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Development of a Neutron TOF Facility at KAERI

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KAERI (Korea Atomic Energy Research Institute) is developing a neutron TOF facility by using KAERI's electron accelerator. KAERI has a superconducting electron accelerator which can produce 17 MeV pulsed electron beams with a pulse width of 20 ps. The pulse current and maximum frequency of the electron accelerator are 20 A and 2 MHz respectively. Fast neutrons can be used for cross-section measurements. A short pulse width can provide a good neutron energy resolution for fast neutrons at relatively short flight lengths. The time resolution related to a neutron source target should be small enough to utilize the short pulse width. We adopted the liquid Pb target which was developed by HZDR (Helmholtz-Zentrum Dresden-Rossendorf). The first step of the neutron source development is to simulate a neutron production. MCNPX was used to simulate the neutron production when electron beams irradiate the Pb target. Those simulations were performed by varying beam energies and target sizes to find out optimal variables related to the beam and target. The information of heat deposition in the target was studied by MCNPX since a proper cooling system should be considered to operate the liquid Pb target safely. The thermal-hydraulic analysis was performed based on the result of heat deposition calculation. The study of the detection system is under progress. The design of an experimental hall and a collimator system is also being progressed with the development of the detection system.

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I. INTRODUCTION

Nuclear data is essential in developing technologies and facilities related to nuclear physics and nuclear engineering. The nuclear data can be obtained by performing experiments or evaluations based on experimental data and some theory. Therefore, nuclear experimental data can be the basis of many areas of nuclear engineering. Although nuclear data experiments have been performed for long time, the updated data are still being requested and will be requested in many areas such as medical application, ion beam analysis, nuclear astrophysics, nuclear safeguards, radiation shielding, critical reactors and accelerator-driven subcritical reactors [1].

There are different types of nuclear data according to the particle types of initiating nuclear reactions. Nuclear data related to neutron induced reactions are most important since it can be used in developing nuclear reactors. In the past, experiments were focused on nuclear data of thermal neutron reactions. Now, nuclear data of fast neutron reactions is also of interest since fast reactors are being developed and will be constructed throughout the world in the near future [2].

KAERI plans to develop a TOF neutron source to perform nuclear data experiments related to fast neutron reactions. The KAERI neutron source is based on a 17 MeV electron accelerator. A liquid Pb target without a moderator is considered to produce fast neutrons by a photo-neutron reaction. In this paper, the concept of KAERI neutron source and some calculation results are described.

II. CONCEPTUAL DESIGN OF A TOF FACILITY

KAERI has been operating a superconducting electron accelerator. Table 1 shows the main parameters of the accelerator. KAERI electron accelerator has been used to irradiate materials with electron beams mainly for industrial purposes. Electron beams with different energies were used to investigate radiation damage, surface modification, material development *etc.*.

The pulsed electron beam can be accelerated up to 17 MeV with a maximum frequency of 2 MHz. The pulse frequency is variable, but the pulse current is fixed as 20 A. If the accelerator is operated with the maximum

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Table 1. Main parameters of KAERI electron accelerator.

Beam energy	17 MeV
Pulse width	20 ps
Pulse current	20 A
Pulse frequency	Max. 2 MHz
Beam power	Max. 13.6 kW
Average current	Max. 0.8 mA

frequency, the average current and beam power are 0.8 mA and 13.6 kW respectively. The pulse width of the beam is about 20 ps, which is very small compared to other conventional electron accelerators. Therefore, a good neutron energy resolution can be achieved in a relatively short flight length, which increases a neutron flux at a measurement position. Since the energy resolution is decided by time uncertainties related to the beam, target and detector system, a neutron production target should be compact. We adopted the liquid Pb target developed by HZDR [3]. HZDR liquid Pb target was designed to dissipate the deposited heat up to 25 kW [4] while the time resolution due to the target is less than 1 ns [3]. Equation (1) is the neutron energy resolution of the TOF measurement for the non-relativistic case.

$$\frac{\Delta E}{E} = \frac{2\Delta T}{T} = \frac{2\sqrt{(\Delta T_{Target})^2 + (\Delta T_{Detector})^2}}{T} \quad (1)$$

T is the flight time and ΔT is the uncertainty of the flight time measurement. ΔT_{Target} and $\Delta T_{Detector}$ are the uncertainties due to the target and detector respectively. If ΔT_{Target} is 1 ns with the assumed $\Delta T_{Detector}$ of 1 ns, the energy resolutions is 0.4% for 1 MeV neutrons with a flight length of 10 m. The time resolution due to the pulse width was not considered since the pulse width of 20 ps is ignorable compared to the time resolutions due to the target and detector. The flight length of KAERI TOF facility is about 10 m.

