Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 24-25, 2024

Radiation Protection for SESAME Synchrotron, a general guidance

Khader Mahmoud [a*], Inyoung Jeon[b]
[a] *Nuclear and Quantum Engineering Dept., KAIST, 291 Daehak-ro, Yuseong-gu, Daejeon, Republic of Korea 34141*
[c] *Korea Institute of Nuclear Safety, 62 Gwahak-ro, Yuseong-gu, Daejeon, Republic of Korea, 34142*
**Corresponding author: m.khader@kaist.ac.kr*

1. Introduction

Radiation protection in synchrotron facilities differs significantly from other nuclear facilities[1], such as research reactors and fuel cycle plants, primarily due to the nature of the radiation sources, operational environments, and the classification of both areas and workers.

- Radiation source: synchrotrons primarily deal with high-energy x-rays and secondary radiation from beam loss[2], whereas nuclear reactors manage sustained fission reactions, producing a broader spectrum of radiation types, including more neutrons and alpha particles.
- Operational environment: synchrotron facilities typically have lower background radiation levels and less complex radioactive waste management compared to nuclear reactors.
- Area classification: in synchrotron facilities, area classification is more dynamic, depending on the operational status of the facility. For instance, SESAME's area classifications (green, yellow, and red) change their access rules and monitoring requirements based on whether the beam is on or off. In contrast, nuclear facilities often have more static classifications due to the continuous presence of radioactive material.
- Protection strategies: while both types of facilities require comprehensive shielding and monitoring, synchrotrons focus more on managing localized radiation from beamlines and preventing beam loss, whereas reactors emphasize containment of radioactive materials and control of chain reactions.

However, due to various types of synchrotrons, up to now there are no international guidances for their radiation protection [3]. The purpose of this paper is to give an outline of general guidance on the radiation protection of synchrotron facilities, based on the operational experiences of SESAME (Synchrotron-light for Experimental Science and Applications in the Middle East).

SESAME is the first synchrotron light source in the Middle East and neighboring countries. SESAME was formally established and became operational on May 16, 2017, in Allan, Jordan. It is constructed as a "third generation" synchrotron light source and aims to be a major international center of excellence in this region. The facility consists of a 22.5 MeV microtron as a source and pre-accelerator of electrons, an 800 MeV booster synchrotron, and a 2.5 GeV electron storage ring circumference of 133.2 m with a maximum operational current of 250 mA, where the electron beam circulates under ultra-high vacuum conditions (around 10−9 mbar) continuously [4].

With the support of 20 or more experiments through independent beamlines (currently three in operation and one in the construction phase), SESAME is designed to ensure safety for its staff, users, the general public, and the environment, from ionizing radiation involving gamma rays, neutrons, and intense X-rays.

2. Methods

The radiation protection and safety measures at SESAME were assessed using a field-based evaluation method, which included a combination of direct observations, interviews with key personnel, and a thorough review of SESAME's radiation protection safety plan and management. This comprehensive approach provided a detailed understanding of the operational practices and safety protocols implemented at the facility.

The effectiveness of SESAME's radiation protection and safety measures was evaluated by comparing the observed conditions and operational practices with the conditions and limits outlined in the facility's radiation protection and safety documents and policies.

The targeted synchrotron for this study is the "third generation" synchrotron like SESAME.

3. Results and Discussions

The field-based evaluation of SESAME showed that there are five prominent features of radiation protection for synchrotrons, such as radiation shielding, beam loss, personal safety systems, radiation monitoring, and classifications of radiation areas.

3.1 Radiation Shielding

SESAME's shielding design follows standard models to ensure that radiation levels outside shielded areas remain well below 0.5 µSv/h, corresponding to an annual dose of less than 1 mSv/y for workers.

- Design considerations: shielding should be designed to cover all potential radiation escape points, including gaps for utilities and personnel access, which are managed using labyrinth designs to block direct radiation paths.
- Regular assessments: continuous assessment and reinforcement of shielding are conducted to address any weaknesses or changes in radiation levels.

Guidance: design and maintain shielding that adheres to the ALARA principle. Regularly review and upgrade shielding based on operational changes or findings from radiation monitoring.

3.2 Radiation Protection Plan for Beam Loss

Beam loss, which occurs when electrons deviate from their intended path, can result in significant radiation hazards. SESAME has implemented a robust beam loss detection and response system:

- Beam loss monitors (BLMs): strategically placed around the facility to detect and respond to beam loss events immediately ensuring accumulated dose outside the shielding walls during any single 4hrs shift not reached 2µSv at any time. The system is integrated with the personal safety system (PSS) to automatically shut down operations if beam loss exceeds this value.
- Shielding enhancements: additional shielding is installed in areas where beam loss is more likely to occur, such as around the injection and extraction points to be less than or equal to 0.5µSv/h.

Guidance**:** Implement a comprehensive beam loss management plan, including BLMs and additional shielding in high-risk areas. Ensure that the response system is integrated with facility-wide safety interlocks to prevent accidental exposure during beam loss events.

3.3 Personal Safety System (PSS)

The Personal Safety System (PSS) at SESAME is an advanced interlock system designed to prevent accidental exposure by controlling access to high-radiation areas.

- Automatic shutdown: the system automatically shuts down beamlines if radiation levels exceed safe limits (2µsv/ 4hrs) or if unauthorized access is detected.
- Access control: the PSS is integrated with facility security and safety systems to ensure that tunnels have been searched and cleared of personnel before turning the beam on, only trained and authorized personnel can enter controlled areas.

