SHIELDING ANALYSIS AT THE UPPER SECTION OF ACCELERATOR-DRIVEN SYSTEM

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A lead-bismuth target/cooled ADS for transmutation of minor actinides proposed by the Japan Atomic Energy Agency adopts a vertical injection of proton beam. In this configuration, the beam duct acts as a streaming path toward the upper section of subcritical core. In this analysis, two issues for radiation shielding related to ADS beam transport are discussed. Several magnets to control the profile and position of the beam are located above the subcritical core and the workmen for the maintenance of these magnets might access the high-dose area. We determined the allowable maintenance time just after the rated operation and obtained several tens of minutes for maintenance per person can be allowable according to the Japanese regulations. To enhance the maintenance time, additional shielding must be located around the upper plug for the beam duct. Our proposed ADS is designed as a tank-type layout of the subcritical core because of the usage of heavy liquid metal coolant. So, the steam generators which are located beside the beam duct have a potential of heavy irradiation by escaped neutron through the beam duct space. We investigated the activation of the secondary coolant and found that no specific addition of shields was required.

I. INTRODUCTION

The currently proposed accelerator-driven system (ADS) employs a vertical injection of a proton beam into the subcritical core (Ref. 1). The beam duct inserted into the subcritical core is several tens of centimeters in diameter to reduce the proton beam current density and is kept under vacuum. In such a configuration, the beam duct acts as a large streaming path for secondary neutrons and photons. On the upper deck, many devices for core cooling, fuel handling, and accelerator components are located and they are activated by streaming particles. Another important subcritical core configuration is the tank-type reactor vessel. The latest ADS adopts lead-bismuth alloy as a target/coolant material and mostly results in the tank-type vessel. In the tank-type core configuration, steam generators are located beside the fuel/reflector region. It may cause the activation of cooling water and may require the additional shielding for the secondary circuits. A streaming analysis of the beam duct to estimate the activation of the magnets and shield plug and irradiation of water in the steam generator are described.

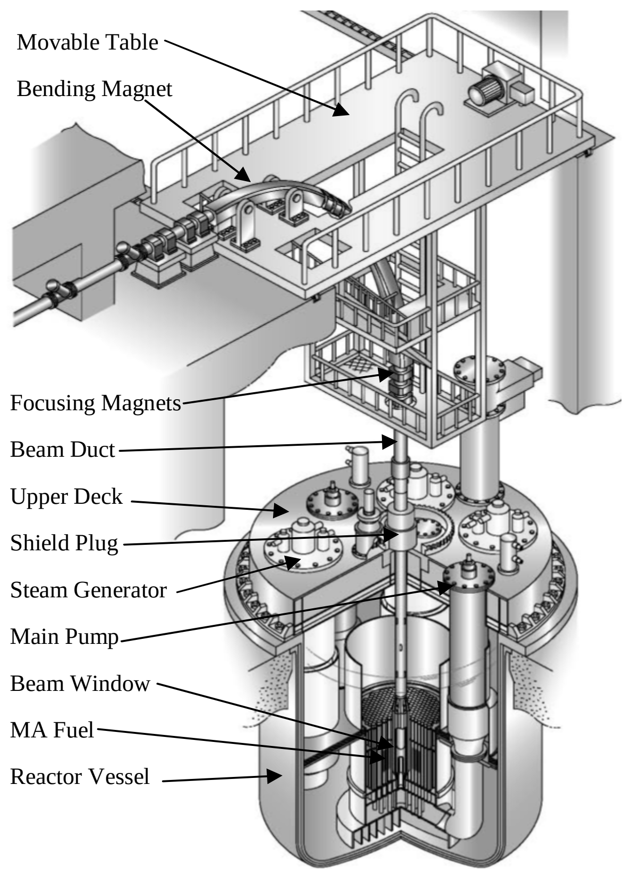

Fig.1 Subcritical Core Arrangement (Ref. 1)

II. DOSE EVALUATION AT THE UPPER SECTION

The JAEA-proposed lead-bismuth (Pb-Bi) target/cooled ADS is operated with 800MW of thermal output through injection of a 1.5GeV/20MW proton beam (Ref. 2). The layout around the subcritical core is illustrated in Fig.1. The beam duct is about 40cm diameter and is inserted at the center of the fuel region. Above the fuel region, the

Pb-Bi upper plenum and concrete upper deck are located. Three steam generators are located close to the fuel region. Other devices indicated in Fig.1 are mounted on the upper deck. It is important to estimate a radiation dose on the upper deck because the accelerator components require the regular personnel maintenance.

