PHITS Workshop and Intermediate Course

at Japan Atomic Energy Agency in Tokai, Japan 2025

February 18-21, 2025

Tokai Mirai Base

PHITS
Particle and Heavy Ion Transport code System

Program of PHITS workshop 2025 @ Mirai-base, Tokai, Japan

Time	Feb. 18 (Tue)
9:20-9:50	Registration
9:50-11:50	Opening and O1 (Recent development)
11:50-13:20	Lunch & group photo
13:20-15:10	O2 (Benchmark I)
15:10-16:00	P1 (Poster session I)
16:00-18:10	O3 (Benchmark II)
18:30-20:30	Welcome party

Time	Feb. 19 (Wed)
9:10-10:20	O4 (Application I)
10:40-11:50	O5 (Application II)
11:50-13:20	Lunch
13:20-15:10	O6 (Application III)
15:10-16:00	P2 (Poster session II)
16:00-17:50	O7 (Application IV)

Time	Feb. 20 (Thu)
9:10-10:20	O8 (Application V)
10:40-11:50	O9 (Application VI)
11:50-13:20	Lunch
13:20-14:50	O10 (Application VII + Education)
15:20-17:40	PHITS intermediate course (autorun+options or VR)
18:00-20:30	Official dinner

Time	Feb. 21 (Fri)
9:10-10:40	PHITS intermediate course (detector response or Therapy)
11:00-11:40	Summary and discussion
11:40-13:30	Lunch
13:30-16:00	Technical tour (J-PARC) or Q&A
16:00-17:30	Q&A

Tuesday, 18 February 2025

9:20-9:50 Registration
09:50-10:05 Announcement (Tatsuhiko Ogawa, JAEA)
10:05-10:10 Welcome message (Toshiyuki Monma, Executive Director of JAEA)
10:10-10:15 Opening message (Koji Niita, RIST)
10:15-11:50 PHITS workshop (O1. Recent development) Chair: Tatsuhiko Ogawa

O1-1. General features and recent progresses of PHITS, Tatsuhiko Sato, Japan Atomic Energy Agency, Japan
O1-2. Track-structure and water-radiolysis simulation in PHITS, Yusuke Matsuya, Hokkaido Univ., Japan
O1-3. New physics and visualization, Yasuhito Sakaki, KEK, Japan
O1-4. Introduction to RadioTherapy package based on PHITS (RT-PHITS), Takuya Furuta, Japan Atomic Energy Agency, Japan
O1-5. New Features in the Upcoming Version of PHIG-3D, Seiki Ohnishi, National Maritime Research Institute, Japan
O1-6. Features and applications of the DCHAIN-PHITS activation code, Hunter Ratliff, Western Norway University of Applied Sciences, Norway

(lunch) + Group photo

13:20-15:10 PHITS workshop (O2. Benchmark I) Chair: Tatsuhiko Ogawa

O2-1. Assessing Secondary Cosmic Ray Propagation and Atmospheric Ionization Using the BIOSPHERE Measurement Campaigns and PHITS/MCNP6 Simulation Codes, Amer Al-Qaaod, Physikalisch-Technische Bundesanstalt (PTB), Germany

O2-2. Neutron Yield Predictions with Artificial Neural Networks: A Predictive Modeling Approach, Benedikt Schmitz, Institute of Nuclear Physics, TU Darmstadt, Germany
O2-3. Simulations of Tritium Production in Various Materials Using PHITS and FLUKA Codes, Dali Georgobiani, Fermi National Accelerator Laboratory, USA
O2-4. Optimization and Evaluation of the Monte Carlo Simulation Model for Various Irradiation Systems and Detectors Utilizing the PHITS Code, Dat Nguyen-Thanh, Ho Chi Minh City University of Education, Vietnam
O2-5. Activation Characteristics of Concrete Shielding Walls Induced by High-Energy Particle Beams, Euna Lee, Hanyang University, South Korea
O2-6. Reactor Radiological Characterization using DCHAIN from Reactor Core Source Generated by OpenMC Flux Tally for Reactor Decommissioning Strategic Plan, Handy Tri Lunar Nugraha, Universitas Gadjah Mada, Indonesia
O2-7. Estimation of neutron induced activity around radioisotope production cyclotron using PHITS, Geant4 and FLUKA, Jonathan Collin, University of Strabourg, France

15:10-16:00 PHITS workshop (P1. Poster session I)

16:00-18:10 PHITS workshop (O3. Benchmark II) Chair: Hiroshi Iwase
O3-1. Investigation of the depth-dose distributions of heavy ions employed in hadron therapy utilizing PHITS code, Hassane El Bekkouri, Ibn Tofail University, Morocco
O3-2. Direct Production of Both Gallium-68 and Technetium-99m Using the Natural Isotopic Compositions as the Main Targets, Luis Fernando Salas Tapia, The university of Tokyo, Japan
O3-3. Code-to-code comparison for the Monte Carlo, Luna Sobczak, University Paris-Saclay, CEA, France
O3-4. Compendium on Monte Carlo simulation of photoneutrons in the Giant Dipole Resonance energy range: the first five elements, Louis Garnaud, CEA, France
O3-5. Characterization of Secondary Neutron Spectra from Therapeutic Proton and Carbon Ion Beams Using PHITS Simulation, Mohamed El-Asery, Ibn Tofail University, Morocco
O3-6. Extension of Intranuclear Cascade Framework for Cluster-Induced Nuclear Reactions in the Intermediate Energy Range, Monira Jannatul Kobra, University of Rajshahi, Bangladesh
O3-7. Neutronic Property Estimation of a Self-cooled Lithium-Lead Blanket Mockup at the IFMIF-DONES Irradiation Environment using PHITS and JENDL/DEU-2020, Takeo Nishitani, Kyoto Fusioneering Ltd / Nagoya University, Japan
O3-8. Radiation Study for the Pion Production System of the COMET Experiment at J-PARC, Yusuke Uchiyama, KEK, Japan

18:30-20:30 (Welcome party, 6000 yen for staffs & 3000 yen for students, CASH only!)

Wednesday, 19 February 2025

9:10-10:20 PHITS workshop (O4. Application I) Chair: Shinichiro Abe
O4-1. PHITS Use at FRIB: Recent Highlights, Thomas Nelson Ginter, Michigan State

University, USA

O4-2. Designing lightweight neutron absorbing composites using a comprehensive absorber areal density metric, Andrew O'Connor, University of Florida, USA

O4-3. PHITS MC Optimisation of a table-top NRTA system for small nuclear material sample analysis, Cebastien Joel Guembou Shouop, Japan Atomic Energy Agency, Japan

O4-4. How to change neutron ambient dose equivalent in LINAC's room, Dang Quoc Soai, Hanoi Oncology Hospital, Vietnam

(Coffee break)

10:40-11:50 PHITS workshop (O5. Application II) Chair: Shinichiro Abe

O5-1. Lead-Free Yb2O3-Doped Transparent Phosphate Glasses for Radiation Shielding: Analytical and PHITS Monte Carlo Analysis, Devendra Raj Upadhyay, Tribhuvan University, Nepal

O5-2. Monte Carlo study of neutron contamination from high-energy medical linac, Dewa Ngurah Yudhi Prasada, Universitas Udayana, Indonesia

O5-3. Evaluation of human equivalent phantom applicability of low-cost 3D filaments by absorbed dose measurement of radiophotoluminescence dosimeter and Monte Carlo simulations, Donghee Han, Kyushu Univ., Japan

O5-4. Nuclear analysis on the magnetic systems of compact fusion reactors with the Monte Carlo code PHITS, Federico Ledda, Politecnico di Torino, Italy

(lunch)

13:20-15:10 PHITS workshop (O6. Application III) Chair: Nobuhiro Shigyo

O6-1. Application of PHITS in Muography Imaging Techniques, Hamid Basiri, The University of Tokyo, Japan

O6-2. Simulation study on the characteristics of thundercloud-related radiation emitted from atmospheric electric fields, Harufumi Tsuchiya, Japan Atomic Energy Agency, Japan

O6-3. PHITS Simulations for the design of HBS: A High Brilliance accelerator-based neutron Source, Jing Jing Li, Forschungszentrum Jülich GmbH, Germany

O6-4. Application of additive manufacturing technology in Linac X-ray and synchrotron microbeam radiation therapy: From dosimetry to radiobiology, John Paul O. Bustillo, University of Wollongong Australia, Australia

O6-5. Evaluation of cosmic rays damage and linear energy transfer on hybrid and inorganic halide lead perovskites in space environment, Joseph Omojola, North-West University, South Africa

O6-6. Development of a composite neutron converter for DDTTNY measurements: A Monte Carlo simulation study, Kawchar Patwary, Comilla University, Bangladesh

O6-7. Optimizing a Photoneutron Source for Bragg Edge Imaging and Reproducing Bragg Edges of an α-Fe Sample Using PHITS Code, Mahdi Bakhtiari, Pohang Accelerator Laboratory, South Korea

15:10-16:00 PHITS workshop (P2. Poster session II)

16:00-17:50 PHITS workshop (O7. Application IV) Chair: Yusuke Matsuya

O7-1. Design of Self-Cooled Lithium-Lead Fusion Blanket and Analysis of Tritium Breeding Performance with PHITS, Maxim Monange, EX-Fusion America Inc., USA

O7-2. Lithium battery in-depth analysis with MIXE: setup and simulations with PHITS., Maxime Lamotte, Paul Scherrer Institute, Switzerland

O7-3. Advancement of Phosphate Glasses Doped with Bismuth Oxide for Photon Shielding Applications, Ornnattha Ornketphon, Chiang Mai university, Thailand

O7-4. Dosimetric study of a Co-60 HDR Brachytherapy Source using PHITS, Patrick Vincent Aquino, Batangas Medical Center, Philippines

O7-5. Shielding Optimization: An Approach for Extending PHITS with Machine Learning, Rajarshi Pal Chowdhury, Facility of Rare Isotope Beams, Michigan State University, USA

O7-6. Validation of Particle and Heavy Ion Transport Code System (PHITS) in generating dose-voxel kernels for internal dosimetry calculations, Shalaine Sana Tatu, Philippine Nuclear Research Institute / Taylor's University, Philippines / Malaysia

O7-7. Small-scale bone marrow dosimetry study for ^{225}Ac, Stephen Tronchin, The University of Adelaide, Australia

Thursday, 20 February 2025

9:10-10:20 PHITS workshop (O8. Application V) Chair: Yuho Hirata

O8-1. Neutron spectrometry with DIAMON detector for characterisation of a newly built neutron calibration facility at SCK CEN, Sita Gandes Pinasti, SCK CEN, Belgium

O8-2. Reduction of the Added Reflected Dose Component at the Patient Location Within a Brachytherapy Room for an Ir-192 Gamma Source: A Monte Carlo Study, Suffian Bin Mohamad Tajudin, Universiti Sultan Zainal Abidin, Malaysia

O8-3. Determination of mass attenuation coefficient for some Taif City rock samples using XCOM and EPIXS simulations, Sultan J. Alsufyani, Ayman M. Abdalla, Rawabi AlThoai, Taif University / Najran University, Saudi Arabia

O8-4. Cosmic-ray exposure assessment using particle and heavy ion transport code system: case study Douala-Cameroon, Takoukam Soh Serge Didier, University of Yaounde I, Cameroon

(Coffee break)

10:40-11:50 PHITS workshop (O9 Application VI) Chair: Yuho Hirata

O9-1. Bayesian Optimization of a HPGe detector for 3D activity reconstruction in radioactive waste drums, Victor Jose Casas Molina, SCK CEN / Ghent University, Belgium

O9-2. Establishing dose coefficients for common paediatric diagnostic fluoroscopic examinations in support of ICRP Task Group 113, Wyatt William Smither, University of Florida, USA

O9-3. Exploring the energy deposition patterns of proton at macro and microscale using

PHITS software, Xianghui Kong, The Hong Kong Polytechnic University, China

O9-4. Constructions of mesh-type cell models and their application research based on PHITS, Yidi Wang, QST, Japan

(lunch)

13:20-14:50 PHITS workshop (O10. Application VII & Education) Chair: Takuya Furuta

O10-1. Analysis of Materials and Thickness of 230 MeV Cyclotron Room Shielding for Proton Beam Therapy using Particle and Heavy Ion Transport Code System Program, Yohannes Sardjono, National Research and Innovation Agency (BRIN), Indonesia

O10-2. Calculation of the Skyshine Radiation Measurement in Baikal-1 RA Research Reactor using PHITS code, Yusuke Yasuno, Mitsubishi Nuclear Fuel Co., Ltd, Japan

O10-3. Education on optimizing radiation protection in X-ray fluoroscopy-guided procedures using extended reality, Toshioh Fujibuchi, Kyushu University, Japan

O10-4. Experience with PHITS Code in the research and training programs at the Nuclear Engineering Area of Technical University of Madrid (Spain), Gonzalo Felipe Fernandez Garcia, Technical University of Madrid, Spain

O10-5. Concepts for Enhancing the North American PHITS Community, Thomas Nelson Ginter, Michigan State University, USA

(Coffee break)

15:20-17:40 PHITS Intermediate course
Autorun + Options (Tatsuhiko Ogawa) or Variance reduction (Tatsuhiko Sato)

18:00-20:30 (official dinner, 8000 yen for staffs & 5000 yen for students, CASH only!)

Friday, 21 February 2025

9:10-10:40 PHITS Intermediate course
Detector response (Tatsuhiko Ogawa) or X-ray therapy (Takuya Furuta)

11:00-11:40 Summary & Discussion Chair: Tatsuhiko Sato

(lunch)

13:00-15:30 Technical tour (J-PARC) / Q&A
16:00-17:30 Q&A

Poster Session I

P1-1. Design study of the neutron source for the neutron shielding performance test at NDPS of RAON, Cheolmin Ham, Institute for Basic Science, South Korea

P1-2. Development of a Bonner Sphere Spectrometer for Aviation Neutron Monitoring, Felipe Lopes Frigi, Aeronautics Institute of Technology, Italy

P1-3. Modeling a list-mode multi-coincidence detection system for neutron and gamma-ray imaging in PHITS, Hunter N. Ratliff, Western Norway University of

Applied Sciences, Norway

P1-4. Evaluation of Parallel Computing on MPI Version PHITS Code, Hyeokjun Gwon, Korea Institute of Radiological & Medical Science, South Korea

P1-5. Computational evaluation of a two-source neutron irradiator, Jayms S. Sagana, Mapúa University, Philippines

P1-6. Calculation of Absorbed Dose Measurements by Fiber-optic Personnel Radiation Dosimeters through Particle and Heavy Ion Transport code System (PHITS) Simulations, Joaquin Marcquo S. Andal, University of Santo Tomas, Philippines

P1-7. Development of Directional vector based Quick evaluation method for Protective plate Effects in X ray fluoroscopy (DQPEX), Kyoko Hizukuri, Kyushu University, Japan

P1-8. Simulation of chest posteroanterior x-ray procedure using stylized phantom and PHITS, Michaela Marie Subion Sta. Ana, University of Santo Tomas, Philippines

P1-9. Simulation Study of Thick Target Neutron Production for NDPS at RAON, Jaesung Kim, Institute for Rare Isotope Science, Institute for Basic Science, South Korea

Poster Session II

P2-1. Problem Formulation Using PHITS to Estimate Types and Depth Distribution of Radioactive Isotopes in Soil, Kanata Nokubo, Kagawa University, Japan

P2-2. Simulation of Radiological Leakage in a Teletherapy Bunker Using PHITS, Noor Farhana Husna A. Aziz, Malaysian Nuclear Agency, Malaysia

P2-3. Particle Bombardment on Liquid Metal Plasma Facing Components, Nopparit Somboonkittichai, Kasetsart University, Thailand

P2-4. Design of Si-TlBr Compton Camera Geometry using PHITS for Measuring Prompt Gamma-rays in BNCT, Jiye Qiu, Osaka University, Japan

P2-5. Exposure Calculation for a Worker with Contaminated Hair, Sangrok Kim, Korea Institute of Radiological and Medical Sciences, South Korea

P2-6. Feasibility Study of Radiation Shielding Capability and Ion-Matter Interaction Parameters of Common South African Building Bricks Using PHITS Monte Carlo Code, Stephen Friday Olukotun, North-West University, South Africa

P2-7. Neutronics Progress in Conceptual Design of the Self-Cooled Lithium-Lead SCYLLA Blanket for a Spherical Tokamak, Jun Takamine, Kyoto Fusioneering Ltd, Japan

P2-8. Monte Carlo Simulation Based Dose Calculation for Varian 2100 CD Linac: A Comparative Study with Clinical Algorithms in Homogeneous and Heterogeneous Media, Tanny Bepari, Gono Bishwabidyalay, Bangladesh

P2-9. Study of INC model for alpha inelastic scattering at 230 MeV/u, Toshimaza Furuta, Kyushu University, Japan

General features and recent progresses of PHITS

Tatsuhiko Sato[1] on behalf of PHITS development team
1. Nuclear Science and Engineering Center, Japan Atomic Energy Agency, Japan

PHITS is a general-purpose Monte Carlo particle transport simulation code that has been widely used in various research fields such as radiation facility design, medical physics, cosmic-ray research, and geosciences. As shown in Fig. 1, it is utilized by more than 10,000 researchers and technicians across over 70 countries. A new version of PHITS is typically released once per year, with additional bug-fix versions provided as necessary. The major upgrades introduced since the release of the current version (3.341) include the following: (1) Incorporation of the JENDL-5 activation cross sections for neutrons, protons, deuterons, alpha particles, and photons, (2) Improvement of the weight window generator tally [t-wwg] [1], (3) Introduction of #all function in [cell] for automatically excluding all cells except for outer void regions, and (4) Revision of source code to be compatible with ifx. The details of these new features will be discussed during the workshop.

