SATIF-15

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Book of Abstracts

Contents

Radiation Transport Simulations in Support of FRIB Initial Operation* 1

Shielding at the European Spallation Source: From Monte Carlo simulations to Reality . 1

Overview of Shielding Analyses at Oak Ridge National Laboratory's Spallation Neutron Source Second Target Station 1

Simulation of Spallation Target Activation and Cask Dose Shielding 2

THE ORNL R2S CODE SUITE (ORCS) FOR SHUTDOWN DOSE RATE SIMULATIONS . 3

MARS15 Code Status and Path Forward 3

Composite Models in the MARS15 Code 4

FLUKA: status and perspectives 5

The FLUKA group- and pointwise neutron treatment 6

FLUKA status and perspectives 6

Recent updates and shielding benchmark of PHITS 7

Moira: A bridge between Monte Carlo worlds 8

Neutronics Calculations with the Unstructured Mesh Model of the ORNL's Second Target Station 8

The On-the-fly Global Variance Reduction Technique and its application for IFMIF-DONES shielding analyses 9

Advanced Monte-Carlo methods for prompt and residual radiation calculations in light-ion accelerators 9

Scaling models for radiation transport calculations at FRIB 10

Attenuation of neutrons in labyrinths: comparison of various calculation techniques . . 10

Inter-comparison of Particle Production (4) 11

The Shielding Integral Benchmark Archive Database (SINBAD) Task Force 12

MCNP6 and PHITS benchmark calculations for proton accelerator shielding applications 12

Simulation studies of a pion production target for the Mu2e-II experiment 13

Activation benchmarking of metals by 9.6 GeV electrons at PAL-XFEL 14

Overview of benchmark studies at the CERN Shielding Benchmark Facility (CSBF) and the CERN High Energy Accelerator Mixed Field (CHARM) facility in the CERN East Experimental Area 14

Radiation protection aspects of Long Shutdown 3 at the CERN LHC experiments: a methodology for residual activation assessments applied to the CMS case study 15

Activation calculations of selected RPV internal components for optimal decommissioning of nuclear power plants 15

Radiation transport calculations supporting the ISIS muon collimator replacement project 16

Radiation protection studies for new beam dumps at ISOLDE at CERN 17

Radiological assessment for the renovation of the CERN East Area primary area and secondary beam lines 18

Radiation protection assessment of the AMBER Drell-Yan program 18

Fundamental investigation on concrete composite for radiation shielding in facilities . . 19

Sensitivity study of water and iron contents for neutron deep penetration in concrete . . 19

ARI-SXN beamlines radiation shielding analysis 20

The skyshine problem at the STAR facility due to the beam dumps and the dark current leakage 20

Measurement of neutron production yields of 345 MeV/u 238U + Cu with a time-of-flight method 21

Photo-neutron emission mechanism at low-energy photon interaction 22

Impact of new delivery methods in proton therapy on radiation protection of Compact Proton Therapy Centers (CPTC) 22

Optimizing the fast neutron flux for radiotherapy purposes and reducing the exposure dose for healthy tissues 23

Modelling of Multilayer Shielding Scenario for High Energy Neutron Accelerator Based using PHITS 24

Dosage Analysis and Irradiation Time Optimization of Negative Pi-Meson Therapy in Prostate Cancer Using PHITS Program 24

Shielding design for NanoTerasu - a compact 3 GeV next generation synchrotron radiation facility - 25

Absorbed-Dose Energy Dependence for Luminophore Materials: A Monte Carlo Intercomparison 25

Optimization of a Neutron Beam Shaping Assembly Design for BNCT and Its Dosimetry Simulation Based on Phits Version 3.26 26

Photon and neutron dose measurements and Monte Carlo evaluation at the Beam Test Facility of the INFN - Frascati National Laboratories 26

Measurements and Monte Carlo evaluations of shielding concrete radioactivation in a nuclear physics facility to verify the clearance levels. 27

GEANT4/FLUKA/MCNP comparison of secondary yields in processes relevant for the Mu2e experiment 28

Methodology and preliminary studies for the evaluation of induced radioactivity for the decommissioning of Synchrotron SOLEIL's storage ring. 28

Preliminary Radiation Shielding Calculations for a New Facility Employing a Commercial Cyclotron at CGN Mianyang, Sichuan in China 29

Measurement and calculation of high energy neutron spectrum and its dose after shielding at KEK electron-positron injector linac 30

Shielding and activation simulations for the High Brilliance neutron Source (HBS) target station 30

Ensuring the Quality of 10 MeV MEVEX LINAC Electron Irradiation Beam based on The Calibration Procedure for Dosimetry System 31

Intercomparison of radiation damage calculations in target materials at proton accelerator facilities using various Monte Carlo particle transport codes 32

Shielding at high-power, high-intensity laser facilities: source term assessment for HED science and the Athena Lab for medical applications at HZDR 32

Solid state dosimeters at Laser-Driven Accelerator Facilities 33

A new methodology for plugging of pipe/cable penetrations in shielding walls for gamma and neutron radiation 33

Atmospheric-like neutrons and muons at the ILC beam dumps 34

Follow-up of past SATIF agreements and future actions 34

Session 1 / 2

Radiation Transport Simulations in Support of FRIB Initial Operation*

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The Facility for Rare Isotope Beams (FRIB) at Michigan State University in East Lansing, Michigan, USA has transitioned from being a construction project to user operations for nuclear science experiments. FRIB is designed for the production of rare-isotope beams from in-flight fragmentation and fission of primary beams of stable isotopes ranging from oxygen to uranium with energies up to 200 MeV/u and a planned beam power ramp up to 400 kW. This report gives an overview of the radiation transport work carried out to meet the unique challenges of a transitioning facility: support for commissioning and experiment work with beams during final construction; incremental hazard evaluation during beam-power ramp-up; and planning input for staging hazard mitigation strategies.

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Session 1 / 11

Shielding at the European Spallation Source: From Monte Carlo simulations to Reality

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The European Spallation Source is currently being constructed in the Lund, Sweden. As expected for a megawatt class facility, the need for shielding is high, extensive and costly. In support of the project a large number of Monte Carlo particle transport calculations have been performed. As for any simulations, even if one attempts to simulate everything in details, reality will not always play by the roles of the Monte Carlo codes. In this presentation same lessons learned will be given from the experience ESS has gained going through this process.

Session 1 / 51

Overview of Shielding Analyses at Oak Ridge National Laboratory's Spallation Neutron Source Second Target Station

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The design of the Second Target Station (STS) at Oak Ridge National Laboratory's (ORNL's) Spallation Neutron Source (SNS) is currently underway [1]. STS will operate at a power of 700 kW with short pulses, less than 1 μs, and a repetition rate of 15 Hz. The new target will be a rotating water-cooled tungsten target, which will have two coupled cryogenic moderators filled with liquid parahydrogen: one above and the other below the target. Sixteen neutron beamlines will view the moderator above the target and six neutron beamlines will view the moderator below the target, for a total of 22 new instruments.

The STS Neutronics Group is responsible for all neutronics analyses related to the design and construction of STS, which includes neutronics optimization of the target and moderator, heating and radiation damage of major components, and all aspects of STS shielding. This paper will present example shielding analyses typically performed for the design of STS. These include shielding along the proton beamline from the existing accelerator to the second target, activation of major components, energy deposition and radiation damage of the proton beam window, and shielding along the neutron beamlines from the target monolith through the bunker and beamline shielding to the instrument caves. The primary computational tool used by the STS Neutronics Group is MCNP6[2], but most of these analyses benefit from auxiliary codes that develop input for MCNP6 or process the output from MCNP6. These examples will highlight the cutting-edge computational methods the STS Neutronics group uses such as unstructured mesh geometries converted from CAD, activation simulations for charged and neutral particles in any energy regime, and advanced automated variance reduction techniques for deep penetration shielding and beamline shielding with long streaming gaps.

[1] ORNL, "Spallation Neutron Source Second Target Station Conceptual Design Report Volume 1: Overview, Technical and Experiment Systems," S01010000-TR0001, R00, Oak Ridge National Laboratory (2020).
[2] C. J. WERNER, ed., "MCNP® User's Manual, Code Version 6.2," LA-UR-17-29981, Los Alamos National Laboratory (2017).

Session 1 / 55

Simulation of Spallation Target Activation and Cask Dose Shielding

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During the 2022 maintenance outage, we are installing a new generation of spallation target-moderator-reflector-shield (TMRS), known as Mark-IV for Manuel Lujan Jr. Neutron Scattering Center (Lujan Center) at the Los Alamos Neutron Science Center (LANSCE). This paper discusses the activation anal-ysis of the previous target Mark III, in service 2010-2021. The TMRS employs a split target geometry consisting of two cylindrical W targets positioned on the axis of the proton beam. The upper target has a cylindrical inconel shell filled with seven W discs, with thicknesses increasing downstream. The tungsten discs have Ta cladding and are surrounded by cooling water flowing through the spaces between them. The lower target is a single W-cylinder cladded with Ta surrounded by an inconel shell. These two targets are expected to be the hotspots from an activation perspective, including its cladding and the shell. Another significant activation contribution is expected to be from the proton beam window located above the upper target. The area around the targets is mostly filled with beryllium. However, there is stainless steel (SS) at the bottom of the lower target. Around

the proton beam window, there is mainly SS as well. These materials act in part as self-shielding. However, to ensure radiation safety, Mark III was placed in a steel-lead shielding cask.
Activation of designated hotspots was calculated by combining MCNPX 2.7.0 [1] with CINDER 1.05 [2] codes. The final dose simulation was carried out by MCNPX using a gamma dose mesh tally and a set of point detectors (PD). The Mark III target was operated for 12 years with approximately half-year run cycles delivering 800 MeV proton beam. Simulations were compared with the Radiation Control Technician (RCT) measurement on the day Mark-III was taken out and placed into a shielding cask.

[1] Mckinney, Gregg. (2011). MCNPX User's Manual, Version 2.7.0.
[2] S. T. Holloway, W. B. Wilson et al., A Manual for cinder2008 Codes and Data (LA-UR 11-00006), Los Alamos National Laboratory, March 1, 2011.

Session 1 / 21

THE ORNL R2S CODE SUITE (ORCS) FOR SHUTDOWN DOSE RATE SIMULATIONS

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Current experimental fusion systems and conceptual designs of fusion pilot plants (FPPs) are growing in complexity and size. Several radiation metrics are crucial to the safe operation of fusion machines, including the shutdown dose rate (SDDR). SDDR is caused by decay gamma rays from radionuclides that become activated by neutrons during the operation of a fusion system. The two state-of-the-art approaches for determining SDDR are the Direct 1-Step method (D1S) and the Rigorous 2-Step method (R2S).

The R2S method is divided in to 2 steps. In the first neutron transport step, spectra are calculated on a mesh covering the complete problem geometry. The calculated neutron spectra are then used in the intermediate isotope inventory calculation step where the decay gamma spectra and specific activities are calculated. The second transport step follows, where gamma rays originating from the activated radionuclides are transported through the system in question. The high computational demand of the R2S technique originates from the need for two transport simulations in complex and often highly attenuating geometries.

