DESIGN OF A BNCT FACILITY AT HANARO

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ABSTRACT

Based on the feasibility study of the BNCT at HANARO, it was confirmed that only thermal BNCT is possible at the IR beam tube if appropriate filtering system be installed. Medical doctors in Korea Cancer Center Hospital agreed that the thermal BNCT facility would be worthwhile for the BNCT technology development in Korea as well as superficial cancer treatment.

For the thermal BNCT to be effective, the thermal neutron flux should be high enough for patient treatment during relatively short time and also the fast neutron and gamma-ray fluxes should be as low as possible. In this point of view, the following design requirements are set up; 1) thermal neutron flux at the irradiation position should be higher than 3×10^9 n/cm^2-sec, 2) ratio of the fast neutrons and gamma-rays to the thermal neutrons should be minimized, and 3) patient treatment should be possible without interrupt to the reactor operation.

To minimize the fast neutrons and gamma-rays with the required thermal neutrons at the irradiation position, a radiation filter consisting of single crystals of silicon and bismuth at liquid nitrogen temperature is designed. For the shielding purpose around the irradiation position, polyethylene, lead, LiF, etc., are appropriately arranged around the radiation filter. A water shutter in front of the radiation filter is adopted so as to avoid interrupt to the reactor operation.

At present, detail design of the radiation filter is ongoing. Cooling capabilities of the filter will be tested through a mockup experiment. Dose rate distributions around the radiation filter and a prompt gamma-ray activation analysis system for the analyses of boron content in the biological samples are under design.

The construction of this facility will be started from next year if it is permitted from the regulatory body this year. Some other future works exist and are described in the paper.

1. Introduction

Boron neutron capture therapy (BNCT) is one of treatment methods to kill cancer cells - especially brain cancer cell - using a very high neutron absorption cross section of ^{10}B and a very short range of $^{10}B(n,\alpha)^{7}Li$ reaction products comparable to cell radius. BNCT was first tried in 1950s but it failed because of low quality of boron compound and low level of irradiation technique. However, there was some success in Japan and the survival probability was reported to be much increased compared with that of other conventional method. With the success in Japan and improvement of effective boron compound and irradiation technique, BNCT was revived in USA and Europe in 1990s and use of epithermal neutron is studing because of the possibility of deep seated cancer treatment and no surgical operation.

Originally, BNCT was not included one of utilization area at HANARO. Through feasibility study for the possibility of BNCT and choice of beam tube[1,2], it was confirmed that only thermal BNCT is possible at the beam tube, called IR, reserved for low temperature material irradiation test if appropriate filtering system is installed.

In this paper, current design features for the thermal BNCT are described. Some future works are also given.

2. Design Criteria

To make the thermal BNCT effective, the thermal neutron flux, of course, should be high and noise of fast neutron and gamma-ray should be minimized as possible. Based on beam criteria of other BNCT facilities, design criteria at the irradiation position for the thermal BNCT at HANARO was set up as follows.

1) Thermal neutron flux, $\Phi_{th} > 3 \times 10^{9}$ n/cm^2-sec
2) Dose due to fast and gamma-ray, $D_f + D_\gamma < 2 \times 10^{-10}$ RBE-cGy/(thermal n/cm^2)
3) Patient irradiation time < 2 hours
4) No interruption to reactor operation

3. Proposed BNCT Facility

3.1 Radiation filter

First of all, materials for attenuating fast neutrons and gamma-rays were searched to minimize those without much loss of thermal neutrons. With the calculated spectrum at the nose from core calculation and parallel beam, attenuation effects for candidate materials were examined using Monte Carlo code MCNP4A[3]. Aluminium and silicon were considered for attenuating fast neutrons and bismuth for attenuating gamma-rays. After a couple of sensitivity calculations, 40cm long Si plus 15cm long Bi was chosen as a radiation filter. Expecially, Si and Bi were decided to be not only used in single crystal form but also maintained at liquid nitrogen temperatures (77K). This is because much more thermal neutrons penetrate the filter in single crystal at 77K compared to that in polycrystal at 300K due to low thermal neutron absorption cross section[4]. Cross section data of single crystals of Si and Bi for MCNP calculation were prepared by the nuclear data group at KAERI[5].

3.2 Water shutter and others

Water shutter of about 135cm length was positioned in front of the radiation filter for the purpose of shielding during reactor operation. While the shutter is filled in water during on-power, the radiation level in the irradiation room is sufficiently low for the preparation work for patient irradiation including temporary surgery. But the water in the shutter is drained during patient irradiation. Thus, the BNCT treatment does not interfere with the reactor operation.

Auxiliary shield was placed around the radiation filter to protect radiations scattered in the filter while the water shutter is open. Selected materials were ployethylene, borated polyethylene, LiF, Cd for thermal and fast neutrons and lead for gamma-rays. The proposed BNCT facility including radiation filter was drawn in Figure 1.