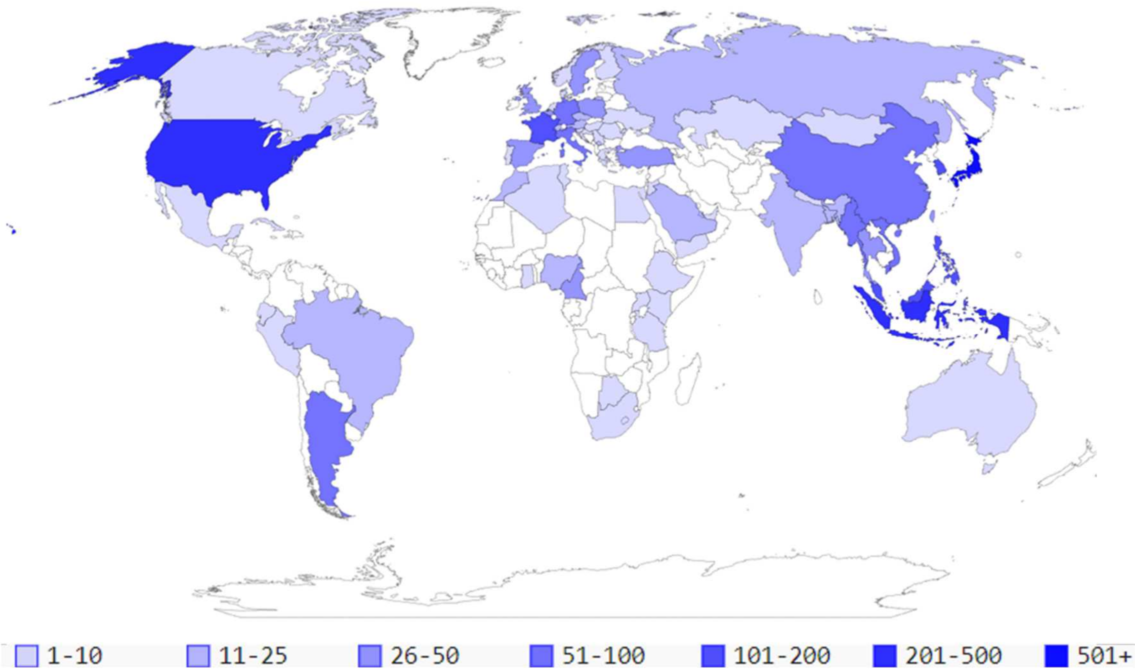

Fig. 1 Number of PHITS users in each country since 2019 (@ March 2024)

References

[1] T. Sato et al., Development of a forward Monte Carlo based weight-window generator using the counter function in PHITS. Nucl. Instr. Meth. B 557, 165535 (2024).

Track-structure and water-radiolysis simulation in PHITS

Yusuke Matsuya[1,2], Takeshi Kai[2], Tatsuhiko Ogawa[2], Yuji Yoshii[3],
Seiki Ohnishi[4], Yuho Hirata[2], Tatsuhiko Sato[2]

1. Faculty of Health Sciences, Hokkaido University, Japan

2. Nuclear Science and Engineering Center, Japan Atomic Energy Agency, Japan

3. Faculty of Health Sciences, Hokkaido University of Sciences, Japan

4. National Maritime Research Institute, Japan

Biological effects after radiation exposure, such as cell death and mutation, are believed to be attributed to initial DNA damage induction by energy deposition (direct effects) and reactions of chemical products to DNA (indirect effects). These effects are intrinsically related to track structure and water radiolysis of ionizing radiation. Track-structure simulation model (*TS modes*) and chemical simulation code (*PHITS-Chem*) have been recently developed in a general-purpose Monte Carlo code, Particle and Heavy Ion Transport code System (PHITS) [1]. In this presentation, we will introduce the current state of the *TS modes* [2] and the *PHITS-Chem code* [3]. To date, not only the TS models dedicated to specific targets, *PHITS-ETS* and *PHITS-KURBUC* for liquid water and *PHITS-ETS for Si*, but also that applicable to various materials, *Ion Track Structure model for Arbitrary Radiation and Targets (ITSART) and Electron Track Structure mode for ARbitrary Targets (ETSART)*, have been implemented in the PHITS code. These models allow the simulation of each atomic interaction between radiation and materials. Meanwhile, focusing on the liquid water, the *PHITS-Chem* code enables the simulation and 3D visualization of chemical product dynamics in liquid water for various types of ionizing radiations. These models for physical and chemical processes would contribute to precisely understanding of radiation effects such as biological impact and detector responses in future study.

References

[1] T. Sato et al., Recent improvements of the Particle and Heavy Ion Transport code System - PHITS version 3.33, *J. Nucl. Sci. Technol.* 61, 127–135 (2024)

[2] T. Ogawa et al., Overview of PHITS Ver. 3.34 with particular focus on track-structure calculation. *EPJ Nuclear Sci. Technol.* 10, 13 (2024)

[3] Y. Matsuya et al., A step-by-step chemical code for estimating yields of free radicals based on electron track-structure mode in the PHITS code. *Phys. Med. Biol.* 69, 035005 (2024)

New physics and visualization

Yasuhito Sakaki
High Energy Accelerator Research Organization, Japan

The major particles and interactions are already implemented in PHITS. However, in some applications, we want to implement new particles and interactions in PHITS. The [User Defined Interaction] and [User Defined Particle] sections, implemented in version 3.33, enable these capabilities. In this talk, I will introduce how to use these sections, using new physics searches in high-energy physics as an example.

Another topic of this talk is the visualization of radiation transport. In version 3.34, [t-4Dtrack] tally was implemented to output radiation track information. I will introduce a method to visualize radiation transport by loading the output file into PHIG-3D.

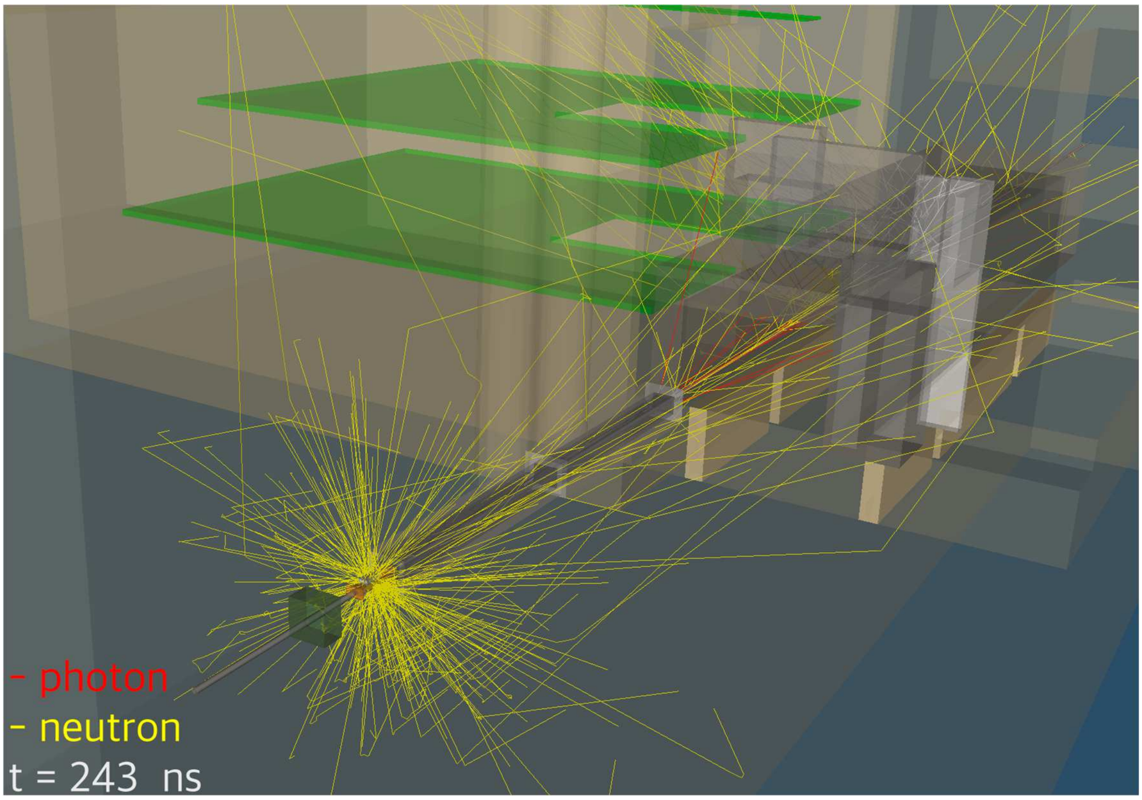

Fig. 1 Radiation visualization using [t-4Dtrack] and PHIG-3D.

Introduction to RadioTherapy package based on PHITS (RT-PHITS)

Takuya Furuta

Nuclear Science and Engineering Center, Japan Atomic Energy Agency, Japan

RT-PHITS is a user support program to help users to perform radiotherapy simulation using medical DICOM data set. RT-PHITS creates a patient specific PHITS input file adopting the DICOM data set of the patient. For instance, beam device geometry can be constructed adopting the RT-plan of the carbon-ion radiotherapy and the patient body geometry can be reconstructed from the patient CT data [1]. Nuclear medicine treatment can be also performed through the RT-PHITS by setting the Radio Isotope (RI) distribution according to the patient PET or SPECT data [2]. RT-PHITS has also an option to convert the dose distribution obtained by the PHITS simulation inside the patient body back to the DICOM format, RT-dose, so that it can be analyzed using general DICOM software. In this talk, the functions of RT-PHITS are going to presented together with the recently developed new functions.

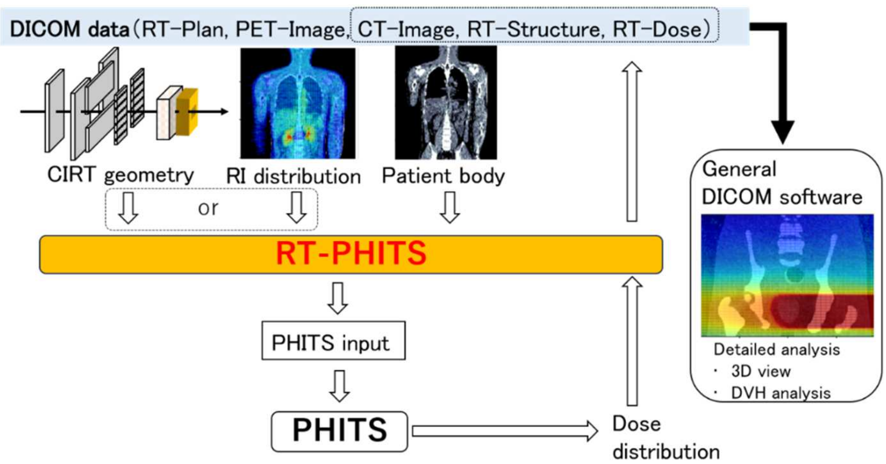

Fig. 1 Overview of RT-PHITS

References

[1] T. Furuta et al., Development of the DICOM-based Monte Carlo dose reconstruction system for a retrospective study on the secondary cancer risk in carbon ion radiotherapy, Phys. Med. Biol. 67, 145002 (2022)

[2] T. Sato et al., Individual dosimetry system for targeted alpha therapy based on PHITS coupled with microdosimetric kinetic model, EJNMMI Phys. 8, 4 (2021)

New Features in the Upcoming Version of PHIG-3D

Seiki Ohnishi

Maritime Risk Assessment Department, National Maritime Research Institute, Japan

PHIG-3D is a visualization tool for PHITS [1] code input files, with functions such as changing viewpoints in real-time with a graphical user interface. In the next version, new features will be added to improve usability and productivity, including a new polygon generation method, color contour display of tally results, and Python scripting.

The new method generates simple polygon meshes from each surface card, and then Boolean operations are performed between polygons according to the logical formulas to visualize complex cells. For a critical assembly shown in Fig. 1, this new method is approximately 60 times more efficient in terms of memory consumption than the conventional marching cube method. The tally results display function paints cells based on three-dimensional field data tallied in a cartesian mesh as shown in Fig. 2. The presentation will introduce and demonstrate these new features.

New method (data size: 750MB) Marching cubes method (45,350 MB)

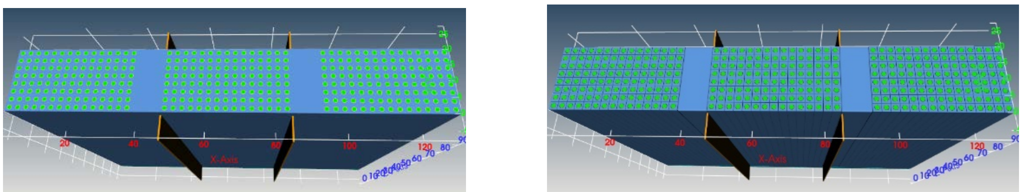

Fig. 1 Comparison of the new and marching cubes methods for a critical assembly LEU-COMP-THERM-009 [2].

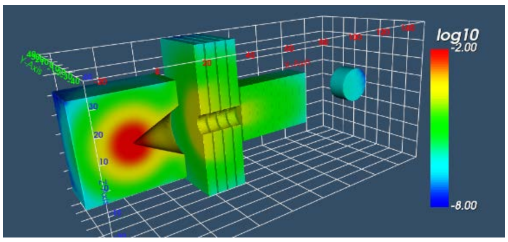

Fig. 2 Example of color contour display.

References

[1] T. Sato et al., Recent improvements of the Particle and Heavy Ion Transport code System - PHITS version 3.33, J. Nucl. Sci. Technol. 61, 127-135 (2024).

[2] Nuclear Energy Agency, International Handbook of Evaluated Criticality Safety Benchmark Experiments, OECD Nuclear Energy Agency, NEA;7328, (2016).

Features and applications of the DCHAIN-PHITS activation code

Hunter N. Ratliff[1,2], Norihiro Matsuda[1], Shin-ichiro Abe, [1] Takamitsu Miura[3],
Takuya Furuta[1], Yosuke Iwamoto[1], Tatsuhiko Sato[1]

1. *Nuclear Science and Engineering Center, Japan Atomic Energy Agency, Japan*
2. *Western Norway University of Applied Sciences, Bergen, Norway*
3. *Research Organization for Information Science and Technology, Japan*

DCHAIN-PHITS [1] is the time-dependent radionuclide production, buildup, burnup, and decay code distributed with and coupled to PHITS [2], as shown in Fig. 1; it is capable of modeling activation scenarios in any radiation environment that PHITS can simulate. This work highlights the code's functions, its integration with PHITS, modernization efforts to notably expand its capabilities and flexibility, and a variety of examples showcasing its utility. Such improvements include statistical uncertainty propagation, restoring fission functionalities, complete modernization of all nuclear data libraries, adding support for tetrahedral (Fig. 2) and three-dimensional grid mesh geometries, fully comprehensive tracking of all nuclide inventory changes per nuclide per reaction per time step, and streamlining the workflow for complex activation and decay dose assessment scenarios.

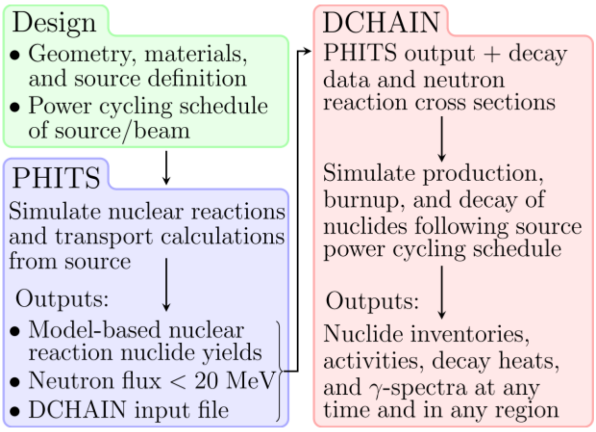

Fig. 1 Flow of PHITS+DCHAIN simulations

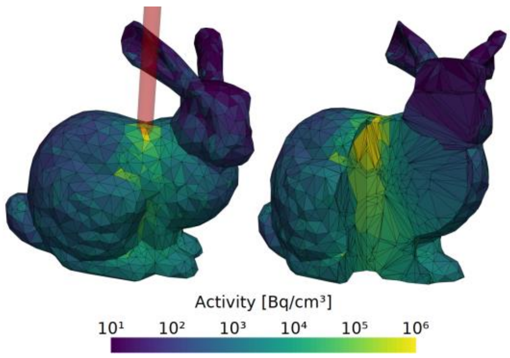

Fig. 2 Tetrahedral activation example

References

[1] H.N. Ratliff et al., Modernization of the DCHAIN-PHITS activation code with new features and updated data libraries, Nucl. Instrum. Methods Phys. Res. B, 484, 29–41 (2020)
[2] T. Sato et al., Recent improvements of the Particle and Heavy Ion Transport code System - PHITS version 3.33, J. Nucl. Sci. Technol. 61, 127-135 (2024)

Assessing Secondary Cosmic Ray Propagation and Atmospheric Ionization Using the BIOSPHERE Measurement Campaigns and PHITS/MCNP6 Simulation Codes

Amer Al-Qaaod, Faton S. Krasniqi

Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig, Germany

The European Partnership on Metrology (EPM) joint research project BIOSPHERE aims to develop advanced methods and instrumentation to evaluate how atmospheric ionization, caused by cosmic rays and solar UV radiation, influences both human and ecological health [1]. One objective of this project focuses on the role of Secondary Cosmic Rays (SCRs) at ground level and their correlation with incoming Primary Cosmic Rays (PCRs). Understanding this link requires high-quality SCR data, PCR flux measurements, and detailed atmospheric profiles, together with comprehensive Monte Carlo simulations to quantify the interactions between SCRs and air masses.

In this study, two different transport simulation codes, PHITS and MCNP6 were utilized to model cosmic sources, atmospheric interactions, and Extensive Air Showers (EAS). Recent developments in the PHITS, version 3.280, and MCNP, version 6, Cosmic-Source model, including automatic source normalization, solar modulation, and geomagnetic rigidity truncation of Galactic Cosmic Ray (GCR) spectra, were employed. The atmospheric model incorporated real density data from radiosondes. The intermediate- and high-energy interactions were transported using different nuclear interaction models such as the INternuclear Cascade Liege (INCL), Intra-Nuclear Cascade (INC CEM) and the Los Alamos Quark-Gluon String Model (LAQGSM). The influence of atmospheric profile on secondary cosmic muon production was investigated, and the calculated muon flux validated using measured data from the BIOSPHERE measurement campaigns. The results showed good agreement between the two codes used in this study.

[1] https://euramet-biosphere.eu/

Neutron Yield Predicitions with Artifical Neural Networks: A Predictive Modeling Approach

Benedikt Schmitz[1 2], Stefan Scheuren[1]
1. Institut für Kernphysik, TU Darmstadt, Germany
2. FB Eletkrotechnik, Hochschule Darmstadt, Germany

The development of compact neutron sources for applications is extensive and features many approaches. For ion-based approaches, several projects with different parameters exist. This work focuses on ion-based neutron production below the spallation barrier for proton and deuteron beams with arbitrary energy distributions with kinetic energies from 3 MeV to 97 MeV. This model makes it possible to compare different ion-based neutron source concepts against each other quickly.
This contribution derives a predictive model using Monte Carlo simulations (an order of 50,000 simulations) and deep neural networks.
A prediction of neutron spectra then takes some milliseconds, which enables fast optimization and comparison.

References

[1] B. Schmitz, S. Scheuren, “Neutron Yield Predictions with Artificial Neural Networks: A Predictive Modeling Approach”, *J. Nucl. Eng 5*(2), 114-127 (2024)

Simulations of Tritium Production in Various Materials Using PHITS and FLUKA Codes

Dali Georgobiani[1], Alajos Makovec[1]

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Tritium is a common byproduct of particle accelerator operations, and its release is actively monitored and controlled at Fermilab to comply with regulatory limits. In this study, we simulate tritium production by modeling a proton beam stopped in a target to estimate yields in various materials commonly used in beamline components in high-energy accelerator environments.