There is a clear need for computationally efficient R2S codes for high fidelity analyses of complex, realistic fusion geometries. The Multi Step Consistent Adjoint Driven Importance Sampling (MS-CADIS) variance reduction method was developed with the SDDR problem in mind. The MS-CADIS methodology is implemented in the Oak Ridge National Laboratory R2S Code Suite (ORCS).

In this paper we will present the capabilities of individual codes that make up ORCS. The paper will also include examples of using ORCS to support experimental campaigns at Joint European Torus (JET), analysis of the Pellet Injection system in Port Cell 16 of ITER, and analysis of the Equatorial Port 9 at ITER.

ORCS is under active development with one of the main research areas on integrating the Shift Monte Carlo transport code.

Session 2 / 58

MARS15 Code Status and Path Forward

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MARS15 Code Status and Path Forward

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Abstract

The MARS15 multi-purpose Monte-Carlo code is Fermilab's particle-matter interaction code that supports the lab's projects along with numerous accelerator facilities in the country and abroad at all stages, from planning and design to operations and decommissioning. The MARS group is involved in the design and upgrades of the high-power targets, beamlines, collimators, absorbers, and experimental flagship facilities at Fermilab, such as LBNF, PIP-II, and mu2e, as well as the MI-8, Delivery Ring, and Booster upgrades, along with detailed modeling of the crucial aspects of future projects such as a Muon Collider. Besides all of these applications, the group's activities are currently focused on the code developments in the following areas: (1) increased physics output by maximizing useful particle yields from target systems and minimizing backgrounds in detectors; (2) modeling of 3D distributions of particle flux, energy deposition density, prompt and residual doses, nuclide production, radiation damage, and spectra by primary and secondary beams for complex accelerator and detector configurations; (3) optimized performance of predictive virtual particle accelerators and experimental setups (e.g., MARSLBNF); (4) safe designs and operations of accelerator systems and experiments; (5) making MARS even more capable, trustable and usable in practically arbitrary parameter phase space; (6) further development of the SRF modules including detailed underlying physics; (7) creation of the CAD ⊠ MARS_ROOT ⊠ CAD user-friendly geometry converters compatible with strict requirements for particle-matter simulation in a challenging accelerator environment.

A MARS geometry model can be imported from a CAD model, converted from a corresponding mesh generated for ANSYS calculations, or created via bilateral geometry model exchange with Geant4 directly using GDML format, with every stage verified using an advanced 3D GUI. The further improved powerful integrated MARS-MADX-PTC system is highly efficient for particle tracking in SRF (with time-dependent electromagnetic fields and Dark Current production), quadrupole, dipole, solenoid magnets, and Machine-Detector Interface (MDI) for use in the 10-5 eV < E < 100 TeV energy range. Further near-term plans include: (1) implementation of modern code-management techniques; (2) perfection of codebase (Fortran & C++, Hbook & ROOT histograms etc.); (3) improve MPI mode to minimize a loss in scalability with a number of MPI ranks > 4×104 on the current petaflop (1015 fpo/s) platform and prepare for the exascale (1018 fpo/s) computing era.

Session 2 / 59

Composite Models in the MARS15 Code

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Studies of the physical phenomena resulting from interactions of intense high-energy beams with matter require – in some cases - the use of models complementary to those used in the MARS15 Monte Carlo code.
An example of such a kind is heating of a target and other accelerator and experiment components by the beam pulses followed by relaxation of the temperature field between the pulses. Solution implies calculation of radiation field characteristics in mesh cells, generated by third-party mesh generators which can produce non-liner meshes of arbitrary shaped cells.

Another example can be a study of impact of beam losses in accelerator on formation of doses to personnel, machine components and environment. In that case, the beam physics models are usually used to generate a source term to feed the particle transport and interaction codes such as MARS15. In general case establishing interaction between models requires implementation of the data transfer and data representation modules. Function of data transfer module is implementation of data flow between models. Data representation module is aimed to convert information obtained from source to representation usable by the receiver. As an example, this module can perform mapping of phase coordinates received from one model to phase space of the model used in receiver.
The approaches and tools used to integrate MARS15 with a third-party simulation software are described in this presentation. The results obtained with these techniques for the Fermilab Long-Baseline Neutrino Facility (LBNF/DUNE) and the Delivery Ring are presented.

Session 2 / 61

FLUKA: status and perspectives

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The present status of the authentic FLUKA code will be presented with particular emphasis to developments and features added in the last couple of years.

High-energy FLUKA's model have been deeply revised in order to improve predictions, and to better match experimental data on the production of intermediate hadronic resonances, data which show a picture rather different from the one usually assumed in hadronization models. Concurrently, hadronic cross section fluctuations are now implemented in the code, improving emitted particle multiplicity distributions, and allowing for the first time to compute quasi-elastic and absorption cross sections directly from the built-in FLUKA Glauber model. A thorough revision and extension of the latter now allows the computation of reliable hadron-nucleus (hA) cross sections up to energies as high as 10^{20} eV. Consequently, non-elastic cross sections (quasi-elastic and absorption/particle production ones) have been completely revised and improved in FLUKA.

The interface with DPMJET-3 was deeply modified and streamlined in collaboration with Anatoli Fedynitch, and it is now integrated into the latest Dpmjet version 3.19.3.1. Moreover, thanks to this work, issues at low energies with meson spectra in DPMJET have been improved. Finally, for intranuclear cascading, DPMJET-3 can now use directly the FLUKA hadronic models as an alternative to the original Hadrin model from the 80's.

In the framework of an effort to extend FLUKA to higher energies, the code has been successfully used up to 10^{19} eV for high energy cosmic ray problems, both for photon, proton, and ion projectiles.

At the same time, several developments in the sub-GeV - few GeV energy range have improved results when compared with experimental data.

A new model for coherent and incoherent (quasi-elastic) hA interactions has been developed and it is now applied to protons and neutrons up to 200 MeV, with parameters optimized against available experimental data and DWBA calculations taken from JENDL-4 and ENDF/B-VIIIR0. The same approach is now used for all hadrons from 1 GeV to infinity, accounting also for quasi-elastic interactions at high energies, which are now explicitly described and no longer treated as a sub-case of coherent elastic interactions.

Concerning energies and projectiles of relevance for hadron-therapy, several developments in cross sections for very light fragments and in the modified rQMD-2.4 interface significantly improved predictions for light ion beams, in particular 4He beams. Those beams are now in clinical use at HIT, also thanks to the improvement carried out in FLUKA.

The addition of a sophisticated electro-magnetic tracking algorithm, based on the 4th order Runge-Kutta-Gill method, enables the accurate description of charged particle motion in complex, time dependent, fields (eg resonating cavities), even starting from almost zero energy.

Another important addition had been the ability to propagate and let excited nuclei interact. Now nuclei on an excited nuclear level of known/finite mean life, will travel until the decay point, rather than de-excite instantaneously at the interaction point. This has consequences both at low and very high energies.

For all these topics examples will be given assuming the time will be enough.

The major changes in the neutron sector will be described in a companion presentation.

Session 2 / 62

The FLUKA group- and pointwise neutron treatment

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The low energy neutron treatment in the authentic FLUKA code has been greatly expanded over the last couple of years.

Until recently, the treatment of neutrons below 20 MeV was based on a 260-group library built with NJOY99 (plus ad-hoc extensions) and to various degrees based on ENDF/B-VIR8, ENDF/B-VIIR0-1, and JEFF-3.2. New evaluations are now available which contain more isotopes, more accurate information, and with new formats (eg for unresolved resonances) which are incompatible with older NJOY versions. Consequently, the entire processing chain is now built on NJOY16 (work with NJOY20 is in progress) and a vast majority of the isotope are now processed out of the most recent evaluations, mostly ENDF/B-VIIIR0. At the same time, the library, besides the residual nuclei cross sections, now contains also the probability of producing isomers with cross sections derived from EAF-10

Fully correlated pointwise treatment for some isotopes (^{1}H, ^{2}H, ^{3}He, ^{4}He) was available also in previous FLUKA versions. However no general pointwise treatment was possible, unless in a few exceptional cases (eg ^{40}Ar, ^{208}Pb) which were not generally distributed because of several limitations. Now, a novel, pointwise based, alternative is provided in FLUKA for all stable isotopes. This approach, using as much as possible the evaluated data file information, which is strictly inclusive, complemented with physics modelling and some reasonable assumptions, is now able to produce event-by-event, exclusive, fully correlated neutron interactions in the 20 MeV - 10^{-5} eV energy range. The pointwise library is based on ENDF/B-VIIIR0 and TENDL-19, and it is built with a combination of PREPRO19, NJOY16 (both somewhat modified) and an extensive in-house developed code.

Examples proving the neutronics performances of the pointwise libraries against the group-wise library will be presented. Applications which otherwise could not be possible without the fully correlated pointwise treatment will also be presented.

During the development of the pointwise libraries, several issues denoting inconsistencies or outright errors in the evaluated data files had emerged. Moreover, some problematic tendencies in the way new evaluated data files are produced were also noted. It is important for our community to be aware of those issues, and possibly exert pressure on the evaluator community to take into account our concerns.

Session 2 / 37

FLUKA status and perspectives

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This contribution summarizes several physics improvements recently implemented in the FLUKA code, as distributed by the FLUKA.CERN Collaboration under new licensing conditions. This follows a new agreement between CERN and INFN (as FLUKA copyrights holders) to prepare the future of FLUKA, drawing on lessons learned and current standards in the organization of software collaborations. Its goal is to ensure FLUKA's long-term sustainability and capability to meet the evolving requirements of its user community.

Since then, the current fourth generation of FLUKA has included the treatment of coherent effects experienced by high energy hadron beams in crystal devices, such as channeling, and the synchrotron radiation emission during charged particle transport in vacuum regions subject to magnetic fields, relevant to various applications. Moreover, a model for low-energy deuteron interactions, from threshold up to 300 MeV, has been developed and released, eventually overcoming a persisting lack. Lately, a major milestone such as the point-wise transport of low-energy neutrons has been finalized. This enables respective event-by-event simulations, without implying major penalties in the calculation time. In addition, direct (p,n) reactions to the Isobaric Analogue State of several target isotopes have been described, while refining reaction cross-sections for proton and alpha projectiles.

The code has been provided with the Arc-DPA estimation capability. Work on the improvement of nuclear elastic scattering is ongoing.
User experience has been enhanced thanks to new cards offering a variety of built-in magnetic field options and a new template for custom sources.

In parallel, as part of a systematic quality assurance plan, a continuous integration pipeline to automatically validate the codebase, now managed through the CERN GitLab instance, is complemented by automatic processing and analysis of a tailored physics-case test suite (FLUKAVAL). The latter probes the release-candidate FLUKA version both at model/interaction level and on full-scale examples representing real case applications.

