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Medical irradiation facility at JRR-4

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Abstract. The operation of JRR-2, in which 33 cases of medical irradiation were performed for clinical trials of BNCT using thermal neutron beam for malignant brain tumour patients since 1990, was terminated at the end of 1996. In order to transfer the medical irradiation for BNCT from JRR-2 to JRR-4, a new medical irradiation facility was installed at JRR-4 in June 1998. The new facility provide a suitable neutron beam (thermal or epithermal neutron beam) for each medical irradiation. It was verified that both thermal and epithermal neutron beams had enough intensity for a clinical trail of BNCT and very low contamination of gamma ray and fast neutron.

1. INTRODUCTION

A medical irradiation facility for BNCT was installed at JRR-2 in 1990. Since then 33 cases of medical irradiation for clinical trials of BNCT using thermal neutron beam were performed for malignant brain tumour patients by Dr. Hatanaka, Dr Nakagawa's and a group at the Tsukuba University. The operation of JRR-2 was terminated at the end of 1996 because of ageing of reactor components. In order to transfer the medical irradiation for BNCT from JRR-2 to JRR-4, a new medical Irradiation facility was installed at JRR-4.

JRR-4 was constructed in 1965 for the purpose of shielding test of the first nuclear ship in Japan "Mutu". It is a light water moderated and cooled swimming pool type reactor with the maximum thermal power of 3.5 MW. The operation mode is daily operation. It was used for shielding experiment, neutron activation analysis, irradiation test of reactor materials and fuels, production of radioisotop~s4 — silicon doping and education and training of nuclear engineer. At the beginning of 1997, the operation was terminated once for modification of reactor system and renewal of utilisation facilities containing installation of the medical irradiation facility, and resumed in January 1999. This paper presents outline of the new medical irradiation facility and results of its characteristic test.

2. OUTLINE OF MEDICAL IRRADIATION FACILITY AT JRR-4

The general arrangement of medical irradiation facility at JRR-4 is shown in Fig. 1. The medical irradiation facility consists of neutron beam facility, medical treatment room and experimental room. And furthermore, a prompt gamma ray analyses system was installed for BNCT.

2.1. Neutron beam facility

The basic design policy of the neutron beam facility is to provide a variety of neutron beams from thermal to epithermal neutron beam. In Japan, thermal 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.

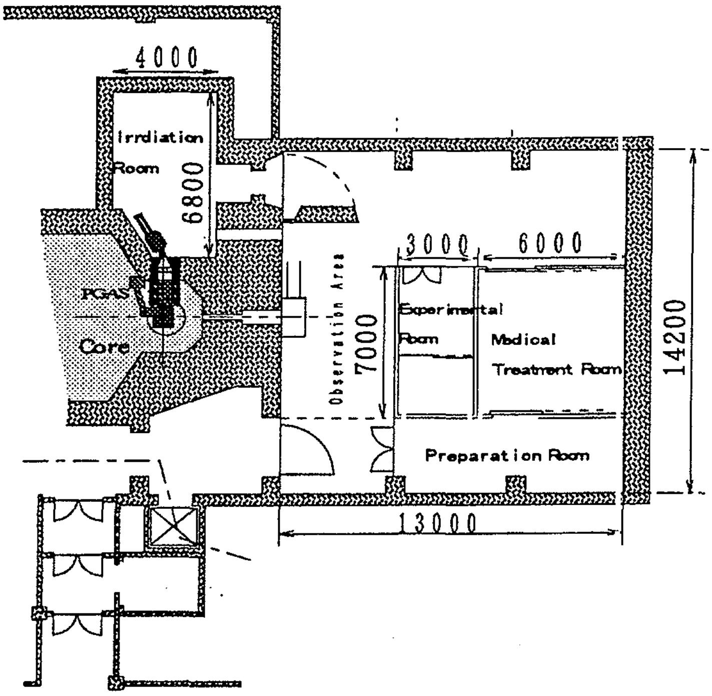

FIG.1. General arrangement of a medical irradiation facility.