We developed a simplified model to facilitate the analysis, and employed two widely used Monte Carlo radiation transport codes, FLUKA and PHITS, to estimate the tritium production rates across various materials and beam energies. Additionally, a model of Fermilab's NuMI target prototype was utilized to represent realistic beam operation conditions. This approach enables a code-to-code intercomparison and provides a valuable tool for optimizing proposed target materials with respect to tritium production.

OPTIMIZATION AND EVALUATION OF THE MONTE CARLO SIMULATION MODEL FOR VARIOUS IRRADIATION SYSTEMS AND DETECTORS UTILIZING THE PHITS CODE.

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The study aimed to optimize the Monte Carlo simulation of an X-ray system and typical nuclear detectors such as NaI(Tl) and HPGe using the PHITS code. While geometrical parameters are usually based on manufacturer specifications, discrepancies between actual and nominal values can affect simulation reliability. We addressed this by evaluating the effect of the Al2O3 reflector on NaI(Tl) detector efficiency and the influence of dead layer thickness on HPGe detector efficiency. We also optimized the X-ray system to collect narrow spectrum qualities of X-rays from N-40 to N-120. Preliminary results showed good agreement between simulated and experimental data, aligning with earlier findings using the MCNP code. These results will help refine the simulation model and improve the application of the PHITS code in future research.

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Activation Characteristics of Concrete Shielding Walls Induced by High-Energy Particle Beams

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After prolonged operation of the radiation facility using high-energy particle beams, the surrounding concrete shielding walls become activated. Disposing of this shielding as radioactive waste presents challenges because of its large volume and associated costs. The activation characteristics of concrete are not constant due to its non-homogeneous composition. Furthermore, an activation behavior needs to be thoroughly studied concerning the various nuclides in the concrete walls to effectively manage concrete radioactive waste in such facilities. In this regard, this study analyzed the activation characteristics of different concrete types subjected to high-energy particle beams.

Using PHITS version 3.34, we simulated targets and concrete layers to resemble a high-energy particle beam facility. Proton, carbon ion, and argon ion beams, representative source terms of large accelerator facilities, were directed at the targets and irradiated onto the concrete layers, forming distinct energy Bragg peaks in a 10-cm depth in a water phantom. Four types of concrete, each with a different nuclide composition, were prepared with 200 cm thickness and divided equally into ten slices. The specific activity of radionuclides was obtained in each slice.

These results showed that, even under identical particle and concrete conditions, the specific activity of radionuclides produced by concrete activation varied. Radionuclides generated from normal nuclides in concrete ('general nuclides') and those from impurities ('impurity-induced nuclides') exhibited similar levels of specific activity but differed significantly in quantity. This phenomenon results from the substantial differences in thermal neutron absorption cross-sections between normal nuclides (e.g., ^{54}Fe(n,x), 2.252 b) and impurities (e.g., ^{151}Eu(n,x), 9,169 b). Moreover, activation patterns also depended on particle mass, showing opposite trends according to differences in neutron flux distribution at low- and high-energy neutrons (p>C>Ar vs. Ar>C>p).

The study identified key activation characteristics of each concrete type when exposed to high-energy particle beams. These results can serve as a foundation for predicting the disposal cycle of concrete shielding walls or developing low-activation concrete materials.

Preference of the presentation style: Oral

Reactor Radiological Characterization using DCHAIN from Reactor Core Source Generated by OpenMC Flux Tally for Reactor Decommissioning Strategic Plan

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The Bandung Research Reactor, a TRIGA Mark 2 reactor in West Java, Indonesia, first criticality in 1965. Since 2009, Indonesian regulations have mandated research reactors to establish decommissioning programs with updates every five years. Consequently, a decommissioning plan for the reactor was initiated, beginning with radiological characterization using OpenMC (the design structure is shown in Figure 1 [1]) and PHITS. This process involves simulations with DCHAIN, requiring neutron flux and operational data to assess radiation impact on reactor structures over time. Neutron flux data from OpenMC is converted into PHITS cylindrical sources, while T-Tract generates neutron flux for volumetric geometry of key reactor components made of various materials like aluminum, stainless steel, and concrete. DCHAIN then processes these inputs to estimate activity levels, guiding decommissioning decisions.

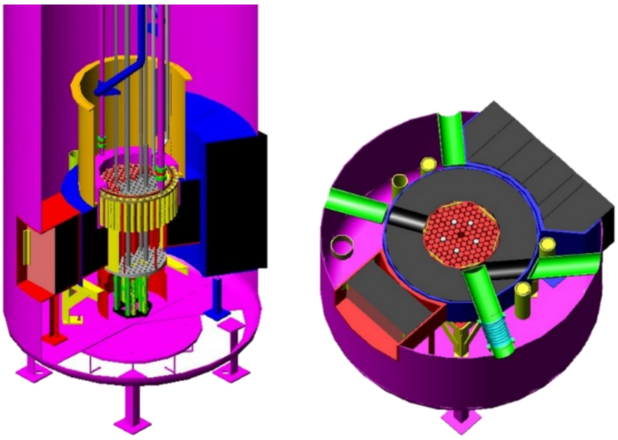

Fig. 1 3D Views of TRIGA 2000 Bandung on vertical and horizontal (bellow) view [1].

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Estimation of neutron induced activity around radioisotope production cyclotron using PHITS, Geant4 and FLUKA

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Nuclear activation is the process of production of radionuclides by irradiation. This phenomenon concerns all operating or soon-to-be dismantled particle accelerators used in various fields, from medical applications with the production of radioisotopes or radiotherapy cancer treatments to industrial applications with the sterilization of materials and food preservation [1].

This work focuses on radioisotopes-producing cyclotrons, in particular with the study of the radioactivity induced in various materials (Sc, Tb, Ta, W, Au) of known composition, irradiated by the secondary neutron field produced from protons of 13.5, 16.5 MeV and 18 MeV energies on three different targets, at the CYRCé facility. We have performed Monte Carlo simulations based on GEANT4, FLUKA, and PHITS to estimate the neutron fields and their associated induced activities [2, 3], associated with FISPACT-II and DCHAIN-PHITS.

A comparative study with nuclear data and MC codes highlighting discrepancies for certain nuclear reactions has been analysed with relevance. We confronted the simulation calculations results with experimental activation measurements performed by high-resolution gamma-ray spectrometry (HPGe, LABSOCS).

These results are strongly correlated to the neutron fields. These fields were characterized experimentally through their thermal and fast neutron components using Solid-State Nuclear Track Detectors (CR-39, Chiyoda Technol) to discuss the MC simulations.

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Investigation of the depth-dose distributions of heavy ions employed in hadron therapy utilizing PHITS code.

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Cancer is a global health crisis, leading to increased adoption of particle therapy, offering superior precision over conventional therapy. This study simulates and investigates the dose distribution of proton, alpha, carbon, and oxygen ions at various energies in a water phantom using the Particle and Heavy Ion Transport Code System (PHITS)[1]. It also visualizes particle fluence of secondary particles such as electrons, positrons, and neutrons. In this study, we utilized a basic cylindrical phantom with a 10 cm radius, confined between two planes along the Z axis (at 0 and 40 cm) and positioned within a central sphere with a radius of 500 cm. These dimensions were chosen to represent a typical tumor size accurately. The energy source is a mono-energetic axial source, and the radial source has a size of 1 cm. Results show positron fluence concentrates around the water phantom, dispersing more at higher energies, while neutron flux focuses along the source path. The PHITS-generated Percent Depth Dose (PDD) curves illustrate varied dose deposition patterns for each ion at different energies. Overall, electron, positron, and neutron fluence visualization highlights higher concentrations around the water phantom, suggesting potential improvements in treatment precision.

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Direct Production of Both Gallium-68 and Technetium-99m Using the Natural Isotopic Compositions as the Main Targets

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Radioisotopes are being used to diagnostic and treat people showing promising results towards the benefit of the human kind. Both Gallium-68 and Technetium-99m represent two powerful nuclides to be employed in nuclear medicine courts on a daily basis around the globe. For those reasons, in this work we seek to establish, fully understand and significantly contribute to the production of both Gallium-68 & Technetium-99m from the physics and engineering point of view. The starting point begins with completely understanding and handling the Monte Carlo codes, the deterministic calculator, and the CAD-based computational programs. All these previous tools are employed to benchmark two previously published experimental works from two academic organizations in Italy and Canada — one for Technetium-99m and the other for Gallium-68 respectively.

Because the target is a critical part during the whole process, we analyze and subsequently design autonomous targets for the production of these two isotopes which can be used in the machine we previously proposed. These targets have the philosophy of using for their construction cheap materials available mostly everywhere in the world. As a relevant issue in these kinds of nuclear facilities is the radiation protection & shielding, we consider the appropriate required materials and their thickness in both the accelerator and the generic facility where the cyclotron is located. The production yields for the nuclear reactions of interest have been calculated bench-marking four different computational codes (PHITS, FLUKA-CERN, FLUKA-INFN, TALYS) and at the end finding which code precisely reproduces the final activity in Becquerel after the irradiation routine. For this specific case, we found out that the TALYS code better calculates the production yield for the $^{100}Mo(p,2n)^{99m}Tc$ nuclear reaction. In the same way, the FLUKA-INFN code better estimates the production yield for the $^{68}Zn(p,n)^{68}Ga$ nuclear reaction. With those important results we calculated the production yield of our targets in our cyclotron for a determined irradiation routine. Relevant results in this part showed that we could eventually perform 8 patients for one of the most common studies in nuclear medicine with 99mTc — nasolacrimal drainage scintigraphy; and about 2 patients for one of the most important nuclear medicine studies using 68Ga — prostate-specific membrane antigen.

Code-to-code comparison for the Monte Carlo simulation of the photofission reaction

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Abstract

The photofission reaction finds many applications ranging from fundamental nuclear physics, to nuclear waste package characterization and detection of Special Nuclear Material (SNM) in cargo containers for border control and homeland security. Monte Carlo particle-transport codes are generally used to simulate the photofission process, design and optimize photofission experimental setups or support the interpretation of experimental results. The aim of this work is to create a reference study on the simulation of the photofission reaction using several Monte Carlo codes, i.e., MCNP6 and PHITS, each code being ran successively with ENDF/B-VIII.1 and JENDL-5 nuclear data libraries. We investigate the photofission rate induced by photofission reaction in several major actinides, i.e., Th-232, U-235, U-238 and Pu isotopes, as well as minor actinides, i.e., Np-237 and Am-241, from the reaction energy threshold of the photofission reaction up to 20 MeV, in the regime of the Giant Dipole Resonance (GDR). In this work, the photofission rate is the main observable, although the emission of photofission particles is investigated in terms of yield, energy spectrum and angular distribution for the cases of prompt neutrons and delayed neutrons. These results could support the experimental nuclear physics community to master the current strengths and limitations of the codes, and code developers to improve the sampling technique of photofission reactions. Moreover, discussions on agreement and discrepancies of results obtained using the two recent photonuclear data libraries should also provide directly applicable conclusions to their evaluators.

Compendium on Monte Carlo simulation of photoneutrons in the Giant Dipole Resonance energy range: the first five elements

Louis Garnaud[1], *Luna* Sobczak[2], *Johann* Piekar[2], *Adrien* Sari*[2], *Alexis* Jinaphanh[1], *Amine* Nasri[3], *Cédric* Jouanne[1], *Tatsuhiko* Ogawa[4], and *Andrea* Zoia[1]

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Abstract. Neutrons generated by photonuclear reactions, "photoneutrons", are encountered in various applications involving high-energy gamma sources, electron accelerators or nuclear reactors. Monte Carlo particle-transport codes are generally used to simulate the emission of photoneutrons, characterize their field or assess their impact on nuclear systems. The aim of this work is to create a compendium on the simulation of photoneutrons using several Monte Carlo codes, i.e., MCNP6, PHITS and TRIPOLI-4, each code being run successively with ENDF/B-VIII.0 and JENDL-5 nuclear data libraries. We study the photoneutron fields produced by 50 elements with their natural isotopic composition from the reaction energy threshold up to 30 MeV, i.e., in the regime of the Giant Dipole Resonance (GDR). The photoneutron fields are characterized according to three observables, i.e., photoneutron current, energy spectrum and angular distribution. This paper presents the results obtained for the first five elements in order of increasing atomic number, i.e., deuterium, beryllium, carbon, nitrogen and oxygen. The compendium could serve as a handbook for users to master the current strengths and limitations of the codes, for code developers to make progress in the sampling of neutron-emitting photonuclear reactions, and more broadly for all researchers working on photoneutrons, whether they are evaluators of nuclear data libraries or experimental nuclear physicists.

Characterization of Secondary Neutron Spectra from Therapeutic Proton and Carbon Ion Beams Using PHITS Simulation

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Hadron therapy (HT) is a cancer treatment technique that uses accelerated ions, primarily protons and carbon ions, to destroy tumors. It has shown high efficacy, particularly in treating cancers resistant to conventional radiation therapy. In HT, most of the radiation dose is delivered to the tumor via electromagnetic interactions with atomic electrons. However, the primary particles used in HT can also induce nuclear reactions, generating secondary radiation, particularly neutrons, which can expose a significant portion of the patient's body to unwanted background radiation. Therefore, evaluating the production of these secondary neutrons is critical. The primary aim of this research is to characterize secondary neutron production (SNP) during HT using 140 MeV protons and 264 MeV/u carbon ions in a soft tissue phantom. Additionally, this study compares neutron spectra (Double-differential thick target neutron yields (TTNYs)) at various angles range from 5° to 120°, for protons and carbon ions across different targets using spallation models (INCL4.6/GEM, Bertini/GEM, JQMD/GEM)[1, 2] and the high-energy nuclear data library JENDL-4.0/HE, implemented in the PHITS code[3]. Specifically, the research investigates neutron production for Fe, Pb, and Bi at 107 MeV. Our results indicate that neutron spectra, particularly for energies below ~20 MeV, are best predicted using the INCL4.6/GEM model for protons, and JQMD/GEM model for carbon ions, making them suitable for Monte Carlo transport simulations in this context.

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Extension of Intranuclear Cascade Framework for Cluster-Induced Nuclear Reactions in the Intermediate Energy Range

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Modeling of cluster-induced nuclear reactions is crucial for numerous applications, such as nuclear transmutation, radiation shielding, and medical physics. However, existing Intranuclear Cascade (INC) models, including those implemented in PHITS (such as INCL and JQMD), face challenges in describing cluster breakup and secondary fragment production, particularly for deuteron- and alpha-induced reactions at intermediate energies.

This study presents an extension of the INC framework, incorporating a virtual excited state formalism, where the ground-state wavefunction of incident clusters is expressed as a superposition of its cluster configurations. This formalism enables a more precise treatment of cluster breakup dynamics and secondary particle emissions. The model predictions are evaluated against experimental double-differential cross-section (DDX) data for a range of nuclear reactions, including deuteron-induced [(d,d'x), (d,px), (d,nx)] and alpha-induced [(α,α'x), (α,^{3}Hex), (α,tx), (α,dx), (α,px), and (α,nx)] reactions with various target nuclei, spanning laboratory angles from 20° to 135°.

The predictive capabilities of the extended INC model are compared with PHITS-INCL and PHITS-JQMD, providing insights into their capabilities for cluster-induced nuclear reactions. Additionally, TALYS calculations are incorporated for comparison, though they exhibit significant deviations from the experimental DDX data, particularly in deuteron-induced reactions. The extended INC model exhibits strong agreement with experimental data. However, deviations remain in the high-energy region, particularly in the production of ^{3}He and tritons, indicating the need for further refinements.

By incorporating the treatment for cluster-induced reaction mechanisms, this work enhances the predictive capabilities for cluster-induced nuclear reactions and contributes to the advancement of PHITS-based transport simulations, with applications in radiation therapy, nuclear engineering, and space radiation protection.

Keywords: PHITS, Intranuclear Cascade model, Cluster-Induced Reactions, Double-Differential Cross-Sections, Nuclear Modeling, Nuclear Reactions.

Neutronic Property Estimation of a Self-cooled Lithium-Lead Blanket Mockup at the IFMIF-DONES Irradiation Environment using PHITS and JENDL/DEU-2020

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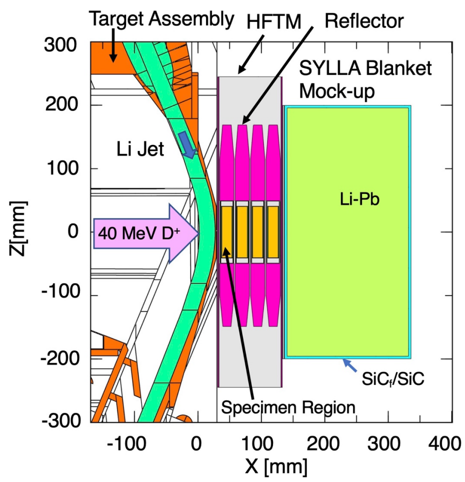
A self-cooled Lithium-Lead (LiPb) blanket is regarded as an advanced concept of the breeding blanket. Kyoto Fusioneering (KF) Ltd. is developing a high-temperature self-cooled LiPb blanket that uses a silicon carbide composite (SiCf/SiC) channel structure, called SCYLLA© (Self-Cooled Yuryo Lithium-Lead Advanced). KF is proposing an irradiation test of SCYLLA© blanket mock-up at IFMIF-DONES (International Fusion Materials Irradiation Facility- DEMO Oriented Neutron Source), which is an accelerator-based neutron source using d-Li stripping reactions, and under construction at Granada, Spain. Neutronic properties of a mockup of the SCYLLA© blanket are estimated at IFMIF-DONES by using PHITS and the deuteron-induced nuclear data library JENDL-DEU/2020. We assume that the SCYLLA© blanket mock-up will be located just bihind the High Flux Test Module as shown in Fig.1. The SCYLLA© blanket mockup is modeled as a simple SiCf/SiC box filled with Li-Pb liquid metal. The front wall of the SiCf/SiC box is covered with a 3mm thick tungsten plate. Figure 2 shows the total neutron flux distribution on the equatorial plane. The other neutronic properties such as energy spectrum, DPA, gas production, and nuclear heating are presented at the workshop.



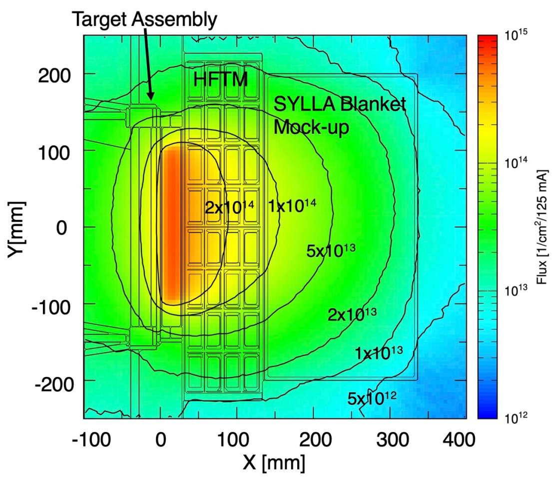


Fig.1 Calculation geometry (vertical cut). Fig.2 Total neutron flux distribution.

