12th International Workshop on Radiation Safety at Synchrotron Radiation Sources

RadSynch25

Tuesday, June 24, 2025 - Friday, June 27, 2025
Brazilian Center for Research in Energy and Materials (**CNPEM**)

Book of Abstracts

Session 1: Facility reports on new design, upgrade and commissioning

Simulation of LINAC and full Energy booster for SESAME Synchrotron

Zahran. I. Y[1] and Hamad. A. M[1]

[1] SESAME (Synchrotron-Light for Experimental Science and Applications in the Middle East), Allan 19252, Jordan

SESAME is a third generation synchrotron light source located in Allan, Jordan. The SESAME machine consists of a 22MeV microtron, 800MeV booster and 2.5GeV storage ring. We aim in the safety office to ensure that the radiation levels outside the shielding walls will not exceed the predefined guideline of 0.5 μSv/h limit for non-exposed workers during normal operation

The future major upgrade foreseen to the machine is replacing the injector with a full energy one, which will enable the top-up injection scheme. In this upgrade the microtron to be replaced with 100MeV linac that is foreseen, in one of the scenarios, to be installed alongside the microtron inside the booster tunnel.

In this work we will discuss the preliminary FLUKA simulations conducted to evaluate impact of the LINAC and beam dumping at the Faraday cup on the dose rate outside the tunnel and how to reduce the radiation level there using further shielding.

Moreover, preliminary simulations were performed to estimate the impact of full energy booster and top-up injection scheme on the dose rate outside the storage ring tunnel.

Shielding calculation for the Diamond II beamline upgrade

Faruk S

Diamond Light Sources Ltd, Harwell Science & Innovation Campus, Didcot,
Oxfordshire, UK, OX11 0DE

The Diamond II machine will be upgraded to enhance the brightness and coherence of the emitted synchrotron light [1]. The Linac will function at 150 MeV, while the Booster and storage ring will operate at 3.5 GeV with a 300-mA current. Diamond-II will replace the existing Double Bend Achromat lattice with a Six Bend Achromat (6BA), creating space for a new insertion device (ID). This design choice will allow for retaining several current flagship beamlines whilst upgrading three bending magnet (BM) beamlines with medium-straight ID (MID) and establishing six new ID beamlines. All the current optics hutch of the BM beamlines were reassessed using the STAC8 [2] code and the FLUKA [3, 4] particle transport code to evaluate potential radiation hazards and assess the integrity of the existing shielding, as well as propose additional and new shielding thicknesses for both the existing and new beamlines. FLUKA simulation investigates the risk from the Gas Bremsstrahlung (GB) coming into the optics hutch and its interactions with beamline components (i.e. filter, slits, collimators etc.) and dose rate through the hutch shielding. We calculated the dose rates outside the existing and proposed shielding using a constraint of 0.5 μSv/h (1 mSv/y for a 2000-hour working year). It was observed that most of the beamlines would require extending the additional shielding area on the end wall with increased thickness, and some would necessitate additional shielding on the side wall or local shielding around beamline components.

References

[1] – R. P. Walker *et al* Diamond-II: Technical Design Report, (2022)

[2] – Shielding design calculation for SPring-8 beamlines using STAC8, Y Asano, J. Synchrotron Rad. (1998). 5, 615-617.

[3] - "The FLUKA Code: Developments and Challenges for High Energy and Medical Applications" T.T. Böhlen, F. Cerutti, M.P.W. Chin, A. Fassò, A. Ferrari, P.G. Ortega, A. Mairani, P.R. Sala, G. Smirnov and V. Vlachoudis, Nuclear Data Sheets 120, 211-214 (2014)

[4] - "FLUKA: a multi-particle transport code" A. Ferrari, P.R. Sala, A. Fasso`, and J. Ranft, CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773.

Challenges in Radiation Safety associated with the ambitious Upgrade of the Storage Ring of Synchrotron SOLEIL

Pruvost J-B.*, Berkvens, P.*

*Synchrotron SOLEIL, Safety Group, L'Orme des Merisiers, 91190 Saint-Aubin, France.

The construction phase 1 of the SOLEIL II upgrade project started in 2025. This first stage includes the dismantling and full reconstruction of the storage ring and the restart and commissioning of the entire accelerator complex. It also includes the commissioning of almost all the beamlines ready to benefit from the new synchrotron source performances.

The SOLEIL II storage ring upgrade project aims at reducing drastically the horizontal emittance of the electron beam from 4 nm.rad for the present ring down to 80 pm.rad for the SOLEIL II new 4th generation storage ring. It is based on the replacement of the present double bend achromat by a mixed multi bend achromat, the so-called 4BA-7BA lattice [1] and a general use of permanent magnets for both dipoles and quadrupoles.
The corresponding long shutdown is scheduled between end of 2028 and end of 2030, when user operation will resume.

Compared to the present storage ring, SOLEIL II will operate with a significant reduced beam lifetime and, consequently, with increased beam loss rates. This leads to many challenges in terms of Radiation Safety and Radiation Damage assessments.

This paper will present the main characteristics of the SOLEIL II storage ring upgrade and the corresponding main challenges in Radiation Safety to maintain the Experimental Hall as a non-radiation area.
A detailed shielding design study is required by the French Nuclear Regulation Authority (ASNR) as a basis of the authorization request that SOLEIL will submit to recover license from ASNR prior to restart the accelerators by the end of 2029.

This paper gives also a status of the shielding design study mainly driven by extensive use of the FLUKA Monte Carlo code [2, 3], the remaining radiation safety challenges to cope with and the foreseen effects of ionizing radiation exposure of the permanent magnets.

References

[1] – Synchrotron SOLEIL Upgrade – Conceptual Design Report, (2021).

[2] – C. Ahdida et al., New Capabilities of the FLUKA Multi-Purpose Code, Frontiers in Physics 9, 788253 (2022).

[3] – G. Hugo et al., Latest FLUKA developments, EPJ Nuclear Sciences & Technologies 10 (2024).

Radiation Protection of the Laser-Plasma Facility KALDERA at DESY

Zander S., Panofski E., Bohlen S., Liang T., Leuschner A.

Deutsches Elektronen Synchrotron DESY, Notkestraße 85, 22607 Hamburg, Germany

DESY, an accelerator center with a history of more than six decades, operates and develops major user facilities such as PETRA III, FLASH, and the European XFEL. In parallel, the investigation of novel accelerator technologies for future applications is a key focus. Among these, laser-plasma acceleration offers the potential to reduce accelerator lengths by orders of magnitude and constitutes a major research area at DESY.

KALDERA is DESY's first laser-plasma accelerator facility and is capable of producing electron beams with energies up to 400 MeV at a repetition rate of 100 Hz. In March 2025, KALDERA successfully accelerated its first electrons.

This new technology presents new challenges for radiation protection. The radiation protection concept for KALDERA will be presented, including the general safety layout, shielding simulations, and dosimetry. Since March 2025, KALDERA has been in operation, and the first challenges encountered during the commissioning and operational phases will be discussed.

Figure 1: Vacuum-Chamber of the KALDERA-Plasma-Cell [1].

References

[1] – Sören Jalas, "DESY's flagship laser KALDERA accelerates its first electrons", *DESY News https://www.desy.de/news/news_search/index_eng.html?openDirectAnchor=3773&two_columns=0* (2025/04/17).