An appropriate pulse repetition rate should be determined to avoid overlap of successive neutron pulses. Once a repetition rate is given, we can calculate the neutron flight time at which a pulse starts overlapping the previous pulse. If the repetition rate is 500 kHz with a flight length of 10 m, 130 keV is the neutron energy at which a pulse overlapping happens. In that case, neutrons with energy lower than 130 keV may not be used for measurements. If the repetition rate is changed to 100 kHz, the corresponding neutron energy becomes 5 keV.

KAERI's superconducting electron accelerator produces pulsed electron beams with a fixed pulse current Therefore, the average current is decreased if the repetition rate is decreased When the repetition rate is 500 kHz, the available beam power is 34 kW, which is 25% of the maximum beam power of the KAERI electron accelerator. Table 2 shows the characteristics of KAERI TOF facility.

Table 2. Characteristics of KAERI TOF facility.

Target	Liquid Pb
Flight length	10 m
Repetition rate	<500 kHz

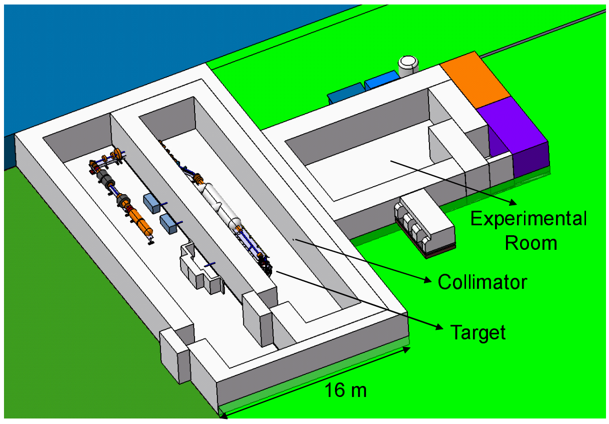

Fig. 1. (Color online) TOF facility to be constructed in the first phase.

Figure 1 shows the conceptual design of the TOF facility to be constructed in the first phase. There is an accelerator building where the 17 MeV electron accelerator is located. It is planned to construct a new building which will be used as an experimental hall. The liquid Pb target system will be constructed and placed at the end of the electron beam line. A collimator system will be installed between the accelerator building and experimental room. Figure 2 shows the conceptual design of the TOF facility to be constructed in the second phase. An additional acceleration system will be installed to increase the beam energy up to 30 MeV with a increased beam current. In the second phase, a separate target room will be constructed and a collimator will be installed between the target room and experimental hall. The detailed dimensions of the target room and experimental room will be decided after shielding calculations are finished.

III. TARGET CALCULATIONS

In a liquid metal target system, liquid metal is circulated through a closed loop. The heat deposited by electron beams is transferred through a secondary cooling loop. KAERI liquid Pb target system was designed based on the HZDR liquid Pb target system [3]. Figure 3 is the design of the liquid Pb target system. Pb is contained in a sump tank. The height of the target is about 2 m. The amount of Pb contained in the sump tank is about 400 kg. Liquid Pb in the sump tank is pressurized by Ar gas to be inserted into the loop in the operational mode.

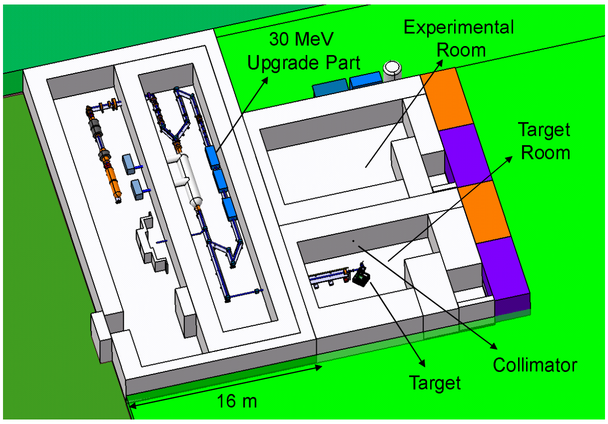

Fig. 2. (Color online) TOF facility to be constructed in the second phase.

