THE CHARACTERISTICS OF LEAD AND TUNGSTEN TARGETS USED IN THE ACCELERATOR-DRIVEN SUBCRITICAL REACTOR

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Abstract

The large proton accelerator program, KOMAC (*KO*rea *M*ultipurpose *A*ccelerator *C*omplex) is used mainly for the development of an accelerator-driven subcritical reactor. We are designing an accelerator-driven transmutation system which adopts 1 GeV, 20 mA proton beam and a fast spectrum reactor. The target system provides source neutrons inside the reactor. We select Pb and W as samples of the liquid and solid target materials respectively. Then we studied the basic characteristics of those target materials by using simulation programs. The basic properties we studied are the characteristics of neutron production and leakage, thermal properties and the activation of the target materials.

1 INTRODUCTION

Korea Atomic Energy Research Institute (KAERI) has been working on the conceptual design of the accelerator-driven transmutation system which is appropriate for transmuting mainly minor actinides. We will design a system adopting 1 GeV, 20 mA proton beam and a fast spectrum reactor.

A target system provides neutrons needed for the operation of a reactor under the subcritical state. We select Pb and Pb-Bi as the first option for our target system since the liquid target has an advantage in cooling. Since the liquid target may have the beam window problem, we study W and Ta as the second option for our target system. We choose the Pb and W for the study of basic characteristics of bare targets.

The basic physical properties we need to study are the following. 1) Neutron production and leakage. 2) Thermal properties. 3) Activation.

Since the basic physical properties of the target material vary according to the beam conditions and target geometry, we also check the effects of beam condition and target geometry on the target properties.

2 NEUTRON PRODUCTION AND LEAKAGE

We use LAHET Code System (LCS) [1] to study the characteristics of neutron production and leakage. We used ENDF/B-V for natural Pb and W.

We assume the cylindrical target and the proton beam is bombarded onto the top surface of the cylinder. We assume the diameter of the circular beam is 10 cm and the center of the beam coincides with the center of the top surface. We fixed the height as 50 cm and varied the diameter (10, 30, 50, 70, 90 cm) and the proton energy (0.5, 1.0, 1.5, 2.0, 2.5 GeV).

2.1 The effects of target diameter

Figure 1 is the plot of the result for 1 GeV beam. We counted neutrons with energy up to 100 MeV.

Since the neutron production per spallation is proportional to the atomic number of a nuclide, one Pb nucleus yields more neutrons than one W nucleus.

But the atom density of W is greater than Pb by a factor of about 2, and as a result, the spallation reaction rate of W is greater than Pb. Therefore, more neutrons are produced in W target.

As the diameter of the target increases, more neutrons are produced because high energy particles have more

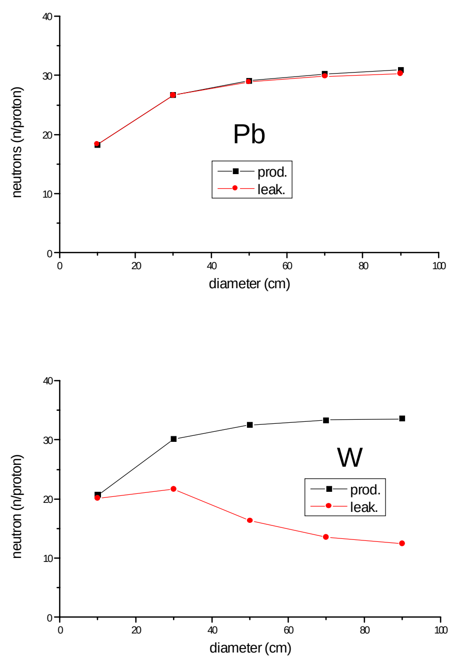

Figure 1: Neutron production and leakage as a function of target diameter (beam energy=1 GeV, height=50 cm).

chances of the neutron production reaction before they escape from the target. In the case of the Pb target, most of the produced neutrons escape from the target due to the low neutron absorption cross section. Therefore, the leakage also increases in the same way as the production does. The absorption cross section of W is larger than Pb, and more neutrons are absorbed before they leak.

