Transactions of the Korean Nuclear Society Autumn Meeting
PyeongChang, Korea, October 30-31, 2008

Sensitivity Study on the Target of the Fast Neutron Sources for the Lead Slowing Down Time Spectrometry with a Monte Carlo Simulation

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1. Introduction

A lead spectrometer has been used to analyze a spent fuel assay to quantify the contents of the fissile isotopes. It is based on the neutron slowing down time method which exhibits different energies which have proportional to the inverse of square time.[1]-[3] Because it requires a high intensity of a neutron source to have a sufficient resolution of the induced fission neutrons from the fissile materials, a linear electron accelerator is widely used. Fast neutron sources are obtained from the target with the combined reaction of the Bremstrahlung effect such as the (e,γ)(γ,n) reaction. It is known that the efficiency in the Bremstrahlung effect strongly depends on the target material and geometry.[4] Additionally, a cooling system of the target should be considered due to a high heat deposition from the high energy of the electron sources. Thus, a set of thin plate type targets was considered to ease with an air or a gas cooled between plates. Another approach is a liquid type target which uses a natural convection. In this study, a plate type of target was considered to optimize the geometry of the target to provide a sufficient neutron source for the lead spectrometer. Several variations of the target are tested with a Monte Carlo simulation for a detailed application for the target.

2. Method and results

Four different parameters were considered in this study: target material, source electron energy, thickness, and radius. The first test was performed with six different elements for the candidate target materials. The calculation was performed via a MCNPX code[5] with a cylindrical geometry of the target and a mono spectrum electron source problem. Fig. 1 shows the neutron tally for the different elements. It is known that the neutron yield increases in proportion to the element mass number (Z) with some irregularities such as a nuclear deformation and a reaction threshold. Around W(Z=74), the neutron yield starts to decrease again with an exception of the uranium. The results in Fig.1, it can be found that the heavier elements produce more neutrons due to larger isotopes with a higher cross section for the gamma reactions. The second test was to check on the effect from the variation of the electron source energy and the thickness of the target. The target was chosen as tantalnium with a conventional reason such as its stability and high thermal conductivity, especially its low price. The price of tantalnium is about a fifth of tungsten. The electron energy was chosen as 20 and 35 MeV. Fig. 2 shows the energy dependent neutron tallies with a variation of the target thickness. The high energy electron provides a higher neutron yield and the neutron yield increases first then saturates as the thickness of the Ta target increases up to 2 cm. The third test was done for the variation of target thickness with five thin plates with air-cooled gaps. Total five types were chosen to investigate an optimal thickness change with the energy deposition in the target material and the total thickness was equally set to be 2 cm. The energy deposition in the cell was obtained with the F6 tally in the MCNP calculation. Table I shows the energy deposition for the different five types. Among them, type 2 provides the best results with high neutron yields and low energy depositions. With an increasing thickness, a bigger fraction of electrons is stopped and more photons are created and more neutrons yield. This increase saturates when all electrons are stopped and an optimal thickness exists for various target materials. The energy deposition for the first cell may well be the highest then decreases with the propagation of the electrons. Thus, like type 2, increasing thickness provides the most preferable option to release the heat due to high energetic induced electrons. The last test was performed with various radius of the target which has the same thickness like type 1. Total 4 types were considered and the results are given in Table I. In this test, the total energy depositions per a cell are similar due to the same thickness. However, the energy deposition per a cell weight is different. Among several types in this test, the type 6 provides the best results with high neutron yields. This cone type is natural for the particle transport with an isotropic and anisotropic scattering. The neutron yields and deposition energies for the various types in test three and test four. From the results, type 2 provides 9.63E-03 n/s and type 6 provides 9.26E-03 n/s. A combined type 2 and type 3, by increasing the thickness and radius in the direction of the source, will be an optimal target to provide a neutron source from a linear electron accelerator.

3. Conclusion

In this study, several sensitivity tests were performed with various target materials, thicknesses, radius, and induced electron energies with a Monte Carlo calculation. From the results, the following results were obtained: (a) A higher mass number of a target provides a higher neutron yield. There is an optimal mass number around tungsten. (b) A higher electron energy provides more photons and neutrons. But there is an additional cooling problem to be solved in the target. (c) The plate type of a tantalnium target with an increasing thickness provides less energy deposition and higher neutron yields. (d) The plate type with an increasing radius in the direction of an electron source gives higher neutron yields.

As a conclusion, there are lots of works to be done for a target design by considering the thermal and mechanical properties as well as the neutronics characteristics.

