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# High Energy Neutron Facility for Radiation Effect Test at KOMAC

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## 1. Introduction

Atmospheric neutrons produced by cosmic-rays span energies from a few keV up to hundreds of MeV. At ground level, these neutrons induce single-event effects (SEEs) and cumulative displacement damage in contemporary semiconductor devices. Replicating this spectrum in a controlled laboratory environment is essential to characterize device vulnerability and to develop robust hardening techniques.

Furthermore, most neutron detection efforts have focused on the thermal-neutron region below tens of MeV, and various nuclear-reaction datasets still require supplementation for the high-energy neutron. With the recent surge of interest in the space environment, studies on the effects of secondary particles such as neutrons on human health in space have become critically necessary.

In response to these user requirements, the Korea Atomic Energy Research Institute has commissioned a high-energy neutron irradiation facility at KOMAC, centered on a 100 MeV proton beam-dump spallation system. Key construction features include segmented access control with interlocks, enhanced gamma shielding around the dump, and integrated dosimetry modules. Since opening in 2023, the facility has delivered neutron beam services at approximately $1\times10^5$ n/cm²/sec to industry and academic labs for semiconductor radiation effect testing and neutron detection research. Research is currently underway to characterize neutron energy/flux distributions and to provide more accurate dosimetry information.

## 2. High Energy Neutron Facility of KOMAC

In the initial facility layout, entering the experimental area required shutting down the accelerator and traversing a highly activated beamline. As a result, once an experiment concluded, re-entry into the test zone was impossible. Consequently, only one experiment could be carried out per day, and test sample troubleshooting was extremely challenging on irradiation time.

The facility's entry route has been reconfigured to the rear of the back-side to the dump. This modification allows safe access to the experimental area without halting accelerator operation and enabling bypass of the activated beamline effectively reducing unnecessary radiation exposure.

Therefore, the high-energy neutron experimental facility comprises an access zone for entry into the controlled area; a laboratory for beam on/off control and experimental equipment monitoring; and an irradiation zone for beam exposure.

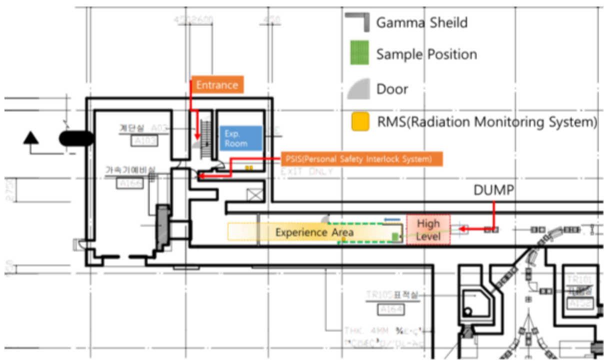


Fig. 1. Schematics of the neutron facility in KOMAC

### *2.1 Neutron Laboratory Room*

The neutron laboratory is equipped with a centralized control console, an internal CCTV network for safety, a neutron monitoring system, and a radiation dose monitoring system. The control console manages beam on/off operations while continuously monitoring beam pulse counts and proton beam dose. It also provides a power-control function that allows remote rebooting of experimental equipment in the event of radiation-induced malfunctions. For internal safety, the sample irradiation area is continuously monitored and recorded via CCTV, and an interlock system linked to motion detectors prevents beam irradiation if personnel remain inside the zone. Furthermore, a variety of detectors monitor and measure neutrons in real time, and a Radiation Monitoring and Safety (RMS) system has been implemented to ensure the safety of both users and operators. Additionally, to secure experimental data, data can be transmitted and received over an Ethernet line from the sample location to the laboratory.

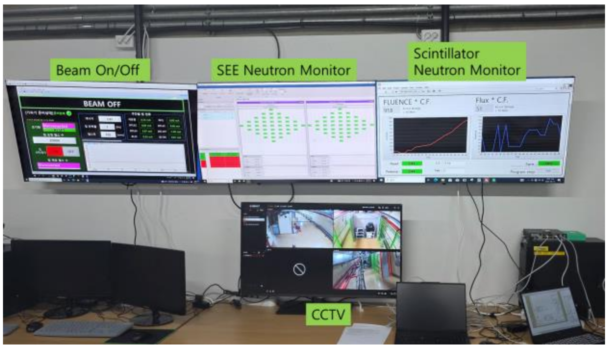


Fig. 2. Picture of the neutron monitoring systems in KOMAC. Main monitoring system consists of the memory SEE neutron monitor, the scintillation counting and the motion detector CCTV.

### *2.2 Enhanced Radiation Shield*

While radiation protection measures are in place for movement through modified entry zones, a radiation safety is still needed to allow access to the sample area after beam irradiation.

The issue of activation in the beam experimental area still remains, as the ambient radiation dose level is high due to the activation of the dump after beam irradiation.

This activation is primarily attributable to gamma-ray emissions arising from the transmutation of the copper-based beam dump into radionuclides Cu-62 and Cu-64 via proton irradiation.