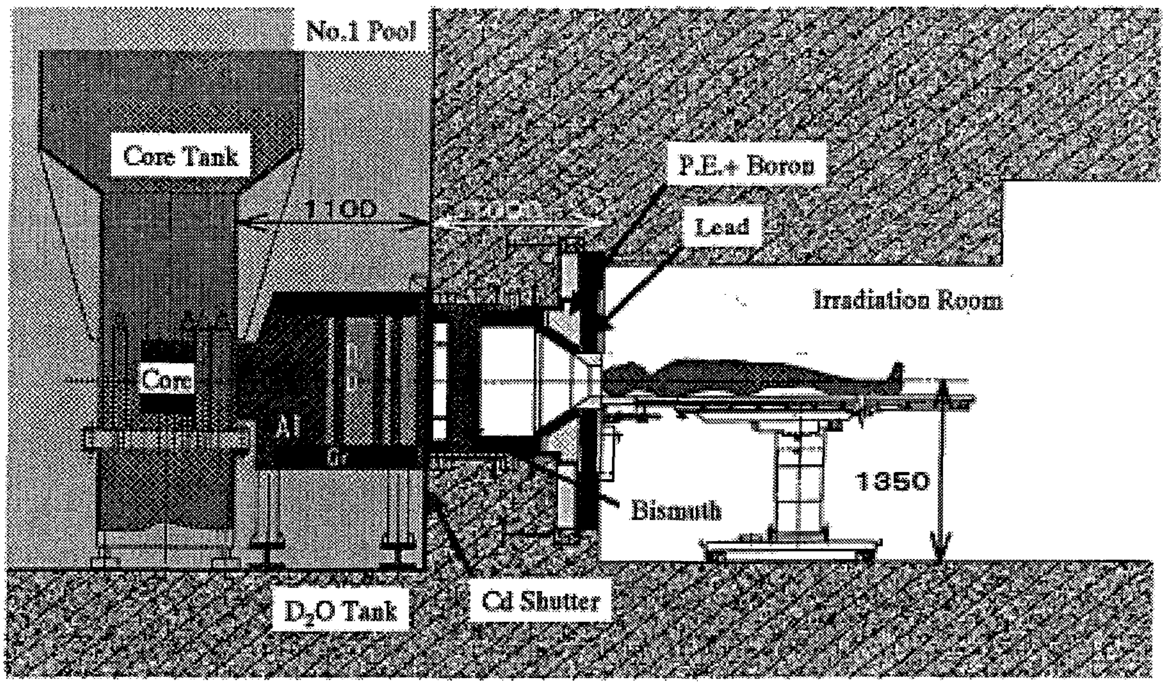

FIG.2. Cross sectional view of neutron beam facility.

2.2. Medical treatment room

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

2.3. Experimental room

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

2.4. Prompt gamma ray analyses system

A prompt gamma ray analyses system was installed to accurately determine boron concentrations in tumour and blood in a short time. Fig.3 shows the system. A Ni/Ti multilayer supermirror guide tube(2) was adopted as a neutron guide tube to obtain higher neutron flux at the measurement position.

