BNCT irradiation Facility at the JRR--4

Y:Torli, TKishi, H.Kumada, K.Ymamoto, K.YoKoo, N.Ohbashi, FSakurai, K.Kaieda

Department of Research Reactor
Japan Atomic Energy Research Institute

Abstract

The JRR--4 was modified for fuel enrichment reducing and reactor equipment renewal. And also a medical irradiation facility for the Boron Neutron Capture Therapy (BNCT) was installed at the JRR--4 in that time. The medical irradiation facility has been composed of a heavy water tank, a collimator and an irradiation room. The heavy water tank has four layers of heavy water for spectrum shifter and 75cm-thickness aluminum for the shield of fast neutron. The collimator is for collimating them al neutron and epithem al neutron using polyethylene with lithium-fluoride and shielding gamma ray by bismuth. The irradiation room has sufficient space at exit side of the beam, to accommodate a large working area for seeing the patient. Both of the medical treatment room and the patientmonitoring area were prepared adjacent to the irradiation room. The medical irradiation facility in the JRR4 is designed to perrr it selection of neutron energies from themmal neutron to epithemmal neutron by changing the thickness of heavy water layers. Therefore it is available to continue the same k nd of BNCT with themmal neutron used to perfomm in the JRR-2, as well as to commence the research and development of BNCT with epithemmal neutron, which will make the brain tumor treatment possible at a deep part of brain. The full power operation of the JRR-4 was resumed with LEU fuel in October 1998 and currently perfom ing some experiments to measure the neutron fluxes and physical doses for determinate characterization of the medical irradiation facility.

Presenting author:
Keisuke KAIEDA Director
Department of Research Reactor, Tokai Research Establishment,
Japan Atomic Energy Research institute
Tokai-mura, Naka-gun, Ibaraki 319-1195, Japan

1. introduction

A medical inradiation facility for BNCT was installed at the JRR-2 in 1990. Since then 33 cases of medical irradiation for clinical trial of BNCT using them al neutron beam were perfom ed for malignant brain tumor patients by Dr. Hatanaka, Dr. Nakagawats and a group of Tsukuba University. The operation of theJRR-2wastem inated at the end of 1996 because of aged reactor components. In order to transfer the medical irradiation for BNCT from the JRR-2 to the JRR4, a new medical Irradiation facility was installed at the JRR-4.

The JRR-4 was constructed in 1965 for the purpose of shielding test of the first nuclear ship in Japan; "Mutsu". it is a light water moderated and cooled swimming pool type reactor with the maximum thermal power of 3.5 MW. It was used for shielding experiment, neutron activation analysis, irradiation test of reactor materials and fuels, production of radioisotopes, silicon doping and education and training of nuclear engineers. At the beginning of 1996, the operation was suspended once for modification of reactor system and renewal of utilization facilities containing installation of the medical irradiation facility, and resumed in October 1998.

2. Outilne of medical Irradistion facility at the JRR-4

The general arrangement of medical irradiation facility at the JRR4 is shown in Fig.1. The medical irradiation facility consists of neutron beam facility, medical treatment room and experimental room. And furthemmore, a prompt gamma ray analyses system was installed for BNCT.

(1) Neutron beam facility

The basic design policy of the neutron beam facility is to provide a variety of neutron beams from themmal to epithem al neutron beam. In Japan, themmal neutron beam is needed to continue the conventional BNCT. Fig. 2 shows the neutron beam facility. It consists of heavy water tank, cadmium shutter, collimator and irradiation room. The irradiation angle of patent is possible to adjust within 90 degree to left side, and 60 degree to right side.

(2) Medical treatment room

The medical treatment room was prepared for pre and post-irradiation surgical operations in the case of BNCT for malignant brain tumor patient using themmal neutron beam. A bed for surgical operation and irradiation, astral lamp, sterilization lamp and medical sink for sterilization are installed in this room.

(3) Experimental room

Incubator, clean bench and draft chamber are set in the experimemal room for fundamental experiments on BNCT.

(4) Prompt gamma ray analyses system

A prompt gamma ray analyses system was installed to accurately detemmine boron concentrations in tumor and blood in a short time. Fig.3 shows the system. A Ni/Ti multi-layer supermirror guide tubed was adopted as a neutron guide tube to obtain higher neutron flux at the measurement position.