2.2 The effects of beam energy

We calculated the neutron production of the cylindrical target at 5 different energies fixing the diameter at 30 cm. Both Pb and W produce about 10 n/p at the 0.5 GeV. As the beam energy increases, the neutron production increases almost linearly. But increasing rate decreases as the beam energy goes beyond about 1.0 GeV. When the beam energy is 2.5 GeV, the Pb and W target produce about 60 n/p and 80 n/p respectively.

3 THERMAL PROPERTIES

Since the large current beam is irradiated into the target in the subcritical reactor, the effectiveness of the heat removal from the target is one of the important things to be considered carefully. To know the heat generation and transfer, we need to use simulation codes.

We used LAHET for the simulation of heat generation. The beam is set to be 1 GeV and 1 mA with the circular shape (diameter=10cm). The cylindrical Pb and W targets are set to be 30 cm in diameter and 50 cm in height. The cylindrical target is divided in 15 cells, that is, 5 sections vertically and 3 sections horizontally. Figure 2 shows 15 cells and their cell numbers.

Table 1 shows the results of the heat deposition rate for each cell. Most of the heat is deposited in cells 1 and 2, and more than 50 % of the beam energy is deposited as heat in the target.

We can calculate temperature and velocity (in case of liquid target) from the LAHET result by using heat transfer code, and that work is under progress.

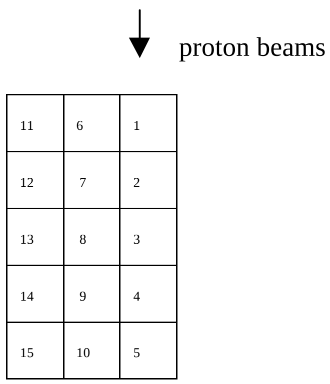

Figure 2: Cell numbers for left half of the cylinder

Table 1: Heat deposition rate for each cell.

cell	Pb	W
1	248 W/cm^3	382 W/cm^3
2	149	151
3	78	49
4	38	5
5	19	0
6	7	10
7	11	12
8	10	7
9	7	1
10	6	0
11	0	0
12	1	1
13	1	1
14	1	0
15	1	0
total	**529 MeV**	**541 MeV**

4 ACTIVATION

4.1 Calculation scheme

We studied the case of W target. The shape of the target is the cylinder with the size of 50 cm in radius and 100 cm in height. The beam is a 0.8/1.5 GeV, 30-mA proton circular beam with a radius of 40 cm. For this study, we use only LAHET to calculate the radioactivity due to the spallation process caused by protons and high-energy (>20 MeV) neutrons. LAHET gives the output of the production rate of activated nuclides, and that output is used for the calculation of the radioactivity by using ORIGEN2 (version 2.1) [2], which handles the decay scheme and the depletion by neutrons.

We set the irradiation time as 1 year and calculate radioactivities at 180 days, 2 years, 20 years and 100 years after the irradiation ends.

4.2 Results

Figure 3 shows the distribution of the number of activated nuclei per one proton as a function of the atomic number. From the figure, we can see the shapes of both distributions are similar, but the number of activated nuclei is increased by a factor of about 2.

The peak is at Z=74, which is the number of all W isotopes. The activation materials having Z number near Z=74 are produced due to the spallation process, where some neutrons and/or protons are ejected. Small Z number nuclides are produced by the high-energy fission, which tends to produce two fission fragments having similar Z numbers.

Figure 4 shows the results of the radioactivity calculation for both 0.8 and 1.5 GeV. In case of 0.8 GeV, the total radioactivity in 90 days after starting the irradiation is $1.2\times10^{+6}$ Ci

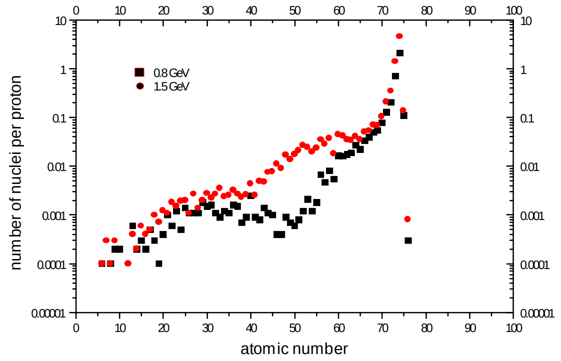

Figure 3: The distribution of the number of nuclei produced by activation as a function of atomic number for proton beam energies of 0.8 GeV and 1.5 GeV.