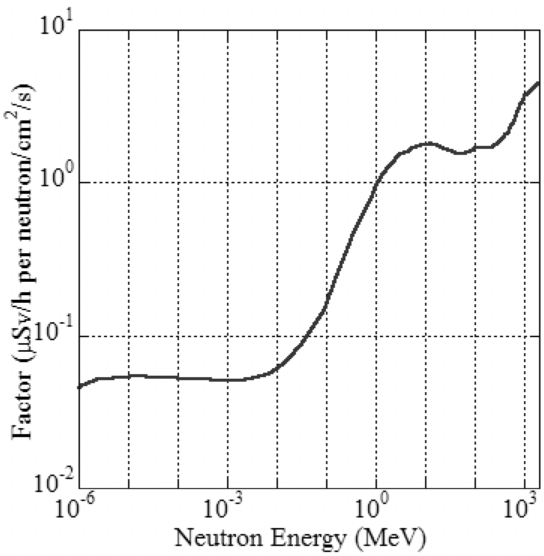

Fig.2 Dose Conversion Factor

II.A. Streaming Analysis through the Beam Duct

To obtain a detailed leakage particle spectrum, streaming analysis through the beam duct by the injection of 1.5GeV protons was performed. The MCNPX (Ref. 3) code and the dose conversion factor (Ref. 4) shown in Fig.2 were used for the analysis. A cylindrical analysis model is illustrated in Fig.3. The Weight Window technique was used to reduce the computation time to obtain a quality secondary particle source file at the bottom surface of the shield plug. For the generation of secondary photons, the cross sections of almost all minor actinides were substituted with those of plutonium data because of lack of gamma production cross section data in JENDL-3.2 (Ref. 5). Figure 4 summarizes the radiation dose rates of neutrons and photons with (Duct case) and without (Bulk case) the beam duct during the rated operation. The graph indicates that the radiation doses at the bulk case which corresponds to the leakage around beam duct give a rather low value because of the large amount of the Pb-Bi at the upper plenum region. However, at the top of the reactor, the neutron radiation dose through the beam duct gives about a factor of 20 higher dose rate than that of bulk case.

II.B. Activation and Accessible Time Evaluation

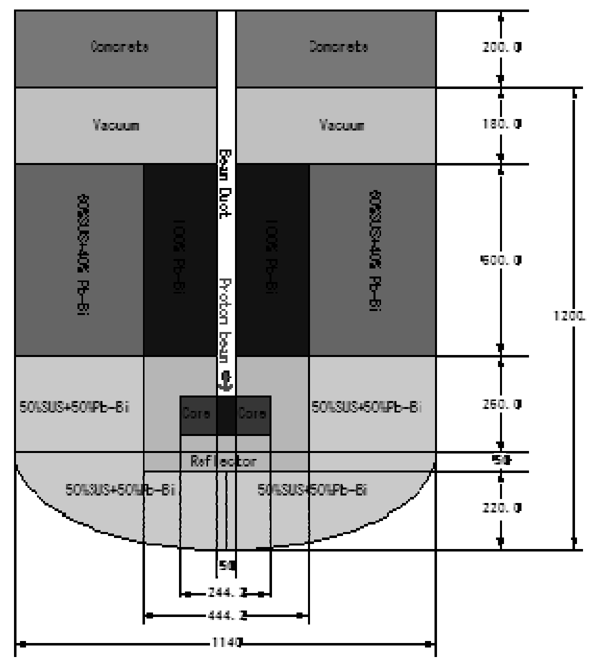

Fig.3 Calculation Model for MCNPX

Activation of the bending magnet, focusing magnets and shield plug was analyzed. The neutron spectrum at each device was obtained by PHITS (Ref. 6) using the neutron source mentioned above. Activation was calculated by DCHAIN-SP (Ref. 7). The proton beam power and operation period are 1.5GeV/20MW and 600 days, respectively. Figure 5 illustrates the two-dimensional calculation model. The calculation results are summarized in Fig. 6.

