-Dimensional Discrete Ordinates Transport Code with Anisotropic Scattering," Report K-1693 (March 1967).
5. W. A. Rhoades and R. L. Childs, "The DORT Two-Dimensional Discrete Ordinates Transport Code," *Nucl. Sci. & Eng.*, **99**, (1) p. 88-89 (May 1988).
6. Iiro Auterinen and Pekka Hiismaki, "Design of an Epithermal Neutron Beam for the TRIGA Reactor in Otaniemi," *CLINCT BNCT Workshop Helsinki 1993*, Edited by Iiro Auterinen and Merja Kallio, TKK-F-A718 (1994).
7. F. J. Wheeler and D. E. Wessol, "Radiation Transport Requirements for Clinical Application of Neutron Capture Therapy: The rrt_MC Monte Carlo Module," Proceedings of the International Conference on Mathematics and Computations, Reactor Physics, and Environmental Analyses, Portland, OR, April 30-May 4, 1995, 876-883 (1995).