Radiation Study for the Pion Production System of the COMET Experiment at J-PARC

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The COMET experiment [1], under construction in the J-PARC Hadron Experimental Facility, searches for the lepton-flavor-violating muon-to-electron conversion process using a 3.2 kW 8-GeV proton beam from the Main Ring. The protons hit a graphite or tungsten target to produce pions, and they are collected using a superconducting pion capture solenoid [2] surrounding the target to make the world's highest intensity muon beam. Since the primary protons as well as secondary particles from the target and a beam dump make a harsh environment in the facility, it is important to study the radiation impact to design the facility and experiment. We have used PHITS to study various aspects of the experiment: the production and transportation yield of the pions and muons as well as background particle production rate; impact, such as heat load and radiation damage, on the superconducting coils and the target; the ambient dose during the beam operation to design the shielding of the facility; and the residual does from the shielding material and beam dump to design the maintenance scenario. In this presentation, we report the results and discuss some issues we are faced in the simulation.

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PHITS Use at FRIB: Recent Highlights

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The Facility for Rare Isotope Beams (FRIB) started operations in 2022 [1] as a premiere facility deploying heavy ion beams to produce rare isotopes. As the primary beam intensity increases from a power of 1 kW initially to 20 kW currently to 400 kW ultimately, PHITS is serving as the primary radiation transport tool used at FRIB. This presentation will give examples of recent PHITS [1] and DCHAIN [2] simulations supporting FRIB's power ramp-up.

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Designing lightweight neutron absorbing composites using a comprehensive absorber areal density metric

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Abstract

Rational design of neutron absorbing composites through performance metrics and physically representative simulations can lead to more lightweight yet still shielding versions of such composites. This effort sought to design an aerospace structural neutron absorbing composite for use as a multifunctional material to shield high-altitude avionics, extraterrestrial surface habitats, deep space crew vehicles, and the like. The boron-10 equivalent areal density metric – considering matrix material, particle size, and more – was introduced based on literature analytical solutions, simulations, and experimental validation [1]. Additional work to understand the potential of such lightweight materials to mitigate space radiation was also shown [2]. These informed metrics and simulations enable rational design of such composites, potentially improving their performance and accelerating their infusion into the aerospace sector.

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PHITS MC Optimisation of a table-top NRTA system for small nuclear material sample analysis

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Neutron Resonance Transmission Analysis (NRTA), a spectroscopic technique that utilises the resonant attenuation of epithermal neutrons to determine the isotopic composition of an object, is especially well-suited for non-destructive analysis of objects containing mid- and high-Z elements in the field of nuclear security, nonproliferation and safeguards verification. While conventional NRTA systems rely on large, fixed accelerator-based neutron sources, recent studies have explored DT and laser-driven neutron sources, which are smaller but less compact than table-top systems. We have developed a table-top NRTA[1] system utilising a compact ^{252}Cf spontaneous neutron source, capable of analysing small samples of nuclear material such as Pu-pellets. The study used Monte Carlo (MC) methods based on the PHITS code to evaluate different components of the table-top system, focusing particularly on assessing the performance of collimator materials, source, and detector. The MC simulation results obtained during the development phase of the table-top NRTA system are presented in this study, including findings related to collimators, the neutron source, and detectors. The simulated transmission results using the table-top NRTA system demonstrate good agreement with the experimental transmission curves for thin Cd, In, and Hf samples. These were assessed to validate the system performance in measuring small nuclear material samples.

Acknowledgements
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How to change neutron ambient dose equivalent in LINAC's room

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Abstract

Purpose: In the photon mode, photons with energy higher than the threshold of the (γ,n) photonuclear reaction of the accelerator produce materials and room construction leads to the release of fast neutrons, secondary gamma rays, and radioactive isotopes. This study aims to investigate the influence of concrete, machine room size, and neutron shielding materials in the machine room on photon and neutron ambient dose equivalent in LINAC's room.

Materials and Methods:

- *Object:* The change of neutron and photon in TrueBeam's room

- *Simulation:* Using PHITS simulation to simulate photon and neutron ambient dose equivalent in LINAC's room with following simulation conditions: 1- with neutron shielding material inside the LINAC's room, 2 – without neutron shielding material inside the LINAC's room, 3 – without affection of concrete, 4 – with the smaller LINAC's room.

- *Measurement:* Photon and neutron ambient dose equivalent were measured at 25 points in LINAC's room. Each point was measured with three radio-photoluminescence detectors for photon, and three solid state track detectors, Truebeam 10 MV photon, open field, 20 × 20 cm^2, 0.5 × 0.5 cm^2, and 5000 MU for each field size.

- The simulated photon and neutron ambient dose equivalents were compared with the measured doses to evaluate the changes in photon and neutron ambient dose equivalent when the simulation conditions were changed.

Results:

Photon ambient dose equivalent: Neutron shielding did not change the photon ambient dose equivalent, concrete increased the photon dose by 20% to 36% at points near the concrete, small LINAC's rooms increased the photon dose by 4% to 8% at points far LINAC's head.

Neutron ambient dose equivalent: With neutron shielding, the neutron doses were reduced by 6% at points in concrete having steel and increased by 2% at points in concrete without steel, concrete increased the neutron dose by 20% to 50% at points near the concrete far LINAC's head, in smaller LINAC's room the neutron dose increased by 4% to 6% at points far the LINAC's head and increased by 21% at points near the floor and beam.

Conclusion: Increasing the size of the accelerator room, using neutron shielding materials in the room, and using suitable concrete materials can reduce the neutron dose in the room.

Keywords: Monte Carlo simulation, radiotherapy, ambient dose equivalent

Lead-Free Yb_2O_3-Doped Transparent Phosphate Glasses for Radiation Shielding: Analytical and PHITS Monte Carlo Analysis

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Abstract

Ytterbium(III) oxide-doped phosphate glasses with the composition $50P_2O_5$-(50 – x)BaO-xYb_2O_3 (x = 0.0, 0.5, 1.0, 2.0, 3.0, 4.0 mol %) [1] were investigated for their radiation shielding capabilities, photon transport, and particle interaction phenomena. The study employed theoretical analyses and the Particle and Heavy Ion Transport System (PHITS) Monte Carlo simulation code. Radiation shielding parameters, including mass and linear attenuation coefficients, half-value layers, and tenth-value layers, were evaluated for gamma-ray energies ranging from 0.015 to 15 MeV. Transport properties such as mean free path, effective atomic number, electrical conductivity, and electron density were also examined. The results indicated that Yb^{3+} doping significantly enhances gamma-ray shielding performance, with the 2 mol% Yb_2O_3-doped glass demonstrating the highest fast neutron removal cross-section. Meanwhile, the 4 mol% Yb_2O_3 sample exhibited superior charged-particle stopping power and shorter projected ranges for electrons, protons, helium, and carbon ions. Monte Carlo simulations validated that Yb^{3+}-doped lead-free transparent glasses provide effective and environmentally friendly protection against ionizing radiation, including photons, electrons, and hadrons. These findings position these glasses as promising alternatives for sustainable radiation shielding applications.

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Monte Carlo study of neutron contamination from high-energy medical linac

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Abstract:
A preliminary Monte Carlo study evaluating photoneutron contamination from an energy medical linear accelerator (linac) has been conducted using PHITS version 3.341. Varian Clinac iX with a 15 MV photon beam and water phantom were modelled in this study as seen in Figure 1a. This study simulates a 10×10 cm^2 open field size at the water surface to be examined. We used 10^8 particle histories in this simulation. We observed the neutron energy spectrum below (reg1) and above (reg2) the flattening filter (FF). Figure 1b shows the neutron spectrum at reg1and reg2. The neutron spectrum shows a large distribution of fast neutrons (0.1 – 1 MeV) below and above the flattening filter. Figure 1b also indicates that the neutron intensity is larger below the FF since the FF materials likely yield more photoneutron interaction[1]. This result agrees well with our previous study using MCNPX[2]. The neutron track in the phantom body is shown in Figure 1c. We expect to calculate the neutron distribution inside the phantom from various field sizes, especially with a field larger than 15×15 cm^2, as this was the limitation of our previous study[2]. Furthermore, further study will replace the water phantom with a simulated human body with a prosthetic.

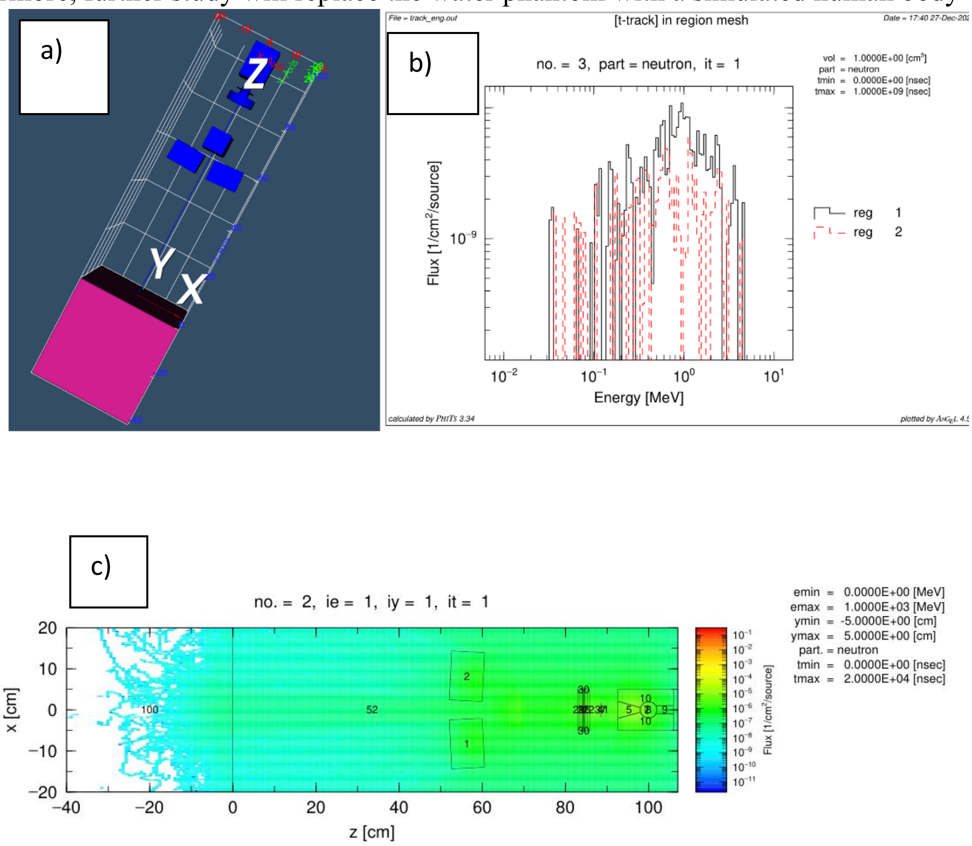

Figure 1. a) The linac model used in the calculation b) The neutron energy spectrum below and above FF, c) The neutron track along the phantom.

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Evaluation of human equivalent phantom applicability of low-cost 3D filaments by absorbed dose measurement of radiophotoluminescence dosimeter and Monte Carlo simulations

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This research aims to investigate the variability of absorbed dose with infill percentages and depth in the 3D phantom through dose measurement and Monte Carlo simulations within diagnostic X-ray energy range for creation using low-cost filaments. Infill percentages of 20 to 100% at 20% intervals, with respective densities of 0.274, 0.423, 0.529, 0.676, and 0.854 g/cm^3 were measured, and radiographic images were acquired and analyzed. Absorbed doses at depths of 10 to 110 mm at 20 mm intervals were also evaluated, and the mean error between the two simulation tools showed good agreement with about 2.6, 2.7, and 3.1% at approximately 1% uncertainty at 80, 100, and 120 kVp. These results can be considered for calculating the dose to various organs of the body when creating human equivalent phantoms, and can be applied to other filament materials with high density or as an additional basis for various irradiation equipment.

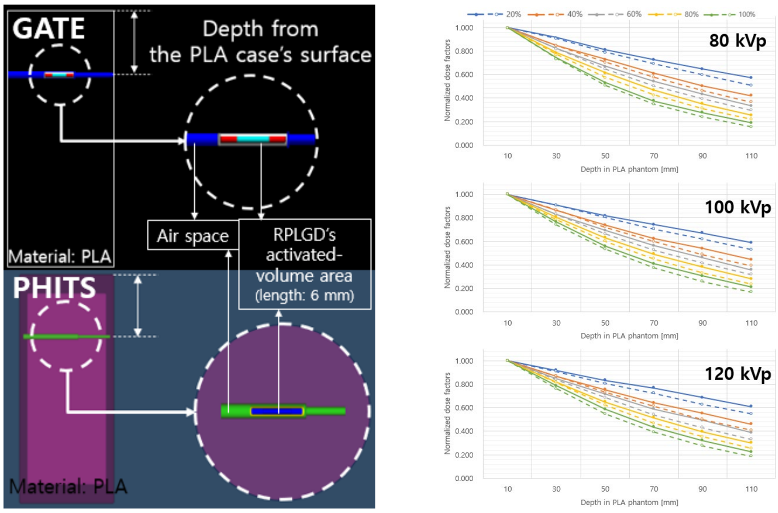

Fig. 1 (Lt) 3D case and RPLD with capsule simulated by simulations (Rt) Comparison of simulation results of normalized absorbed dose by depth in PLA cases with infill percentages as a function of tube voltage (Solid: PHITS v3.341, Dashed: GATE v8.0)

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Nuclear analysis on the magnetic systems of compact fusion reactors with the Monte Carlo code PHITS

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High temperature superconducting (HTS) magnets represent one of the enabling technologies for compact fusion reactors, thanks to the high achievable magnetic field [1-3]. Due to the reduced size of the new reactor concepts and to the sensitivity of HTS to radiation damage, however, the precise evaluation of the radiation environment now emerges as a key parameter for the design of the magnetic system [4]. In this framework, PHITS represents a well-suited tool, thanks to its capability of transporting both neutral and charged particles, of supporting MPI, OpenMP, and hybrid parallelization schemes and of easily handle very complex geometries. [5],[6].
In this talk, we will present the workflow that we adopted to perform Monte Carlo calculations on CAD-imported models of fusion reactors [7],[8] and of HTS cables [9] on HPC clusters, as well as our results in terms of neutron and secondary particles spectra impinging on the HTS material at the working conditions, maps of the deposited power and information about the damage in terms of displacement per atom (dpa) and Primary Knock-on Atom (PKA) spectra. We will also briefly introduce our approach to couple the output of PHITS with our atomistic calculations for radiation damage.

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Application of PHITS in Muography Imaging Techniques

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Muography utilizes cosmic-ray muons to probe the internal structures of various objects by employing muon absorption and scattering techniques. Targets range from large-scale structures like volcanoes and underground reservoirs to smaller-scale objects. These muons, generated naturally by cosmic rays interacting with the Earth's atmosphere, offer high penetration power and sensitivity to density variations within materials.

A significant challenge in cosmic-ray muon measurements is the extended observation time required, especially for large targets. Estimating the muon flux prior to deploying detectors or even before the target exists is essential for planning and optimizing muography measurements. For instance, when planning to image a building or geological formation, predicting the muon flux before its construction or natural development is crucial. Accurate simulations are therefore needed to model muon interactions in these scenarios.

Traditional Monte Carlo codes like Geant4 often require coupling with other codes such as CRY to simulate cosmic-ray muon generation, complicating the simulation process. In contrast, PHITS (Particle and Heavy Ion Transport code System) incorporates the PARMA (PHITS-based Analytical Radiation Model in the Atmosphere) model, enabling direct and realistic generation of cosmic-ray muons without additional coupling. In this study, we demonstrate the effective utilization of the PHITS code for muography applications. The simulations were validated against experimental muography data, confirming their reliability. The results highlight PHITS as a robust tool for muography simulations.

Keywords: Muography, Cosmic-ray Muon, PHITS, Monte Carlo Simulations, Imaging Techniques

Simulation study on the characteristics of thundercloud-related radiation emitted from atmospheric electric fields

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Electrons are accelerated by electric fields inside thunderclouds and produce high-energy photons via bremsstrahlung. These photons have been observed by groups around the world. In addition to the detection of photons, some studies have claimed to detect electrons escaping from nearby thunderclouds. Observations of these photons and electrons are expected to help elucidate the underlying production mechanism of high-energy radiation, because their characteristics are linked to the structure and intensity of the electric field within thunderclouds. Thus, PHITS simulations are used to examine how the properties of thundercloud radiation change when cosmic rays are injected into electric field regions of different dimensions and intensities, as shown in Figure 1. In this talk, by analyzing the PHITS results on photon and electron emissions originating from various electric-field configurations, we discuss the potential to infer electric-field information from observed radiations.

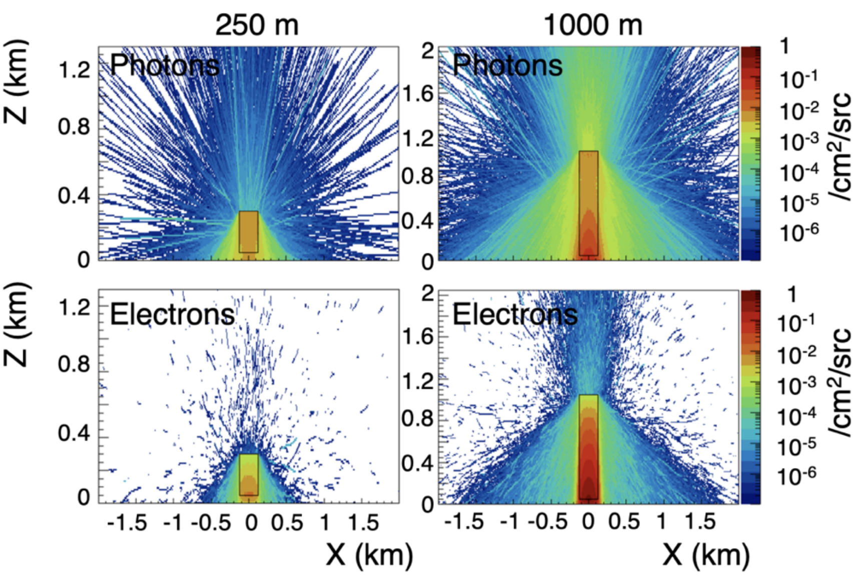

Fig. 1 Comparisons of PHITS results showing the spatial distributions of the fluence of >10 MeV photons (top) and >10 MeV electrons (bottom) generated by cosmic rays incident from above the electric field region. Reder (bluer) indicates higher (weaker) fluence. Assumed field region lengths are 250 m (left) and 1000 m (right). The rectangle in each panel represents the assumed electric field region with an intensity of 260 kV/m.