Radiation Shielding Analysis for New 4th Generation Storage Ring (4GSR) Tunnel in Korea

Bakhtiari Mahdi, Jung Nam-Suk, Lee Hee-Seock

Pohang Accelerator Laboratory, POSTECH, Pohang, 37673, South Korea
bakhtiari@postech.ac.kr

A new 4th-generation storage ring (4GSR) facility is currently under construction in Korea. The facility comprises a 200-MeV linear accelerator (Linac), a Booster ring, and a 4-GeV hybrid MBA storage ring with a circumference of 799.297 m. The stored beam current is 400 mA. Both the Booster and storage rings are housed within the same tunnel.

In our previous work, the bulk shielding calculations as well as preliminary shielding analysis of synchrotron radiation (SR) beamlines were performed [1,2]. In this work, the shielding analysis was performed to determine the detailed structure and wall geometry for SR beamline of the tunnel. The calculations were carried out using the FLUKA 4-4.0 Monte Carlo code [3]. The analysis considered various beam loss scenarios under both normal and abnormal operating conditions. A 90% injection efficiency from the Booster to the storage ring was assumed, with 4 mA of beam current injected every 2 minutes.

Since the Linac-to-Booster injection, Booster extraction, and Booster-to-storage ring injection points are located close together, more complicated calculations have been done at the injection area. The shielding requirements for the non-injection area include an 80 cm-thick ordinary concrete (O.C.) ratchet wall, a 50 cm-thick O.C. inner wall, and a ceiling of 50 cm-thick O.C. The ratchet end wall for the ID beamlines requires 130 cm-thick O.C. with 4 cm-thick Pb, and 180 cm-thick O.C. for the bending magnet (BM) beamlines. Shielding requirements for the injection area include, 100 cm-thick O.C. ratchet wall, a 70 cm-thick O.C. inner wall, and 70 cm-thick O.C. ceiling. Ratchet end walls consist of 130 cm-thick O.C. with 4 cm-thick Pb for ID beamline, and 180 cm-thick O.C. for BM beamline.

Shielding design followed the regulatory standards of Korea's Nuclear Safety Act and the As Low As Reasonably Achievable (ALARA) principle. These simulations provide a radiological safety foundation for the Korea 4GSR facility based on the current design specifications.

Acknowledgements
This research was supported in part by the Korean Government (MSIT: Ministry of Science and ICT) (No. RS-2022-00155836, Multipurpose Synchrotron Radiation Construction Project) and also supported by Pohang Accelerator Laboratory (PAL). PAL is supported by Korean Government (MSIT) and POSTECH.

References

[1] N. S. Jung, "Radiation Shielding Evaluation of 4th Generation Storage Ring in Korea", 11th International Workshop on Radiation Safety at Synchrotron Radiation Sources (RadSynch23), Grenoble, France 30 May-2 June (2023).

[2] M. Bakhtiari, N. S. Jung, H. S. Lee, "Radiation shielding analysis for synchrotron radiation beamlines of 4th generation storage ring in Korea", The 16th workshop on Shielding aspects of Accelerators, Targets and Irradiation Facilities (SATIF-16), Italy, May 28-31 (2024).

[3] C. Ahdida et al., "New Capabilities of the FLUKA Multi-Purpose Code", Frontiers in Physics, **9**, 788253, (2022).

LINAC Upgrade Project at the Canadian Light Source

Grant Cubbon

Canadian Light Source,44 Innovation Blvd, Saskatoon, SK S7N 2V3, Canada
grant.cubbon@lightsource.ca

The Canadian Light Source (CLS), Canada's only synchrotron, is located in the city of Saskatoon, Sk, Canada. Construction of the synchrotron facility began in 1999, with User beam first available in 2005. The new building construction was attached to a facility known as the Saskatchewan Accelerator Laboratory, and the existing 250 MeV linear accelerator was included as the electron source for the new synchrotron facility. In 2018 a failure of the electron source, coupled with maintenance concerns due to the aging equipment, resulted in a desire to replace the existing LINAC with newer equipment. The CLS LINAC Upgrade Project will be presented with emphasis on the radiological aspects of planning, regulatory approval, decommissioning of the existing LINAC, through to installation and commissioning of the new LINAC.

Five years of operational radiation protection experience with the new EBS storage ring at the ESRF

Colomp P., Berkvens P.

ESRF, 71 Av. Des Martyrs, 38000 Grenoble, France

The 4th generation EBS storage ring at the ESRF was put into operation over five years ago. As part of the ALARA optimization during the EBS shielding design study, two dedicated beam loss collimators and their specific local shielding were defined. Despite the higher bean losses with respect to the former storage ring, and the fact that the new storage ring had to be housed inside the existing storage ring tunnel, the insertion of these collimators resulted in predicted dose rates outside the storage ring tunnel which were lower that the dose rates measured around the former storage ring. Also, concentrating the beam losses on these collimators resulted in a significant reduction of activation inside the storage ring tunnel, in particular inside the injection area.

The present paper gives an overview of the operational radiation protection experience during these first years of operation of the new facility, both in terms of dose rates and in terms of residual activation. Comparisons with predicted dose rates are made. Some further ALARA optimisations are presented as well.

Radiation protection issues for the Elettra 2.0 project: Monte Carlo simulation studies

Casarin K., Tromba G., Berkvens P.

Elettra-Sincrotrone Trieste S.C.p.A. S.S. 14 - km 163,5 in Area Science Park, 34149
Basovizza, Trieste (I)

The Elettra 2.0 upgrade program, scheduled to start in July 2025, is designed to significantly increase the brilliance and coherence of the current Elettra facility. The new machine lattice will be completely changed: the existing double-bend achromat will be replaced by a symmetric six-bend achromat configuration. Several existing Insertion Devices (IDs) will be kept in the upgraded machine, some new ones, such as three in-vacuum undulators, will be realized exploiting the new machine characteristics. In addition, two super-conducting bending magnets will be installed to serve high energy X-ray beamlines.

From the radiation protection point of view, the beamlines hutches have been re-evaluated, taking into account the new machine characteristics. The radiation challenges posed by the beamlines from the new IDs and from super-conducting bending magnets have also been considered. Furthermore, the impact of the expected beam loss scenarios for the new machine during normal operations and malfunctions has been evaluated on radiation levels outside the tunnel shielding walls. All these evaluations have been performed by means of Monte Carlo simulation studies using FLUKA code.

Session 2: Activation and decommissioning

Assessment of activation for the decommissioning of the Diamond I accelerator

Faruk S

Diamond Light Sources Ltd, Harwell Science & Innovation Campus, Didcot,
Oxfordshire, UK, OX11 0DE

The Diamond I accelerator, operational since 2007, is slated for an upgrade to Diamond II by 2028, aiming to enhance the brightness and coherence of the emitted synchrotron light [1]. This upgrade will involve replacing the booster and storage ring. To expedite the decommissioning process, we aimed to assess the potential activation of the accelerator components and determine their activity and surface dose rate, ensuring a safe disposal route in line with regulatory requirements. Using a handheld radiation isotope spectrometer, we measure the activated components after each run to anticipate the possible location and activation of the storage ring components. Activation calculations are performed with a simplified Python model and with the FLUKA [2, 3] particle transport code to evaluate potential activation over 21 years of machine operation, during which there is an average of 10 weeks of cooling time and an average electron loss across all known materials (such as copper, iron, steel, tungsten, etc.) that could interact with the beam. It was observed that, under the initial approach, most activation occurs in the injection area, upstream of the ID joint, DDBA, and similar locations, with isotopes varying from those with very long lifetimes (>1 year) to those with short lifetimes (<1 hour). This indicates that some components may require storage for several years before being disposed of as low-level radioactive waste, which entails costly disposal. With further refinement of the Python code, the calculations became more accurate due to realistic physics modelling, which includes functions for neutron energy spectrum modelling, secondary activation pathways, and self-shielding effects, resulting in a significant reduction in activation. This agrees with the routine measurements and also indicates that the simplified model estimated activities 10 to 100 times higher. Additional work is underway to enhance the FLUKA model.