Session 3 / 16

Recent updates and shielding benchmark of PHITS

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General-purpose radiation transport code PHITS has been improved in recent years. Following is the list of major updates.
1, The extension of the cross section data reading module. Previously, it was compatible with those of protons, neutrons and electron-gamma shower. The current version can read cross sections of alphas, deuterons, and photo-nuclear reactions.
2, The modernization of burn-up calculation code DCHAIN. Neutron activation cross section, decay data and photon dose conversion coefficient libraries were replaced with modern ones. The uncertainty in the transport phase is considered.
3, The functionality to calculate the response of the result to input parameters.
4, Interactive 3D geometry viewer PHIG-3D.

5, Cosmic ray source function.
6, Track-structure calculation models, which calculate atomic-scale reactions of charged particles on event-by-event basis, for electrons, positions, and heavy ions.
7, RT-PHITS, an interface dedicated to radiation therapy, which can handle DICOM data on treatment planning,PET-images, CT-images and phase space files.
8, Random number by Xorshift64
9, User-defined stopping power
10, Mu-pair production

In addition, PHITS has been recently benchmarked against the shielding experimental data of SINBAD. This benchmark illustrated that the use of high energy cross section data library JENDL-HE/4.0 is effective to reproduce the measured reaction rates and spectra. Calculation by the default settings using nuclear reactions models, INCL4.6 and GEM, overestimated the scattering in thick shielding and failed to consider secondary neutron spectral peaks.

Session 3 / 36

Moira: A bridge between Monte Carlo worlds

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In this paper, the development of a Geant4 application enabling simulations with FLUKA input files is presented. The creation of this novel tool, named Moira, obeys two main motivations: to allow the execution of FLUKA and Geant4 simulations using the same setup with minimal user intervention as well as to prepare the long-term evolution of the FLUKA code, aiming to exploit natural synergies between both Monte Carlo communities.
Consistently with the FLUKA user experience, Moira currently supports combinatorial geometries, scoring options, biasing techniques, complex magnetic fields, transport and production cutoffs as a function of the particle's energy, among other features. It is also fully integrated in the Flair graphical interface.
The level of maturity achieved by Moira so far is detailed, and comparisons of simulation results concerning various real cases are presented. These include studies concerning complex radiation environments, such as the CHARM facility at CERN and the LHC.

Session 3 / 23

Neutronics Calculations with the Unstructured Mesh Model of the ORNL's Second Target Station

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The Second Target Station (STS) at the Oak Ridge National Laboratory's Spallation Neutron Source is designed to become the highest peak-brightness source of cold neutrons in the world. The current conceptual design of STS consists of a segmented rotating tungsten spallation target driven by a 1.3-GeV, 700-kW short-pulsed proton beam and two coupled parahydrogen neutron moderators surrounded with water premoderators and a beryllium reflector. To advance the STS design in a timely manner and cope with a large volume of supporting neutronics calculations, we employ the

most efficient computational tools that are available. Key among these tools is the Unstructured Mesh (UM) geometry capability of the radiation transport code MCNP6.2 [1]. The UM geometry capability allows us to automatically convert the computer aided design (CAD) models into high-fidelity models for neutronics calculations, reduce the time necessary to generate the models, and deliver crucial results for the subsequent thermal and structural stress analyses with high spatial resolution.

In this talk we review a wide range of applications of the UM geometry capability within the scope of the STS conceptual design. We focus on building a hybrid UM/constructive solid geometry (CSG) model to calculate energy deposition and displacement per atom (dpa) in the core vessel (CV) and CV shielding. We also demonstrate the application of CADIS/FW-CADIS variance reduction techniques to provide well-converged results in more distant regions of the shielding.

[1] C. WERNER (ed.), et al. "MCNP User's Manual, Code Version 6.2," LA-UR-17-29981, Los Alamos National Laboratory (2017).

Session 3 / 26

The On-the-fly Global Variance Reduction Technique and its application for IFMIF-DONES shielding analyses

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IFMIF-DONES facility is a deuterium-lithium (d+Li) neutron source driven by a deuteron accelerator (40 MeV and 125 mA) striking at the liquid Li target, and producing neutrons through stripping reactions to provide irradiation data for the construction of a DEMO fusion power plant. The shielding analyses of the accelerator and target demand efficient variance reduction (VR) technique, in particular the global radiation distributions. Due to the complicated particle-material interactions in the accelerator facilities with streaming paths, there are often issues raised during the generation and utilization of the weight-window mesh (WWM). The common methodology such as the deterministic-based FW-CADIS method is widely used, yet still not straightforward to handle the complex source modelling and particle streaming.

An "on-the-fly" global variance reduction technique will be presented. It is based on iterations of flux map and WWM, generating and improving the WWM on-the-fly along with the particle transport simulation. Since it is a Monte Carlo (MC) based method, no extra step is needed for geometry and source modelling and WWM generation. One common issue caused by the streaming path is that, a particle history could be extremely long due to the over-splitting of particle tracks, since the high flux gradient around the streaming path will cause the high gradient of WW. A novel dynamic WW upper bound method has been proposed to limit the splitting by increasing the WW upper bound once sufficient particles have been scored for specific mesh cells. This method has been implemented in the MC transport code MCNP and OpenMC. This method has been tested with computational benchmarks, with promising speed-up achieved compared with the analogue run and FW-CADIS WWM simulation. Similar speed-up have been observed in the application to the IFMIF-DONES shielding calculation, with neutron flux maps being produced over the 3~6 m thick concrete shielding.

Session 3 / 35

Advanced Monte-Carlo methods for prompt and residual radiation calculations in light-ion accelerators

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Ion accelerators may produce intense secondary radiation fields from intended or unintended nuclear interactions of the accelerated particles with their environment. Besides interactions in the target or beam dump, some of the accelerated particles are unavoidably lost to the beam pipe and some other collided to scrapers and collimators resulting in intense neutron and gamma fields. These fields pose a risk for workers and public during operation, and also result in material activation, which may difficult the hands-on maintenance of the device. The proper calculation and transport of prompt and residual sources of radiation is critical for the licensing of equipment and experimental setups. Here two new and advanced methods for radiation field calculation are presented. These methods are based on the MCNP6 code, which is one of the most used tools for radiation transport:

1. *srcUNED-Ac* is a user-defined source module, where secondary particle sources in typical simple geometries (pipes, scrapers, target) can be easily defined with an arbitrary number of double differential neutron and (prompt or residual) gamma spectra. It is a tool intended for making quick flexible calculations for estimating doses when accelerated particles are fully contained in the beam pipe.
2. *MCUNEDplus* is a code extension, using the detailed transport of accelerated ions to directly compute the prompt and residual radiation fields originated by them, or any of its progeny. Residual gamma sources are computed using specially processed nuclear data libraries, with the D1S algorithm, which is fully valid to most accelerator applications.

These tools are here described with some applications to the evaluation of the IFMIF-DONES facility, based on a 125 mA, 40 MeV deuteron accelerator.

Session 4 / 53

Scaling models for radiation transport calculations at FRIB

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The Facility for Rare Isotope Beams (FRIB) have recently started first operations. FRIB is designed to accelerate stable ions ranging from oxygen to uranium at energies above 200 MeV/u with a beam power on the production target up to 400 kW. The fast rare isotope beams produced via in-flight fragmentation (or fission) can be stopped, or stopped and then re-accelerated. Therefore, the radiation conditions in this facility can be very varied depending on the user needs and applications. A large variety of radiation transport calculations for different beam energies and isotopes are required to ensure the safe operation of the FRIB experimental program. Scaling models for radiation transport calculations can be an alternative method to provide a relatively fast prediction in different scenarios. An overview of the models and the current status of the project are presented in this contribution.

Session 4 / 12

Attenuation of neutrons in labyrinths: comparison of various calculation techniques

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To estimate attenuation of accelerator-produced neutrons in labyrinths and penetrations, we use a semi-analytical technique developed at Fermilab, as well as Monte Carlo radiation transport codes MARS, PHITS, and MCNP. The semi-analytical formalism suggests calculating the neutron attenuation factors for the labyrinth legs based merely on the source term at the entrance of the labyrinth; the source term could be either calculated using a Monte Carlo code, or simply estimated from the beam parameters. On the other hand, Monte Carlo codes, with their realistic underlying physics, calculate the radiation environment inside and outside of the labyrinths in great detail. The Monte Carlo results are more reliable, but they are usually computationally expensive. Knowing the relation between the semi-analytical and Monte Carlo results, one can use a more appropriate technique in time-sensitive situations.

Session 4 / 13

Inter-comparison of Particle Production (4)

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We propose new inter-comparison problems of particle production from targets to find the reason of
relatively large differences between codes in neutron production as presented at SATIF-14.

In addition to neutron, proton, pion+, pion- and photon above 20 MeV are requested
to calculate in the revised problem.

At SATIF-15, we will present comparison between major Monte Carlo codes concerning
proton, pion+, pion- and photon production with high energy protons.

"Inter-comparison problems of particle production (4)"

1. Incident particle
   Pencil beam of protons with the following energy
   (a) 1 GeV
   (b) 10 GeV
   (c) 100 GeV
2. Target materials and their sizes
   Target geometry is the cylinder.
   Source protons incident on the center of the cylinder bottom.
   Target detector distance from the center of the cylinder is 500 cm.

(a) Al : length 40 cm, diameter 4.0 cm and density 2.7 g/cm^3
(b) Cu : length 16 cm, diameter 1.6 cm and density 8.63 g/cm^3
(c) Au : length 10 cm, diameter 1.0 cm and density 19.3 g/cm^3

3. Quantities to be calculated
(1) Neutron, proton, pion+, pion- and photon spectrum above 20 MeV in particles/MeV/sr/proton at 0, 15, 30, 45, 60, 90, 120, 150 degrees with angular width plus/minus 0.5 degrees.
Photons from produced radionuclides are not necessary to include.
(2) Angular integral spectrum above 20 MeV in particles/MeV/proton
(3) Energy integral neutron fluence for (1) and (2)

Session 4 / 52

The Shielding Integral Benchmark Archive Database (SINBAD) Task Force

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The management of the Shielding Integral Benchmark Archive Database (SINBAD) is now maintained by a devoted Task Force under the auspice of the OECD NEA Expert Group on Physics of Reactor Systems (EGPRS). This new SINBAD Task Force (TF) was mandated in February 2021 and established in Q1 2022 to oversee the future development of SINBAD, which is consistent with the strategy of the Nuclear Energy Agency (NEA) to continuously improve data available from the Data Bank. The TF consist of shielding experts, experimentalists, and benchmark evaluators from the EGPRS and other invited experts and is to operate on a three-year renewable mandate.

The proposed aim of the TF is to maintain and initiate the process of modernizing SINBAD benchmark entries. There are two major factors that led to the EGPRS establishing the TF. First, the international community recognizes that the rate of SINBAD development does not match the importance of the shielding benchmark topic. The TF will reinvigorate benchmark creation with a sustainable target of 3-4 new evaluations per year. The second motivating factor is to modernize the database while building upon previous work, which includes all entries currently in SINBAD and quality reviews provided over the years by several SINBAD evaluators. In this modernization effort the TF will operate like a technical review group and will strive to achieve a similar level of quality as the International Criticality Safety Benchmark Evaluation Project (ICSBEP) and the International Reactor Physics Experiment (IRPhE) Project. The EGPRS and the TF members have defined several goals for the TF, which include: avoid loss or removal of any existing information from the database, involve the nuclear data community and other user communities, include additional supplemental data (e.g. CAD files, simulation code inputs and outputs), and produce a single, peer-reviewed and approved summary document for each evaluation that follows the SINBAD evaluation guide approved by the Expert Group. The SINBAD database is now maintained in a GitLab environment hosted by the NEA, which ensures complete traceability of its update cycles.