Leveraging PHITS for the design of the High Brilliance Neutron Source (HBS)

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Over the last years, High-Current Accelerator-driven Neutron Sources (HiCANS) have met with increasing interest and represent a promising option for the next generation of neutron sources. The High Brilliance Neutron Source (HBS), developed by the Jülich Centre for Neutron Science at Forschungszentrum Jülich, is a project which aims to provide a high neutron flux source for various scattering, analytical, and imaging applications in science and industry [1]. The HBS design features a linear particle accelerator that generates a pulsed beam with a proton energy of 70 MeV. The target-moderator-reflector unit is equipped with a tantalum target, water as thermal moderator and a lead reflector, resulting in a neutron yield of 10^{15} s^{-1}. Solid methane and liquid hydrogen are considered as one-dimensional cold moderators.

Monte Carlo simulations of particle transport play a crucial role in the development of the HBS project. The Particle and Heavy Ion Transport code System PHITS [2] was used extensively for the simulation within the project. It provides valuable insights into the design. At the PHITS Workshop, a comprehensive approach for the design of the neutron source using PHITS will be presented. Key aspects such as determination of neutron yield, optimization of moderator-reflector unit, benchmark of cold moderator systems and evaluation of shielding to ensure safety and efficiency as well as target station development for radionuclide production will be addressed.

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Application of additive manufacturing technology in Linac X-ray and synchrotron microbeam radiation therapy: From dosimetry to radiobiology

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Additive manufacturing (AM), also known as 3D printing, is a rapid manufacturing method based on 3D computer-aided designs. It has been a popular research topic in manufacturing medical physics imaging and radiotherapy equipment such as bolus, test tools, and phantoms. Various AM materials and techniques can be used to have a more accurate representation of radiological tissue equivalence. This talk aims to present an overview of radiological characterization of different AM materials (i.e. polymers, ceramics, metals, hydrogels), 3D printed phantoms (i.e. slabs, rat, and human head) and 3D bioprinted tumor construct. A computed tomography (CT) machine, a clinical linear accelerator, and synchrotron imaging and radiotherapy beams were utilized to characterize the 3D printed phantoms and bioprinted constructs using X-ray beam energies. Polylactic Acid (PLA) can mimic both soft tissue and solid water, acrylonitrile butadiene styrene has equivalence to adipose, while nylon simulates water and brain. Both hydroxyapatite and tricalcium phosphate have excellent match with the attenuation properties of cortical bone. Comparison of dose readings and treatment calculated doses using our 3D printed head phantoms show a match within ±3%. Furthermore, incorporating 3D bioprinted glioma tumor construct inside 3D printed phantoms has been done by encapsulating cancer cell lines into gelatin methacryloyl (GelMA) hydrogel useful in radiobiological response studies for microbeam radiation therapy. Overall, Dosimetry, Geant4 Monte Carlo simulation, in vitro cell viability, and fluorescence microscopy were performed to correlate the relationship of the radiation dosimetry with the radiobiological response.

Keywords: Synchrotron radiation, Attenuation coefficient, X-ray dosimetry, Microbeam radiation therapy, 3D printing, 3D bioprinting

Topic: Radiotherapy, and Radiobiology

Evaluation of cosmic rays damage and linear energy transfer on hybrid and inorganic halide lead perovskites in space environment

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The cosmic ray damage, the absorbed dose and linear energy transfer on hybrid halide lead ($CH_3NH_3PbI_3$) and inorganic ($CsPbI_3$) halide lead perovskites were evaluated using the Particle and Heavy Ion Transport code System (PHITS) cosmic ray source mode. This included contributions from galactic cosmic rays (GCRs), solar energetic particles (SEPs), and the radiation trapped within the Earth's low orbit (LEO). Between the two materials, $CsPbI_3$ exhibits a higher displacement per atom (dpa) and lower absorbed dose due to its higher mass density. Solar energetic particles are the primary cause of damage because they have a higher linear energy transfer and cause a higher displacement per atom in both materials due to their low to medium proton energy. The higher mass density of Cs^+ as an inorganic cation used in the synthesis of inorganic halide lead perovskites may make them more susceptible to structural damage when used as a long-term energy source for the exploration of the inner planets. However, they may be a better sensor of space radiation due to their good energy absorption per unit volume and lower ionization energy. $CH_3NH_3PbI_3$, if properly encapsulated, might be better able to withstand the challenging space environment for energy generation.

Development of a composite neutron converter for DDTTNY measurements: A Monte Carlo simulation study

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In the design of deuteron accelerator-based neutron sources for radioisotope production, accurate nuclear data on double-differential thick-target neutron yields (DDTTNYs) from ^{9}Be(d,n) and ^{12}C(d,n) reactions are crucial. While ^{9}Be is an effective neutron converter material due to its high neutron yield, its propensity for blistering under deuteron irradiation—resulting from thermal expansion—limits its operational longevity. To overcome this limitation, a novel composite neutron converter incorporating ^{9}Be and ^{12}C has been developed. Monte Carlo simulations using the Particle and Heavy Ion Transport code System (PHITS) [1] were conducted with 12, 20, and 30 MeV deuterons to assess the converter's performance and durability. The design features a ^{9}Be layer, positioned to face the incident deuterons, optimized to generate high-intensity neutron fluxes. The ^{9}Be layer is intentionally configured 0.1 mm thinner than the full deuteron range in metallic ^{9}Be, facilitating downstream absorption of nearly 99.9% of the incident deuterons within a ^{12}C backing layer. This configuration not only minimizes neutron contributions from ^{12}C but also significantly enhances the structural integrity of the converter. Simulated DDTTNYs indicate that the ^{12}C/^{9}Be composite neutron converter exhibits more than 90 times the durability of a ^{9}Be-only converter while maintaining comparable neutron yields. These findings demonstrate the feasibility of this innovative design for reliable neutron production in medical radioisotope applications, effectively addressing structural durability challenges in high-energy deuteron environments.

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Optimizing a Photoneutron Source for Bragg Edge Imaging and Reproducing Bragg Edges of an α-Fe Sample Using PHITS Code

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Neutron Bragg edge imaging is an advanced, nondestructive technique extensively applied in materials testing for industrial and research purposes. A compact photoneutron source using a small electron Linac was optimized using the PHITS-3.28 Monte Carlo code [1] for Bragg edge imaging. The optimal target-moderator-reflector (TMR) configuration provided a neutron flux of 1.16×10^4 n/cm²/s, assuming the electron beam current of 275 μA, and a wavelength resolution of 1.05% at 1000 cm at 5 meV (0.4 nm). The energy spectrum of generated photoneutrons from the optimized TMR with their time distributions were defined as a source in the PHITS code. An α-Fe sample with dimension of $10 \times 10 \times 1$ cm^3 was placed at 2093 cm from the defined source to achieve a wavelength resolution of 0.5% that was used in the measured data [2,3]. A 10×10 cm^2 neutron time of flight (TOF) detector with TOF bin size of 10 μs was defined behind the α-Fe sample. Thermal scattering cross sections of the α-Fe sample were utilized in the PHITS-3.28 code to generate Bragg edges. TOF spectra were calculated with and without α-Fe sample and the neutron transmittance was calculated by taking the ratio of two TOF spectra, resulting in well-appeared Bragg edges. The simulated Bragg edges of α-Fe sample were compared to the experimental data, showing excellent agreement [3]. This presentation highlights the application of the PHITS code in reproducing the Bragg edges of the α-Fe sample, thereby validating the optimized TMR as a neutron source for Bragg edge imaging [3].

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Design of Self-Cooled Lithium-Lead Fusion Blanket and Analysis of Tritium Breeding Performance with PHITS

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Maximizing the tritium breeding ratio, while taking into account the cost of lithium-6 enrichment is required to enable the commercialization of fusion energy. This study designed a simple spherical Self-Cooled Lithium-Lead (SCLL) blanket varying the thickness of the blanket and the enrichment of Lithium-6 in the lithium-lead breeder. The goal was to maximize the Tritium breeding ratio while accounting for the cost of lithium-6 enrichment. To reach this objective, an iterative methodology was adopted, alternating between design enhancements and rigorous simulations to refine the design approach. Per this analysis, 32.3 at % enrichment at a 134.9 cm blanket thickness is recommended for a cost optimized SCLL design to achieve a tritium breeding ratio of 1.3. This research on the intersection of design and economic analysis is a crucial step towards showing the economic feasibility of inertial fusion energy.

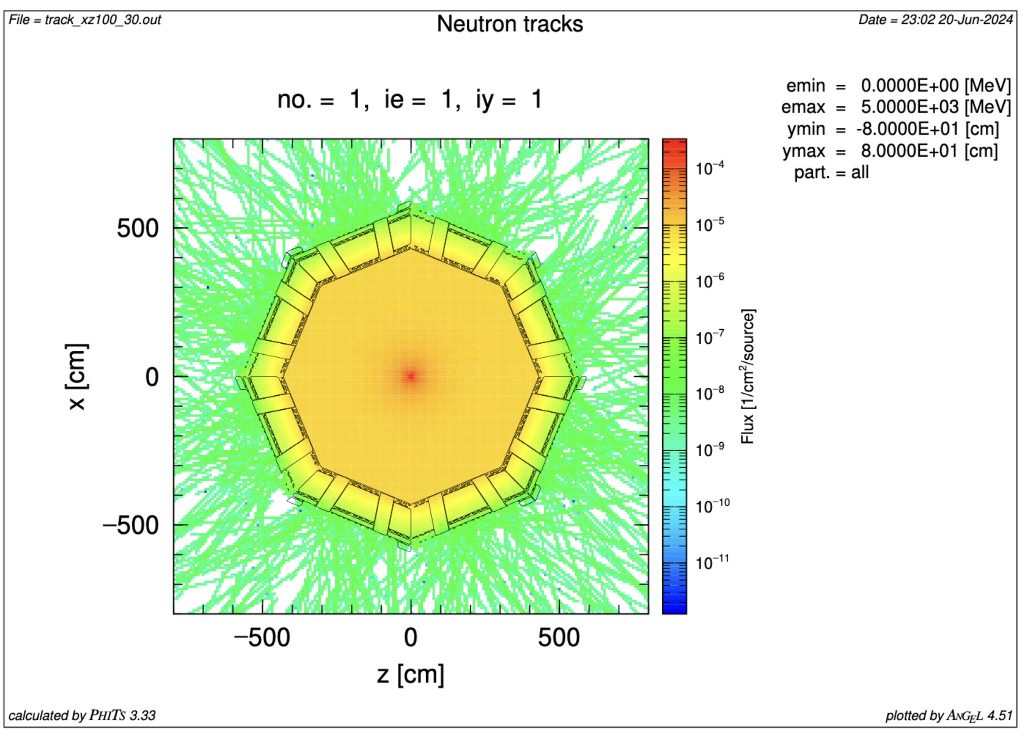

Figure 1: Neutron tracks through a cross-section of the geometry, for 100 cm thickness and 30% enrichment

Lithium battery in-depth analysis with MIXE: setup and simulations with PHITS.

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The Laboratory for Muon Spin Spectroscopy (LMU) of Paul Scherrer Institut (PSI) proposes its expertise in Muon-Induced X-ray Emission (MIXE) for in situ characterization of various high technology objects, such as electrochemical batteries. The recent results of MIXE in terms of isotopic and chemical non-destructive analysis of materials through thick envelopes have unlocked new ways to optimize lithium and sodium batteries. Optimization of muon beam momenta is performed by a PHITS model of our setup in different configurations, including a Time Projection Chamber (TPC). Comparison of GEANT4, PHITS and experimental results are presented. Good agreements are found for muon implantation depths, however, PHITS muonic X-ray cascade model fails to match experimental results.

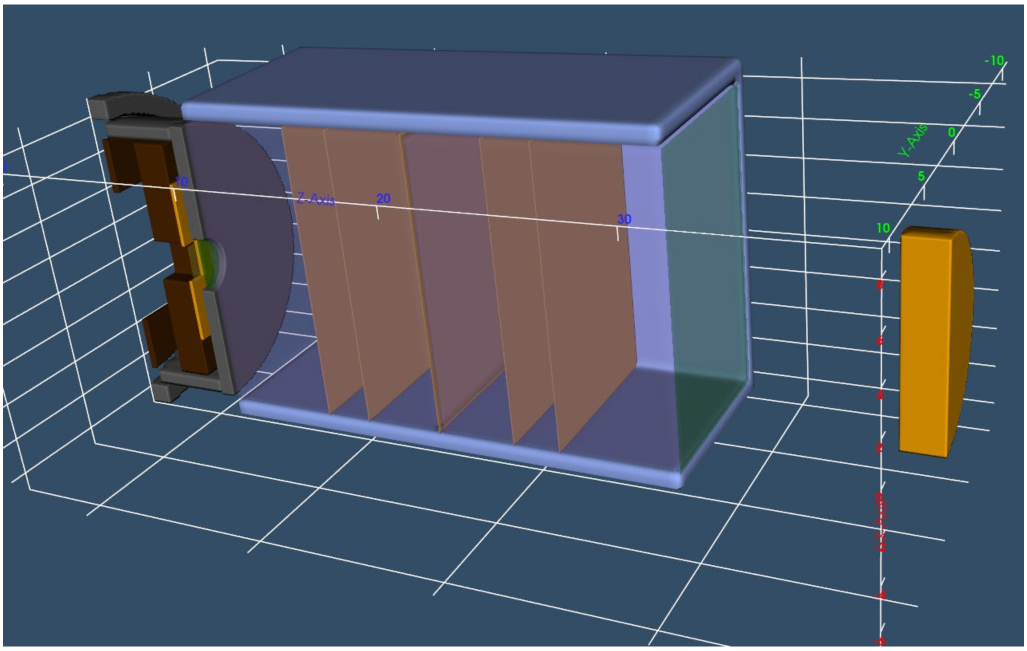

Fig. 1 3-D view of our PHITS simulation model of a MIXE analysis with a TPC.

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Advancement of Phosphate Glasses Doped with Bismuth Oxide for Photon Shielding Applications

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Abstract

In this study, glass with the formula (65-x)P_2O_5-5CaF_2-10NaF-10KF-10AlF_3-xBi_2O_3 (x = 0, 5, 10, 15 mol%) was produced using the conventional melt-quenching technique at 1200 °C for 3 hours for photon shielding applications. The effects of these glasses on physical properties and their ability to shield against gamma rays and x-rays were examined. Results indicated that density increased with higher concentrations of Bi_2O_3. Radiation shielding properties, including mass attenuation coefficients (μ_m), effective atomic number (Z_{eff}), and effective electron density (N_{eff}), were theoretically calculated using Monte Carlo simulation (PHITS) and showed an increase with higher Bi_2O_3 concentrations. Conversely, the half-value layer (HVL) decreased. When using an x-ray source, the linear attenuation coefficient (μ) increased with higher Bi_2O_3 content, and HVL decreased as Bi_2O_3 concentration increased. Glass samples with 15 mol% Bi_2O_3 exhibited superior shielding performance compared to standard materials at 120 kVp. Consequently, Bi_2O_3 glass systems are promising candidates for future radiation shielding materials.

Keyword: Radiation Shielding; Bi_2O_3; Gamma ray; Monte Carlo simulation; Shielding materials

Dosimetric study of a Co-60 HDR Brachytherapy Source using PHITS

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In brachytherapy, consensus dosimetry datasets serve as a standard reference for dose distribution calculations in treatment planning. The availability of these datasets promotes consistency in dosimetry practices and reduces variability across different practitioners and planning systems. These dosimetric datasets are developed through a comprehensive and rigorous process that integrates experimental measurements with results from Monte Carlo simulations [1]. This study examines the dose distribution parameters of a Co-60 brachytherapy source obtained using the Particle and Heavy Ion Transport System (PHITS) [2] code and compares them against consensus datasets.

The BEBIG Co-60 source type Co0.A86 was modeled using PHITS version 3.34. A T-Deposit tally was employed to score dose distributions up to a distance of 10 cm surrounding the source, with a total of 10^9 particle histories simulated. Relative doses were obtained at different distances to calculate the radial dose function, $g_L(r)$, and 2D anisotropy function, $F(r,\theta)$, based on the TG-43U1 formalism [3].

The relative differences between the calculated values for $g_L(r)$ and the TG-43 consensus data are all within 2%. Similarly, the relative difference for $F(r,\theta)$ fall within 2% for $10 < \theta < 170$, but increases significantly outside this range. These angles correspond to the direction of the source tip (θ < 10) and the direction along the wire opposite the tip ($\theta > 170$). The relatively high difference at these angles can be attributed to larger statistical uncertainty on this direction due to more attenuation at the tip and the wire. This can be improved in future studies by increasing the number of simulation histories.

The derived values for $g_L(r)$ and $F(r,\theta)$ align closely with the consensus dataset established for the Co0.A86 source type. The developed model can serve as a reliable basis for future PHITS-based Monte Carlo studies involving brachytherapy sources.

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Shielding Optimization: An Approach for Extending PHITS with Machine Learning

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Radiation transport simulations are essential for establishing the safe operation of accelerator facilities such as the Facility for Rare Isotope Beams (FRIB). Neutrons account for most of the radiation exposure when high-energy heavy-ion beams are stopped.

A common method for evaluating neutron radiation transport is the use of Monte Carlo-based stochastic radiation transport codes, which rely on detailed physics models and embedded cross-section data. FRIB uses one such code, the Particle and Heavy-Ion Transport Code Systems (PHITS) [1], as its primary option for analyzing prompt and delayed radiation effects. Given that stochastic radiation transport is computationally intensive, a single calculation can take hours to weeks to yield statistically significant, high-fidelity results.

This presentation discusses efforts to extend the use of PHITS [2] through a machine learning-based model trained with simulation data. The model utilizes a simplified geometry to provide fast and realistic, but rough, estimates of neutron flux passing through shielding. This model offers a rapid way to evaluate alternative shielding materials, thicknesses, and configurations, allowing optimized options to be identified and subsequently validated through detailed PHITS simulations.

This work demonstrates a strategy of augmenting PHITS with machine learning to increase computational efficiency for radiation transport simulations at FRIB. It also illustrates the promise of deploying machine learning to enhance the use of PHITS for uncertainty quantification [3] and range of radiation protection challenges relevant to FRIB.

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Validation of Particle and Heavy Ion Transport Code System (PHITS) in generating dose-voxel kernels for internal dosimetry calculations

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Dose-voxel kernels (DVKs) denote the absorbed dose in a target voxel per decay in a source voxel. In this study, we aimed to validate DVKs generated using Particle and Heavy Ion Transport Code System (PHITS) as a first step in establishing a quantitative SPECT/CT-based dosimetry framework for selective internal radiation therapy (SIRT). A 1-MBq source of ^{90}Y, ^{153}Sm, ^{177}Lu, ^{188}Re, and ^{166}Ho located in central cubic voxels of 1 mm, 3 mm, and 6 mm dimension within soft tissue (1.04 g·cm^{-3}), was simulated using 2.5 x 10^7 histories in PHITS. The DVK results were compared to published data [1]. In a pilot study, 17 MBq of ^{153}Sm microspheres were injected into a liver tumor-bearing rat and imaged 24 hours later using SPECT/CT. SPECT/CT images were then converted to cumulated activity and convolved with a ^{153}Sm DVK using Fast Fourier Transform in MATLAB to create an absorbed dose map. As expected, DVKs for the radionuclides showed a steep decrease from the source voxel to the maximum continuous slowing down approximation (CSDA) of beta components. Beyond the CSDA, gamma and bremsstrahlung contributed minimally (10^{-6} to 10^{-4}) to voxel doses. Observed DVK changes as voxel size increased were in good agreement with published data, with differences in source voxel ranging from 1% to 24%. Rat imaging revealed ^{153}Sm microspheres localized at injection sites, with mean and maximum doses of 45 Gy and 194 Gy, respectively. The DVKs calculated in PHITS were successfully validated. ^{153}Sm dose maps were produced from SPECT/CT images in a rat model. Further studies on the application of DVKs in heterogeneous media will be conducted.