References

[1] – R. P. Walker *et al* Diamond-II: Technical Design Report, (2022)

[2] - "The FLUKA Code: Developments and Challenges for High Energy and Medical Applications" T.T. Böhlen, F. Cerutti, M.P.W. Chin, A. Fassò, A. Ferrari, P.G. Ortega, A. Mairani, P.R. Sala, G. Smirnov and V. Vlachoudis, Nuclear Data Sheets 120, 211-214 (2014)

[3] - "FLUKA: a multi-particle transport code" A. Ferrari, P.R. Sala, A. Fasso`, and J. Ranft, CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773.

Session 3: Operational experience and lesson learned

The radiological commissioning process for MAX IV beamlines

Paulsson J.[1]

[1] MAX IV Laboratory, Lund University, PO Box 118, SE-221 00 Lund, Sweden

The radiological commissioning of beamlines at MAX IV follows a structured process which has evolved over time. It consists of four main phases: pre-commissioning, commissioning, transition to normal operation, and normal operation. The work is carried out in close collaboration with other stakeholder groups at MAX IV.

During pre-commissioning, the insertion device (ID) is installed with mechanical and software safety measures to prevent unintended use before receiving a permit from the regulatory authority. A checklist is followed to prepare the beamline, and a detailed survey plan is established.

The commissioning phase involves monitoring with radiation safety staff present whenever the ID gap is decreased, or the front-end (FE) shutters are opened. Beamline staff must also be on-site during FE shutter operations. Radiation safety technicians perform sweeps of the ring tunnel wall, optics hutch, and experimental hutch at predefined commissioning parameters.

To transition to normal operation, a commissioning report is submitted to the regulatory authority. Beamline staff are trained in hutch searches and user safety introductions. Once approved, software alarms related to commissioning are removed.

In normal operation, routine checks with varying periodicities apply.

The radiation safety team currently does not verify that installed radiation safety components match documented designs, nor that hutches are lead-lined. These tasks are not currently part of radiological commissioning but are recognized as areas for future attention.

Proposal of 3^{rd} RADSYNCH Survey: Update from 2017 survey and Extending to Accident Scenarios

*Lee H.S.(Hee-Seock), Jung N.S.(Nam-Suk)

Pohang Accelerator Laboratory, POSTECH, Pohang, 37673, South Korea
lee@postech.ac.kr

This small community, RADSYNCH, is very effective and useful to share every synchrotron radiation facilities' information in the world and common issues, eventually for improving radiation protection condition, skill and knowledge of each facility's radiation protection groups. The short survey had been done in 2011 and the 2nd full package survey was carried out by PAL and NSRRC[1]. The survey results let us allow to understand each facility's and country's different policy or common system. Therefore, we want to update survey results by reflecting the present situation and new facilities which didn't join at last survey campaign and propose the method at this workshop.

The accident scenario, which called abnormal condition as well, is fundamental data for a risk analysis. However, a risk consists of event probability and consequence. Nobody has reliable event probability data now and the estimation method is also limited. So before conducting the risk analysis, the accidental scenario should be reviewed and resolved at large-scale particle accelerators, especially synchrotron radiation facilities. At this proposal, the identified scenarios which can happen at particle accelerators, are introduced. Even unreviewed or unexpected safety issues are discussed. The accidental scenarios were considered according to each step of life cycle of large-scale particle accelerator: Design, Construction, Commissioning, Operation and Decommissioning.

References

[1] – H.S. Lee "Radsynch2017 Questionnaire and Survey Results" proceedings of 9th Int. Workshop on Radiation Safety at Synchrotron Radiation Sources, NSRRC (2017).

Session 4: Personnel Safety Systems and Risk Assessment

Personnel Safety Systems at DESY and XFEL in Transition: From Legacy Infrastructure to Modern Safety

Panofski, E., Clement W., Zander S., Dressel M., Rathjen A.

Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, 22607 Hamburg, Germany

The Deutsches Elektronen-Synchrotron (DESY) in Hamburg is a world-leading research center for accelerator science and photon-based research. With a wide range of facilities—from large-scale accelerators like PETRA III and the European XFEL to compact test setups such as the laser-plasma accelerator KALDERA—DESY requires stringent safety measures to protect personnel from exposure to ionizing radiation. A key component of these protection measures is the Personnel Safety System (PSS), which prevents unauthorized access to hazardous areas while the accelerator is in operation.

As DESY continues to expand through the construction of new accelerator facilities and the reconfiguration or upgrade of existing ones, modern PSS are essential to meet evolving technical and safety standards. At the same time, aging PSS in the existing infrastructure must be refurbished or replaced to maintain reliability and regulatory compliance.

Figure 1: Comparison of components in legacy (XFEL, left) and modern (FALCO, right) Personnel Safety Systems at DESY.

A central part of this transition is the structured implementation of a modern risk assessment process. This process ensures systematic identification and integration of safety requirements into new and upgraded PSS to meet required safety integrity levels and operational reliability.

This talk presents the current status of PSS at DESY and XFEL, outlines the ongoing transition to modern, standards-compliant solutions, and highlights the implementation of the structured risk assessment process as one key element of this modernization effort.

Implementation of risk assesment requirements, especially for applications with a high safety level (SIL3 safety integrity level)

Rathjen, A.

Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, 22607 Hamburg, Germany

Personell interlock systems are used where inherentic protection is not conceptually possible. Their task is to protect people from harmful radiation. To achieve this, risks must be identified and reduced to an acceptable level through functional safety. A risk assesment must be done to determine the required risk reduction and to prove whether these objectives have been achieved. The requirements of the risk assesment must be implemented and evaluated when designing the functional safety.

After construction and cabling of the interlock system the technology must be tested during initial commissioning, after significant changes and periodical once a year. Initial and annual testing differ in their scope, and a suitable design with appropriate devices can also be used to reduce interim manual testing via diagnostics.

An example shows how the requirements of safety standards (IEC62061, ISO13849) have been implemented at DESY in the FLASH project, which is currently being set up.

Radiation safety risk matrices at MAX IV and other synchrotron light sources

Rosborg A.

MAX IV Laboratory, Lund University, PO Box 118, SE-221 00 Lund, Sweden

The Swedish Radiation Safety Authority's regulations specify that events and conditions that have an impact on radiation safety shall be identified and assessed before starting an activity, while it is in progress and when it is decommissioned. The events and conditions include both normal operating conditions and abnormal situations. The regulations do not give detailed specifications on how the assessment should be done and it is thus up to each individual licence holder to decide on a suitable methodology.

