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Technical Note

Metal plate target design for the lead slowing down time spectrometer (LSDTS)

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ABSTRACT

A better technology for lead slowing down time spectrometer (LSDTS) has been developed to quantify the fissile isotopes in any kind of nuclear fuels. A linear electron accelerator is usually considered due to its high efficiency neutron production and a flexible size depending on the beam power. Neutrons produced from the collision between the electron beam and a metal target propagate into the lead medium and finally react with the fissile isotope. In order to have a marginal resolution of the induced fission neutron from the fissile isotope and to have a high statistical accuracy of the measured signal for fissile isotope analysis, it is required to have a high intensity neutron source through the proper target design. In this study, parameters of plate shaped metal targets are investigated with Monte Carlo calculations. Some experimental results are also provided to verify the target design of LSDTS.

1. Introduction

The lead slowing down time spectrometer (LSDTS) technology has been developed to analyze a spent nuclear fuel assay or a recycled fuel. It enables a direct and real time investigation of the contents of the fissile isotopes in any kinds of nuclear fuels (Krinninger et al., 1969; Radulescu et al., 1999). The neutron slowing down time method exhibits different energies proportional to the inverse of time square (Lee et al., 1999; Rochman et al., 2005). Because a high intensity of a neutron source is required to ensure a high statistical accuracy of the measured data for a good resolution of the fissile isotopes, accelerators are widely used. Among several accelerators, an electron accelerator is the first priority due to its compact size depending on the beam power. Fast neutron sources are obtained from a metal target with the combined reaction of the Bremstrahlung effect such as the $(e,\gamma)(\gamma,n)$ reaction. It is well known that the efficiency of the Bremstrahlung production strongly depends on material and geometry of target (Baltateanu et al., 2000).

However, a cooling system for the target should be considered additionally because of a high deposited heat which comes from the high energy of the electron and secondary gamma and neutron sources when introducing a high power of the incident electron beam. Therefore, a set of thin plates has been proposed to cool target easily by providing a coolant flow channel between thin plates. Another prevalent approach for the higher energy neutron is to use a liquid metal target which is good for a natural convection cooling. The hydrogen in the water moderate neutron significantly, which is not good characteristics in LSDTS. Only a few collisions, neutron will be slowed down to the thermal energy range and it is poor to use the slowing down time spectrometry. Thus water cooling is not recommended in LSDTS system. In this paper, a metal target is proposed by changing the number of plates and the shape and the gap between plates in order to optimize the neutron production capability. The computational simulations are also carried out with a Monte Carlo method for evaluation of design parameters of the target. Furthermore, a couple of sample targets have been tested in the test linear accelerator (LINAC) in PAL (Pohang Accelerator Laboratory). Total rate of neutron production is compared for various shapes of sample targets to confirm the target design.

In Section 2, some results of the target design are described including several sensitivity tests. The experimental results with a test LINAC in PAL are provided in Section 3. Finally, the conclusion is presented in Section 4.

2. Target design for neutron source

The main objectives of the target design for the LSDTS are high neutron yield, structural robustness, good thermal performance, low radiation activation, and easy maintenance. Therefore, several designs of photon neutron targets have been carried out (Baltateanu et al., 2000) however, the target design presented here is performed by varying several parameters for both geometry and material. And they have found that the neutron yield increases in

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Table 1
Maximum intensity for different elements.

Maximum neutron intensity (n/s)						
Al35 MeV[a]	Fe35 MeV	Ta35 MeV	W35 MeV	U35 MeV	Ta20 MeV	Ta50 MeV
2.59E−04 0.0302[b]	3.25E−03 0.0176	1.81E−02 0.0262	2.03E−02 0.0251	4.05E−02 0.0211	5.17E−03 0.0464	2.92E−02 0.0211

[a] Incident beam energy.
[b] Fractional standard deviation (FSD, relative error).

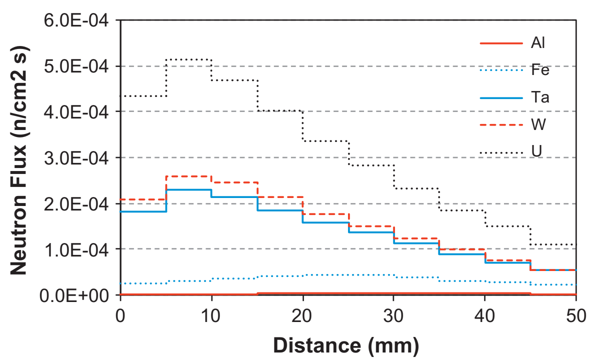

Fig. 1. Neutron yields for various elements for a simple cylindrical geometry.