After the loop is filled with liquid Pb, an electromagnetic pump forces liquid Pb to be circulated through the loop. The velocity of liquid Pb is measured by an electromagnetic flow meter. The loop is made of stainless steel pipes except the beam irradiation part. The beam irradiation part is made of Mo since Mo has high fracture strain and thermal conductivity [3]. When the liquid Pb is irradiated by a 17 MeV electron beam to produce neutrons, heat is also deposited. The deposited heat is dissipated through a heat exchanger. The heat exchanger adopts InGaSn coolant. The deposited heat is transferred to InGaSn coolant first, and in turn water coolant dissipates heat from InGaSn.

A thermal-hydraulic calculation was performed to estimate appropriate operational conditions. MCNPX 2.5.0 code was used to calculate the heat deposition in the target. The Pb target has a shape of 1.6 cm (width) ×1 cm (depth) ×2 cm (height). The Pb target is surrounded by a 0.5 mm thick Mo pipe. A uniform beam with a diameter of 1 cm was assumed. The beam power was set to be 4 kW. The MCNPX calculation results were used as the heat source information in the CFX 5.7.1 code which is a thermal-hydraulic calculation code. The inlet temperature of liquid Pb was set to be 400 °C. The inlet velocity of liquid Pb was varied from 1 m/s to 5 m/s.

Table 3 shows the CFX calculation results for the inlet velocities of 1, 2 and 5 m/s. The average outlet temperature was calculated to be 453 °C for the inlet velocity of 1 m/s. The average outlet temperature was estimated at 20 cm above the center of beam. The temperatures of Mo pipe and liquid Pb were also analyzed. The maximum temperatures were 501 °C and 472 °C for Mo pipe and liquid Pb respectively. Although high temperature liquid Pb may cause a corrosion problem to the stainless steel pipe, the maximum Pb temperature of 472 °C is not such high temperature to cause a corrosion problem [5]. It was also proved that Mo wall was chemically resistant to the liquid lead at 450 °C [3]. When a liquid Pb velocity was increased to 2 m/s and 5 m/s, the maximum Pb temperatures were decreased to 440 °C and 418 °C respectively. Therefore, an appropriate Pb flow velocity is in the range of 1 − 2 m/s. Figure 4 shows the temperature distributions of Mo wall and liquid Pb for the case of 2 m/s.

Table 3. CFX calculation results.

Pb inlet velocity	1 m/s	2 m/s	5 m/s
Max. oulet temp. (°C)	453	428	412
Avg. outlet temp. (°C)	414	407	403
Max. Mo temp. (°C)	501	467	444
Max. Pb temp. (°C)	472	440	418

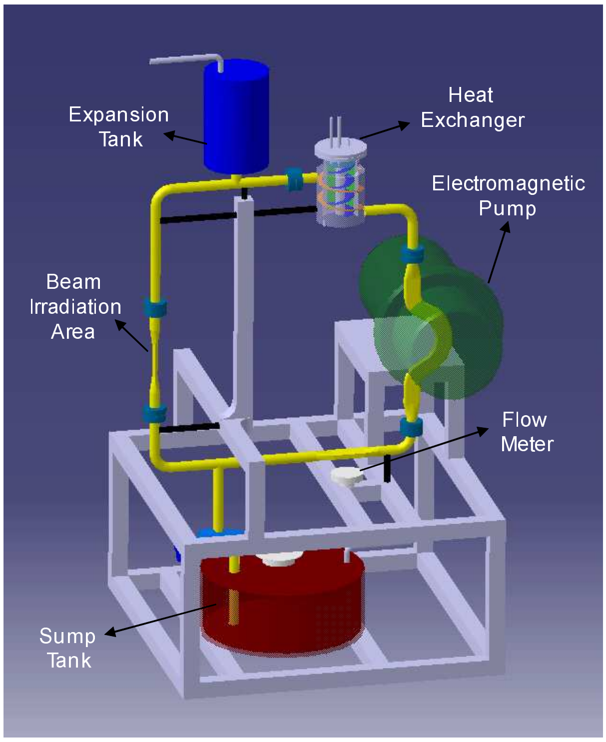

Fig. 3. (Color online) Liquid Pb target system.