At MAX IV, a 5x4 risk matrix is used to assess risks related to ionizing radiation by considering the likelihood of occurrence against the potential consequence severity of different events and conditions before and after mitigation. The radiation safety risk assessments include normal and abnormal events inside and outside the accelerators and beamlines. In this presentation, the risk matrix used at MAX IV is presented and a brief overview is given of how the risk assessments are performed, with examples of evaluated risks.

Using a risk matrix is one possible risk management tool. To know more about the situation at other facilities, MAX IV reached out to other synchrotron light sources to ask if a risk matrix is used to assess risks related to ionizing radiation or if some other method is used. A summary of the responses is included in this presentation, with particular focus on the radiation safety matrices for the facilities that use them.

Session 5: Radiation design and assessment

Enhancements in FLUKA for radiation protection at synchrotron facilities

Augusto R.S.[1] and Batkov K.[2] for the FLUKA collaboration

[1] Radiological Control Division, Brookhaven National Laboratory, Upton, NY 11973–5000, USA
[2] MAX IV Laboratory, Lund University, PO Box 118, SE-221 00, Lund, Sweden

FLUKA, a widely used Monte Carlo particle transport and interaction code, has undergone significant updates in recent releases [1]. This talk presents an overview of FLUKA's capabilities tailored to radiation protection at synchrotron light sources, focusing on two key aspects: photonuclear interactions and dosimetric changes in radiation field assessments.

Photoneutrons resulting from photonuclear interactions, driven by gas bremsstrahlung, can significantly impact radiation fields outside shielding. We demonstrate the influence of photoneutrons in radiation protection scenarios and highlight improvements in their modeling in recent FLUKA updates.

Additionally, we examine the effects of changes in operational dosimetry, specifically the transition from H*(10) to H*. Beam loss scenarios were simulated to evaluate the shifting in dose estimates outside of shielding due to energy-dependent weighting coefficients for electrons and photons. The potential implications of these changes, particularly at high energies, will be also assessed.

To illustrate these improvements, several practical examples will be provided, including X-ray reflectivity simulations and coherent scattering at low energies. By showcasing tangible impacts rather than theoretical improvements alone, we emphasize the practical relevance of these new FLUKA features for radiation protection at synchrotron facilities.

References

[1] F. Ballarini et al., The FLUKA code: Overview and new developments, EPJ Nuclear Sci. Technol. 10, 16 (2024) https://doi.org/10.1051/epjn/2024015

Radiation Shielding Design for Non-Standard Synchrotron Beamlines

Moraes I. C.[1], F. A. Bacchim Neto[1][1]Brazilian Center for Research in Energy and Materials, Campinas, SP, Brazil.

Machine dosimetry in synchrotrons often focuses on shielding design for standard X-ray beamlines. However, non-traditional beamlines, such as those extracting infrared (IR), visible, or ultraviolet (UV) radiation, present unique challenges that require customized shielding approaches. This work presents the radiation shielding calculations and design solutions developed designed using FLUKA.CERN [1] for three distinct beamlines at Sirius: IMBUIA, CARCARÁ, and SAPÊ.

IMBUIA is a mid-IR beamline where radiation is extracted at the same level of the storage ring from a low-field bending magnet and reflected at approximately 90º inside the accelerator tunnel. The shielding strategy involved tungsten and lead elements within the accelerator's concrete walls, as well as a small external shielding hutch to mitigate photon and neutron contributions. The primary challenge was achieving a satisfactory dose reduction at the hutch tube exit after multiple perpendicular scatterings.

CARCARÁ extracts into two regions: 11 keV in the conventional extraction and visible light at 90º from the machine, but in this case, the extraction is through the storage ring ceiling. The shielding assessment considered electron loss, synchrotron photon scattering, and Gas Bremsstrahlung, leading to the design of elements such as masks, walls, and shutters with optimized thicknesses for different shielding materials, including tungsten, steel, and lead.

SAPÊ, a UV-C beamline, required containment of scattered radiation within the concrete shielding of the storage ring while allowing only UV extraction via mirrors installed inside the concrete shielding, in the front-end region. To ensure compliance with dose limits outside the shielding, a lead mask and a steel wall were implemented inside the ring.

For all three cases, biasing techniques and geometric optimizations were applied to achieve satisfactory simulation results. The effectiveness of these shielding solutions was confirmed through experimental measurements, validating the accuracy of the simulations and design choices. This study highlights the importance of adapting radiation protection strategies, ensuring safe operation and compliance with radiological constraints in synchrotron facilities.

References
[1] F.Cerutti et al., "New Capabilities of the FLUKA Multi-Purpose Code", Frontiers in Physics 9, 788253 (2022). ISSN: 2296-424X

Design and Shielding Calculations for a New White Beam Beamline at DESY

Wefer A., Mokhtari Oranj L.

Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, 22607 Hamburg, Germany

DESY's 2.3 km storage ring, PETRA III, is one of the world's most brilliant X-ray sources, covering an energy range from 4 eV to 200 keV. It operates at 6 GeV particle energy with a beam current of 120 mA. The facility's beamlines are distributed across three experimental halls, with 25 currently in user operation, providing 5000 hours of beam time annually. Between 2026 and 2028, two additional beamlines, P25 and P63, will become available. Beamline P25 will focus on industrially relevant biomedical applications, powder diffraction experiments, and testing new instrumentation for PETRA IV. It features a 2 m spectroscopy undulator with a 3.14 cm period length. The existing optics hutch for P25 is shared with Beamline P24. P25 has two experimental hutches: EH1, which accommodates both white and monochromatic beams, and EH2, which is dedicated to monochromatic beams up to 50 keV. This work describes the design, construction, and radiation shielding analysis of the P25 beamline. In accordance with DESY's shielding policy, the white beam hutch is constructed with heavy concrete, while the monochromatic beam hutches use lead shielding. The adequacy of these shielding materials was assessed using FLUKA Monte Carlo [1] and STAC8 analytical [2] codes.
FLUKA calculations indicate that EH1 requires 40 cm of heavy concrete barium for the lateral wall and 50 cm for the downstream wall to shield against high-energy gamma rays, neutrons, and gas bremsstrahlung. For the EH2, which operates with a monochromatic beam, the required lead wall thickness was determined based on a 0.01% bandwidth of maximum energy of beam from the Double Crystal Monochromator (DCM) and its third harmonic. A 7 mm lead shield for the lateral walls and 11 mm lead shield for downstream wall is necessary to ensure that the radiation dose outside the hutch remains below 1 mSv per year.