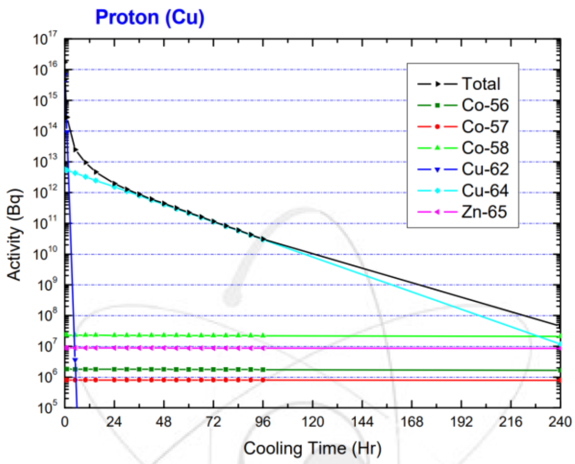


Fig. 3. Induced radionuclides generated by beam dump activation [1]

Accordingly, enhanced gamma-ray shielding was designed and constructed to ensure radiation maintaining convenient protection while accessibility.

First, the sample irradiation point was placed 5 m from the beam dump, and the installation site was also set space for accelerator 5 m away to allow maintenance. Enhanced gamma-ray shielding was then designed and built to protect against radiation while keeping the sample change. A safety fence area easy to access was added to block direct view from the maintenance door to the dump. After the layout was finalized, the best shielding thickness was calculated. Before running the simulation, a simple calculation was performed to estimate the required thickness of the shielding wall, assuming a 1 kW beam operated for 3 hours and considering lead thicknesses of 5 cm and 2 cm. The activity was conservatively estimated based on the maximum reaction cross section, giving values of $7.59 \times 10^{10}$ Bq for Cu-64 and $5.05 \times 10^{11}$ Bq for Cu-62. These activities correspond to absorbed dose rates of 0.11 mSv/h and 3.86 mSv/h, respectively. Using the linear attenuation coefficient, the dose rates were calculated for different lead thicknesses, as shown in Table 1.

Tab. 1. Simple calculation result of dose rate with different shield thickness

| Thickness [cm] | 2 | | 5 | |
|---|---|---|---|---|
| | Cu-64 | Cu-62 | Cu-64 | Cu-62 |
| Dose rate EOB[μSv/h] | 4.28 | 133.94 | 0.03 | 0.87 |

Based on these results, as shown figure 4 an MCNP simulation was conducted, and it was found that the ambient radiation dose rate behind the shielding wall averaged approximately 8.31 μSv/h after beam irradiation. Although this exceeds the facility's own entry limit of 5 μSv/h, it remains below the 12.5 μSv/h entry limit specified in the safety report, indicating improved accessibility safety and a reduction in required entry time compared to before.

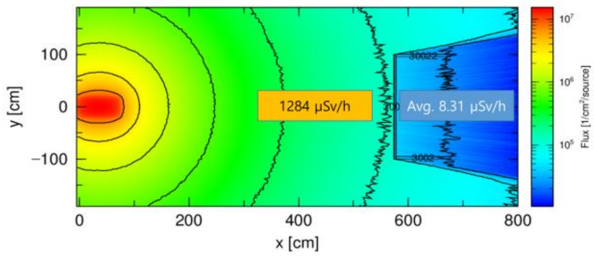


Fig. 4. Simulation results of enhanced radiation shield in ambient radiation rate.

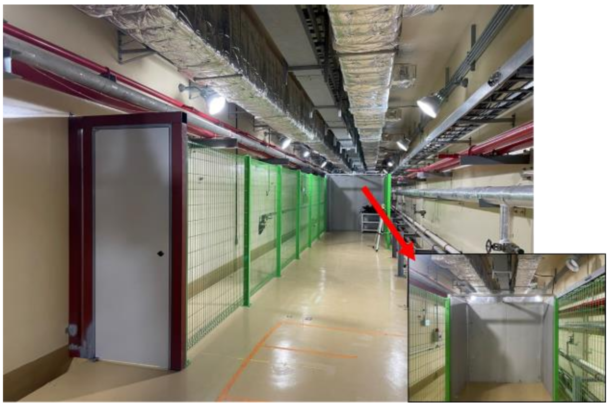

Fig. 2. Picture of a neutron laboratory equipped with enhanced gamma shielding

### 3. Conclusions

The high-energy neutron facility operated a pilot user service from 2023 through the first half of 2025.

During this period, various detectors and equipment were upgraded, and safety systems for users were installed. Beginning in the second half of 2025, the facility will commence full-scale operations.

Through these efforts, overseas telecommunications companies utilized the facility and obtained results comparable to those from similar overseas facilities. This has demonstrated that the high-energy neutron facility is the only domestic facility capable of evaluating the effects of atmospheric radiation on semiconductors.

### REFERENCES

[1] C.S. Gil, Development of Beam Dump, KAERI RR-2898, 2007