IRSTI 58.33.37 https://doi.org/10.26577/phst-2019-2-p8

Feasibility study of Tritium recoil barrier for neutron reflectors

E.Ishitsuka[1] and N.Sakamoto[2]

[1]*Sector of Fast Reactor and Advanced Reactor Research and Development, Japan Atomic Energy Agency (JAEA), 4002 Narita-cho, Oarai-machi, Higashi Ibaraki-gun, Ibaraki-ken, 311-1393, Japan*
[2]*NGK Insulators, Ltd., 2-56, Suda-cho, Mizuho, Nagoya 467-8530, Japan*
e-mail : ishitsuka.etsuo@jaea.go.jp

Tritium release into the primary coolant of the research and test reactors during operation had been studied, and it is found that the beryllium components used as a neutron reflector in the core strongly affect the tritium release into the primary coolant, and it is also found the recoil release from chain reaction of ^{9}Be is dominant. To reduce tritium concentration of the primary coolant, feasibility study of the tritium recoil barrier for the beryllium neutron reflectors was carried out, and the tritium recoils of various materials such as Al, Ti, V, Ni, Zr, etc., were calculated by PHITS. From these calculation results, it is clear that the thickness of tritium recoil barrier depends on the material and 20-40 μm is required for three orders reduction. Additionally, the denser materials have shorter recoil length in general, however, it is clear that the recoil lengths of Zr and Pb are similar with Ti.

Key words: primary coolant, tritium release, research and test reactors, beryllium, neutron reflectors, tritium recoil barrier.
PACS numbers: 28.50.Dr, 28.41.Bm.

1 Introduction

Tritium release into the primary coolant during operation of the JMTR (Japan Materials Testing Reactor) and the JRR-3M (Japan Research Reactor-3M) had been studied [1-9], and it is clear that the beryllium components used as a neutron reflector [10] in the core strongly affect the tritium release into the primary coolant. The sources and mechanisms for the tritium release into the primary coolant are evaluated by calculations of the MCNP [11], PHITS [12] and ORIGEN2 [13,14], and it is found that the recoil release [15,16] from chain reaction of ^{9}Be is dominant [17].

These studies show that the prevention of recoil release from beryllium is most effective to reduce the tritium release into the primary coolant. To prevent tritium recoil release, the surface area of beryllium neutron reflectors needs to be minimum in the core design and/or shielded with other material. In this paper, as the feasibility study of the tritium recoil barrier for the beryllium neutron reflectors, the tritium recoils of various materials were calculated.

2 Calculations of tritium recoil

Al, Ti, V, Ni and Zr shown in Table 1 are selected as the candidate materials from the viewpoint of low activation materials and forming intermetallic compound with beryllium [18]. The formation of the intermetallic compound considered that will prevent troubles such as peeling during the reactor operation. H_2O and Pb are selected as the reference materials.

The calculations of tritium recoil lengths were carried out by PHITS(Ver. 3.170) [12]. The calculation model for Al is shown in Figure 1. The tritium recoil was directly calculated using a triton (same meaning with tritium in this paper) source without the calculation of nuclear reactions [7], and small beryllium sphere is used in this model to get enough triton density even if short calculation time. The triton monochromatic energy (2.73MeV) of $^{6}Li(n_t,\alpha)^{3}H$ reaction is used in these calculations [7]. The material densities are used from reference [19,20]. 10^9 triton particles were generated in this calculation, and results are shown in Figure 2~ Figure 4.

2D distribution of triton flux is shown in Figure 2, and enlarged view near boundary is shown in Figure 3. 1D distribution of triton flux near boundary is shown in Figure 4. It is clear from this calculation that the recoiled triton reached to about 40μm in Al from the boundary.

Similar calculations were carried out with different materials shown in Table 1 which surrounding beryllium sphere. Calculation results of the triton recoil length in various materials are shown in Figure 5. From these calculation results, the recoil barrier thickness that reduced to 1/1000 are estimated, and shown in Table 1.

Table 1 – Density and recoil protetion thickness

Materials	Density (g/cm^3)	Recoil barrier thickness* (μm)
H_2O	0.99	59
Al	2.7	35
Ti	4.5	25
V	5.87	19
Ni	8.8	16
Zr	6.49	23
Pb	11.34	25