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Small-scale bone marrow dosimetry study for ^{225}Ac

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Abstract

Background: Targeted alpha therapy (TAT) with ^{225}Ac-labelled radiopharmaceuticals is a growing therapeutic option for the treatment of various cancers. Due to the short range of alpha particles in tissue, the absorbed dose can be non-uniform on a microscopic scale. Therefore, understanding bone marrow toxicity in TAT requires small-scale dosimetry.

Method: We developed a voxelised trabecular bone model, based off µCT slices, with a voxel size of (37 x 37 x 37) µm^3. A small-scale dosimetry study was performed to assess the marrow toxicity from uptake of unlabelled ^{225}Ac in the trabecular bone. The Particle and Heavy Ion Transport Code System (PHITS) was used to simulate the decays and score the absorbed dose to each voxel from the alpha and beta emissions of the ^{225}Ac decay chain.

Results: For the alpha decays on the trabecular surface; 57% of the marrow voxels received zero alpha dose, and the mean non-zero voxel dose was 0.35 Gy. The beta-emissions from the trabecular surface irradiated all the marrow voxels, with a mean voxel dose of 3.9 mGy.

Conclusion: Our model demonstrated a non-uniform absorbed dose profile to the red marrow due to alpha emissions on the trabecular bone surface. More than half the marrow voxels receiving zero alpha dose, while the beta emissions irradiated all marrow voxels. This could potentially suggest a lower marrow toxicity from alpha-emitters compared to beta-emitters when skeletal metastases are present.

Presentation summary: In this presentation we will cover how the µCT slices of trabecular bone were used to construct a voxelised trabecular bone model in PHITS. We will then cover how the decays of ^{225}Ac were simulated and how the dose to each voxel was scored. We will then cover how the output dose file of PHITS was analysed using Python.

Neutron spectrometry with DIAMON detector for characterisation of a newly built neutron calibration facility at SCK CEN

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Personal neutron dosimeters often experience significant overestimation or underestimation when used in neutron fields that differ from those in which they were calibrated. This discrepancy highlights the highly field-dependent nature of these dosimeters and the necessity for precise neutron field characterisation to ensure accurate calibration and reliable dosimetry. In this study, we conducted a comprehensive neutron field characterisation at the newly constructed neutron room of the Secondary Standard Dosimetry Laboratory (SSDL) of SCK CEN, Belgium, using ^{252}Cf and ^{241}Am-Be sources. The DIAMON neutron spectrometer and Bonner Sphere Spectrometer (BSS) were employed, alongside Monte Carlo simulations. The primary objectives were to evaluate the performance of the DIAMON spectrometer against the BSS, which serve as the gold standard, and to validate the simulation model of the neutron room. The shadow cone method was utilised to separate direct and scattered neutron components. Monte Carlo simulations using the PHITS code, which mimicked the actual neutron room geometry, materials, and sources, were conducted to develop the neutron room model which is validated by the measurements. Analysis of neutron ambient dose equivalent rates from both sources, in terms of direct neutron under controlled scatter conditions (in this case, below 3 m), revealed that DIAMON measurements agreed with LNK reference values within a 16% margin. The deviations of BSS measurements and PHITS simulations from the LNK reference values were kept within 19% and 10%, respectively. These findings demonstrate the reliability of the DIAMON spectrometer and the robustness of the PHITS simulation model.

Reduction of the Added Reflected Dose Component at the Patient Location Within a Brachytherapy Room for an Ir-192 Gamma Source: A Monte Carlo Study

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While considering the photon attenuation coefficient (μ) to protect people outside of the treatment area, it is necessary to account for its reflected average photons energy and dose components from the concrete walls and floor. As an example, the walls closest to the source could likely be the most significant contributors to the scattered radiation at the patient location. It is important to evaluate the particles that might be reflected by a certain region in designing an irradiation facility shielding, particularly in the medical application where the patient or personnel are within the room during the procedure. Radiation delivery to cancer patients for radiotherapy could be including leakage and scatter radiation which provides unnecessary additional radiations or dose to other parts of the patient's body. However, it is generally difficult to predict accurately. The difficulty of implementing to take measures to reduce reflection could be reduced with the aid of the Monte Carlo method.

By using Monte Carlo method (PHITS code [1, 2]), the reflected photon dose component to the patient location within the Brachytherapy Room at Advanced Medical and Dental Institute (AMDI), Universiti Sains Malaysia, Penang, Malaysia was calculated. Previously, we had found and solved the edge effect that is evident on the left side of our entrance door as shown in Figure 1 [3]. From the particle trajectory (as shown in Figure 2), the walls closest to the gamma source would likely be the largest contributors to the scattered radiation at the patient location which contribute about 15% of additional dose. From a dose standpoint, it is necessary to protect patients from unnecessary additional radiation, even typically at lower levels, as a patient dose optimization strategy consideration. It has to be noted that patients may undergo repeated radiation procedures.

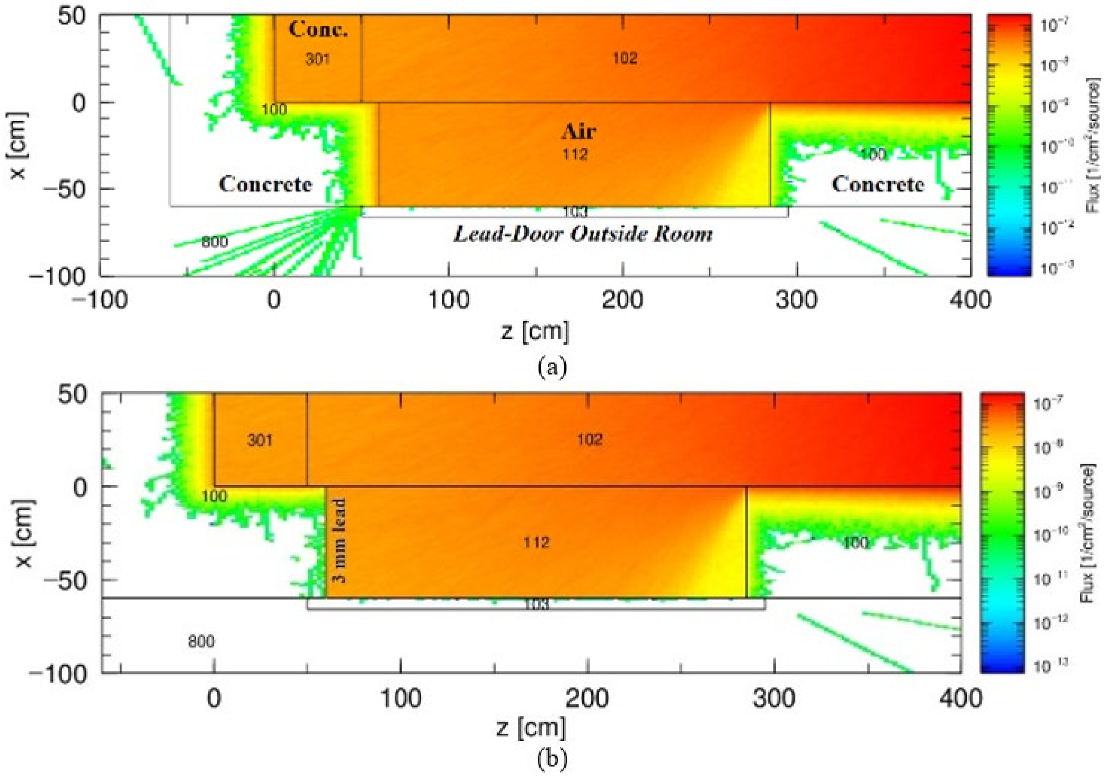
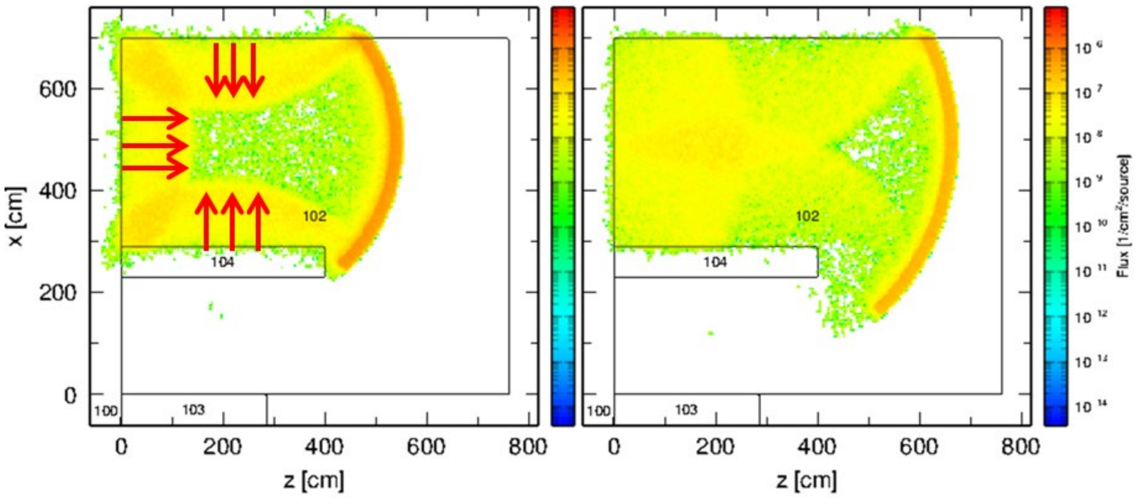
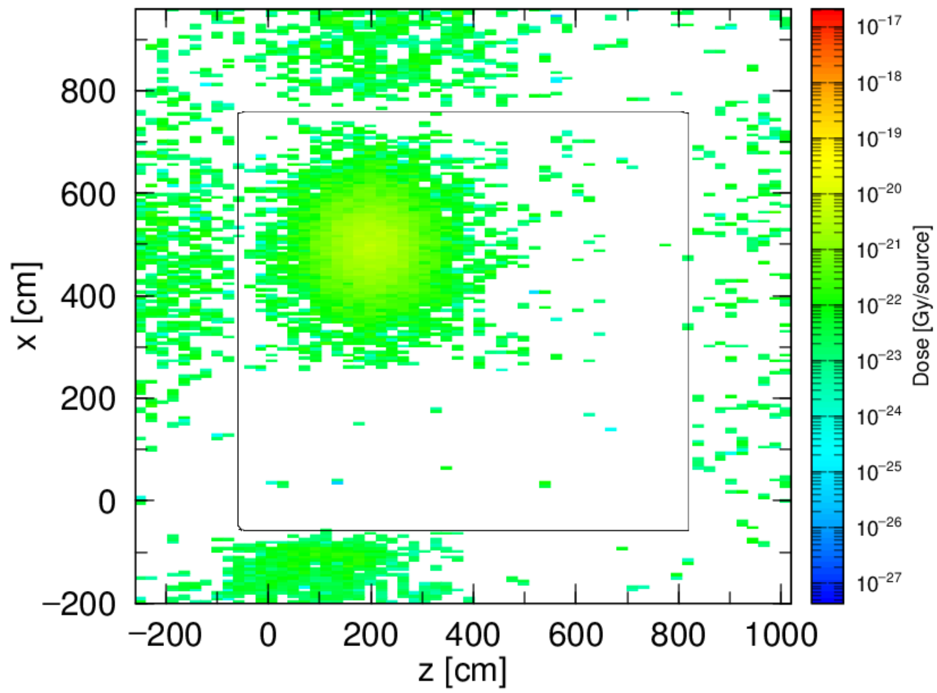


Fig. 1 Edge effect of the entrance door for (a) outside the room, while (b) is the sliding lead with the 3-mm thick lead layer added on the left-side of concrete walls to reduce the edge effect.



(a)



(b)

Fig. 2 The arrows in the left figure (a) indicated the photons trajectory that reflected from the concrete walls, while 2 (b) is show the dose contributions by only scattered photons.

A Compton scattered photon at energy of 95 keV appeared as a result of large scattering angle within 130º -140º from Ir-192 source. Adding a 4 m x 4 m square lead slab as thin as 2 mm on the three walls and floor at the patient location was adequate to reduce almost 92.5 % of the reflected photons dose for Ir-192 source to the patient location. Using lead layer is may not good for patient or cosmetic perspective despite its high cost. By replacing the ordinary concrete to the heavy concrete material reduced the scattered photon dose about 87%. The impact of the shape of walls such as with many bumps (as shown in Figure 3) would also expect able to reduce scattered dose exposure for the patient, are going to be discussed in this presentation.

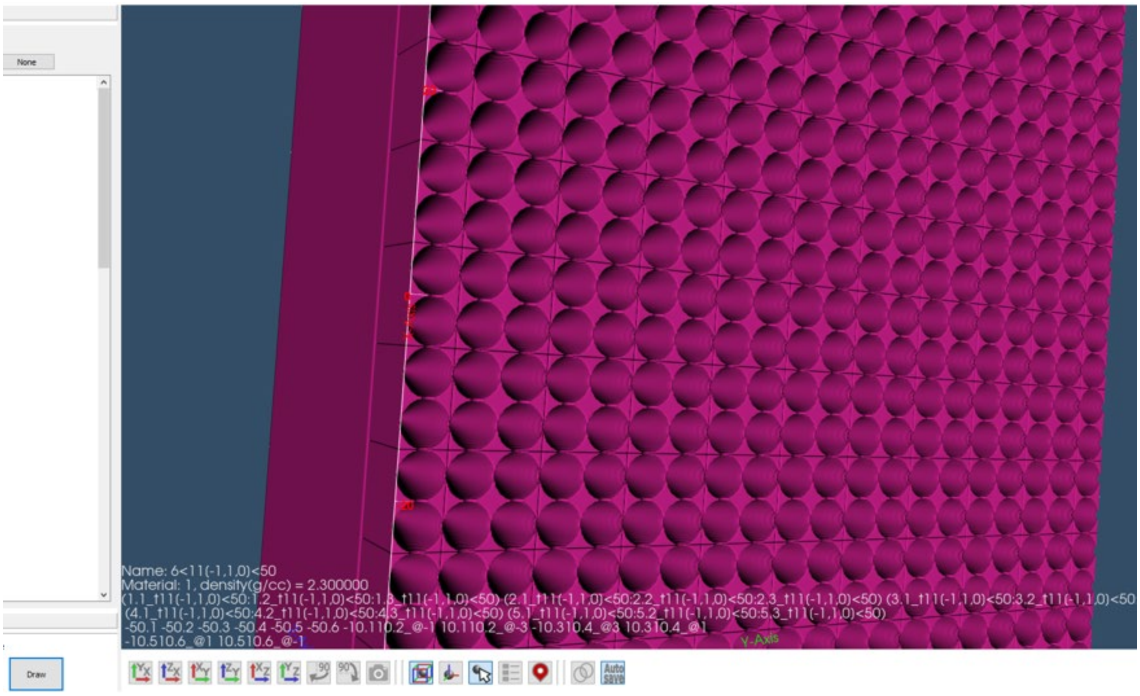


Fig. 3 An example of alternate walls design with 20 x 20 inverted holes, with each measuring of 5 cm x 5 cm and 10 cm depth**.**

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Abstract for the PHITS workshop 2025.

Determination of mass attenuation coefficient for some Taif City rock samples using XCOM and EPIXS simulations

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The majority of building materials are made from rock, either directly or as aggregate in concrete. Radiation shielding properties should be studied because the shielding material is critical for radiation protection. Rock samples were taken from various locations of the Kingdom of Saudi Arabia's Taif region to examine its shielding against γ-rays. The densities of these samples range from 1.81 to 2.55 g/cm^3. The linear attenuation coefficient (LAC) and mass attenuation coefficient (MAC) have been determined theoretically with the NIST XCom, EPIXS. These rock samples' radiation shielding properties are comparable to those of previously investigated rock samples from various locations of the world. The study demonstrates the potential of using affordable, locally accessible rocks for low-energy γ-ray shielding in many areas..

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Cosmic-ray exposure assessment using particle and heavy ion transport code system: case study Douala-Cameroon

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According to UNSCEAR, cosmic radiation contributes to ~16% (0.39 mSv/y) of the total dose received by the public at sea level. The exposure to cosmic rays at a specific location is therefore a non-negligible parameter that contributes to the assessment of the overall public exposure to radiation. In this study, simulations were conducted with the Particle and Heavy Ion Transport code System, a Monte Carlo code, to determine the fluxes and effective dose due to cosmic rays received by the population of Douala. In minimum solar activity, the total effective dose considering the contribution of neutron, muon+, muon-, electron, positron and photon, was found to be 0.31 ± 0.02 mSv/y at the ground level. For maximum solar activity, it was found to be 0.27 ± 0.02 mSv/y at ground level. During maximum solar activity, galactic cosmic rays are reduced by solar flares and winds, resulting in an increase in the solar cosmic-ray component and a decrease in the galactic cosmic-ray component on Earth. This ultimately leads to a decrease in the total cosmic radiation on Earth. These results were found to be smaller than the UNSCEAR values, thus suggesting a good estimation for the population of Douala city located near the equatorial line. In fact, the cosmic radiation is more deflected at the equator than near the pole. Muons+ were found to be the main contributors to human exposure to cosmic radiation at ground level, with ~38% of the total effective dose due to cosmic exposure. However, electrons and positrons were found to be the less contributors to cosmic radiation exposure. As regards the obtained results, the population of Douala is not significantly exposed to cosmic radiation.

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Bayesian Optimization of a HPGe detector for 3D activity reconstruction in radioactive waste drums

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Segmented Gamma Scanning (SGS) is an important technique for inspecting radioactive waste packages, utilizing gamma spectrometry to identify and quantify gamma-emitting isotopes. Collimated High-Purity Germanium (HPGe) detectors are commonly employed due to their superior resolution.

However, calibrating HPGe detectors equipped with complex collimators poses challenges, especially regarding the modelling of the spatial response of the detector. This work introduces a calibration methodology for the Full Energy Peak Efficiency (FEPE) of HPGe detectors equipped with variable aperture collimators using Bayesian optimization (BO) to evaluate PHITS detector response simulations aiming to calibrate complex geometries.

The method and the model were then validated for all the range of application of the detector-collimator arrangement using experimental FEPE measurements demonstrating the model's potential for accurate SGS simulations.

The objective of this model, is to generate data for training a surrogate model of the detector by using techniques such as Gaussian Processes (GPs) or Bayesian Neural Networks (BNN) in a Data-Efficient Machine Learning (DEML) strategy.