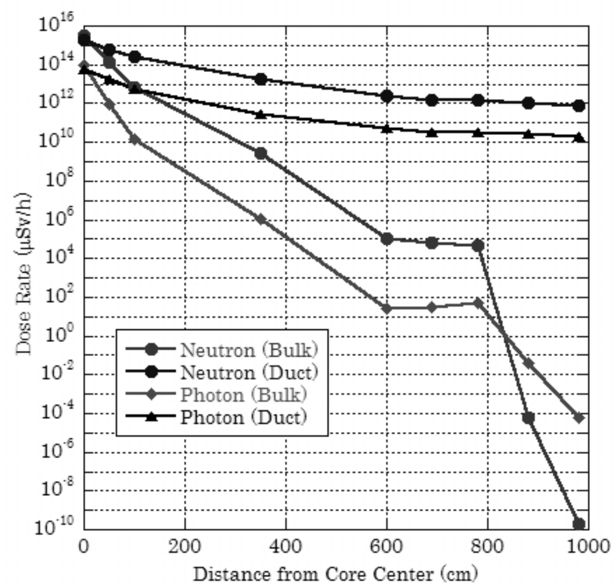

Fig.4 Axial Radiation Dose Distribution

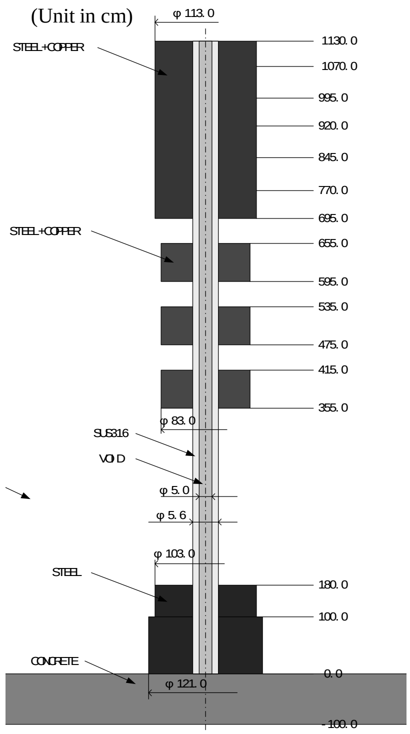

Fig.5 Analysis Model for PHITS

The results shown in Fig.6 indicate that the radioactivity of the shield plug is 10^{15} Bq during rated operation. Radioactivity of the shield plug is almost the same as that of the beam window of the Pb-Bi target/cooled ADS (Ref. 8). Focusing magnets also have high radioactivity. Additional shielding, therefore, must be required to reduce the irradiation by streaming particles.

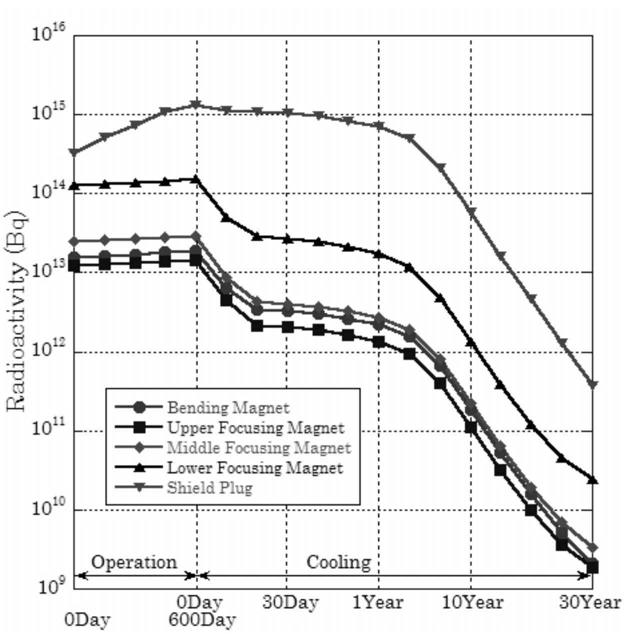

Fig.6 Time Evolution of Radioactivity

Using these activated sources, gamma-ray transport analysis was performed to determine the radiation dose to the workers during the maintenance period. The radiation doses were calculated at 3 time periods after system shutdown, ten days, thirty days, and one year. Figure 7 shows the radiation dose level at 10days after system shutdown in unit of mSv/h. From the figure, maximum radiation dose are found around the additional shield plug that exceeds 1Sv/h, and near the magnets are in order of 1 to 100 mSv/h. These high radiation doses are caused from components closed to the reactor, namely an additional shield plug and the lower part of the focusing magnet. These high dose rates are kept through one month because of the contribution of Fe-55 (2.7 years half-life) and Mn-54 (312 days half-life) generated from (n, gamma) reaction of Fe-54.