There are a few conditions for reporting and operating that the EGPRS has specified for the TF. Otherwise, the TF has the freedom to define an optimum update process for SINBAD. The TF is required to report their progress each year at the annual EGPRS meeting. The EGPRS allotted a three-year period for the TF, which started in March 2021 and will end in March 2024. After those three years the EGPRS will review the progress of the TF and decide if it will be renewed.

If you or your colleagues have interest in participating in the SINBAD TF, please contact the authors of this paper.

Session 4 / 17

MCNP6 and PHITS benchmark calculations for proton accelerator shielding applications

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MCNP6 (Monte Carlo N-Particle) and PHITS (Particle and Heavy Ion Transport System) codes are widely used for many real-world shielding problems at accelerator facilities around the world. Nuclear interactions are described in these codes by both built-in physics models and tables with evaluated cross sections and secondary energy-angular distributions. Over the decades, many validation efforts were made owing to the availability of shielding benchmarks to test the nuclear data and verify the accuracy of the codes. In the framework of reactor criticality calculations, particle transport codes and cross section libraries are well validated for low-energy neutrons. However, in case of proton accelerators, a little attention is given in the literature for the validation of these codes and cross section libraries for proton induced reactions.
Therefore, variety of proton beam experiments was used in this work for the comparison of calculations performed with both MCNP6 and PHITS codes. The experiments relevant to the energy domain and the materials to be used in the design of MINERVA facility of MYRRHA (Multi-purpose hYbrid Research Reactor for High-tech Applications) project were selected. The results of this study demonstrate that quality or accuracy of the physics models and proton induced libraries used for the proton interactions are prevailing factors to determine the neutron yield and transmitted flux and consequently the shielding design. It is also found that among the investigated proton induced nuclear data libraries, JENDL-4.0/HE nuclear data library produces more accurate results compared to the ENDF/B-VII.0 and TENDL-2017. Therefore, depending on the target material, SCK CEN proton library based on TENDL-2017 as covering broader range of nuclides than JENDL-4.0/HE library, is continually upgraded using the cross section data from JENDL-4.0/HE. This work confirms an obvious choice of JENDL-4.0/HE data for graphite.

Session 4 / 34

Simulation studies of a pion production target for the Mu2e-II experiment

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The Mu2e experiment, which is currently under construction at the Fermi National Accelerator Laboratory near Chicago, will search for the neutrinoless conversion of muons to electrons in the field of an aluminum nucleus with a sensitivity four orders of magnitude better than previous experiments. This process, which violates charged lepton flavor, is highly suppressed in the Standard Model and therefore undetectable. However, scenarios for physics beyond the Standard Model predict small but observable rates.

An extension of the Mu2e experiment making use of the PIP-II accelerator upgrade at FNAL is currently studied. The Mu2e-II experiment aims to improve the sensitivity by at least a factor of 10 compared to Mu2e.

To achieve this, it will utilize an 800 MeV proton beam with a beam power of 100 kW hitting a production target to produce the required amount of pions and muons. This high beam intensity requires a substantially more advanced target design with respect to Mu2e.

We will present simulation studies for several target designs. In particular, we will compare results for energy deposition, radiation damage and particle yields for both the targets and the surrounding materials using the MARS15, FLUKA2021 and GEANT4 particle transport and reaction code packages.

Session 5 / 40

Activation benchmarking of metals by 9.6 GeV electrons at PAL-XFEL

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In our previous work [1], samples of low carbon steel, stainless steel, aluminum and copper were irradiated in the stray radiation field results from the 9.6 GeV electron beam hitting a thick copper target at the PAL-XFEL main beam dump bunker. The induced activity concentration in the samples were measured using gamma-ray spectroscopy and were compared with the old version of FLUKA, 2011.2x. In this work, we used the latest versions of the Monte Carlo codes FLUKA 4-2.2 (CERN branch) and PHIS-3.28/DCHAIN-SP-3.23 for benchmarking. The measured and the calculated induced activities in the samples will be discussed.

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Session 5 / 14

Overview of benchmark studies at the CERN Shielding Benchmark Facility (CSBF) and the CERN High Energy Accelerator Mixed Field (CHARM) facility in the CERN East Experimental Area

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The CERN High Energy AcceleRator Mixed Field (CHARM) Facility is situated in the CERN Proton Synchrotron (PS) East Experimental Area. The facility receives a pulsed proton beam from the CERN PS with a beam momentum of 24 GeV/c with 5e11 protons per pulse with a pulse length of 350 ms and with a maximum average beam intensity of 6.7e10 protons per second. The extracted proton beam impacts on a cylindrical target, made of copper or aluminium.

The shielding of the CHARM facility includes the CERN Shielding Benchmark Facility (CSBF) situated laterally above the target that allows deep shielding penetration benchmark studies of various shielding materials. This facility has been significantly upgraded during the extended technical stop at the beginning of 2016.

One week of beam time at the CHARM facility is typically allocated during a normal operational year for radiation benchmark studies. This paper presents an overview of benchmarks for Monte Carlo radiation simulation transport codes performed with data from the CSBF and the CHARM facilities over the last years. This includes a series of benchmarks for activation inside the CHARM target room, in the shielding structure of the CSBF as well as in the access maze of the CHARM facility. These benchmarks cover high energy neutron reactions, low energy neutron activation and activation in mixed fields and have been performed with the FLUKA and PHITS Monte Carlo codes. Several active measurements will be discussed, including neutron spectra measurements using NE213 scintillators and Bonner spheres as well as ambient dose equivalent measurements.

The CSBF and CHARM facilities are very versatile with ample benchmark potential still to be explored. Lessons learnt from the previous measurement campaigns and ideas for future benchmark experiments at the CSBF and CHARM facilities are finally presented.

Session 5 / 15

Radiation protection aspects of Long Shutdown 3 at the CERN LHC experiments: a methodology for residual activation assessments applied to the CMS case study

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The Large Hadron Collider (LHC) at CERN is currently in the early stages of Run 3, i.e. the third operational period of its lifecycle during which the machine will provide particle collisions to the four experiments located along the accelerating ring. Starting from the end of 2025, a three-year Long Shutdown (LS) period, denoted as LS3, will follow. The upgrade work foreseen during this stop represents an essential milestone for the LHC, bringing it to the second phase of its physics programme (High Luminosity LHC, HL-LHC).
To fully exploit the HL-LHC increased delivered luminosity, the LHC experiments have scheduled major upgrades to their detectors. Among the others, this is the case for the Compact Muon Solenoid (CMS), which has planned the installation of new components, as well as the dismantling of some others. This process is organised according to a complex work plan, during which the CMS configuration is sequentially modified over time to make accessible its various parts, including the innermost areas of the detector. In such a complex scenario, the radiological impact of the activated components must be assessed.
This paper focuses on the preparation of a Long Shutdown inside the LHC experiments from an operational radiation protection viewpoint, presenting CMS as a case study. In particular, the computational methodology developed at CERN to assess the residual ambient dose equivalent rates inside the experimental caverns based on the FLUKA Monte Carlo code is discussed.
First, LHC Run 3 operational parameters are addressed, as well as the computational tools required for the analysis. Afterwards, focusing on the CMS case study, the pipeline of configurations foreseen for LS3 is illustrated. Eventually, the most representative results of this assessment are presented and briefly discussed. These will provide the CMS collaboration with useful data to organise LS3 following a dose optimization approach.

Session 5 / 32

Activation calculations of selected RPV internal components for optimal decommissioning of nuclear power plants

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By the end of this year, all German nuclear power plants (NPPs) will have been shut down. The final shutdown is followed by a post-operational phase in which measures can be carried out to prepare for the NPPs dismantling and decommissioning. One of the important tasks in preparation for the dismantling is to acquire precise knowledge of the specific activities of the reactor pressure vessel (RPV) and its internal components. Such knowledge is essential for optimal planning of these massive components' disposal and minimizing the radioactive waste.
In this study, the specific activities of selected RPV components' segments (such as the RPV, core barrel, etc.) of a German PWR were calculated with a novel method based on the combined use of two Monte-Carlo codes, MCNP6.2 and FLUKA2021. In the first step, the MCNP6.2 code was used to calculate the neutron fluence rate characteristics (spectrum, distribution, and current entering the segment surfaces) in the studied segment using a 3D detailed reactor model. The neutron fluence rate prediction capability of the MCNP6.2 model has been validated via metal foil-activation measurements carried out in two German PWRs. The validation studies showed that the MCNP6.2 model is reliable and suitable for evaluating the neutron radiation field in the reactor for the ensuing activation calculations. In the second step, the FLUKA2021 code was used to calculate the specific activity distribution in the studied segment using a 3D exact model of the segment and complex source terms built based on the neutron fluence rate parameters calculated using the MCNP6.2 code. The results of the calculations were obtained with great accuracy and evidenced that the used method can serve as a powerful and non-destructive tool for the radiological characterization of the RPV and its internals.

Session 5 / 63

Radiation transport calculations supporting the ISIS muon collimator replacement project

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The ISIS spallation and muon facility uses a proton beam accelerated to 800 MeV in a linac and synchrotron to generate neutrons and, via an intermediate carbon target, muons. The muon intermediate target is located on the extracted proton beam before the neutron spallation target on ISIS target station one. After the muon target there are a series of collimators followed by quadrupole magnets to shape the proton beam before the neutron target.

In 2020 the ISIS muon collimator 1 had a small leak in an area which had previously been repaired, the decision was made to replace the muon collimator. This paper details the radiation transport simulations performed both for the calculation of the induced activity in the collimator as a result of the proton beam interactions and the shielding design of the flasks to enable the safe removal of the highly active muon collimator.

The induced activity calculations were performed using FLUKA [1,2], this was chosen due to the ability to perform proton and neutron transport, activation and decay dose rates calculation in a single simulation.

The shielding flask design calculations were made using MCNP [3] based on the decay photon source term calculated using FLUKA. There were several flasks designed for the different high dose rate components including a steel inner layer into which the most active component was winched before it could be removed from the area and placed within its final shielded storage cask.

The MCNP simulations utilised global variance reduction using the FWCADIS method built into Advantg [4] to generate weight windows in order to achieve low variance around all sides of the casks.

MCNP simulations were also performed to investigate the shielding design of the collimator and its surrounding shielding, to determine if there were any improvements and if the dose rates during proton beam operations would be acceptable within the ISIS target station one hall.

The results of the simulations are compared against the health physics measurements taken as the collimator was removed. The agreement is very good given the differences in cooling times between the planned and actual removal times, the uncertainties the irradiation history of the collimator due to varying beam conditions over its lifetime and the material composition uncertainties.