If there is no transition from other nuclides, the radioactivity of a nuclide at time *t* is $S - Se^{-\lambda t}$, where *S* is production rate and λ is decay constant. This means the increased rate of the radioactivity decreases over time. After the irradiation ends, the radioactivity decreases exponentially. The radioactivity of 0.8 GeV case is $5.7 \times 10^{+5}$ Ci in 180 days after the end of irradiation, which corresponds to 0.73 Ci/cm^3.

Since a nuclide with a short half-life and large production rate contributes predominantly to the total radioactivity during irradiation, nuclides such as W179 ($T_{1/2}$=38 min.), Ta178 ($T_{1/2}$=9.3 min.) etc. can also be

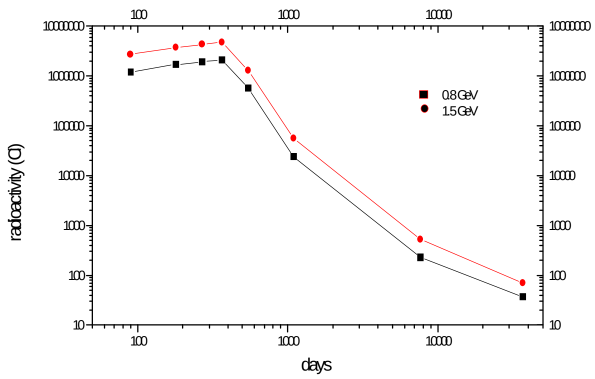

Figure 4: Radioactivity as a function of time

dominant nuclides during irradiation, but the ORIGEN2 decay library does not include these nuclides. As the result, the radioactivity due to these nuclides is not included. In addition, other nuclides, such as W178 ($T_{1/2}$=21.5 day), Ta179 ($T_{1/2}$=1.8 yr.), Hf172 ($T_{1/2}$= 1.9 yr.) etc., are missing in this library. Therefore the radioactivity due to these nuclides is not included in the total radioactivity shown in Figure 4. This means our calculation is somewhat underestimated. The radioactivity of a 1.5-GeV beam shows the same pattern as the 0.8-GeV case, except the radioactivity is increased by a factor of about 2.

5 CONCLUSION

KOMAC is the facility using a multipurpose 1 GeV, 20 mA proton accelerator. The accelerator will be used mainly for operating a subcritical reactor which is being designed for the transmutation of long-lived nuclides in the LWR spent fuel.

The neutron source target is located inside the subcritical reactor to provide extra neutrons needed for the reactor. Since the large current is required, liquid targets such as Pb and Pb-Bi are preferred. But liquid targets may cause the material problem related to the beam window , so solid targets such as W and Ta are considered as second option target materials. We are studying the basic characteristics of Pb and W by using simulation codes. In this paper, we present the following results.

1) Neutron production and leakage
: We calculated neutron production and leakage of the Pb and W cylindrical targets. We varied the diameter of the cylinder and proton energy to learn the effects of target shape and beam energy on neutron production and leakage.
2) Thermal properties
: We calculated the heat deposition rate in the Pb and W targets.
3) Activation
: We studied the kinds of nuclides produced in the W target due to the spallation process and calculated the radioactivity as a function of beam irradiation and cooling time.

We will continue to study the detailed characteristics of the target materials and design the target system appropriate for our subcritical reactor based on the results of the study.

6 REFERENCES

[1] R. E. Prael et al., User Guide to LCS : The LAHET Code System, Los Alamos National Laboratory, LA-UR-89-3014, 1986

[2] Radiation Shielding Information Center, ORIGEN2.1 Isotope Generation and Depletion Code Matrix Exponential Method, Oak Ridge National Laboratory, ORNL Report CCC-371