3. Neutron Beam Facility

3.1 Objectives of beam design

The beam pertommances were designed as follows with free beam;

(1) Themmal neutron flux at beam port Thermal neutron mode): > 1 x 109 n/cm3/sec

(2) Epithemmal neutron flux at beam port (epithemmal neutron mode): > 1 x 1 Or, nicm2/sec

(3) Gamma ray contamination: < 3 x 10'3 Gy cm3/n

(4) Fast neutron contamination: < S x 1 0 13 Gy cm2/n

3.2 Design optimization

Design optimization studies were performed for aluminum and heavy water thickness of heavy water tank, position and thickness of bismuth shield. Two-dimensional calculations using DOT3.5'3' (2-d Discrete Ordinate Transport code version 3.5) and library data based on JENDL3.1'9 (Japanese Evaluated Nuclear Data Library version 3.1) were perfommed in the design optimization studies. 21 group neutron and 9 group gamma-ray energy structure were used in the calculations.

The aluminum thickness of 75 cm was chosen to reduce fast neutron contamination in riot e me al neutron beams, while themmal and spit h e n n al neutron flux were enough to satisfy the design objectives,

The thickness of the heavy water layer can be arbitrary chosen from 0 cm to 28 cm by 4 cm step. The maximum thickness is 33 cm. The beam design objectives are pradically satisfied for every available heavy water thickness.

3.3 Performance test of neutron beam hclllty

Calculated perfommances of the neutron beam facility were verified experimentally for following three typical beam modes; Them al Neutron Beam Mode 1,Thermal Neutron Beam Mode 2 and Epithemmal Neutron Beam Mode.

Thermal neutron flux distributions measured by Au foils in a cylindrical head water phantom with diameter of 18.6 cm and depth of 24 cm are shown in Fig. 4. In Epithemmal Beam Mode, a remarkable peak is observed at the depth of 1.7 cm from the surface of phantom. Maximum themmal neutron fluxes of Them al Neutron Beam Mode 1, Thermal Neutron Beam Mode 2 and Epithemmal Neutron Beam Mode are 5.9, 1.5 and 4.0 x 103 nicm2/sec respectrvely, and have enough values for clinical trail of BNCT.

4. Conclusion

The medical irradiation facilrly at the JRR-4 can provide a wide variety of neutron beams by changing the thickness of heavy water in heavy water tank, and by inserting/removing the cadmium shutter. It was measured that all beam modes have enough neutron beam imensities for BNCT with very low contamination of fast neutron and gamma ray. In addition to the above, accessory equipmen and facilities necessary for BNCT were installed at the JRR-4.

References

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Table 1 Performance of the beam facility at the JRR-4

Items	Thermal Neutron Beam Mode 1	Thermal Neutron Beam Mode 2	Epithermal Neutron Beam Mode
Condition			
Heavy Water Thickness(cm)	12	33	8
Cadmium Shutter	off	off	on
Neutron Flux (n/cm^2/sec)			
Thermal (< 0.53eV)	2.0 X10^9	6.5 X10^8	3.6 X10^8
Epithermal (0.53 eV - 10KeV)	9.0 X10^8	3.2 X10^7	2.2 X10^9
Fast (> 2.6MeV)	3.6 X10^5	5.0 X10^4	4.7 X10^5
Cadmium Ratio	2.5	13.5	1.15
Contamination (Gy cm^2/n)			
Fast Neutron	1.1 X10^{-13}	1.3 X10^{-14}	3.1 X10^{-13}
Gamma Ray	5.0 X10^{-13}	3.0 X10^{-13}	3.0 X10^{-13}