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Session 5 / 19

Radiation protection studies for new beam dumps at ISOLDE at CERN

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ISOLDE is a CERN facility dedicated to the production of radioactive ion beams for applications in atomic physics, nuclear astrophysics, fundamental interactions and life sciences. The 1.4 GeV proton beam from the Proton Synchrotron Booster, with a maximum current of 2 μA, impinges on a thick target kept at high temperature during irradiation. The generated radionuclides diffuse out of the target and are ionized by an ion source. Then, the radioactive nuclei are extracted and a mass separator is used to select the radionuclides of interest, which are transported to the experimental area via a beam line system.

About the 80% of the primary proton beam does not interact with the target and is intercepted by a beam dump, one for each of the two target stations. The ISOLDE beam dumps are currently operating at their limit in terms of temperature and mechanical stresses. For these reasons, their replacement is currently being studied together with the design of new beam dumps and related shielding to meet future operational needs (higher beam energy, i.e. 2 GeV, and intensity, up to 6 μA) as well as modern radiation protection standards.

Besides the studies for the future dismantling worksite, a detailed radiation protection analysis via the FLUKA.CERN Monte Carlo code is being performed for the new beam dumps and the related facility consolidation. This work covers various RP aspects such as the study of the envelope target configuration for stray radiation and the definition of the radiological area classification. Moreover, the evaluation and optimisation of shielding requirements (volume, material, cost), material activation, residual dose rate and atmospheric releases from air activation cannot be neglected.

Session 6 / 18

Radiological assessment for the renovation of the CERN East Area primary area and secondary beam lines

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The East Area renovation project aimed at completing by the end of Long Shutdown-2 the consolidation and renovation of the CERN East Area, served by the Proton Synchrotron accelerator since more than 55 years. In particular, the Primary Area and the secondary beam lines of the East Area have been completely redesigned, highlighting some singular safety challenges.

The East Area receives a primary proton beam extracted from the Proton Synchrotron with a beam momentum of 24 GeV/c and an average beam intensity of 6.6e10 protons per seconds. Then, the primary beam impacts on dedicated targets located in the Primary Area, producing secondary beams from 15 GeV/c down to low beam momenta for the test beam lines T9, T10 and T11. The primary beam can also be directly transported through the T8 beam line in the East Area to the IRRAD and CHARM facilities.

The study details the challenges of the radiological assessment of the East Area renovation, starting by the dismantling of the old installation. Then, the focus is brought on the shielding calculations performed for the new design, the drivers of the radiological assessment, and the resulting compromises made to achieve prompt ambient dose equivalent rate levels compatible with the CERN radiological area classification. In addition, the layout has also been optimized with respect to residual radiation levels and air activation, to reduce the dose received during interventions. Finally, the study analyses the measurements made with the new radiation monitor network, both during the commissioning phase and the first year of operation.

The measurement data from the radiation monitors coupled with the shielding calculations performed with FLUKA for the different scenarios considered for the study has proven to provide useful feedback during the commissioning and beam optimization periods.

Session 6 / 22

Radiation protection assessment of the AMBER Drell-Yan program

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In the context of the Physics Beyond Colliders Project, a QCD facility named AMBER/NA66 was developed as a successor of the COMPASS experiment. AMBER is located in the surface hall EHN2 in the CERN SPS North Area. The approved physics program of AMBER includes, amongst others, measurements of the pion-induced Drell-Yan process. This process shall be studied with a high-intensity 190 GeV/c pion beam impinging on a tungsten and several carbon targets followed by a 2.2 m-long absorber. A total of 3.07×10^14 pions on target per year shall be reached. This corresponds to a beam intensity increase by 68% with respect to the previous COMPASS Drell-Yan run. During the latter, the annual dose at a nearby environmental monitoring station close to the CERN fence reached 76% of the annual limit of 1 mSv. A radiation survey inside of the EHN2 hall and in its direct vicinity further allowed identifying several locations with elevated radiation levels.

To increase the beam intensity delivered to EHN2 while staying compliant with CERN's radiation protection code regarding doses to personnel and members of the public, detailed studies for improving the shielding around the AMBER target area and along the M2 beam line were performed. These studies include the evaluation of the prompt dose rates in the accessible areas of EHN2 and next to it, at the CERN fence and at the surrounding publicly accessible places. In addition, the residual dose rates inside of the target area were evaluated for different cooling times to determine adequate access requirements. Finally, the air activation inside the EHN2 hall and the exposure of members of the public due to air releases into the environment were assessed. The studies were performed with the FLUKA Monte Carlo particle transport code and the ActiWiz Creator tool.

Session 6 / 46

Fundamental investigation on concrete composite for radiation shielding in facilities

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For the buildings where radiation exists, such as nuclear power plants or accelerator facilities, concrete is not only used as structural materials but also widely used as shielding materials. On the other hands, only few discussions had conducted for the constant of shielding calculation. In addition, very old and/or foreign data have been used for the calculation, such as ANL-5800 and JAERI-M 6928, which had few information except for elemental composition. And some of the elemental fraction value are away from these of the actual concrete, typically Hydrogen. So major analyzed element data in various concrete samples used in actual facilities were presented, comparing the data in the past work, and were discussed referring the idea of concrete engineering. In addition, the recent activity of Standardization of concrete composite for radiation shielding in working group in AESJ would be introduced.

Session 6 / 43

Sensitivity study of water and iron contents for neutron deep penetration in concrete

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The sensitivity of water and iron contents to the attenuation length of neutron deep penetration in concrete is discussed. According to previous researches, the contents of water in radiation shielding concretes varies from about 2 to 20%, and the iron 1 to several %. It is noted that the iron in this study means the frame itself embedded inside concrete against the tensile strain. Since the hydrogen is the most effective nucleus in order to moderate neutron and also iron used for same purpose to high energy neutrons, it is interesting to look how much the attenuation length will be changed as a function of the water content and iron content respectively. The sensitivity study will be performed for variety of concrete compositions, which were measured or reported in literature.

Session 6 / **38**

ARI-SXN beamlines radiation shielding analysis

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ARI (NanoARPES and NanoRIXS) and SXN (Soft X-ray Nanoprobe) are a pair of soft x-ray beamlines under development at NSLS-II, in the framework of the NEXT-II project, which is funded by the United States Department of Energy Basic Energy Sciences (DOE-BES).

Each beamline will have two branches that will be provided with soft x-rays from two elliptically polarizing undulators, with periods of 70 and 50 mm for ARI and SXN, respectively. These branchlines lead to endstations, where the x-rays will be utilized for research in various scientific domains.

In this work, the Monte Carlo particle transport and interaction code FLUKA was employed to generate and model the Gas Bremsstrahlung and Synchrotron Radiation throughout the beam lines. The shielding design process to keep chronic ambient equivalent dose rates ALARA on the experimental floor during operation will be detailed. Furthermore, a comparison with the analytical code STAC8 will be also provided for the synchrotron radiation.

These simulation data is currently being used to validate the shielding design and the overall radiological framework in anticipation of the beamline's commissioning in 2027.

Session 6 / **33**

The skyshine problem at the STAR facility due to the beam dumps and the dark current leakage

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STAR (Southern Europe Thomson Back-Scattering Source for Applied Research) is an "inverse-Thompson scattering" facility based in the Calabria's University campus in Rende, Italy. It will be a facility for advanced scientific investigation on fundamental and applied materials research, with monochromatic X-rays production.
The facility upgrade consists in two electron beam lines: the first allows to accelerate electrons up to 150 MeV, while in the second one the beam is accelerated up to 85 MeV. The X-rays produced through electron beam-laser interaction will be used in two experimental areas to perform investigation on biological, polymeric and composite materials and in the cultural heritage field.
In order to obtain the radiation safety license for STAR, several radiation protection studies have been performed through the Monte Carlo code FLUKA. In particular, an in-depth study of the skyshine radiation related problem has been performed. The importance of this topic is mainly due to the presence of this machine inside the university campus, as well as the presence of offices and other occupied areas.
The skyshine radiation problem has been evaluated for:
• the prompt radiation related to the beam dumps designed for each beam line;
• the prompt radiation due to the dark current leakage;
• the local shielding proposed for this leakage.
The starting points for the skyshine evaluation have been the ambient dose equivalent determination in two areas situated on the roof, in the direction of the areas of interest.
The FLUKA simulations, performed with different conservative approaches, kept in evidence the non-radiological relevance of the skyshine radiation. Thanks to the proposed shielding assessment, negligible dose levels have been achieved in all areas of interest.

Session 7 / 28

Measurement of neutron production yields of 345 MeV/u 238U + Cu with a time-of-flight method

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With obtaining radioactive isotope (RI) beam with a wide range of mass number, the utilization of high-intensity uranium-238 beam is adopted or planned, such as Facility for Rare Isotope Beams.
As one of the such facilities, Radioactive Isotope Beam Factory (RIBF) at RIKEN provides uranium-238 beam, the energy of which is 345 MeV/u. The current intensity of the uranium-238 beam is 70 pnA. Aiming at high-efficient RI beam production, a future improvement of the uranium-238 beam intensity is in progress. Because a number of neutrons is generated due to the reaction between the uranium-238 beam and a copper beam dump, the optimization of a radiation shielding is indispensable. The shielding around the beam dump at RIBF was originally designed by the Moyer model with estimating the source term from the neutron production thick target yields (TTYs) data of neon beam. Due to the derivation, an uncertainty of the source term was remained. Thus, the more accurate source term is absolutely important at RIBF. An improvement of the performance for computers enabled us to estimate the source term by nuclear reaction models, such as Quantum Molecular Dynamics (QMD). However, the availability of the models should be examined prior to applying the source term calculation. Therefore, a measurement of the TTY is strongly desired at RIBF.

The purpose of this study is to measure the neutron production TTY from uranium-238 beam of 345 MeV/u on a copper target for 0˚, 45˚, and 90˚ with a time-of-flight technique and to obtain the benchmark of the QMD models implemented in Particle and Heavy Ion Transport code System and Geometry ANd Tracking 4.
The comparison among our measured data and the calculations shows that QMD results underestimate our measured data at all measured angles. Especially, the underestimation by approximately 70% is observed at 90˚.