Guidance: Implement a safety interlock system that integrates with radiation monitoring and access control. Ensure that the system is regularly tested and maintained to achieve the desired safety integrity level.

3.4. Radiation Monitoring (Area and Personal Monitoring)

SESAME's radiation monitoring program includes both area and personal monitoring systems:

- Live area monitoring: fixed radiation detectors are placed outside the radiation shield wall in key locations such as near beamlines and storage rings, connected to PPS system providing real-time data to the control room. Total gamma and neutron dose rate and total accumulated dose every 4 hours, with two alarm thresholds.
- Handheld monitors for dose rate measurement and general survey, telescopic gamma dose rate meter for monitoring radiation levels and activation at a secure distance.
- Environmental dosimeters: spread throughout specific spaces inside and around the facility, these dosimeters provide additional dose measurements, contributing to experiments and long-term environmental monitoring.
- Passive radiation monitoring system (PRMS): SESAME uses specialized beta and photon storage dosimeters distributed at critical points within the facility to provide long-term data on radiation levels, which are crucial for evaluating the effectiveness of the radiation safety program.
- Personal monitoring: all personnel in radiation-controlled areas are forced to use at least one of three kinds of personal dosemeters (one of them refers to a third party for quality assurance) to track individual exposure over time.

Guidance: Implement a comprehensive radiation monitoring system that combines live area monitoring with handheld and environmental dosimetry. Ensure that personal dosimeters are used consistently in all radiation-controlled areas, with quality assurance provided by third-party verification. Regular calibration and maintenance of all monitoring devices are critical to ensuring their accuracy and reliability.

3.5. Area Classification and Radiation Zoning

SESAME employs a unique and effective system for classifying facility areas based on radiation risk and operational status as shown in Figure 1:

- Green area (experimental hall): classified as a normal supervised radiation area, accessible to technical and scientific staff and users. Personal dosimeters are required when the machine is operational.
- Yellow area (service areas): classified as a highly supervised radiation area, accessible only to technical staff, who must wear personal dosimeters whether the machine is on or off.
- Red areas (tunnels and beamline hutches): classified as highly controlled radiation areas. no one is allowed entry during operation when the beam is on, as the area is controlled by the PSS system. when the beam is off, only technical staff with personal dosimeters are allowed access.

Guidance: Adopt a similar area classification system that accounts for both the area itself and the operational status of the synchrotron. Ensure that access controls are strictly enforced and supported by safety interlock systems. Training on the significance of these zones and proper safety protocols should be provided to all personnel and visitors.

.

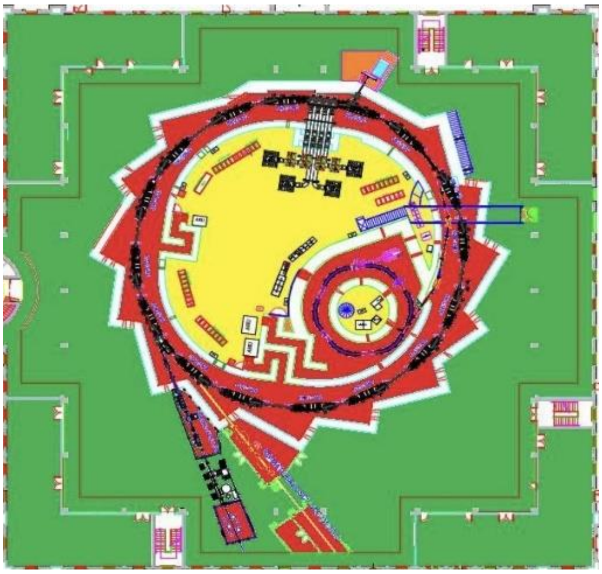

Fig. 1. SESAME, main building includes tunnels, service areas, experimental hall, and some beamlines.

4. Conclusion

This study has provided a comprehensive analysis of the radiation protection measures implemented at the SESAME synchrotron facility in Jordan, with a focus on deriving general guidelines that can be applied to similar facilities. Using a Field-Based Evaluation Method, which included direct observations, interviews, and a review of SESAME's Radiation Protection Safety Plan, we have identified five key areas for radiation protection of synchrotrons, such as radiation shielding, beam loss, personal safety systems, radiation monitoring, and classifications of radiation areas. strategies and practices that ensure the safety of workers, researchers, and the environment.

Importantly, the study indicated that the radiation protection of synchrotron facilities should be distinguished from those of other nuclear installations, such as research reactors and fuel cycle plants due to unique challenges related to high-energy X-rays and localized radiation management of synchrotrons

However, the study results also suggested that approach to radiation protection for synchrotrons should adhere to the ALARA (As Low As Reasonably Achievable) principle, which underpins all aspects of its radiation safety program of other nuclear facilities.

In conclusion, this study provided a comprehensive and adaptable framework that can serve as a benchmark for the synchrotron community worldwide.

REFERENCES

[1] EMRC. [2] Law No. (43) For the Year 2007 Radiation Protection, And Nuclear Safety and Security Law. Energy and Minerals Regulatory Commission. https://emrc.gov.jo/echobusv3.0/systemassets/law43 2007_english.pdf.

[2] Instructions for procedures for granting synchrotron facility licenses and permits. Energy & Minerals Regulatory Commission.

[3] Lima, L.; Moura, F. Radiation Protection on Sirius, the new Brazilian synchrotron. Brazilian Center for Research in Energy and Materials.

[4] SESAME, R. S. SESAME's Accelerators | SESAME | Synchrotron-light for Experimental Science and Applications in the Middle East. Sesame.org.jo. https://www.sesame.org.jo/accelerators (accessed 2024-08-19).