Acknowledgements

This work has been carried out under the Nuclear Research and Development program of the Korea Ministry of Science and Technology.

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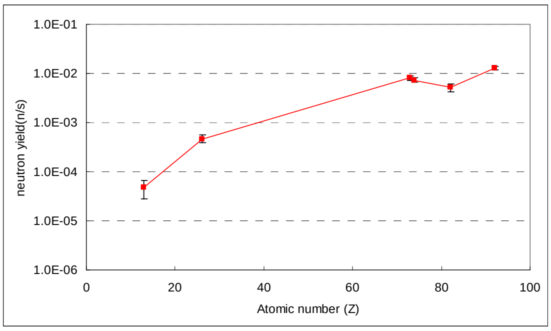

Fig. 1 Neutron yield for the 35 MeV electron source for various target materials.

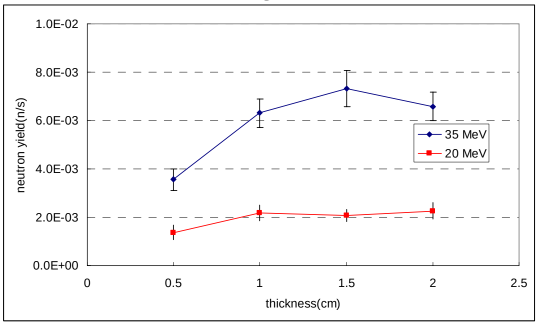

Fig.2 Neutron yield of the Ta target with 20 and 35 MeV electron sources with various thicknesses.

Table I. Results for the Various Ta Target Types

Types	Thickness Radius	Neutron (n/s)	Energy Deposition (J/g, J)				
			Cell 1	Cell 2	Cell 3	Cell 4	Cell 5
1	(4-4-4-4-4)[a] (5-5-5-5-5)[b]	8.29E-03[c] 6.39E-04[d]	5.37E-15[e] 2.80E-12[f]	4.12E-15 2.15E-12	2.05E-15 1.07E-12	1.40E-15 7.28E-13	9.63E-16 5.02E-13
2	(2-3-4-5-6) (5-5-5-5-5)	9.63E-03 8.31E-04	4.31E-15 1.12E-12	6.15E-15 2.41E-12	3.31E-15 1.73E-12	1.76E-15 1.15E-12	1.07E-15 8.38E-13
3	(6-5-4-3-2) (5-5-5-5-5)	8.14E-03 6.28E-04	5.27E-15 4.12E-12	2.57E-15 1.68E-12	1.53E-15 7.98E-13	1.11E-15 4.34E-13	8.57E-16 2.23E-13
4	(3-4-6-4-3) (5-5-5-5-5)	8.71E-03 7.49E-04	5.00E-15 1.96E-12	5.01E-15 2.61E-12	2.11E-15 1.65E-12	1.28E-15 6.67E-13	9.14E-16 3.58E-13
5	(5-4-2-4-5) (5-5-5-5-5)	9.01E-03 9.44E-04	5.43E-15 3.54E-12	3.32E-15 1.73E-12	2.01E-15 5.24E-13	1.52E-15 7.93E-13	1.01E-15 6.60E-13
6	(4-4-4-4-4) (3-4-5-6-7)	9.26E-03 7.13E-04	1.48E-14 2.79E-12	6.40E-15 2.14E-12	2.05E-15 1.07E-12	9.74E-16 7.32E-13	4.95E-16 5.06E-13
7	(4-4-4-4-4) (7-6-5-4-3)	5.91E-03 4.55E-04	2.74E-15 2.80E-12	2.86E-15 2.15E-12	2.05E-15 1.07E-12	2.16E-15 7.20E-13	2.55E-15 4.79E-13
8	(4-4-4-4-4) (7-5-3-5-7)	8.33E-03 6.71E-04	2.74E-15 2.81E-12	4.11E-15 2.14E-12	5.56E-15 1.04E-12	1.37E-15 7.15E-13	4.90E-16 5.01E-13
9	(4-4-4-4-4) (3-5-7-5-3)	5.64E-03 4.85E-04	1.48E-14 2.79E-12	4.11E-15 2.14E-12	1.05E-15 1.07E-12	1.40E-15 7.28E-13	2.55E-15 4.79E-13

[a] Thickness(mm), [b] Radius(cm), [c] Mean, [d] Standard deviation,
[e] Energy deposition per weight(J/g), [f] Energy deposition (J).