Session 7 / 48

Photo-neutron emission mechanism at low-energy photon interaction

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A photonuclear reaction consists of the photoabsorption and particle emission. Once the photon is absorbed, the excited nucleus decays via direct, preequilibrium and compound (evaporation) mechanisms. Photoneutron production yields and production mechanisms were investigated by comparing results of the well-known estimation methods. Differential photoneutron yields from ^{nat}Pb,197Au, ^{nat}Sn and ^{nat}Cu targets irradiated with 16.6 MeV photons were calculated using PHITS-3.1, FLUKA 4-2.1, and MCNP6.1. JENDL/PD-2004 library was used in PHITS for photoabsorption cross section and neutron emission was handled by generalized evaporation model (GEM). FLUKA uses the IAEA photonuclear cross section library as well as other experimental data and neutron emission is calculated by PreEquilibrium Approach to NUclear Thermalization (PEANUT) model. The ENDF/B-VII.0 and IAEA/PD-2019 photonuclear libraries were used in MCNP6.1 and compared together. The results were compared with experimental data in the literature. Compound, preequilibrium and direct reaction contributions to neutron double differential cross sections were calculated by TALYS. All Monte Carlo codes generated the compound part of neutron spectra well but failed at higher energy range. MCNP6.1 using ENDF/B-VII.0 and IAEA/PD-2019 libraries were more reasonable than PHITS and FLUKA. MCNP6.1 with ENDF/B-VII.0 reproduced the neutron spectra up to 8 MeV for 197Au target and agreed well with experimental data. The preequilibrium mechanism significantly contributed to the photoneutron production for the natPb, 197Au and natSn above 4 MeV, while for the natCu target, compound mechanism was dominant over the whole neutron emission energies.
Results in this study showed the necessity of improvement of nuclear data libraries or nuclear models implemented in the codes for describing photonuclear reactions beyond the evaporation part, namely preequilibrium and direct mechanisms

Session 7 / 57

Impact of new delivery methods in proton therapy on radiation protection of Compact Proton Therapy Centers (CPTC)

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In their eagerness to improve clinical results, the delivery methods in proton therapy are moving towards more precise techniques with the goal of increasing their therapeutic index. Once the primal passive scattering methods were overcome by current active scanning process, the evolution continues and news delivery methods such as arc therapy, minibeams or flash therapy, among others, are currently in several stages of development and research. For example, Proton Monoenergetic Arc Therapy (PMAT) uses isoenergetic fields from 360º degrees, with lower energies than conventional ones, but for a longer time. On the other hand, Flash-Therapy with Protons (PFT) involves irradiation for less than 500 milliseconds of a total dose greater than 5 Gy, that is, pulsed fields of high energy and intensity, above 40 Gy/s. Obviously, trials of these new methods are being carried out in existing facilities, so the big question that arises is if the current radiation protection measures of proton centers are ready for these new challenges. Consequently, the main goal of this work has been to carry out the comparative analysis, using Monte Carlo codes and experimental measurements, of the impact on the radiation protection of different proton dose delivery modes with greater projection and development. The current and new proton delivery methods compared were Intensity Modulated Proton Therapy (IMPT), PMAT and PFT. For PMAT, both experimental measurements and simulations with several Monte Carlo codes (MCNP6, PHITS and GEANT4) have been reached. For Flash, results have only been calculated with Monte Carlo simulations. The results show that with PMAT higher neutron fluences are generated, but with lower energy, therefore, its impact is greater on activation, but lower on the ambient dose equivalent, therefore, the shielding requirements could be reduced. For Flash, however, the current shields should be reviewed since the energies used are the maximum and the instantaneous doses rates (IDR) outside the barriers could overtake legal limits in some cases, depending on the country. Mitigating actions could be limiting orientation of beam and occupancies in some spaces, using special concretes in different areas, or change the design and location of treatment control room. Experimental measurements could help to achieve more precise assumptions, but neutron monitors must be able of measuring high-energy neutrons in pulsed fields. Active measurements should be supported with reliable data from passive monitors. Evenly, the impact over others relevant aspect of radioprotection, as activation or personal dosimetry should be carefully reviewed.

Poster Session / 39

Optimizing the fast neutron flux for radiotherapy purposes and reducing the exposure dose for healthy tissues

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Introduction
The success of the medical application of fast neutron radiation therapy largely depends on how perfect their sources used in clinical practice are. Despite the obvious importance of the work on their creation, many aspects of this topic are still underdevelopment. This work is focusing on creation of high-intensity sources of fast neutrons based on the cyclotron for use in medicine and other fields. It is required to show that the improvement of the characteristics of the neutron source can be achieved by the optimal choice of the geometry of the beam collimator and the properties of the target. By changing them, one can increase the neutron flux by several times and significantly improve the spectrum. As a result, this allows reducing the duration and improving the quality of patient treatment and at the same time improving the radiation protection around source and collimator
Methods
The neutron characteristics were calculated using computer programs available in open sources. In particular, the transfer processes were modelled using the MCNP code. The PHITS code was used to calculate the neutron flux depending on the type of target, current, and energy of the accelerated ions. All work was carried out on the basis of the U-120 cyclotron of the Tomsk Polytechnic University. In the course of the experiments, deuteron beams with energy of 13.6 MeV, beryllium targets cast and pressed from powder were used. The activation method was applied to determine the neutron flux using iron and aluminium foils as fast neutron detectors in the range of 1-14 MeV. The radioactivity of the samples was measured by gamma spectroscopy using an HPGe detector. The PACE4 (LISE++) program was used to predict the neutron spectra resulting from the 9Be(d, n)10B reaction.

Results
1. The performed calculations showed the fundamental possibility of a significant (several times) increase in the neutron flux density with an optimal choice of the geometry and materials of the neutron collimator. This is relevant for radiation radiotherapy, since in this way it is possible to reduce the duration of the patient's exposure procedure and reduce the radiation load on him.
2. The results obtained make it possible to generate a narrow neutron beam, which makes it possible to treat small tumors and minimize the irradiation of healthy tissues.
3. The proposed beam control technique can be extended to the irradiation channels of nuclear reactors, where the fast neutron flux density can be much higher and improve the radiation protection conditions.
4. The results obtained in the study of the transport characteristics of fast neutrons in the collimator channel are of great importance for the development of high-intensity sources of these particles with optimization of the radiation protection goals.
Conclusion
The possibility of obtaining a narrow neutron beam (with a diameter of 1-2 cm or even less) has been proved. This makes it possible to significantly (by a factor of 15) increase the flux density of fast neutrons compared to a cylindrical channel. There is reason to hope that narrow beams will make neutron beam radiotherapy for the treatment of small and irregularly shaped tumours more accurate and safer for the patient. The fraction of the flux density of fast neutrons with energies in the range $1 - 6$ MeV is about 83% of the total flux. This minimizes the number of neutrons above 6 MeV and below 1 MeV, undesirable for clinical use, which do not contribute to the radiation therapy process. As a result, we minimize the dose absorbed by healthy tissues.

Poster Session / 29

Modelling of Multilayer Shielding Scenario for High Energy Neutron Accelerator Based using PHITS

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Neutron shielding calculations have complex challenges that require conservative planning in designing shielding to meet radiation protection standards. Formerly, hydrogenous materials such as concrete, water, and polyethylene have been chosen to against neutron radiation. However, in high energy neutron sources, the use of these materials will require a very thick shielding design so that it has an impact on increasing the footprint and cost requirements. Therefore, in this paper, a multi-layer shielding scenario will be modelled for high-energy neutron sources using metal and hydrogenous materials such as Fe, Cu, concrete, and borated polyethylene. Parameter data from simulation results are distribution of neutron flux, spectrum energy, neutron depth dose, and ambient dose H*(10) equivalent. The simulation results show that Cu has the best effectiveness in attenuating high-energy neutrons even though it has the highest build-up factor value. Meanwhile, the multilayer combination of Fe-Fe-BPE and Fe-concrete-BPE provides the best choice compared to other material combination scenarios with the lowest flux values and ambient dose* $H(10)$ equivalent.

Poster Session / 24

Dosage Analysis and Irradiation Time Optimization of Negative Pi-Meson Therapy in Prostate Cancer Using PHITS Program

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Negative pi-meson therapy has potential as an alternative radiotherapy method because it has a high radiation level, while healthy organs around it receive a low radiation dose. Negative pi-meson-based treatment is suitable for targeting tumours with many vital organs around them, one of which is prostate cancer. This study aims to analyse the dose and time of irradiation of negative pi-meson therapy for prostate cancer cases. The simulation is run on the PHITS program by modelling prostate cancer on the geometry of the body organs and tissues. The radiation source is negative pion with an intensity of 2.5 × 108 pion/second with an energy range of 40 MeV to 58 MeV. Optimization is done by placing the Bragg peak in the target depth area and determining the dose weight and irradiation time. The irradiation was carried out in 25 fractions with a dose per fraction is 2 Gy. The irradiation time per fraction was 91.23 seconds. The OARs reviewed in this study were the skin, bladder, testes, rectum & large intestine, spinal cord, kidney and soft tissue. The doses received by the OAR respectively were 0.09023 Gy; 1.35349 Gy; 0.22417 Gy; 0.38557 Gy; 0.00622 Gy; 0.00438 Gy and 0.11899 Gy.

Poster Session / 9

Shielding design for NanoTerasu - a compact 3 GeV next generation synchrotron radiation facility -

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A compact 3 GeV next-generation synchrotron radiation facility, NanoTerasu, is currently constructed at Aobayama New campus of Tohoku University in Miyagi prefecture, Japan. NanoTerasu provides both soft and hard x-rays, and is to be operational from April of 2024 with 10 beamlines; it will have 28 beamlines in the future. The electrons are accelerated up to 3 GeV by LINAC, and injecting into the storage ring, then extracted x-rays by insertion devices. NanoTerasu is the first facility in Japan where an experimental area is set to a non-restricted area under the policy that "users can use this facility as much as possible without the license of radiation workers". To achieve that purpose, gas bremsstrahlung radiation (GB) that is generated by interacting electrons with residual gas in the beam pipe must be shielded. We have saved the costs for shielding of GB for all beamlines by optimizing local shields with a Monte-calro simulation. Synchrotron radiation also must be considered even though it has lower energy.

We present shielding designs for beamlines including their optical and experimental hatches, and local shields.

Poster Session / 20

Absorbed-Dose Energy Dependence for Luminophore Materials: A Monte Carlo Intercomparison

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In this study, Monte Carlo methods were used to estimate the absorbed-dose energy dependency of 4 widely used optically and thermally stimulated luminescence materials: CaSO4, LiF, BeO, Al2O3. The examined X-ray / photon energy range was 20 keV to 400 MeV. Three well-known general-purpose Monte Carlo codes were used: FLUKA, GEANT4, and PHITS. The results obtained from these completely independent codes are directly compared to each other and presented in this paper for the first time. Their excellent agreement is shown.

Poster Session / 25

Optimization of a Neutron Beam Shaping Assembly Design for BNCT and Its Dosimetry Simulation Based on Phits Version 3.26

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This article involves two main objectives of the BNCT system. The first goal includes optimization of 30 MeV Cyclotron-based Boron Neutron Capture Therapy (BNCT) beam shaping assembly. The second goal is to calculate the neutron flux and dosimetry system of BNCT in the head and neck soft tissue sarcoma. A series of simulations has been carried out using a Particle and Heavy Ion Transport Code System program to determine the final composition and configuration of a beam shaping assembly design to moderate the fast neutron flux generated from the thick beryllium target. The final configuration of the beam shaping assembly design includes a 39 cm aluminium moderator, 8.2 cm of lithium fluoride as a fast neutron filter and a 0.5 cm boron carbide as a thermal neutron filter. Bismuth, lead fluoride, and lead was chosen as the aperture, reflector, and gamma shielding, respectively. Epithermal neutron fluxes in the suggested design were 2.83 x 109 n/s cm-2, while other IAEA parameters for the BNCT beam shaping assembly design have been satisfied. In the next step, its dosimetry for head and neck soft tissue sarcoma is simulated by varying the concentration of boron compounds in the ORNL neck phantom model to obtain the optimal dosimetry results. PHITS version 3.26 calculation showed that the optimal depth for thermal neutrons was 4.8 cm in tissue phantom with the maximum dose rate found in the GTV on each boron concentration variation. The irradiation time needed for this therapy was less than an hour for each level of boron concentration.