If successfully trained, the surrogate will serve as a forward model in an inverse problem to infer the 3D activity distribution, which, to the best of our knowledge, has not been accomplished yet, and to perform uncertainty quantification for 200 L waste drums by using probabilistic modelling.

Establishing dose coefficients for common paediatric diagnostic fluoroscopic examinations in support of ICRP Task Group 113

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*Early career investigator

Abstract

Task Group 113 is responsible for developing reference organ and effective dose coefficients for common diagnostic x-ray imaging examinations. This task group recognizes that the primary dosimetric data available from diagnostic medical imaging procedures are entrance air kerma (for radiography), air kerma-area product (for fluoroscopy), and $CTDI_{vol}$ and DLP (for CT). While these dose metrics are useful in the establishment of Diagnostic Reference Levels, they are a limited surrogate for the quantity of effective dose. To date, the ICRP has not provided reference dose coefficients that would allow converting readily available dosimetric data reported from medical imaging equipment to estimates of effective dose, or a surrogate thereof, and organ absorbed doses. Consequently, disparate methodologies—often relying on older stylized hermaphroditic phantoms—are being used to estimate effective dose; thus, highlighting the need for standardization by way of ICRP reference dose coefficients.

To this end, our subgroup has developed ICRP reference dose coefficients for common paediatric diagnostic fluoroscopic examinations. The major tasks of this effort were to define representative imaging fields of the voiding cystourethrogram, lower GI series (commonly called the contrast enema), upper GI series, and modified barium swallow examinations; to develop ICRP reference dose coefficients by performing Monte Carlo radiation transport calculations using the Particle and Heavy Ion Transport code System (PHITS) for each imaging field on each of the ICRP reference paediatric voxel computational phantoms; and finally, to report all methods, assumptions, and results in a written report to the ICRP. The work done by this subgroup was limited to those procedures previously listed, does not cover the full range of clinical practice, nor address variability in patient-specific anatomy and disease.

Fifty-nine diagnostic fluoroscopy protocol outlines encompassing 545 distinct x-ray fields were developed for the mentioned clinical protocols. Each protocol consisted of multiple x-ray fields with information on anatomic area-of-interest, field collimation, fluoroscopy time per field, patient angulation, contrast volume per organ, and the number of radiographs per field. These reference imaging fields are consistent with national and international imaging protocols that outline typical techniques. Detailed iodinated and barium contrast models were implemented in the PHITS simulations. Abnormal clinical diagnosis protocols were also created which include Hirschsprung disease, intussusception, laryngeal/tracheal aspiration, malrotation with volvulus, posterior urethral valve, and grade 3 vesicoureteral reflux. PHITS simulations to define reference organ and effective dose coefficient for each field within each exam were calculated as dose per dose-area product and per dose to a reference point. These developments have the potential to assist low-dose research programs studying radiogenic health risks in cohorts of medically exposed patients as well as informing clinical practice for these procedures.

EXPLORING THE ENERGY DEPOSITION PATTERNS OF PROTON AT MACRO AND MICROSCALE USING PHTIS SOFTWARE

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Purpose: To achieve refined proton therapy and more accurate modelling of the proton relative biological model, this work aims to explore the energy deposition patterns of protons in biological tissues at different scales.

Methods: At the macroscopic scale, the human voxel model Korean Typical Man (KTMAN)[1] was used to simulate and recreate the actual irradiation scenario of protons. The dose deposition patterns at various depths were calculated. At the microscopic scale, the mesh-type model replicating the realistic morphology of cells was constructed. At the microscale, a monolayer cell population model of the same size as a real experimental culture dish was created based on many single-cell models [2]. The Monte Carlo "Condensed History" model was used to investigate the energy deposition distribution in cells within the population caused by the proton spread-out Bragg peak (SOBP). The general method is shown in Fig 1.

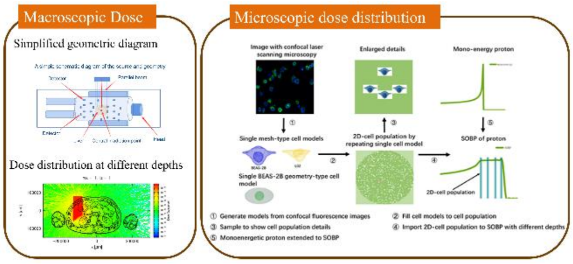

Fig 1: Schematic diagram exploring proton SOBP energy deposition patterns in biological tissue at macro and microscale

Results I. Macro-dose distribution

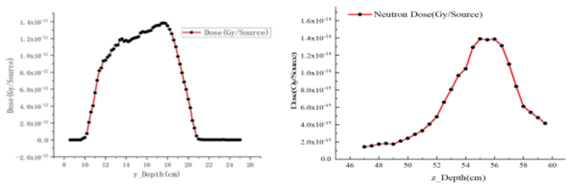

Fig 2: The energy distribution along the Z-axis and Y-axis in a human phantom for the proton SOBP composed with an energy range of 79.9 MeV -122.4 MeV.

The left image shows the dose deposition of protons at human depth including primary and secondary particles within the liver and normalized to each source's energy. As shown in the fig 2, even within the proton SOBP, significant variations in the energy deposition pattern are evident, increasing from approximately 1.0×10^{-11} Gy/Source at the entrance of the SOBP to around 1.4×10^{-11} Gy/Source. The deviation between the maximum and minimum values is 40%, indicating that the SOBP dose is not uniform. Analyzing neutron dose deposition along the Z-axis reveals a relatively flat distribution, suggesting a high degree of uniformity in the beam structure.

Results II. Micro-dose distribution

Fig 3 shows the difference in specific energy distribution calculated using the geometry-type model and the mesh-type model for the SOBP. The volume difference between the two models is 43% due to the irregular shape of the cell and the concavity of the surface. Compared with the geometry-type model, the maximum difference of nuclear specific energy $\bar{z}$ of mesh-type cell is about 10.3%, and the maximum difference of cytoplasm $\bar{z}$ is about 7.5%.

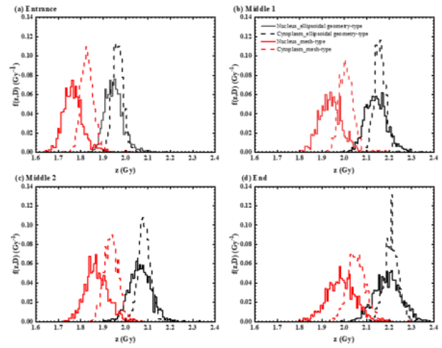

Fig 3：The specific energy distribution f(z,D) of the nucleus (solid lines) and cytoplasm (dashed lines) of the cell population constructed by BEAS-2B geometry-type model (black) and mesh-type model (red) at SOBP four different depths with an initial proton energy of 175 MeV and a broadened width of 25%.

Conclusion: Different models are needed to investigate the energy deposition patterns of protons at different scales. Simulation reveals that the average of specific energy in the nucleus differs from the macroscopic dose of SOBP, and the energy distribution varies with different cell morphologies, highlighting the necessity of using realistic cell models to simulate the actual dose at the microscale.

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Constructions of mesh-type cell models and their application research based on PHITS

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Background: Accurate assessment of both therapeutic effects and side effects in radiotherapy relies on estimating the radiation dose delivered to tumors and normal tissues. Cells, as the fundamental units of organs and tissues, are the primary "targets" for radiation-induced biological effects. Thus, predicting and evaluating these effects based on the dose received by individual cells is crucial. However, current methods for cell dose estimation overlook the morphological differences between cell types, hindering precise dose assessments within the target volume.

Objective: This study aims to develop mesh-type cell models from micro-tomography images of realistic cells, with potential for extension to multicellular structures. These models will be applied within PHITS for dose estimation in various radiation scenarios, including both internal and external exposures, to clarify the microdosimetric properties of radiation at the cellular level and explore the relationship between these characteristics and radiation effects.

Methodology: We developed a method to construct individual mesh-type cell models from fluorescence confocal micro-tomography images. These models were evaluated based on PHITS for cellular dose estimation in support of further research applications. For the application in the low-dose radiation, human normal lung epithelial cells (BEAS-2B) were exposed to Cs-137 photon radiation with low doses, and gene expression differences were analyzed using 10×Genomics single-cell RNA sequencing. The dose distribution in the cell nucleus was determined via PHITS and compared to gene expression differences to identify low-dose-affected genes. For the application in the β-emitter internal irradiation, various cellular cluster models were constructed, and internal exposure doses were estimated using PHITS. The MIMC-β method, for rapid β-emitter dose estimation, was developed and compared with PHITS and MIRDcell software.

Results: Mesh-type cell models with varying morphologies and volumes can be imported into PHITS for dose assessment under different source configurations, demonstrating the reliability and versatility of the construction method. This approach also shows potential for extension to other cell lines. In the low-dose radiation study, the simulation showed a trend in the specific energy distribution within the cell nucleus: as the dose increased, the variability decreased, and the distribution approached a normal distribution. Bioinformatics analysis identified potential signaling pathways sensitive to low-dose radiation. For β-emitter internal irradiation, the MIMC-β method provided quick dose estimates for cellular clusters, addressing computational inefficiencies while maintaining accurate cell morphology representation.

Conclusions: This study advances cellular dose quantification and microdosimetric analysis through refined cellular models. It offers new insights for predicting radiobiological effects and serves as a valuable reference for research on radiation dose-effect relationships.

Keywords: mesh-type cell models; microdosimetry; Monte Carlo simulation; low-dose radiation; β-emitter internal irradiation.

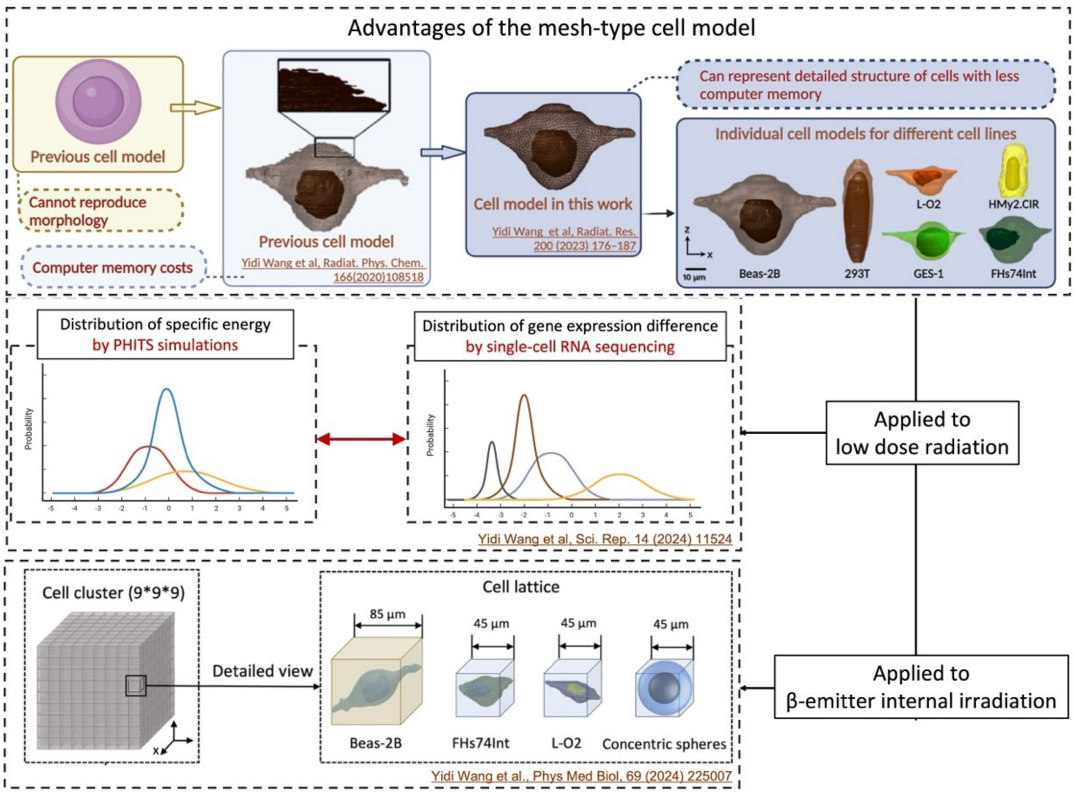

Figure. Outline of this work

Analysis of Materials Thickness for 230 MeV Cyclotron Room Shielding of Proton Beam Therapy using Particle and Heavy Ion Transport Code System Program

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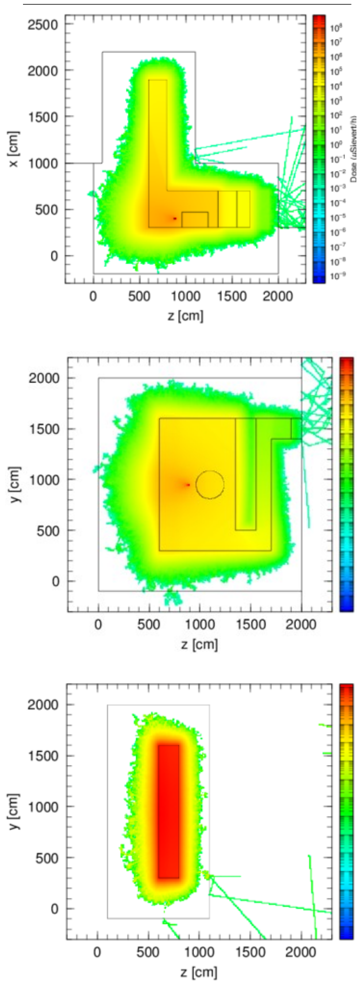
Graphical abstract



ABSTRACT

Proton Beam Therapy (PBT) is an external radiotherapy that uses high energy protons accelerated up to 230 MeV by a cyclotron. However, high-energy protons can endanger personnel and the public. Radiation shielding is necessary to prevent radiation leaks above safety limits at the installation, including the cyclotron room. This research will analyze the material type and thickness of the cyclotron room shielding. A compact vertical cyclotron room was modeled using different materials, including concrete only, concrete with B4C plate, and magnetite concrete. The shielding thickness was varied to determine the optimal thickness. The Particle and Heavy Ions Transport code System (PHITS) Monte Carlo simulation program was used to calculate the dose rate in the cyclotron room. T-Track and T-Gshow tallies were used to observe the dose rate distribution and cyclotron room geometry. Based on calculations, the three materials could reduce the dose rate below the dose limit regulated by BATAN and ICRP (5 μSv/hour for radiation workers and 0.25 μSv/hour for the public). On the thickest side of the wall, the concrete material required a thickness of 550 cm, 530 cm for concrete with B4C, and 440 cm for magnetite concrete to achieve a dose rate below the dose limit.

Keywords: Radiation, shielding material, cyclotron room, proton beam therapy, PHITS.

Calculation of the Skyshine Radiation Measurement in Baikal-1 RA Research Reactor using PHITS code

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Mitsubishi Nuclear Fuel (MNF) calculates the skyshine dose and the direct dose at a facility boundary using conservative code and model. To upgrade the calculation code and to apply a detailed model, MNF confirms the accuracy of 3D Monte Carlo code PHITS [1] on dose calculation. In this paper, MNF performed calculation of exposure dose measurement at Baikal-1 RA research reactor (Baikal-1 reactor) in Kazakhstan [2]. Baikal-1 reactor consists of 37 air-cooled fuel assemblies with 90% ^{235}U enriched uranium carbide. The nominal thermal power is 300kW±12%. This reactor was able to emit high-intensity flux of neutron and photon to the atmosphere by removing the upper shielding block. The physical quantities flux, dose rate, energy and spatial distribution, of neutron and photon flux was measured at various distances from reactor.

The dose calculation was performed with detailed model of the Baikal-1 reactor. The number of histories was approximately 2.5 billion, and the calculation error was up to 3%. Figure 1 shows the effective dose from skyshine radiation (gamma rays) at a distance from the reactor. The calculation results show the good consistency between PHITS results and the measurement results of the Baikal-1 reactor.

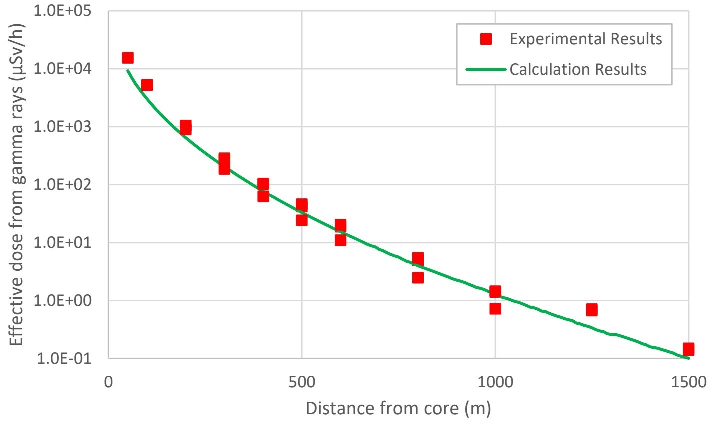

Fig. 1 Effective dose from skyshine radiation (gamma rays)

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Education on optimizing radiation protection in X-ray fluoroscopy-guided procedures using extended reality

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In X-ray fluoroscopy, medical staff performing fluoroscopy-guided procedures such as ERCP are often exposed to occupational radiation. Therefore, appropriate radiation exposure reduction measures are required. We developed an extended reality application that simulates the 3D scattered radiation distribution in a fluoroscopy room and instantly calculates the dose at multiple points when medical staff are placed in any position. We created an educational scenario using this app to evaluate the effectiveness of optimizing protection by distance from the patient and shielding, and verified the effectiveness of the teaching material.

The scattered radiation distribution in a room during X-ray fluoroscopy was calculated using PHITS as a Monte Carlo simulation [1]. We developed an iPad application that places medical staff models that can be freely placed in virtual space and displays the scattered radiation distribution in the room and the dose to the lens, neck, chest, abdomen, and fingertips. We calculated the lens equivalent dose and effective dose per fluoroscopy procedure when the distance from the patient is changed and when radiation protection glasses, protective clothing, and protective curtains are used, and created an educational scenario to consider the optimization of radiation protection.

The effective dose to the lens equivalent of a single ERCP performed at a position 60 cm from the patient without protective equipment was nearly 1 mSv. By using all protective equipment, the dose was reduced to one-fiftieth of the original amount. This app facilitated understanding by allowing the spread of scattered radiation to be observed from any viewpoint.

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Experience with PHITS Code in the research and training programs at the Nuclear Engineering Area of Technical University of Madrid (Spain)

Gonzalo F. García-Fernández[1], Óscar Cabellos[1], Emilio Castro[1], Eduardo Gallego[1], Nuria García Herranz[1]

1. Nuclear Engineering Area, Faculty of Industrial Engineering (ETSII), Technical University of Madrid (UPM), Madrid, Spain

The Nuclear Engineering Area at the Department of Energy Engineering, Faculty of Industrial Engineering (ETSII) of the Polytechnic University of Madrid (UPM), has been a leader in nuclear science and technology research and education since its inception. Its educational and research programs are a benchmark in the nuclear sector of Spain and Europe. The main goal of the Nuclear Area is to train nuclear engineering professionals with expertise in simulation methodologies, design, and advanced analysis, crucial for both professional practice and research. These professionals have become a key source of experts for nuclear facilities and international research institutions.