* : Thickness reduced to 1/1000

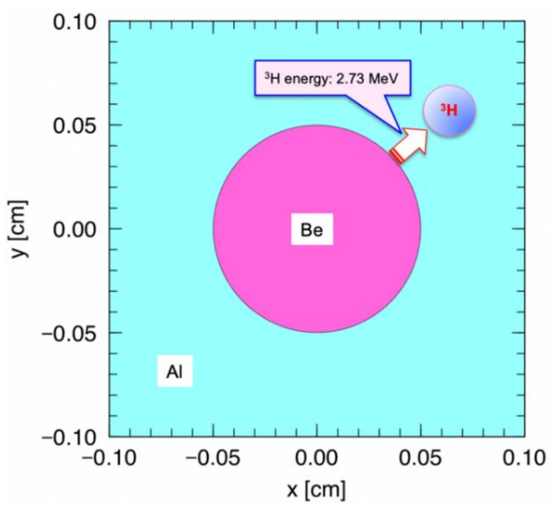

Figure 1 – Calculation model for Al

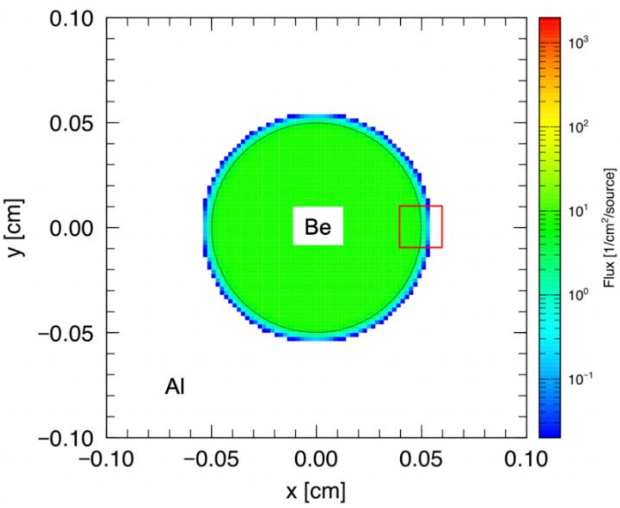

Figure 2 –2D distribution of triton flux

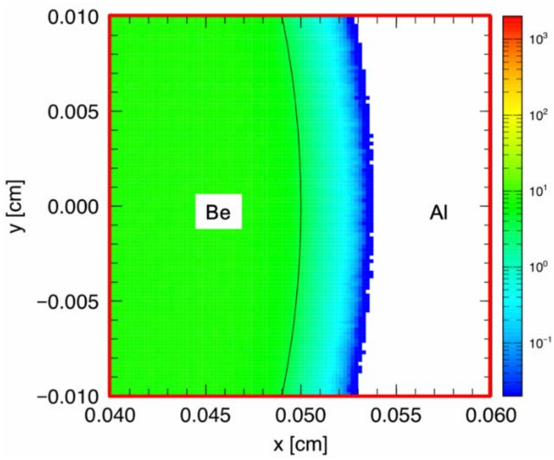

Figure 3 –2D distribution of triton flux near boundar

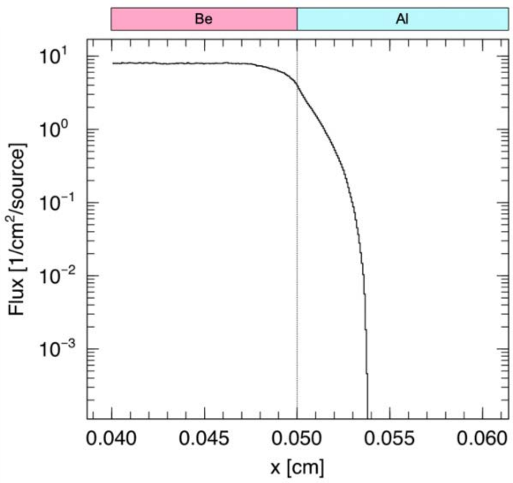

Figure 4 – 1D distribution of triton flux near boundary

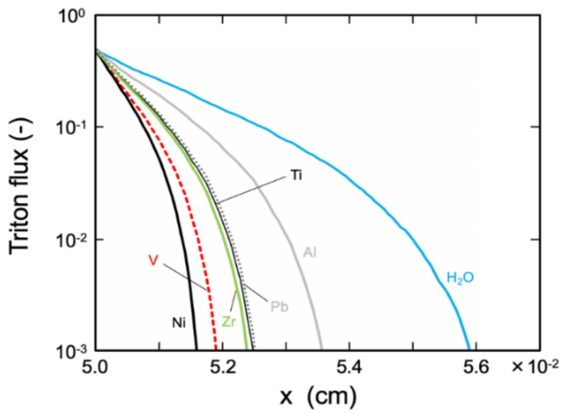

Figure 5 – Triton recoil lengths in various materials

3 Discussion

The denser materials have shorter recoil length in general, however, the triton recoil lengths of Zr and Pb are similar with Ti in these calculations. The tritium recoil release can be reduced by increasing the thickness of barrier. However, the tritium concentration in the primary coolant cannot be reduced to zero because tritium is also generated from the primary coolant. The tritium recoil release from beryllium is reported three orders of magnitude larger than that of the generated tritium from the primary coolant [17]. Therefore, the reduction performance of three orders of magnitude is sufficient as the tritium recoil barrier.