References

[1] - G. Battistoni, T. Boehlen, F. Cerutti, P.W. Chin, L.S. Esposito, A. Fassò, A. Ferrari, A. Lechner, A. Empl, A. Mairani, A. Mereghetti, P. Garcia Ortega, J. Ranft, S. Roesler, P.R. Sala, V. Vlachoudis, G. Smirnov, Ann. Nucl. Energy 82, 10, (2015)

[2] - Y. Asano and N. Sasamoto, Radia. Phys. Chem. 44,133 (1994)

Brief overview of the radiation shielding calculations for the NEXT-II and NEXT-III projects at NSLS-II

Augusto R. S.[1], Lee R. J.[1], Bacescu D. M.[1], Antonelli S.[1], Dvorak J.[1], Johanson M.[1], Lienhardt L.[1], Chubar O.[1], Breitfeller M.[1], Li Y.[1], Walter A. L.[1], Yang Y.[1], Broadbent A.[1], Lee W.-K.[1], Adams J.[1]

[1]Brookhaven National Laboratory, Upton, NY 11973-5000

Ten years since its first beam, the National Synchrotron Light Source II (NSLS-II) facility is now at half capacity, with 30 beamlines delivering high quality X-rays to experiments serving a worldwide scientific community. As NSLS-II continues to mature, we will provide a brief overview of the radiation physics work recently carried out in the framework of its major development projects - NSLS-II Experimental Tools II and III [1] (NEXT-II and NEXT-III, respectively) - mainly using the Monte Carlo particle transport and interaction code FLUKA [2,3]. NEXT-II is currently underway and comprises three beamlines: CDI, which is getting ready for commission, and ARI & SXN which are scheduled to see first light before 2028. The latter two will be the focus of this work, illustrating the radiation shielding paradigm at NSLS-II to mitigate the radiological impact of Gas Bremsstrahlung, Synchrotron Radiation, and major electron beam losses. The NEXT-III project is far more ambitious and is set to deploy 8 to 12 new beamlines alongside their supporting infrastructure over the next 10 to 12 years, at a rate of 2 or 3 beamlines being built every 1 to 2 years. Preliminary radiological work for NEXT-III first beamline, QCT, will be highlighted in the present work, emphasizing the impact that certain beamline features can have in the radiation shielding design and optimization process.

References

[1] – D. Yazak et al., “NEXT-III at NSLS-II: A New Approach to Beamline Design and Development”, *Synchrotron Radiation News*, **38**(1), 10–13 (2025) https://doi.org/10.1080/08940886.2025.2454854

[2] – A. Ferrari, P. R. Sala, A. Fasso`, and J. Ranft, “FLUKA: a multi-particle transport code” CERN-2005-010 (2005), INFN/TC_05/11, SLAC-R-773
https://cds.cern.ch/record/898301/

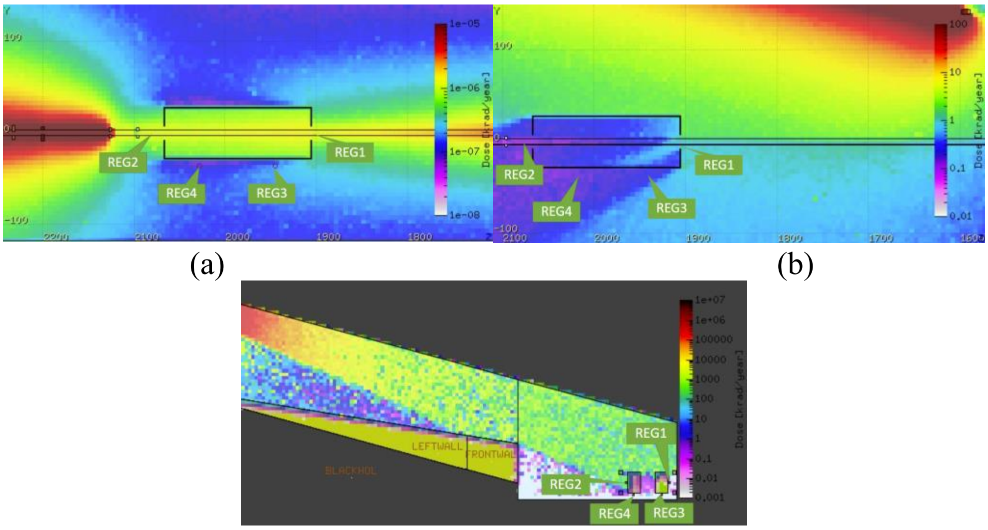
[3] – F. Ballarini et al., “The FLUKA code: Overview and new developments”, *EPJ Nuclear Sci. Technol.* **10**, 16 (2024) https://doi.org/10.1051/epjn/2024015

Radiation Levels Expected in Electronic Devices for Mirror Control at Sirius

Moraes I. C.[1], F. A. Bacchim Neto[1]

[1]Brazilian Center for Research in Energy and Materials, Campinas, SP, Brazil.

The first mirror for a bending magnet beamline at Brazilian Synchrotron Light Source, Sirius, will be placed inside the accelerator concrete shielding. This change brings several gains, such as the thickness reduction required for the first hutch's walls [1]. However, the mirror components are subject to more radiation sources, such as photons and neutrons, due to electron losses, synchrotron contributions and gas-bremsstrahlung, and higher radiation levels. Therefore, the radiation levels were computationally estimated to predict the expected scenario of operation and evaluation of the impact of eventual shielding materials. This study was developed with the Monte Carlo code FLUKA.CERN [2]. Electron losses, gas bremsstrahlung, and synchrotron radiation scattering inside and around the mirror were simulated. Dose distributions (Fig. 1a–c) allow us to determine the best position for the electronic device to reduce the radiation levels. The absorbed dose found was majorly from synchrotron radiation and other contributions were below the lowest threshold for failure found in literature, in the order of tens of krad. Results indicate a warning mainly inside the mirror. Additionally, orders-of-magnitude dose reductions were archived with added tungsten and steel plates.



(a) (b)

(c)

Figure 1: Annual dose maps (krad/year) values from (a) Gas bremsstrahlung, (b) electron losses and (c) synchrotron radiation scattering.

References

[1] I.C.Moraes et al., "Análise para cálculo de blindagem de cabana óptica para linha de luz do Sirius", Annals of 7º CBMRI (2020). ISBN: 978-65-990471-2-1.

[2] F.Cerutti et al., "New Capabilities of the FLUKA Multi-Purpose Code", Frontiers in Physics 9, 788253 (2022). ISSN: 2296-424X

Radiation Protection of FLASH2020+ at DESY

Liang T., Bohlen S., Leuschner A., Panofski E., Zander S.

Deutsches Elektronen Synchrotron DESY, Notkestraße 85, 22607 Hamburg, Germany

The FLASH electron accelerator at DESY is currently undergoing its upgrade project into FLASH2020+. There are significant changes to the FLASH1 line in terms of both synchrotron beam delivery from fixed-gap to movable-gap undulators and also electron beam transport. Figure 1 shows the layouts of the FLASH accelerator after the 2021/2022 shutdown and after the current 2024/2025 shutdown. The FLASH1 electron beam transport line is shifted laterally in the tunnel, and electrons are given an additional horizontal deflection before reaching the new electron beam dump location. These changes have a significant impact on the radiation fields and radiation shielding within the tunnel and in the surrounding facilities, for example: the intersecting PETRA tunnel, the downstream FEL user hall (Albert Einstein), and the publicly accessible space above [1, 2].