Poster Session / 31

Photon and neutron dose measurements and Monte Carlo evaluation at the Beam Test Facility of the INFN - Frascati National Laboratories

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The Beam-Test Facility (BTF) of the INFN - National Laboratories of Frascati is an extraction and transport line of DAFNE LINAC. It is optimized for the production of electrons and positrons in a wide range of intensity, energy (30 MeV – 750 MeV), beam spot dimensions and divergence, using both primary and secondary beam of the DAFNE LINAC.
Through the years, the BTF has gained an important role in particle detectors electron/positron beam test and development. A small fraction of the BTF's shifts have been dedicated to radiation damage test using LINAC electron primary beam up to 5×10^{10} e-/s.
As radiation protection group, we are in charge of dose evaluation when electrons impinging on a target from:
- photon Bremsstrahlung production on a Pb target;
- photo-production of neutrons from electrons impinging on a Pb target.

Two dedicated tests with 503 MeV electrons impinging on a $\sim$ 16 cm tick Pb target have been carried out in February and June 2022 using TLD700 and TLD600, measuring doses at several charge intervals. The detector response have been calibrated at Cs-137, so that a MC comparison has needed to validate the results at higher energies and benchmark the simulation itself.
For the last exposition test in June, in addition to TLDs, more detectors have been exposed in the same experimental condition and at 90 degrees w.r.t. the lead target: two WENDIs from Thermo Fisher; two Gamma Tracers Wide from Bertin and CR39s.

The experimental setup, data acquisition and analysis, together with FLUKA modeling of the test will be presented. A great MC-data agreement has been achieved for gamma dose estimation. At the moment of writing, the neutron dose study is ongoing.

Poster Session / **27**

Measurements and Monte Carlo evaluations of shielding concrete radioactivation in a nuclear physics facility to verify the clearance levels.

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The Laboratori Nazionali del Sud (LNS) of Italian National Institute for Nuclear Physics (INFN) is a facility devoted to research activities in the field of Nuclear Physics, Nuclear and Particle Astrophysics, but also of Applied research, such as medicine, cultural heritage, and industry. The main particle accelerators are a K800 Superconducting Cyclotron (CS) and an electrostatic 16 MV Van der Graaf Tandem. Some LNS concrete shields of experimental rooms have been demolished due to an upgrade of the Cyclotron. The shields could be radioactive because was exposed to ambient neutron fields generated by the experiments carried out during the last 30 years of LNS activity. To dispose of concrete, measurements and estimations of residual radioactivity have been carried out to verify the clearance levels.
In order to verify the radioactivity quantity, gamma-emitting, some measurements were carried out with a HPGe detector. Furthermore, to estimate the presence of pure beta-emitting radionuclides, impossible to be detected by HPGe, and to confirm the measurements made for the gamma-emitting radionuclides, we simulate a simplification of the last 30 years experiments using the code of calculation Monte-Carlo FLUKA. Moreover, to determine the Minimum Detectable Activity (MDA) for the HPGe measurements and to confirm the reliability of simulation, a sample of concrete identical to the demolished one was prepared and irradiated with a high intensity field of a known Am-Be source.

The results, even in the worst condition of the CS beams, evidence that the concrete is in conditions of no radiological relevance and could be disposed of. In this work we present the performed simulations and the measurements.

Poster Session / 54

GEANT4/FLUKA/MCNP comparison of secondary yields in processes relevant for the Mu2e experiment

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The Mu2e experiment, which is currently under construction at the Fermilab Muon Campus, will search for the charged-lepton flavor violating (CLFV) neutrino-less conversion of a negative muon into an electron in the field of a nucleus. The conversion process results in a monochromatic electron with an energy of 104.97 MeV, and observations of a signal would require physics beyond the Standard Model. Aim of the experiment is to reach a sensitivity four orders of magnitude better than previous experiments .
The primary beam will start with the Fermilab Booster, supplying 8 GeV kinetic energy protons on a tungsten target. To reduce beam-related backgrounds, a pulsed structure (200 ns wide pulses spaced at 1700 ns intervals) is used. The muon beam will be formed through a sophisticated magnetic system composed of three consecutive solenoids, and will hit an aluminum target with the goal to examine $\sim 10^{18}$ stopped muons in three years of running.

In order to reach the desired sensitivity, the control of the backgrounds is a crucial issue, resulting in the need of very reliable Monte Carlo predictions. Extensive code-code comparison between GEANT4, version 11.01 with different hadron interaction models, FLUKA, version 2021 and MCNP, version 6.1 have been therefore performed in several cases, both for beam-related and cosmic rays-related backgrounds:
(a) double-differential distributions and yield of antiprotons produced from 8 GeV protons on a simplified tungsten target, to evaluate the background produced from the antiprotons that are backscattered and transported through the transport solenoid;
(b) double-differential distributions and yield of charged pions from 8 GeV protons on tungsten and tantalum targets, with a comparison with available experimental data in the latter case;
(c) transmission of O(1) GeV neutrons, which are the main expected component of cosmic background, by 1 m of concrete;
(d) absorption of O(100) MeV neutral kaons by 1 m of concrete.

All the results of this comparison, which show in some cases relevant differences that can be ascribed to the different hadronic models used in the Monte Carlo codes, will be presented and discussed, together with their impact on the experiment.

Poster Session / 45

Methodology and preliminary studies for the evaluation of induced radioactivity for the decommissioning of Synchrotron SOLEIL's storage ring.

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The upgrade of the storage ring of Synchrotron SOLEIL, the French 3rd generation synchrotron light source, to a 4th generation ring, based on multi-bend achromat to achieve a very low emittance electron beam (~80 pm.rad), has entered the TDR phase.

This upgrade will led to the decommissioning of the present storage ring. In France, it is mandatory before the shutdown to submit to the French Nuclear regulation Authority (so call ASN) a demand of authorisation for both the decommissioning of present storage ring and to operate the new one. If, in France, there are no real clearance levels for induced radioactive materials, there is a brand-new regulation that allows nuclear waste recovery only for very low induced radioactivity of metallic materials if able to be recycled by a dedicated industrial partner and below both total (Bq) and specific radioactivity (Bq/g) threshold levels. Our application for decommissioning authorisation must bring the demonstration that the induced radioactivity of the storage ring components will be below these very demanding criteria.

This paper presents the methodology, calculations and measurements that will be conducted to evaluate the actual induced radioactivity that will be present in the storage ring components at the moment of the shutdown. This study will mainly rely on Monte Carlo simulations, thanks to the capabilities of FLUKA4-2 code, based on a very detailed geometry, as accurate as possible, including the magnetic fields produced by the storage ring magnets and realistic beam loss pattern as observed and measured during operation nowadays to comply with ASN's requirements.

Poster Session / 60

Preliminary Radiation Shielding Calculations for a New Facility Employing a Commercial Cyclotron at CGN Mianyang, Sichuan in China

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One Best 35p Cyclotron is planned to be assembled and subsequently operated at CGN Mianyang, Sichuan in China. As a previous preparation for the arriving of this commercial accelerator, it is required to perform shielding calculations in order to verify and or improve the current proposed design for the facility — this proposed design is the one suggested by the manufacturer of the machine. This kind of nuclear installation is supposed to be used to produce a considerable wide range of typical and emergent medical isotopes used in the nuclear medicine area. Among them, we can mention gallium-68, germanium-68, technetium-99m, fluorine-18, etc. Different types of target materials and target physical states such as solid, liquid and gas can be employed at the target stations. This depends of the specific requirements to the use of medical radioisotope of the end user in the city. This cyclotron has the possibility of holding four irradiation beam lines. Then four irradiation routines can be carried out for different purposes at the same time.

In this work, we replicated the entire facility model given by the manufacturer using two CAD-based software. This replica contains exact information of the real dimensions to be executed during the construction of the installation. As we aim to use some Monte Carlo codes for the shielding calculations, this model is exported to SuperMC code in order to assign the materials of the facility and the materials of the shielded parts of the cyclotron. These shielded parts of the cyclotron include the different layers of the machine which are covering the accelerating cavities. SuperMC allows us to exactly export the concerning cards related to materials and geometrical aspect to Monte Carlo software such as PHITS, FLUKAs, etc. We plan to use the recent version of PHITS, and the recent versions of FLUKA by the current developers, namely CERN & SLAC. Therefore, we will be benchmarking three codes for the radiation shielding calculations. Physics quantities of interest and to be

calculated with the three software include: ambient dose rate during the irradiation routine, ambient dose rate after some cooling time of the target, neutron flux during the irradiation routine, and long half-life activation products in the target after the bombarding process. This information at key physical points inside the entire facility will help us to verify and or correct some dimensions and materials for walls and doors. These outcomes will also give us insights the level of radiation exposure the workers will receive during the daily routines.

Poster Session / 42

Measurement and calculation of high energy neutron spectrum and its dose after shielding at KEK electron-positron injector linac

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At high-energy electron accelerator facilities, neutron shielding is one of the main considerations in radiation shielding due to the generation of secondary neutrons by the interactions of primary and secondary particles with surrounding materials. Neutrons produced from these interactions will have wide-energy spectrum based on the incident particle energy. Higher part of neutron energy contributes significantly to the neutron dose equivalent. Therefore, neutron energy spectrum after shielding is important to properly address radiation shielding in such facility.

This study aims to confirm the exposed dose contribution from high energy neutron component at high-energy electron accelerator facility. In this study, neutron spectrum and its dose at klystron gallery in KEK injector linac were measured. KEK injector linac provides the positron beam and electron beam. To produce positron beam, tungsten target were hit by 3.3 GeV electron beam. At this target, neutron dose is at its highest.

Conventional moderator-based survey instruments are not sufficient to perform neutron measurement at this facility due to limited energy range until 20 MeV. By using extended range survey instrument such as FHT 762 WENDI-2, neutron dose up to 5 GeV can be measured. By using these two types of survey instruments, a significant amount of neutron contribution above 15 MeV has been measured at injector linac after shielding. Monte Carlo code, Particle and Heavy Ion Transport code System (PHITS) simulation for this measurement was also performed.

To measure neutron energy spectrum, a dose and spectrum monitoring system applicable to neutrons, photons, and muons over wide range of energy (DARWIN) has been used. DARWIN use liquid scintillation detector and capable to measure neutron doses from thermal energy to 1 GeV. To estimate energy spectrum, DARWIN uses the unfolding technique based on the maximum entropy deconvolution (MAXED) code.

By performing neutron dose and spectrum measurement, coupled with Monte Carlo code calculation, the contribution of the high energy component at high-energy electron accelerator were confirmed.