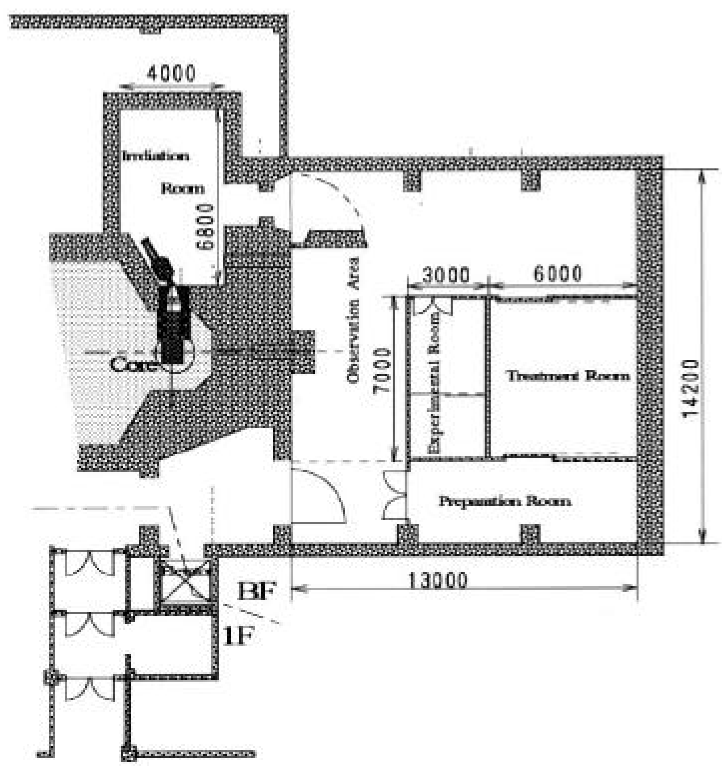

Fig. 1 General arrangement of medical irradiation facility at the JRR-4

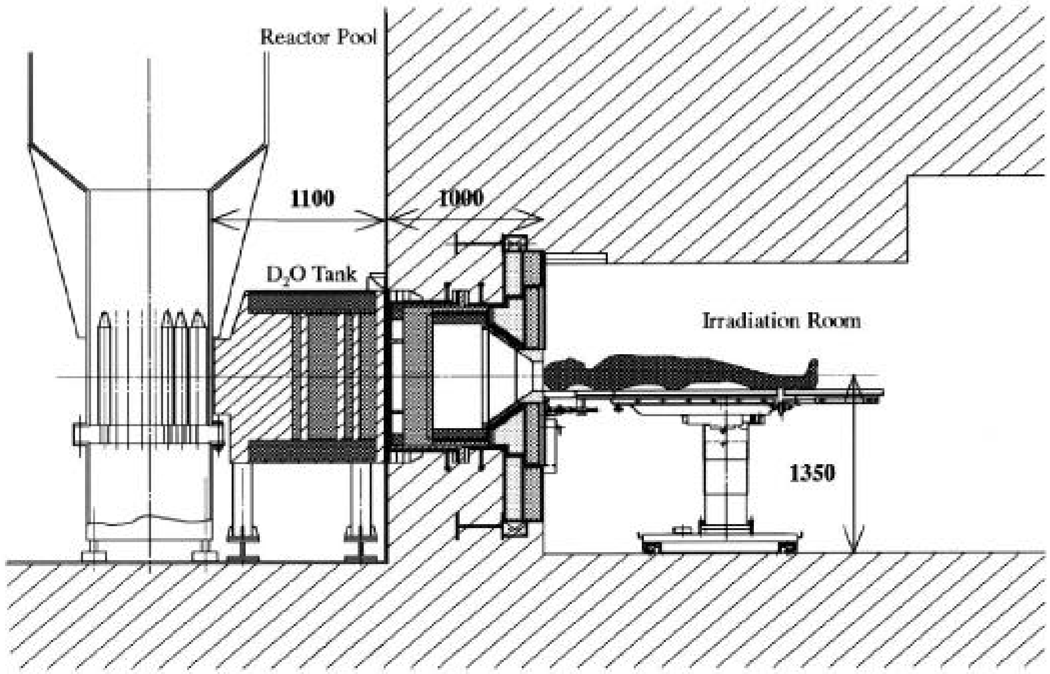

Fig. 2 Neutron beam facility for BNCT at the JRR-4