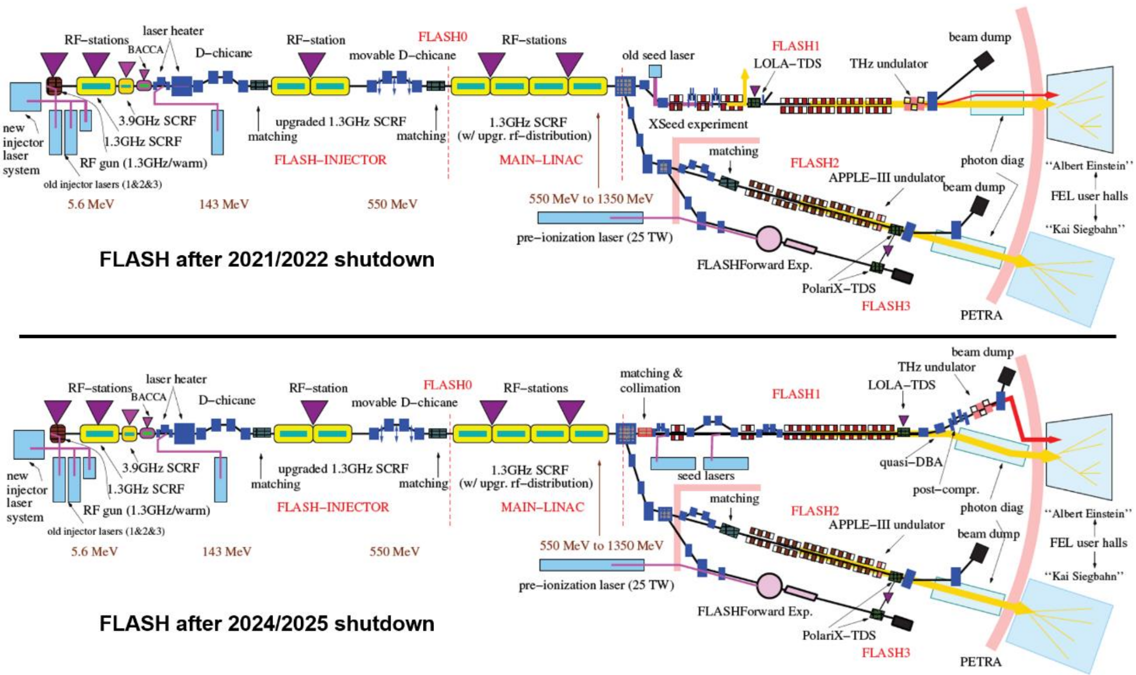


Figure 1: electron beam and photon delivery transport changes for FLASH1 as part of the FLASH2020+ upgrade project.

In this study, the D3 radiation protection group at DESY evaluates different plausible electron beam loss scenarios within the accelerator tunnel to determine where additional radiation shielding is required and to mitigate dose to personnel for the FLASH2020+ upgrade.

References

[1] - Martine Beye et al. "FLASH2020+ Upgrade of FLASH", *DESY Conceptual Design Report*, (2020).
[2] - Mathias Vogt et al. "The FLASH2020+ Upgrade Project", *21st International Conference on Radio-Frequency Superconductivity SRF2023*, (2023).

Radiation Shielding Design for SSRL Beamlines at SLAC

Ahmed M., Xiao S., Liu J.C.

SLAC National Accelerator Laboratory, 2575 Sand Hill Rd, Menlo Park, CA 94025

The Stanford Synchrotron Radiation Lightsource (SSRL) is a 3 GeV, 500 mA electron beam storage ring that currently operates with 16 beamlines. This work presents the methodology used for beamline shielding design at SLAC, illustrated here through the specific case of a new SSLR beamline, BL10.

Two types of radiation need to be considered in the shielding design: synchrotron radiation (SR) and gas bremsstrahlung (GB). At SSRL, a set of pre-calculated shielding curves [1] for both SR and GB were generated from FLUKA simulations of simplified but conservative models with the source terms from bend and typical ID lines. The generic curves define the required shielding thickness as a function of critical energy, scattering angle, and beam flux.

For SR shielding, the generic shielding curves were used to define the hutch wall thickness as well as the thickness and size of any required local shielding. Additional studies were only needed for special cases, for example, BL10 monochromatic beams might hit the downstream hutch wall directly without any scattering.

For GB shielding, FLUKA [2, 3] simulations were used to optimize shielding requirements from the generic shielding curves based on constraints of the beamline. Figure 1 illustrates a FLUKA-calculated GB dose rate map of BL10 at one operation mode.

This work was supported by the United State Department of Energy contract DE-AC02-76SF00515.

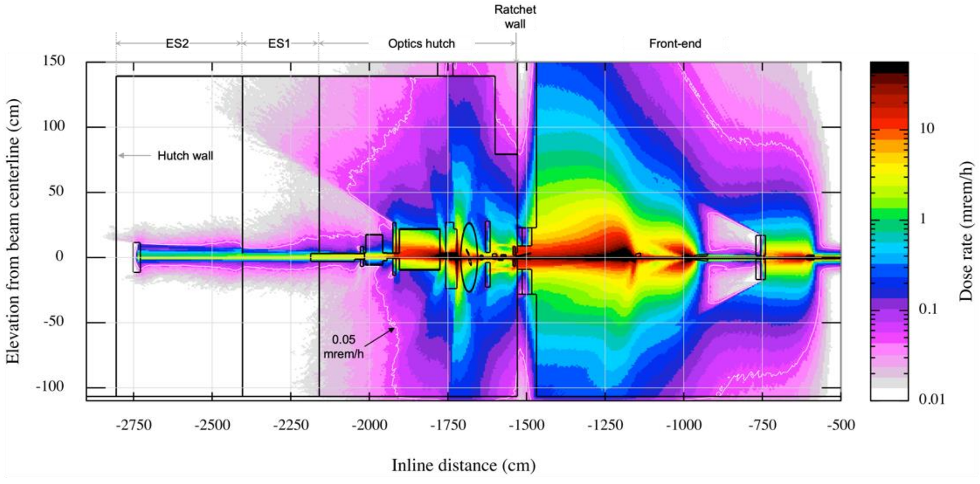


Figure 1. Elevation view of FLUKA-calculated GB dose rate considering normal losses for the SSRL BL10.

References

[1] – Liu, J. C. et al., Rad. Meas., *41*, S156-S162, (2006)
[2] – Ahdida, C. et al., Front. Phys. 9, 788253, (2022)
[3] – Battistoni, G. et al., Ann. Nucl. Energy 82, 10-18, (2015).

Session 6: Radiation detection and measurements to evaluate shielding design

Investigation of the radiation fields inside the accelerator tunnel during operation of the NanoTerasu

Akihiro Takeuchi[1], Masayuki Hagiwara[1], Hiroki Matsuda[1], Toshiro Itoga[2]
Seiya Hayakawa[1], Takeshi Nakatani[1], Noriyuki Morikawa[1], Norikazu Otsuka[3]
Nao Hoshi[3]

[1] National Institute for Quantum Science and Technology, 6-6-11-901, Aza Aoba, Aramaki,
Aoba-ku, Sendai-shi, Miyagi, 980-8579, Japan
[2] Japan Synchrotron Radiation Research Institute, 1-1-1, Kouto, Sayo-cho, Hyogo, 679-5198, Japan
[3] Tokyo Nuclear Services Co., Ltd., 1-3-5, Taito, Taito-ku, Tokyo, 110-0016, Japan

The NanoTerasu is a 4th generation synchrotron light source in Japan. The user operation was started in April 2024. NanoTerasu provides both soft and hard X-rays from insertion devices installed in the 3 GeV storage ring [1,2]. At present 10 of the 28 beamlines designed are available; the remaining 18 beam lines will be installed in the future. The storage ring is currently operated with a storage electron current of 200 mA by a top-up mode injection.

The electron beam losses in the storage ring can be caused by different effects, like Touschek effect, residual gas scattering, geometrical features, component failure and other effects [3,4]. These effects results in losses that may be uniformly distributed along the ring or localized to specific areas. In particular, unexpected beam loss is a problem not only for the stable operation of the accelerator but also for radiation safety.