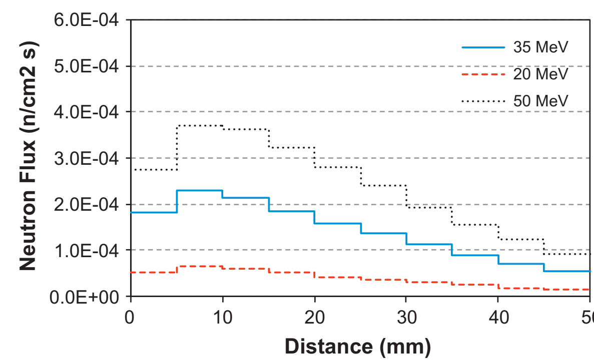

Fig. 3. Neutron spectra for Ta targets with various electron beam energies.

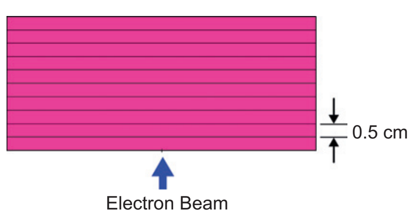

Fig. 2. Configuration of lump target model.

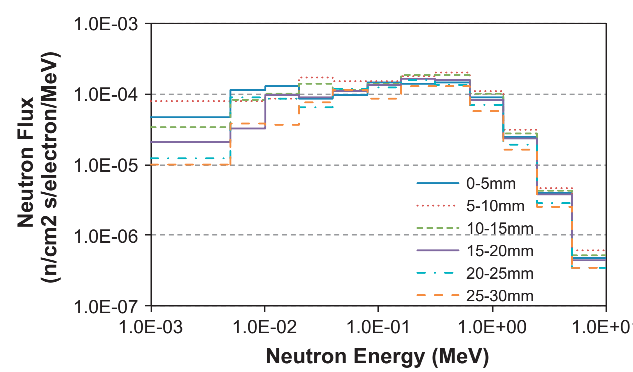

Fig. 4. Neutron spectra for various thickness of Ta target with 35 MeV electron beam energy.

proportion to the element mass number (Z) with some irregularities such as a nuclear deformation and a reaction threshold. The maximum neutron yields are obtained around tungsten (W, $Z = 74$), and after that the neutron yield starts to decrease again with an exception of the uranium (U, $Z = 92$). For simulation, the MCNPX code (Pelowitz, 2005) is used, which is based on the Monte Carlo particle transport method. A multiple mode option is used such as 'mode n p e' in the MCNPX to simulate electron, photon, and neutron simultaneously and the ENDF7U library is also used to accommodate the photonuclear reaction in metal target. However, it takes long computing time compared to a single mode problem, thus some calculations are performed in a parallel LINUX cluster system.

Table 2
Plate radius and thickness for various cases.

Cases	Type	Radius (cm)	Thickness (mm)
Case1	Plate	3–4–5–6–7	2–3–4–5–6
Case2	Plate	5–5–5–5–5	2–3–4–5–6
Case3	Plate	7–6–5–4–3	2–3–4–5–6

2.1. Target material selection

In order to test metal targets, several elements are considered for a simple cylindrical geometry. Total six elements are provided for an evaporated neutron source such as Al, Fe, Ta, W, Pb, and U. The thickness and radius of target is assumed to be 1.5 cm and 5 cm, respectively. The incident electron beam energy is 35 MeV and the point source is assumed for simulation. The cell flux is obtained for a certain mesh of the cylindrical target with F4 card in the MCNPX code. The particle number is given 5E+05 and the relative error of the flux is obtained about 0.03 for Ta target in Table 1. Fig. 1 shows the neutron yield for various elements. From the results, the neutron yields of metal targets distribute from 1E−5 neutrons/s to 1E−2 neutrons/s when assuming that one electron is incident to the metal target. The maximum neutron yield happens around W and Ta elements and the neutron yield increases again around U elements. Table 1 shows the estimated maximum neutron intensity for different elements. Among several elements, U and W provide the maximum neutron production capability. However, a safeguard equipment should be installed if a U target is considered for LSDTS system and additional remote system is required for the fission fragments contamination.