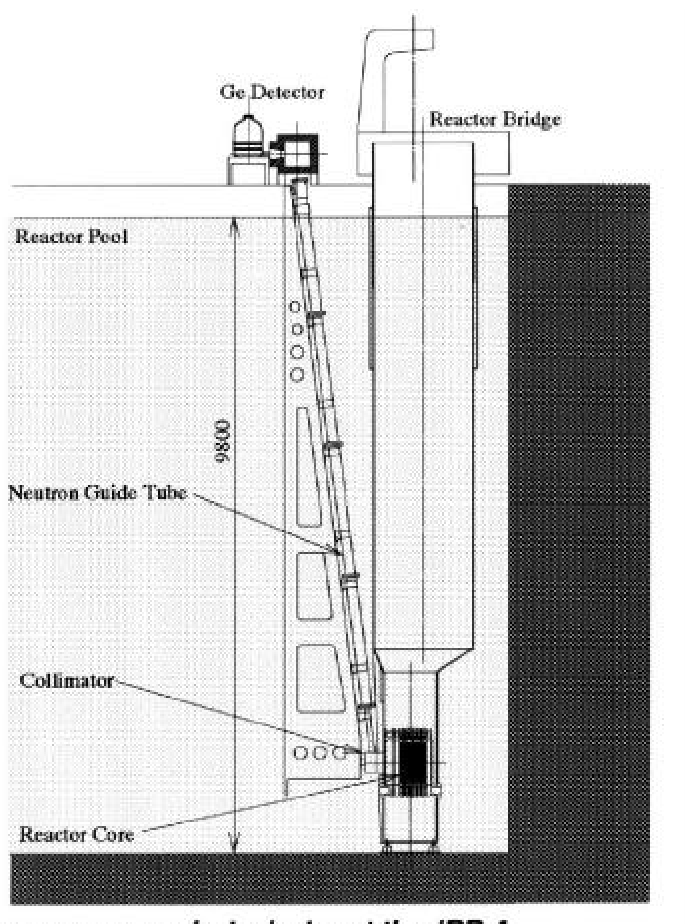

Fig. 3 Prompt gamma ray analysis device at the JRR-4

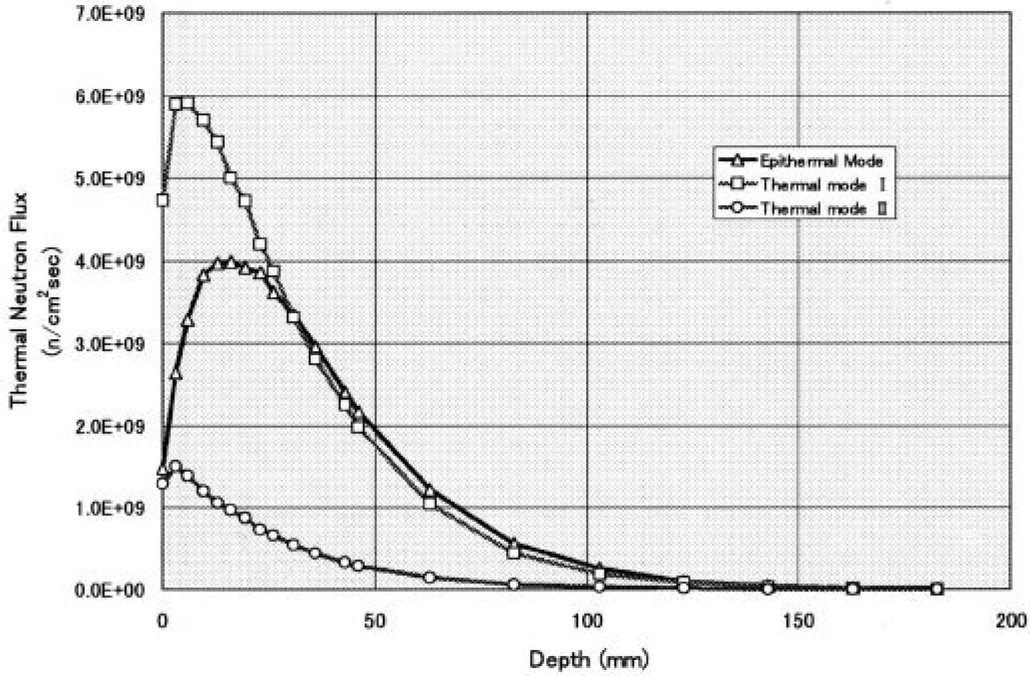

Fig. 4 Thermal neutron flux distribution in phantom