We have measured secondary neutrons generated by electron beam loss to obtain information on the position, timing and amount of electron beam loss. Secondary neutrons produced by photonuclear reactions have a peak energy around 2 MeV and more isotropic than secondary photons emitted in the interaction between a high-energy electron and materials. The neutron dose in the accelerator tunnel attenuates simply with distance from the beam loss position regardless of the direction of electron beam. On the other hand, secondary photons as a bremsstrahlung have a strong forward peaking; the photon dose depends on not only distance from the beam loss position but also the direction of electron beam. We used a passive personal dosimeter with CR-39 (Luminess Badge; Nagase Landauer, Japan) and a semiconductor-type active personal electronic dosimeter DMC3000N (Mirion Technologies, USA) coupled with neutron module to measure the secondary neutron dose (Fig.1). We investigated beam loss around the whole circumference of the storage ring for CR-39 and locally for DMC3000N. We present the results of dose distribution and local beam loss measurements inside the storage ring tunnel.

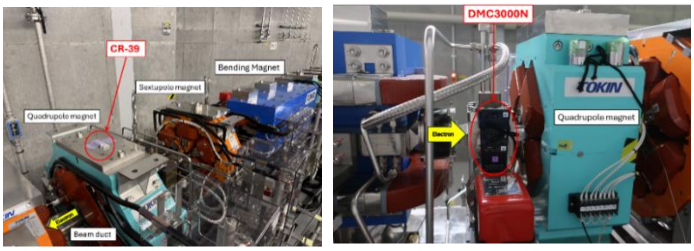


Figure 1: Photo of the measurement setup.

References

[1] A. Takeuchi et al., “Estimation of Absorbed Dose due to Gas Bremsstrahlung Based on Residual Gas in Electron Storage Rings”, Nucl. Sci. Eng, vol. 2, issue 2, 2024
[2] H. Matsuda et al., “Shielding design of NanoTerasu for gas bremsstrahlung and photonuclear reaction”, J. Nucl. Sci. Technol., vol. 61, issue2, 2024
[3] QST, “Accelerator design report for 3-GeV Next-Generation Synchrotron Radiation Facility”, 2020; https://www.qst.go.jp/uploaded/attachment/18596.pdf
[4] V. Kain, “Beam Dynamics and Beam Losses – Circular Machines”, Proceedings of the 2014 Joint International Accelerator School: Beam Loss and Accelerator Protection, Vol. 2, CERN, Geneva, 2016

Assessment of trench radiation shielding needs

Faruk S

Diamond Light Sources Ltd, Harwell Science & Innovation Campus, Didcot,
Oxfordshire, UK, OX11 0DE

Approximately 100 trenches surround the Diamond accelerator storage rings and run various cabling connections between the accelerator components and the data racks in the CIA. These trenches were filled with lead bags and high-density polyethylene (HDPE) beads to prevent gamma-neutron radiation for years. Over time, the integrity of those lead bags has deteriorated, releasing toxic lead dust during movement. We were investigating alternative options to replace or potentially eliminate the lead bags. We examined the estimated radiation dose inside the trench and on the floor using the semi-analytical method [1], as well as DUCT-III calculations [2] and FLUKA simulations [3,4]. The calculations and simulation results indicated values below 8 µSv/h at the trench mouth on the outer wall, with an average of 9 photons/s and 15 neutrons/s at 30 cm from the mouth. Additionally, we prepared for long-term measurement using a matrix array of about 100 TLDs along with gamma and gamma-neutron detectors. Promising indications from the live measurements suggested a negligible presence of gamma radiation, with a random presence of neutrons and neutron-induced gamma. This agrees with the calculations and simulation results. Does this indicate that we might be able to remove lead bags from the trench, though not in every instance? Let us examine the presentations.

References

[1] – NCRP Report No. 51. "Radiation Protection Design Guidelines for 0.1-100 MeV Particle Accelerator Facilities".

[2] - DUCT-III: A Simple Design Code for Duct-Streaming Radiations, R. Tayama, H. Nakano, H. Handa, K. Hayashi, H. Hirayama, K. Shin, F. Masukawa, H. Nakashima, and N. Sasamoto, High Energy Accelerator Research Organization, Nov 2001.

[3] - "The FLUKA Code: Developments and Challenges for High Energy and Medical Applications" T.T. Böhlen, F. Cerutti, M.P.W. Chin, A. Fassò, A. Ferrari, P.G. Ortega, A. Mairani, P.R. Sala, G. Smirnov and V. Vlachoudis, Nuclear Data Sheets 120, 211-214 (2014)

[4] - "FLUKA: a multi-particle transport code" A. Ferrari, P.R. Sala, A. Fasso`, and J. Ranft, CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773.

Machine Dosimetry in Synchrotrons: Neutron and Photon Mapping Using Alanine and CR-39 Detectors

Moraes I.C.[1], Silva J.V.[2], Rodrigues Jr. O.[3], Moura F.N.[1], Lixandrão-Filho A.L.[2], F. A. Bacchim Neto[1], Guedes S.[2]

[1]Brazilian Center for Research in Energy and Materials, Campinas, SP, Brazil.
[2]University of Campinas, Campinas, SP, Brazil.
[3]Nuclear and Energy Research Institute, São Paulo, Brazil.

Sirius, the new Brazilian synchrotron light source, operates at 3 GeV and presents unique challenges regarding radiation exposure and the long-term stability of its permanent magnet components [1]. In a previous study [2], we combined alanine/EPR dosimeters and Monte Carlo simulations using the FLUKA.CERN code [3]. The results identified the first bending magnet (BC01), just downstream the injection section, as the region with the highest dose deposition, a trend expected due to the electron losses during the beam transfer to the storage ring.

This work extends that study by increasing the monitoring period for one year and incorporating neutron-sensitive CR-39 detectors for comparative analysis. While alanine dosimeters were positioned exclusively in the BCs, CR-39 detectors were deployed in various locations, including BCs, undulators, dipoles, quadrupoles, and other areas identified as neutron-producing or radiation hot spots.

The results reaffirmed BC01 as the region with the highest readings for both alanine dosimeters and CR-39 detectors. However, the alanine dose measurements indicated a reduction in dose by photons over time, suggesting a decrease in electron losses, which aligns with expected beam dynamics improvements. Another significant hotspot was the neutron flux observed by CR-39 near the copper absorber at the end of the bending magnet, where high-flux and high-energy photons interact with copper, leading to neutron production.

Future work aims to convert track densities in CR-39 detectors into dose values, allowing a quantitative comparison between dosimetric methods. Since alanine dosimeters are insensitive to neutrons, CR-39 proved to be a useful tool for neutron flux evaluation, complementing the previous dosimetric analysis. This approach enhances our understanding of the radiation environment in synchrotrons and provides critical data for ensuring long-term machine reliability.