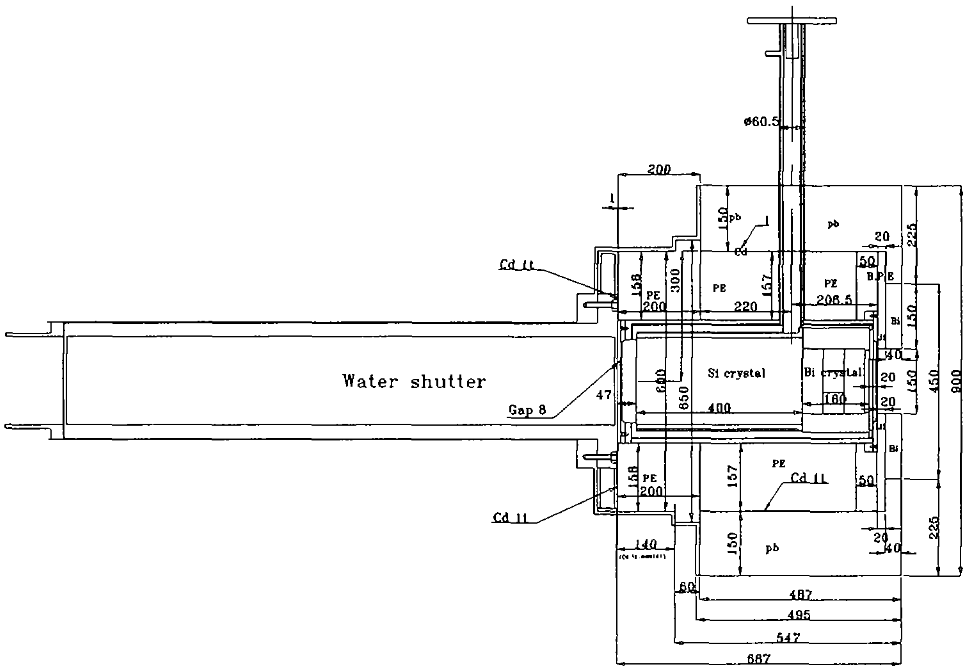

Figure 1. Proposed BNCT facility at IR beam tube in the HANARO

Boron concentration at biological samples can be determined by the prompt gamma-ray activation analysis (PGAA) detecting 478 keV gamma-rays emitted from $B^{10}(n, \alpha)Li^{7}$. Its determination is important to determine the absorbed dose at cancer and normal cells and irradiation time. A diffracted neutron beam is under consideration for this purpose to minimize background radiation level.

4. Calculated Radiation Levels at IR Tube Exit

The flux and absorbed dose of neutrons and gamma-rays for the proposed radiation filter in Fig. 1 were calculated using Monte Carlo code MCNP4B[6]. Even though long beam tube is not easy to be analyzed by a Monte Carlo calculation, whole beam tube was included in the MCNP model to track particles inside the tube as accurate as possible. It is assumed an isotropic source distribution at the beam tube nose. Geometry splitting with Russian roulette was employed to reduce variances of the results. The calculations were performed for two separate sources, that is, neutron plus secondary gamma-ray and prompt gamma-ray.

Since the MCNP gives the results per one source particle, an appropriate normalization factor should be used to get the absolute values. As a normalization factor in this calculation, the fluxes at the beam tube nose from the core calculation were used, which were calculated by assuming 200MeV and 2.442 neutrons released in each fission event and reactor power 30MW. As shown in Table 1, thermal neutron flux at the filter exit with phantom model is calculated to 7.2×10^{9} n/cm^{2}-sec, and dose of fast neutrons and gamma-rays per unit thermal neutron is 8.3×10^{-11} RBE-cGy/(thermal neutrons/cm^{2}) by assuming RBE (Relative Biological Effectiveness) values 5 for fast neutron and 1 for gamma-ray. Thus, design targets given in Section 2 are proved to be satisfied.

Table 1. Calculated fluxes and absorbed doses at phantom surface for radiation filter consisting of 77K silicon and bismuth single crystals

Beam tube exit condition		Air	Brain phantom	RBE
Thermal neutron flux (E<10 keV) (#/cm^{2}-sec)		2.76×10^{9}	7.20×10^{9}	
Dose (cGy/hr)	Fast neutron	6.96	34.2	5
	Gamma-ray	82.0	1984	1
Ratio (RBE-cGy/(thermal n/cm^{2}))[a]		1.2×10^{-11}	8.3×10^{-11}	

[a] (Dose due to fast neutrons and gamma-rays)/(thermal neutron flux)

5. Future Plan

Ongoing works and future plan are as follows

- Cooling capability using liquid nitrogen system under vacuum condition will be tested after making mockup of radiation filter of Si and Bi single crystals.
- Detail design of the water shutter and test
- Detail design of the prompt gamma-ray activation analysis system

- Detail design of the irradiation room based on the dose rate distribution in the irradiation room
- Measurement of the neutron and gamma-ray distribution at the IR tube exit
- Detail dosimetry analysis for effective patient treatment

The construction of this BNCT facility will be started from next year if it is permitted from the regulatory body this year. In completion of the BNCT facility, *in-virto and in-vivo* irradiation test will be started by medical doctors. It is anticipated that the patient treatment will be started from 2001.

References

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