Compared with Japanese regulations, the radiation dose near the magnets gives a factor of 2 or 3 higher values. To suppress the radiation exposure of workers, the additional shield plug must be removed before the maintenance by remote operation. After the removal of the additional shield plug, about 10 to 30 minutes of maintenance time is allowable depending on the maintenance positions.

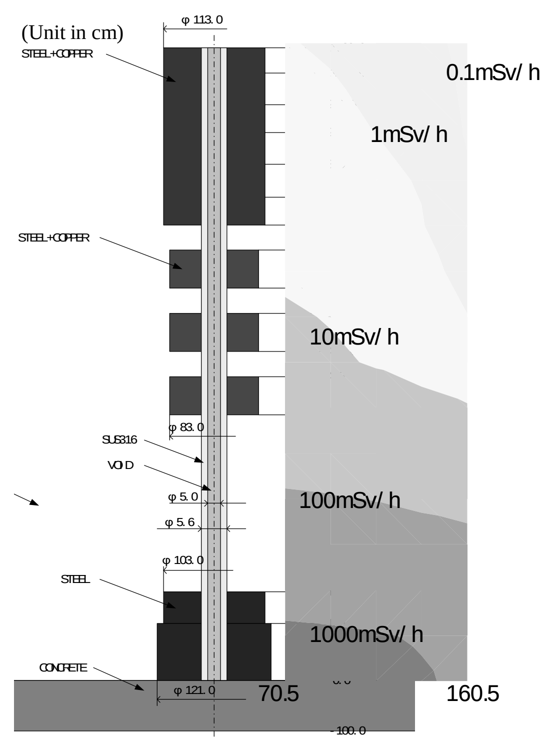

Fig.7 Radiation Dose around Upper Section

III. SHIELDING ANLYSYS OF THE SECONDARY COOLANT CIRCUIT

Because of the heavy weight of lead and bismuth, the JAEA-proposed ADS adopts a tank-type reactor vessel. The multi-loop configuration is used and cooling circuit components are located near the core barrel. The size of the steam generator is slightly large due to the maximum operation temperature to suppress the corrosion of structural materials. Considering these conditions, the activation of secondary coolant might be larger than that of other fast reactors. The analysis using MCNPX code with the LA150 library and the JENDL-3.2 based cross section library was performed to specify the requirement of secondary coolant circuit shielding.

Figure 8 indicates the two-dimensional cylindrical calculation model for MCNPX. Inside the core barrel was modeled in detail to determine the leakage neutrons reaching the steam generator. Material compositions of the inner structure of the core barrel were homogenized by referring to the fuel assembly structure and assembly layout. To conserve the computation time, the steam generator was modeled in a homogenized annular shape by taking into account the volumetric ratio of lead-bismuth, water and structural material. At first, reaction rates of O-16 (mainly a O-16(n, p)N-16 reaction) were calculated and then, the following formula was used to calculate radioactivity of reaction products;

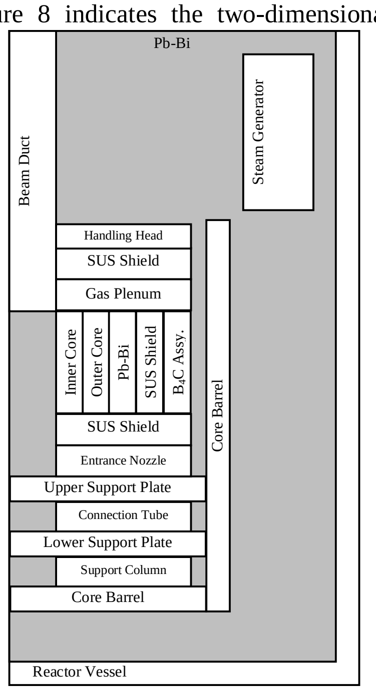

Fig.8 Analysis Model for MCNPX

$$A_i = \sum_g N_i \cdot \sigma_g \cdot \phi_g \frac{1-e^{-\lambda_i t_0}}{1-e^{-\lambda_i t}} \tag{1}$$

where

A_i : Activity of nuclide i in steam generator (Bq/gram),

g : Energy group number,

N_i : Number density of nuclide i (10^{24}/gramH_2O),

σ_g : Activation cross section of nuclide i (barn),

ϕ_g : Neutron flux in steam generator (n/cm^2·s),

λ_i : Decay constant of decay products of nuclide i (s^{-1}),

t : Round time of coolant in secondary loop (s), and

t_0 : Secondary coolant transit time in steam generator (s).