Neutron production simulation was also performed using MCNPX. The geometry of the neutron production target is the same as the case of thermal-hydraulic calculation except the width of Pb target. The width of Pb target was set to be 2.0 cm in the neutron production simulation. The depth of the Pb target was varied from 0.2 cm to 1.8 cm to investigate the effect of target depth on the production of neutrons and gamma-rays. The beam condition was the same as the case of thermal-hydraulic calculation

Table 4 shows the result of the 0.5 MHz beam case, which is equivalent to the beam power of 3.4 kW. Since the neutron production is isotropic, neutron flux was estimated by $1/r^2$ law. The flux with a target depth of 1.0 cm is 7.0×10^4 n/cm^2·s at 10 m away from the target.

MCNPX simulations were performed with different beam energies to investigate the variation of neutron

Table 4. Target depth effect on the production of n and γ with a beam power of 3.4 kW.

Depth (cm)	Neutron (n/s)	Photon (γ/s)
0.2	1.7×10^{11}	3.2×10^{15}
0.6	7.7×10^{11}	3.4×10^{15}
1.0	8.8×10^{11}	3.0×10^{15}
1.4	1.1×10^{12}	2.8×10^{15}
1.8	1.2×10^{12}	2.7×10^{15}

Table 5. Beam energy effect on the production of n and γ with an average current of 0.2 mA.

Energy (MeV)	Neutron (n/s)	Photon (γ/s)
17	8.8×10^{11}	3.0×10^{15}
20	1.6×10^{12}	3.6×10^{15}
30	3.7×10^{12}	5.3×10^{15}

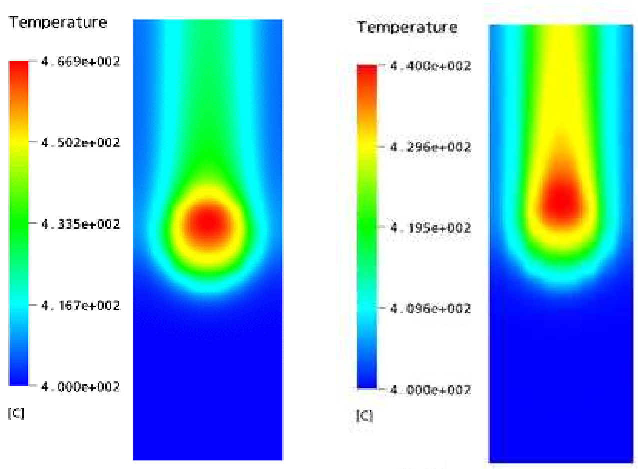

Fig. 4. (Color online) Temperature distributions of the Mo outer surface (left) and Pb surface contacted by Mo wall (right) at a velocity of 2 m/s.

and gamma-ray production as a function of beam energy. Table 5 shows the production rates of neutron and gamma-ray at three different energies The target depth was set to be 1.0 cm. When the electron accelerator is upgraded to produce a 30 MeV beam in the second phase of development, the neutron production rate will be increased by a factor of ∼4 with the same current.

IV. CONCLUSIONS

Nuclear experimental data can be the basis of many areas of nuclear engineering. KAERI has a plan to develop a neutron source by using KAERI's 17 MeV electron accelerator. The neutron source will be mainly used for the cross-section measurements of fast neutron induced reactions based on the time-of-flight method. Currently, a conceptual design work is under way.

Since an excellent time resolution is required, a liquid Pb target is adopted. KAERI's superconducting electron accelerator produces pulsed electron beams with a fixed pulse width of 20 ps and a pulse current of 20A. When the repetition rate is 0.5 MHz, the available beam power is 3.4 kW, which is 25% of the maximum beam power of KAERI electron accelerator.

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