References

[1] Samin, Adib J. "A review of radiation-induced demagnetization of permanent magnets." Journal of Nuclear Materials 503 (2018): 42-55.
[2] Moura F.N. et al., “Combining Alanine Dosimeters and Monte Carlo Simulations: A method for demagnetization forecast by high dose exposure”, 11th International Workshop on Radiation Safety at Synchrotron Radiation Sources (2023).
[3] F.Cerutti et al., “New Capabilities of the FLUKA Multi-Purpose Code”, Frontiers in Physics 9, 788253 (2022). ISSN: 2296-424X

Session 7: Radiation safety issues for FEL and next generation facilities / Safety protection against high power laser used in FEL and synchrotron facilities

SLAC's LCLS-II Superconducting Accelerator Facility: Ramp-up to Higher Power

Bauer J., Blaha J., Frosio T., Liu J.C., Santana M., Rosenstrom A., Xiao S., Rokni S.H.

SLAC National Accelerator Laboratory, 2575 Sand Hill Road, Menlo Park, CA 94025

The Linac Coherent Light Source (LCLS) was expanded with a new superconducting (SC) accelerator, called LCLS-II, that is designed for up to 4 GeV electrons, 1 MHz repetition rate, with a maximum power of 240 kW. Before reaching the dumps, the electrons from LCLS-II pass through the same long undulators that the electrons from the previously build normal-conducting (NC) accelerator pass through. In these undulators, free electron laser interaction generates from these electrons the very short and high-intensity X-rays that are used for experiments in a wide variety of scientific areas.

LCLS-II reached first light late 2023 and started delivering beam to experiments, but the commissioning with its ramp-up to high power is still continuing. The talk presents the challenges experienced during the commissioning.

The high SC electron power requires the use of an active safety system that ensures the beam stays within its approved limits. One of these systems, a loss monitor based on quartz fibers, developed issues. To allow commissioning while the fiber system is being upgraded, the Radiation Protection group worked with the accelerator department on alternative controls. Currently operation is permitted to maximal 16 kW in electron beam power, and a repetition rate of up to 33 kHz and an electron power of up to 8 kW was achieved.

An outlook will also be given for the planned LCLS-HE upgrades, which extends the LCLS-II accelerator to enable electron energies of up to 8 GeV.

This work was supported by the United State Department of Energy contract DE-AC02-76SF00515.

FEL Bootstrap Experiments for the Ramp-Up of LCLS-II Superconducting Linac

Xiao S., Rosenstrom A., Heimann P., MacDonald S., Rokni S.H.

SLAC National Accelerator Laboratory, 2575 Sand Hill Rd, Menlo Park, CA 94025

This work summarizes bootstrap experiments for the ramp-up of Linear Coherent Light Source-II (LCLS-II) superconducting linac. LCLS-II superconducting linac is designed for 4 GeV electron beams up to 120 kW and 929 kHz repetition rate. Its commissioning started in 2023. Currently it runs up to 3.8 GeV, 8 kW and 33 kHz electron beams, delivering up to ~15 W Free Electron Laer (FEL) beams (~0.5 mJ at 33 kHz). The high power FEL has the potential to damage materials, and thus it is critical to verify the design of safety systems before high power operation.

Two types of experiments, material drilling and air attenuation, were performed to confirm the safety of photon instruments for power ramp-up. The material drilling experiment aims to determine the speed that FEL beams drill through materials as well as the footprint of holes drilled by FEL beams. The air attenuation experiment examines the tunneling effect from high repetition rate beams. This presentation shows the results from the latest experiments performed at different FEL beam parameters and for different samples.

This work was supported by the United State Department of Energy Contract DE-AC02-76SF00515.

Integrating High-Power Lasers into a Free Electron Laser Environment: Insights from the ReLaX Laser at European XFEL

Boyd. E, Brambrink. E, Tschentscher.T, de Diego. I

European XFEL: Holzkoppel 4, 22869 Schenefeld, Germany

The integration of high-power lasers into a Free Electron Laser (FEL) environment presents unique challenges in safety, regulatory approval, and operational procedures. At European XFEL, the Relativistic Laser at XFEL (ReLaX) is a high-intensity, short-pulse titanium-sapphire laser system that has been an integral part of the High Energy Density (HED) experiment since its commissioning in 2019. Since then it has been successfully operated within strict radiation protection limits, with no measurable dose detected outside the heavy concrete shielding of the experimental area.

Building on this operational experience and ongoing technical advancements, plans are now underway to expand the capabilities of the ReLaX laser. A key upgrade involved increasing the peak power from 100 TW to 400 TW, enabling experiments at intensities up to 10^{22} W/cm². Additionally, new scientific objectives required expanding the range of target materials beyond solid-density samples to include liquids, foams, and gases. Furthermore, an upcoming counter-propagation experiment, designed to investigate fundamental quantum physics, will involve directing the laser beam against the XFEL beam—a previously unforeseen setup that introduces new radiation protection considerations.

This presentation will outline the regulatory approval process for the initial commissioning and later upgrades of the ReLaX laser system, including interlock, shielding and radiation monitoring strategies. Simulations indicate that increasing laser intensity and modifying target materials will lead to higher-energy electron generation, with maximum average electron energies potentially increasing from 2 MeV to 15 MeV. Radiation protection measures, such as enhanced shielding, dose monitoring, and emergency shutdown mechanisms, will be discussed to ensure continued compliance with the existing annual dose limit of less than 1 mSv.

By sharing insights from the ReLaX laser's evolution at European XFEL, this presentation aims to provide valuable guidance for integrating high-power lasers into large-scale accelerator facilities while maintaining rigorous safety standards.

Radiation Protection Analysis of LCLS-II-HE Soft X-Ray Undulators

Rosenstrom A., Xiao, S, Rokni S.H.

SLAC National Accelerator Laboratory 2575 Sand Hill Rd, Menlo Park, CA 94025

This work analyzes the impacts of the planned change for the soft x-ray undulators (SXUs) as a part of the Linear Coherent Light Source-II High Energy Upgrade (LCLS-II-HE) project. The period and number of the SXUs will increase from 39 mm & 21 undulators to 56 mm and 30 undulators to accommodate the increase in the electron beam energy from 4 GeV to 8 GeV. As the upgrade to the undulators will occur simultaneously with existing normal conducting (NC) LCLS operation and superconducting (SC) LCLS operation, the effect of this change is analyzed for both the LCLS-I normal conducting copper linac and for the LCLS-II superconducting linac. The work also addresses the intermediate configurations of the undulator strings, during which different undulators coexist, leading to 29 unique configurations of the undulator string based on the project's installation plan.

The analysis of the undulator installation requires the review of two parts of the radiation safety system: shielding and the beam containment system. With the change in the period and magnetic field strength, the synchrotron energy spectrum and fluence also change. The change in synchrotron radiation was assessed on a per-undulator basis by examining the relative change in the synchrotron spectrum to ultimately, in conjunction with previous analysis, establish conservative shielding safety factors for the planned operation (5 GeV / 120 kW) during the undulator swapping relative to the shielding design envelope (10 GeV / 240 kW).

As a result of the installation and swapping of the undulators, the FEL pulse energy and divergence also change, which affects the W/cm^2 incident on different beam containment system devices such as FEL stoppers and collimators. The change in FEL intensity has further consequences in several safety analyses related to the sublimation rate of diamond stoppers, material drilling speed which is related to interlock response time requirements, single and multi-pulse damage of components, and the tunneling effect seen by FEL beams in air. All of these safety aspects were assessed as a part of the approval to enable operation with mixed undulator configurations.

Following the completion of the analysis, the requirements for operation were developed to adequately mitigate the impacts of a changing source term used in safety analysis.

This work was supported by Department of Energy contract DE-AC02-76SF00515.