For the analysis of the radiation dose around the secondary loop, the dose rate calculation at the exit piping of the steam generator was performed using MCNPX code because of the short life time of N-16 (7.1 seconds half-life) by one dimensional cylindrical model. Figure 9 shows the neutron spectrum around the steam generator. The statistical error is too large in the high energy region, so the neutron flux in the 0.5 MeV region is extrapolated above the 2 MeV energy region to determine the reaction rates. By using the above mentioned formula, the N-16 concentration is determined to be 0.12 Bq/gramH_2O. Figure 10 illustrates the gamma-ray radiation dose around the piping. It is shown that the radiation dose at the outside of the piping is 0.002 μSv/h and therefore, no specific shields are required for secondary cooling circuits.

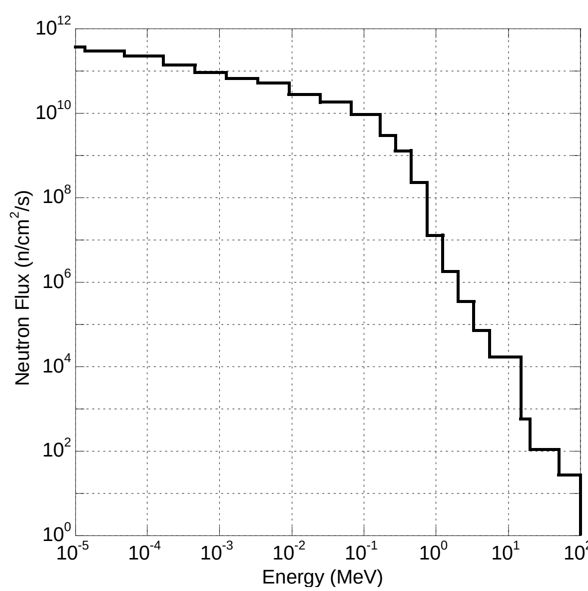

Fig.9 Neutron Energy Spectrum at Steam Generator

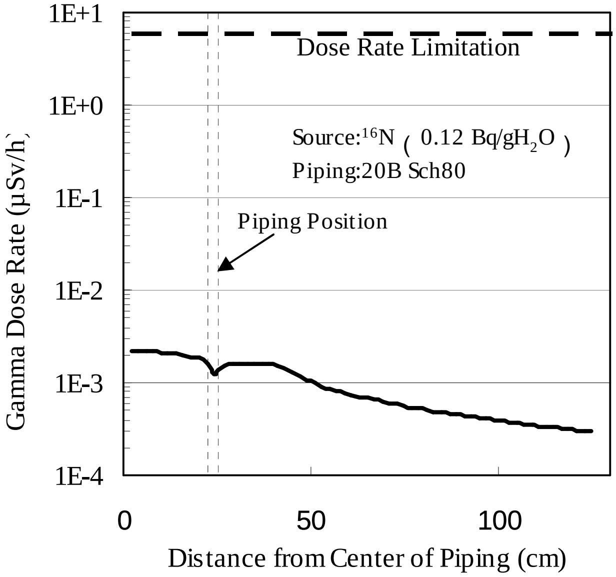

Fig.10 Gamma Dose Rate around Coolant Piping

IV. CONCLUSIONS

From Fig.4, the neutron radiation dose through the beam duct gives a higher activation dose than that of the bulk case. To suppress the leakage of particles, a narrower beam duct might be effective. However, to apply a narrower beam duct at the shield plug position, optimization of the beam transport components especially for the beam expansion section must be performed simultaneously.

The analysis of the activation of secondary coolant was performed. Even using the detailed core configuration, which takes into account the closed layout of secondary cooling circuit to the fuel region, the radiation dose caused by the activation of water/steam was not too high. In this case, Pb-Bi in reactor vessel acts as a shield. It indicates that no additional shielding is needed for secondary cooling circuits.

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