Poster Session / 47

Shielding and activation simulations for the High Brilliance neutron Source (HBS) target station

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In recent years, the development of high-current accelerator-based neutron sources (HiCANS) has gained in interest to propose an alternative to research reactors. In HiCANS high neutron yields are achieved by irradiating metal targets with proton beams with energies in the MeV range bellow the spallation threshold and currents of several tens of milliamps. Based on this concept, the High Brilliance neutron Source (HBS) project was developed at Forschungszentrum Jülich to deliver a high flux of neutrons to various scattering, analytics and imaging instruments.

In HBS, fast neutrons are induced by the (p,xn) reaction in a tantalum target irradiated with 70 MeV protons at a peak current of 100 mA. The fast neutrons are thermalized into a water moderator surrounded by a lead reflector and a shielding. Finally, the optimized thermal and cold neutrons are passed through the neutron guides and fed to the instruments.

The shielding design of the target system is considered from the point of view of radiation protection. The shielding components consist of four layers of lead and four layers of borated polyethylene housed in a steel casing. In addition, the bunker walls of the target room, in which the target system and shielding is placed, are considered as a secondary shielding. These walls consist of 70 cm of concrete doped with polyethylene and an additional 70 cm of borated concrete.

The entire target room is modelled and the CAD model is converted into Monte Carlo inputs (mcnp6.1 and phits3.27) for particle transport simulation. The dose rate map, neutron and gamma flux distribution in the target room and also at the outside of the bunker walls are calculated during beam operation and also when the beam is switched off. The aim of shielding design is to restrict the dose rate in the supervised area well below the radiation protection criteria. The detailed analysis of the data will be presented.

Poster Session / 50

Ensuring the Quality of 10 MeV MEVEX LINAC Electron Irradiation Beam based on The Calibration Procedure for Dosimetry System

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One of the most crucial elements in following reasonable radiation procedures is calibrating and measuring the radiation doses to ensure the process is done correctly. Due to its small size and precise requirements for its dose-measuring equipment, the B3 dosimeter—a radiochromic film made of polyvinyl butyral (PVB) resin mixed with the radiochromic dye (pararosaniline)—is being used more frequently to measure absorbed doses in radiation on practices for both gamma and electron beam (EB) facilities. We carried out an in-plant calibration of the dosimetry system by using the EB to irradiate the B3 film dosimeters at the MEVEX LINAC EB facility. We then compared it to the alanine dosimetry supplied and provided by the Ris High Dose Reference Laboratory (HDRL) as the reference standard. The findings showed that the relative variation was within the allowed limit (about 3.0 percent in the intended range of 2.0-10.0 kGy) between the values of absorbed doses acquired with our dosimeter and the transfer standards dosimeter assessed by HDRL. Additionally, 180 days of storage did not affect the post-irradiation stability of B3 film dosimeters. It has been proposed that the B3 film dosimetry could be used in routine radiation processing at the MEVEX LINAC EB facility with the investigated dose range for quality assurance of the irradiated products, especially foods and foodstuffs processed under the 10 MeV EB accelerator at the MEVEX LINAC EB facility.
Keywords: B3 dosimeter, electron beam radiation, MEVEX LINAC, in-plant calibration.

Session 8 / 10

Intercomparison of radiation damage calculations in target materials at proton accelerator facilities using various Monte Carlo particle transport codes

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High-power proton accelerators with wide energy range between several ten MeV and a few hundred GeV have been used for production of secondary particles with target materials for material science, radiation therapy and physics research. In the design of accelerator facilities, it is important to evaluate the radiation damage quantities of the target material, such as displacement per atom (DPA) and energy deposition, as well as the particle fluences. Monte Carlo (MC) particle transport codes such as FLUKA, MARS, MCNP, and PHITS are widely used to calculate these quantities in accelerator facilities. Even though same nuclear data libraries can be used in some of the above codes, different implementation of the libraries can give different results. Moreover, the nuclear physic models, which are mainly used here to define the nuclear interactions between proton and the target materials since the interested beam energy is higher than nuclear data libraries, are all different in all those codes. Therefore, it is essential to validate the calculation results by comparing the results of radiation damage calculations using these MC codes with each other.

In this work, the following four cases were selected for intercomparison of radiation damage calculations for target materials: 1) a neutron source with 30 MeV protons injected into a beryllium target, 2) a spallation neutron source at LANCE with 800 MeV protons injected into a tungsten target, 3) a neutrino source with 30 GeV protons injected into a graphite target, and 4) an antiproton source at FNAL's pbar target station with 120 GeV protons injected into a copper target. The quantities used for the intercomparison are depth distributions of NRT-DPA (standard index of displacement damage), Arc-DPA (modified index of displacement damage), energy deposition, and particle (proton, neutron, pion+, and pion-) fluence. Results of intercomparison will be presented at the conference.

Session 8 / 56

Shielding at high-power, high-intensity laser facilities: source term assessment for HED science and the Athena Lab for medical applications at HZDR

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Physics of high power, ultra-intense lasers interacting with plasma is a field that dramatically evolved in the last years, with a growing number of multi-TW and PW-class dedicated facilities around the world. In a such scenario an optimized shielding assessment still appears to be a challenge: if on one hand the constant technological improvements are allowing increased energies and intensities of the emitted ionizing radiation, on the other hand some aspects of the underlying physical phenomena still need more investigation.
In this work the shielding concept for two different, complex laser-induced radiation fields will be presented, as significant cases:

(1) After accurate investigation of the dynamics of hot refluxing electrons in the interaction of an ultra-short relativistic laser pulse with a thin foil target via particle-in-cell (PIC) simulations, and comparison with experimental data, the typical Bremsstrahlung source term has been evaluated, taking into account for the first time the photon radiation emitted from the recirculating electrons in the plasma. This source term primarily drives the radiation protection assessment in the facilities dedicated to the investigation of the matter under extreme conditions.
(2) The shielding concept of the ATHENA Lab, which is at present in construction at HZDR and will use the PENELOPE PW laser for biology and medical applications, will be presented. The shielding assessment has been realized considering two different operation modes: (a) a 'full energy' mode, where we assume that the full energy spectrum of interest for the biology/medical applications (up to 250 MeV) is reached via advanced acceleration schemes; (b) a 'routine operation' mode, with a lower, stable working point as maximum proton energy (100 MeV). The data-driven source terms used, together with the optimization process, will be described and discussed.

Session 8 / 44

Solid state dosimeters at Laser-Driven Accelerator Facilities

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Over the past few decades, laser-based particle accelerators have made tremendous progress and attracted ever more interest from the wider scientific community. Multiterawatt and petawatt high-power lasers facilities are now a reality and have applications in physics, material science, medicine, life science, and laboratory astrophysics. The radiation generated in experiments using such laser systems leads to high prompt doses and potentially to the activation of the surrounding materials. Unfortunately, in comparison with conventional accelerators, accurate dosimetry at laser-accelerated beams is still a challenge. The radiation fields produced are pulsed, mixed, and with high instantaneous fluxes and high dose rates. While new dosimetric techniques are being developed, important efforts are being put in the study of the behavior of known dosimetry systems in radiation fields at laser accelerators.
This work presents a study of passive solid-state detectors for the measurement of pulsed radiation performed at experimental station ALFA. ALFA was commissioned at the ELI Beamlines laser-driven user facility. Laser pulses (<20 fs, 1kHz, 1.5 TW) were carefully focused inside supersonic gas targets to generate an ultra-short (fs) ultra-relativistic (10s MeV) electron beam. The produced secondary radiation field was studied and has provided useful insights in dosimetry at laser accelerator. To achieve better understanding, a combination of different solid-state dosimetric systems were irradiated: film badges and optically stimulated luminescence, thermoluminesce, and radiophotoluminescence dosimeters. Furthermore, detailed Monte Carlo simulations were performed. This contribution presents the obtained experimental data and their comparison to Monte Carlo predictions.

Session 8 / 30

A new methodology for plugging of pipe/cable penetrations in shielding walls for gamma and neutron radiation

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In the frame work of shielding design for the OL3 nuclear power plant (NPP) a special design solution was required to shield the areas close to the circular wall inside the Reactor Building.
In the Reactor Building of the OL3 NPP, large equipment areas with high neutron and gamma radiation levels are separated from accessible areas by one circular shielding wall comprising the Reactor Coolant System. This shielding wall is penetrated by a large number of openings for cables and piping of different diameters and temperature requirements. The openings are generally realized during the construction phase by using sleeve pipes in the first concreting of the shielding wall. These openings may be used by a single pipe as well as by different pipes routed through the opening at different angles.
The installation of the piping has generally to include enough flexibility to allow moving of the piping due to thermal stress and other possible impacts. Furthermore, the installation of the piping shall include the option to remove and exchange piping during plant outage. These openings have to be sealed according to the radiological requirements of very low radiation levels given for the accessible areas. This was quite demanding taking into account the huge impact induced by the Reactor Coolant System in the large equipment areas.
After the sleeving – a very common standard technique - of each pipe (in some cases sleeving of pipes of small bore as a bundle) to allow enough flexibility after installation, the opening is filled with PE granules. This was done by a commonly used fan systems conveying the granules into the openings. These PE granules yield good neutron attenuation due to their high hydrogen content. Lead wool packages (used for OL3, comparable gamma attenuation materials can be used instead) were introduced in the openings at both ends to shield any gamma radiation impact.
The complete design yielded enough space to add additional sealing for room closure (HVAC) and fire protection sealing as final steps of the overall sealing procedure. The sealing procedure is quickly performed. The preparatory works as well as the impact on the areas around are quite low. The seals can easily be removed for exchange or addition of pipes etc.
It is shown on examples that the implementation method for the PE granules into the openings yielded a density that was high enough to provide sufficient neutron radiation attenuation. Calculations by Monte Carlo particle transport code, MCNP, showed that the total radiation dose rate attenuation of the complete seal is as good as of the unpenetrated wall. Radiological measurements during plant start-up measurements at OL3 at 60 % reactor power (commissioning of the plant and further increase of the reactor power is still ongoing) demonstrated in April that the neutron and gamma radiation dose rate levels at these openings are kept. According to the measurement results it can already be stated that the dose rates at these plugged openings will remain at the predicted low levels when reaching 100% reactor power. The patent applications for the plugging methodology are in progress. It is available under its Framatome product name "Flexible Radiation Plugging - Flex Rad Plug".

Session 8 / 41

Atmospheric-like neutrons and muons at the ILC beam dumps

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We evaluate the neutron and muon fluxes produced in the ILC beam dump by Monte Carlo simulations and discuss their potential use in irradiation fields. We find that the beam dumps can deliver neutrons about 10^{11} times the cosmic radiation on spaces perpendicular to the beam axis and muons 10^8 times downstream of the beam dumps in the initial phase of the ILC. Large-area irradiation of the order of 1 m^2 or more is possible. Differences in the energy distribution of muons in electron and positron beam dumps are also discussed.

Concluding Session / 64

Follow-up of past SATIF agreements and future actions

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