From the above calculation results, it is clear that the thickness of tritium recoil barrier depends on the material and 20-40 µm is required. As a next development step, the selection of materials in consideration of activation, the construction methods for the tritium recoil barrier, the stability under neutron irradiation, etc., will be listed.

4 Conclusions

As the feasibility study of tritium recoil barrier for the beryllium neutron reflectors, the tritium recoils of various materials were calculated, and the following results were obtained.

- The reduction performance of three orders of magnitude is sufficient as the tritium recoil barrier.
- The thickness of tritium recoil barrier depends on the material and 20-40 µm is required.

References

1. Terunuma, N., Nagao, Y., Yokouchi, I., & Sato, M. (2007). Concentration of Radio Active Elements in Primary Cooling Water at Reactor Operation of JMTR. JAEA-Review 2007- 034.
2. Department of Research Reactor. (1992). Annual Report of Department of Research Reactor, 1991 (April 1, 1991~March 31, 1992). JAERI-M 92-154.
3. Ishitsuka, E., Motohashi, J., Hanawa, Y., Komeda, M., Watahiki, S., Mukanova, A., Kenzhina, I., & Chikhray. Y. (2014). Study of Origin on Tritium Release into Primary Coolant for Research and Testing Reactors, -Tritium Release Rate Evaluated from JMTR, JRR-3M and JRR-4 Operation Data-. JAEA-Technology 2014-025.
4. Ishitsuka, E., Kawamura, H., Sugai, H., Tanase, M., & Nakata. H. (1990). Experiments on Tritium Behavior in Beryllium (2), - Tritium Released by Recoil and Diffusion-. JAERI-M 90-013.
5. Shimakawa, S., Ishitsuka, E., & Saito, M. (1992). HEINBE, The calculation program for Helium production in Beryllium under neutron Iirradiation. JAERI-M 92-174.
6. Kenzhina, I. et al. (2016). Evaluation of Curve for Tritium Release Rate into Primary Coolant of Research and Testing Reactors. 4th Asian Symposium on Material Testing Reactors, Hanoi, Vietnam, 3-4 March 2016.
7. Ishitsuka, E., Kenzhina, I., Okumura, K., Takemoto, N., & Chikhray, Y. (2016). Calculation by PHITS Code for Recoil Tritium Release Rate from Beryllium under Neutron Irradiation. JAEA-Technology 2016-022.
8. Sezaki, K., Takeda, K., Sakurai, F., Komukai, B., & Kondo, I. (1976). Correspondence between JMTR and JMTRC (No. 34 operation cycle) . JAERI-M-6686.
9. Ho H.Q., E. Ishitsuka. (2018). Calculation of tritium release from driver fuels into primary coolant of research reactors. Phys. Sci. Technol, 5 (2), 53-56.
10. Stonehouse, A.J. (1986). Physics and chemistry of beryllium. J.Vac.Sci.Technol, A3(3), 1163-1170.
11. Goorley, T. et al. (2012). Initial MCNP6 Release Overview. Nuclear Technology, 180-3: 298-315.
12. Sato, T., Niita, K., Matsuda, N., Hashimoto, S., Iwamoto, Y., Noda, S., Ogawa, T., Iwase, H., Nakashima, H., Fukahori, T., Okumura, K., Kai, T., Chiba, S., Furuta, T. & Sihver, L. (2013). Particle and Heavy Ion Transport Code System PHITS, Version 2.52. J. Nucl. Sci. Technol, 50:9, 913-923.

13. Suyama K. (2006). ORIGEN2.2-UPJ: A complete package of ORIGEN2 libraries based on JENDL-3.2 and JENDL-3.3. OECD NEA Data Bank: NEA-1642.

14. Okumura K, Sugino K, Kojima K, Jin T, Okamoto T, & Katakura J. (2012). A set of ORIGEN2 cross section libraries based on JENDL-4.0: ORLIBJ40. JAEA-Data/Code 2012-032.

15. Ward, J.C. (1961). Radioactivity of Nuclear Reactor Cooling Fluids, ORNL-3152.

16. Schmitt, R.A., & Sharp, R.A. (1958). Measurement of the range of recoil atoms. Third-Annual Radiation Effects Symposium, III (October, 1958).

17. Ishitsuka, E., Kenzhina, I., Okumura, K., Ho Hai Quan, Takemoto, N., & Chikhray, Y. (2018). Calculations of tritium recoil release from Li and U impurities in neutron reflectors. JAEA-Technology 2018-010.

18. Webster, D., & London, G.J. (1979). Beryllium Science and Technology, vol.1.

19. Table of Isotopes, 7^{th} ed. (1978). Joho Wiley & Sons. Inc.

20. Murakami, S., et.al. (Eds.), (1982). Radiation data book. Chijinsyokan (in Japanese).