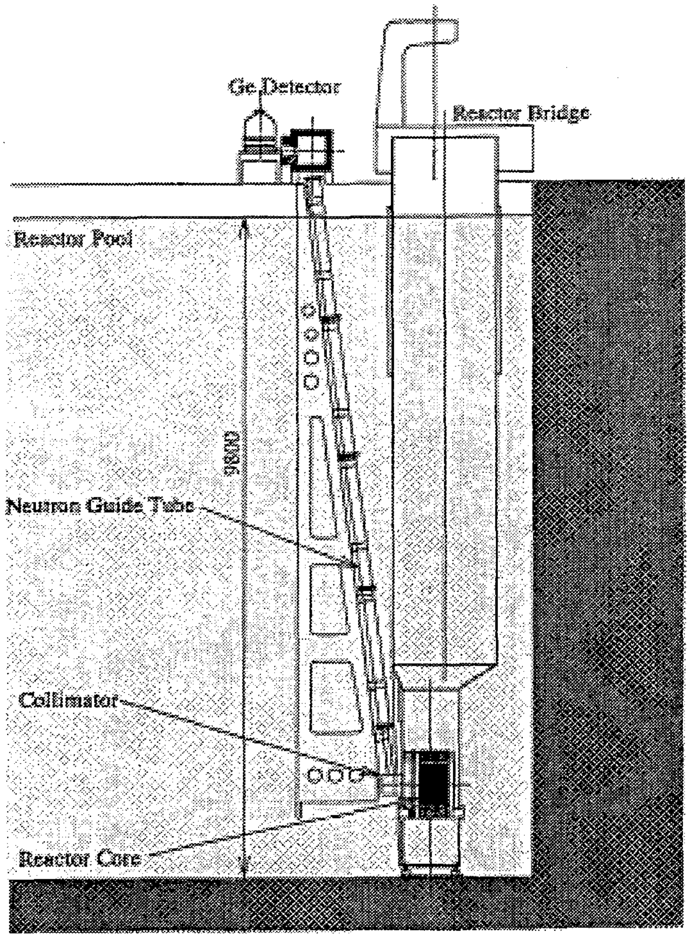

FIG.3. Outline of prompt gamma ray analysis system.

3. NEUTRON BEAM FACILITY

3.1. Objectives of beam design

The objectives of the beam design were set as follows for free beam model:

(1) Thermal neutron flux at beamport (thermal mode): $\geq 1 \times 10^9$ n/cm^2/sec
(2) Epithermal neutron flux at beam port (epithermal mode): $\geq 1 \times 10^9$ n/cm^2/sec
(3) Gamma ray contamination: $\leq 3 \times 10^{-13}$ Gy cm^2/n
(4) Fast neutron contamination: $\leq 5 \times 10^{-13}$ Gy cm^2/n

3.2. Design optimization

Design optimisation studies were performed for aluminum and heavy water thickness of heavy water tank, position and thickness of bismuth shield, etc. Two dimensional calculations using 2-D discrete ordinate transport code DOT3.(3) and library data based on JENDL3.1(4) (Japanese Evaluated Nuclear Data Library version 3.1) were performed in the design optimisation studies. 21 group neutron and 9 group gamma ray energy structure were used in the calculations.

Dependence of beam performance on aluminum thickness is shown in Fig. 4a and 4b. Increasing the aluminum thickness, the fast neutron contamination in epithermal neutron beam decreases rapidly. Therefore, the aluminum thickness of 75 cm was chosen to reduce fast neutron contamination in epithermal neutron beams, while thermal and epithermal neutron fluxes 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. Dependence of beam performance on heavy water thickness is shown in Fig. 5a and 5b. The beam design objectives are practically satisfied for every available heavy water thickness.

3.3. Performance test of beam facility

Performances of the beam facility were verified experimentally for following three typical beam modes ; Thermal Beam Mode I ,Thermal Beam Mode II and Epithermal Neutron fluxes, fast neutron and gamma ray contamination and Cadmium ratio of each beam mode at the beam port are shown in Table 1. Neutron spectra of each beam mode at beam port are shown in Fig. 6–8. The neutron spectra calculated by DOT 3.5 are good agreement with ones measured by foil activation method using Au, Au covered by Cd, Cu and Ni foil. Thermal neutron fluxes shown in Table 1 were measured using Au foils, and epithermal and fast neutron fluxes were determined based on neutron spectra shown in Fig.6–8. The typical neutron beams have very low contamination of fast neutron and gamma ray.

Thermal neutron flux distributions measured by Au foils in a cylindrical head water phantom with diameter of 18.6 cm and height of 24 cm are shown in Fig. 9. In Epithermal Beam Mode, a remarkable peak is observed at the depth of 1.S cm from the surface of phantom. Maximum thermal neutron fluxes of Thermal Beam Mode I, Thermal Beam Mode II and Epithermal Beam Mode are 5.9, 1.5 and 4.0 X 10^9 n/cm^2/sec respectively, and have enough values for clinical trail of BNCT.

4. CONCLUSION

The medical irradiation facility at 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 verified that all beam modes have enough neutron beam intensities for BNCT and very low contamination of fast neutron and gamma ray. In addition to the above, accessory equipment and facilities necessary for BNCT were installed at JRR-4.

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