Monte Carlo simulations and nuclear data are central to the educational and research programs, especially in radiation shielding, reactor physics, and dosimetry. Since its adoption in 2007, the PHITS Code System has become a key tool in these efforts. For example, PHITS has been coupled with the UPM Code for activation and transmutation calculations, ACAB, with one example detailed in the ACAB manual. (https://www.oecd-nea.org/tools/abstract/detail/nea-1839/). By 2019, PHITS was fully integrated into both teaching and research, playing a key role in simulating particle transport in applications ranging from nuclear reactors to space missions.

This presentation, part of the Workshop in PHITS organized by the Japan Atomic Energy Agency (JAEA), highlights over 100 research outputs from ETSII-UPM, including 15 peer-reviewed articles, 32 international conference presentations, 22 undergraduate theses, 15 master's theses, 2 doctoral dissertations, and 3 book chapters. PHITS is also involved in two European research projects, including the OECD/NEA TVA Watts Bar Unit 1 Multi-Physics Benchmark, particularly, Exercise 8 on Reactor Pressure Vessel neutron fluence evaluation. Another notable milestone was the first in-person PHITS training course in Spain, held in March 2024 and organised by the Nuclear Engineering Area. This work underscores PHITS growing role in advancing nuclear engineering research and education, both in Spain and globally.

Concepts for Enhancing the North American PHITS Community

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PHITS is the primary radiation transport tool in use at the Facility for Rare Isotope Beams (FRIB). As a premiere facility deploying heavy ion beams to produce rare isotopes, it is in FRIB's interest to promote a strong and dynamic community of PHITS users within its part of the world. It is in this spirit that we present possible initiatives for growing and strengthening the North American PHITS user community.

These ideas originated from discussions among experts during the first North American in-person PHITS tutorial in North America hosted by FRIB in the Fall of 2024. Another outcome of these discussions was the establishment by the PHITS team of the PHITS North American Consortium (PhiNACo), committed to building a cohesive and vibrant PHITS user community in North America. PhiNACo provides the ideal framework for implementing such initiatives.

Fig. 1 Participants at the Advanced PHITS Tutorial hosted by FRIB in fall 2024

The concepts explored in this presentation include creating application-specific user groups, organizing targeted workshops, and hosting annual themed tutorials. Additional ideas are integrating PHITS into academic curricula to cultivate the next generation of researchers and creating a PHITS-dedicated journal/magazine to nourish the user community. We believe that such initiatives can provide a win-win scenario not only for the PHITS team and its North American user community, but also for the global PHITS community.

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics and used resources of the Facility for Rare Isotope Beams (FRIB), which is a DOE Office of Science User Facility, operated by Michigan State University, under Award Number DE-SC0000661.

Design study of the neutron source for the neutron shielding performance test at NDPS of RAON

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A neutron experimental system, called the Nuclear Data Production System (NDPS), has been constructed at RAON (Rare Isotope Accelerator complex for ON-line experiments) in Korea. The NDPS can produce neutron beams with energies up to a few tens of MeV using various ion beams and targets. The NDPS provides neutron beams not only for nuclear data measurements but also for various applications such as nuclear reactor design, radiation safety, nuclear medicine, and space radiation research. In fast neutron reactors, particularly Small Modular Reactors (SMRs), neutrons in the keV range are more dominant than thermal neutrons in traditional nuclear power plants, such as Pressurized Water Reactors (PWRs). Consequently, establishing a new neutron experimental facility capable of evaluating shielding performance in such fast neutron environments is essential. Therefore, Monte-Carlo simulations are performed to optimize the target system at NDPS of RAON. This presentation will cover the design study and current development of the neutron target system for shielding performance tests at NDPS.

Development of a Bonner Sphere Spectrometer for Aviation Neutron Monitoring

The Bonner Sphere Spectrometer (BSS) was developed to precisely measure cosmic neutron fluxes as a function of energy at high altitudes. Neutron spectrometry can have direct applications in monitoring radiation doses experienced by aircraft crews during flights. In this context, a spectrometer setup will be created with six polyethylene moderating spheres and one sphere with high atomic number inserts, each equipped with a ^{3}He spherical proportional counter pressurized to 10 atm. This configuration ensures accurate neutron detection over a wide energy range, from thermal to fast neutrons. The BSS to be developed was modeled and analyzed using the PHITS Monte Carlo code to investigate the optimal combination of materials and moderator diameters. Specifically designed for aviation environments, the instrument relies on Monte Carlo simulations to compute its response matrix and optimize performance, accounting for neutron interactions with the detector and surrounding materials. These advanced features make the spectrometer an essential tool for evaluating neutron-induced radiation doses, contributing to aviation safety and ensuring compliance with international radiation protection standards.

Modeling a list-mode multi-coincidence detection system for neutron and gamma-ray imaging in PHITS

Hunter N. Ratliff[1], Ilker Meric[1]

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The NOVO Project is pursuing "Next generation imaging for real-time dose verification enabling adaptive proton therapy" through the development of a dual-particle—neutron and gamma-ray—imaging and range verification system utilizing an array of optically segmented organic scintillators [1]. PHITS [2] has played an important role throughout the project in scintillator characterization methodology development [3], scintillator array design iteration, design and verification of neutron imaging experimental campaigns, and generating training data for machine learning models predicting detector system response for treatment delivery plans. An overview of these efforts is provided with emphasis placed on modeling NOVO's imaging system, which requires double-coincident neutron and triple-coincident gamma-ray interactions with interaction location, energy deposition, and timing data needed on an event-by-event basis. While this can be achieved with a mix of various tally dump files, the inability to enforce coincidence criteria results in a substantial excess of data being written, encumbering event construction and further analyses. A custom "user-defined" tally was written that outputs list-mode data for only neutron and gamma-ray events of desired multiplicity and minimum energy deposition, vastly simplifying this process and emulating the physical detector system and its logic.

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Acknowledgements: The NOVO project has received funding from the European Innovation Council (EIC) under grant agreement No. 101130979. The EIC receives support from the European Union's Horizon Europe research and innovation program. Partners from The University of Manchester have received funding from UK Research and Innovation under grant agreement No. 10102118.

***Disclaimer:** Views and opinions expressed are, however, those of the author(s) only and do not necessarily reflect those of the European Union or the European Innovation Council and SMEs Executive Agency (EISMEA). Neither the European Union nor the granting authority can be held responsible for them.*

The Message Passing Interface (MPI) technique is an old solution and an improvement on the Monte Carlo N-Particle Transport (MCNP) method's enormous computational time, which has not been evaluated based on PHITS code—a recently developed Monte Carlo simulation code. We conducted simulations on Varian Clinac iX 6MV phase space data from the IAEA. Venselaar et al.'s method and criteria were used to validate the Monte Carlo simulation. The PC cluster has also been tested in terms of processor count and bch, which stands for unit calculation count per operation. The MPI version PHITS code's speedup factor and the K-factor, which represent the serial portion of the cluster, were both evaluated. All calculated data met the criteria except δ2, high dose, and high gradient of the beam profile data set. It was very clear that PC clusters with MPI were better than simple nodes up to 70.6%. Additionally, the speedup factor shows a tendency to follow Amdahl's law. At the same time, the K-factor was saturated by a certain measure. The study concludes by arguing that the cluster has limitations that come from its serial composition. If we consider how improvements in specifications affect simulation time, this cluster system could be more effective.

Keywords: PHITS; MCNP; cluster; parallel computing; radiotherap

Computational evaluation of a two-source neutron irradiator

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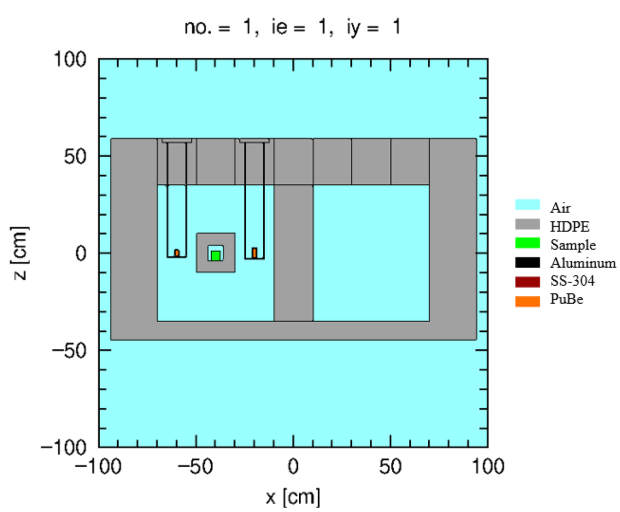
The Philippine Nuclear Research Institute (PNRI) is currently establishing the Neutron Irradiation Facility (NIF) which features two legacy plutonium beryllium (^{239}PuBe) neutron sources with source strengths of 3.6×10^6 n/s and 1.8×10^6 n/s. In this paper, a PHITS (Particle and Heavy Ion Transport Code System) computational model was developed based on the existing MCNP (Monte Carlo N-Particle) LUNIS file provided by PNRI. The PHITS model was then used to optimize a configuration for NAA applications by maximizing the total fluence and its thermal neutron component. It was determined that the optimal thickness for the HDPE was 6 cm, providing the highest distribution of thermal neutron flux with minimal absorption by the moderator. At this thickness, a significant thermal neutron flux of 6.57×10^3 n/cm^2 s is achieved, representing 60.05% of the total neutron flux. The configuration allows the maximum contribution of thermal neutrons while also maximizing the total number of neutrons in the irradiation location.

Keywords: Neutron irradiation, Plutonium Beryllium, Neutron flux, PHITS



Calculation of Absorbed Dose Measurements by Fiber-optic Personnel Radiation Dosimeters through Particle and Heavy Ion Transport code System (PHITS) Simulations

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Radiation physics studies how ionizing radiation, natural or artificial, interacts with matter, focusing on energy absorption [1]. This high-energy radiation, including X-rays, gamma rays, and ultraviolet light, finds applications in medicine, industry, and space exploration [2]. Due to its impact on the environment and human health, accurate radiation monitoring and dosimetry are crucial. Dosimetry quantifies the radiation received and its effects on materials [3]. Notably, the absorbed dose is not uniformly distributed within exposed objects. Researchers are now exploring fiber optics, a technology that revolutionized data transmission, as a new dosimetry tool. O'Keeffe et al. acknowledged these types of dosimeters as attractive devices. They highlighted their potential for low-dose applications due to their sensitivity, replicable results, immunity to electromagnetic interference, and compact size for specific areas of the body.

Thus, this research investigates the absorbed dose deposited and distributed within the fiber optic material through Particle and Heavy Ion Transport code System (PHITS) simulations. The study involves constructing a virtual dosimeter to simulate interactions of ionizing radiation from x-rays(photon beams) or gamma rays(point sources) within the Fiber-optic medium. The simulations will closely replicate real-world clinical trial conditions as described by O'Keeffe et al. Simulated energy depositions show the spatial distribution of absorbed dose within the dosimeter core and surrounding shielding materials(coating and cladding), illustrating dose gradients and their relationship to the given geometry of the Fiber-optic material. Preliminary findings reveal an exponential dose decay along the z-axis and a stable lateral dose profile in the XZ plane for beam simulations, consistent with experimental observations reported in prior literature[4]. These results indicate the dosimeter's intrinsic linearity and stability, which are essential for achieving precise and reliable radiation measurements.

In conclusion, this research helps pave the way for further development of Fiber-optic dosimeters. These dosimeters have the potential to be used not only as personnel dosimeters but also in a wide range of versatile applications. These applications could include radiation protection and therapy, environmental monitoring, industrial radiation measurements, and even space applications. By enhancing the reliability and accuracy of fiber-optic materials used as dosimeters, this research could significantly improve the safety and effectiveness of radiation therapy and inspire the development of new applications in other fields involving radiation transport in fiber-optic and similar materials.

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Development of Directional vector-based Quick evaluation method for Protective plate Effects in X-ray fluoroscopy (DQPEX)

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One of radiation protection measure for medical personnel engaged in X-ray fluoroscopy is using radiation protective plates. A real-time interactive tool visualizing radiation dose distribution varied with the protective plate position will help greatly to train medical personnel to protect themselves from unnecessary radiation exposure. Monte Carlo simulation can calculate the individual interactions between radiations and objects in the X-ray room and reproduce the complex dose distribution inside the room. However, Monte Carlo simulation is computationally time-consuming and not suited for real-time feedback system. Therefore, we developed a new method to calculate the dose distribution with the presence of protective plates instantly using pre-computed directional vectors, named Directional vector-based Quick evaluation method for Protective plates Effects in X-ray fluoroscopy (DQPEX). DQPEX uses a database of dose distributions and directional vectors precomputed by Monte Carlo code, Particle and Heavy Ion Transport code System (PHITS) [1]. Assuming the dose at each position was all contributed from radiations in the direction indicated by the directional vector, the dose reduction by the protective plates at the position was determined whether the backtrace line of the directional vector has a intersect with the protective plate or not. With DQPEX, the whole dose distribution in X-ray room with the presence of a protective plate can be computed about 13 sec, which is approximately 1/6000 of the full PHITS simulation. Sufficient accuracy of DQPEX to visualize the effect of a protective plate was confirmed by comparing the obtained dose distribution with those obtained by the full PHITS simulation and measurements.

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Simulation of chest posteroanterior x-ray procedure using stylized phantom and PHITS

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We simulate computational chest phantom for diagnostic chest x-ray imaging using PHITS. The phantom includes the heart, lungs, ribs, spine, and sternum. The material composition and dimension of the phantoms are based on the ICRP Publication 89 and Dongyoul Lee's study, respectively [1]. We use an x-ray point source that emits photons over a solid angle. We use a 15° angle to get a field size of 20 × 20 cm[2]. The source was placed 100 cm at the back of the chest phantom. We use x-ray spectral data of 120 kVp from Birch and Marshall to simulate the interaction of x-ray with the phantom [3]. The chest PA x-ray image from our simulation shows the shape and position of the organs and bones in the chest phantom. The grayscale reflects the organ dose of x-ray radiation, which provides an estimate of the radiation dose received by a patient's organs during a real x-ray procedure. The organ dose of the lungs and heart are 0.64 mGy and 0.72 mGy, respectively. The study demonstrates the potential of using computational chest phantoms and PHITS simulation to provide a better understanding of gaining a good quality image without compromising the safety of the patient.

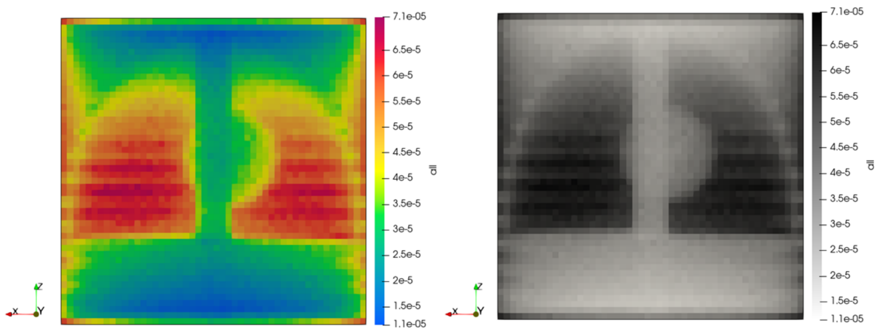

Fig. 1. Image of particle flux (acquired at 120 kVp x-ray) of the chest phantom including the lungs, heart, spine, and sternum. The variation of colors in the image reflects the attenuation map of x-rays, where low attenuation areas appear darker and high attenuation areas appear brighter.

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Simulation Study of Thick Target Neutron Production for NDPS at RAON

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The Nuclear Data Production System (NDPS) is one of the research facilities of the Rare Isotope Accelerator complex for ON-line experiments (RAON). It is designed to produce and utilize high-energy neutrons, generated using ion beams ranging from protons to heavy ions, with energies exceeding several tens of MeV. Prior to the operation of NDPS, it is crucial to accurately measure the neutron energy spectrum, which forms the foundation of research. However, data on neutron measurements from heavy ions remains scarce. In this study, neutron energy spectra were simulated and compared using Monte Carlo particle transport codes—PHITS, FLUKA, and MCNP—for various combinations of ion beams and target materials expected to be used in NDPS. The optimal ion beam–target combinations for different experimental environments are discussed. Additionally, to evaluate the reliability of each code, the simulation results are compared with experimental data obtained under conditions similar to those of NDPS.

Problem Formulation Using PHITS to Estimate Types and Depth Distribution of Radioactive Isotopes in Soil

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To develop decontamination plans for soil mixed with radioactive isotopes (RIs), we have developed a rod-shaped measuring device. The device is buried in soil and counts the number of photons in each depth layer of soil. In this report, we deal with a problem to estimate the types and distribution of RIs in each depth layer of soil.

For a situation illustrated in Fig. 1, we formulated a problem to estimate the types and depth distribution of RIs as simultaneous equations: $\boldsymbol{s} = \boldsymbol{A}\boldsymbol{x}$, where $\boldsymbol{s}$ represents the counted number of photons, $\boldsymbol{x}$ expresses the intensity of each RI to should be estimated, and $\boldsymbol{A}$ means an observational operator for all RIs and can be previously computed using PHITS. To solve the simultaneous equations using a solver described as continuous-time dynamical systems [1], the types and depth distribution of each RI can be estimated.

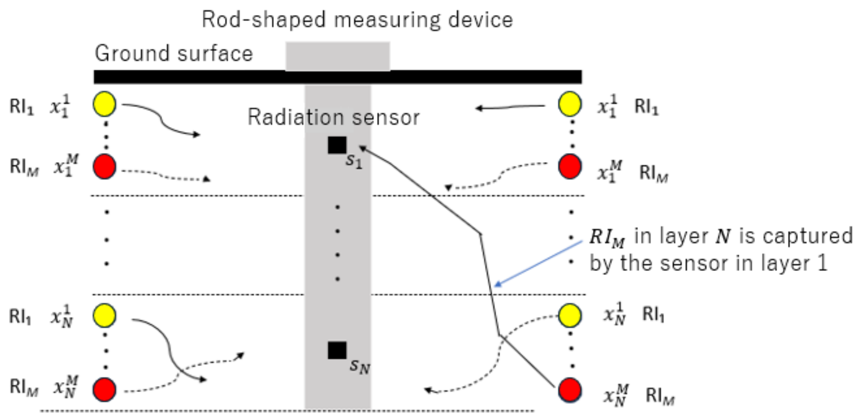

Fig. 1. Schematic diagram of problem to estimate types and distribution of RIs in soil.

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Simulation of Radiological Leakage in a Teletherapy Bunker Using PHITS

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The Particle and Heavy Ion Transport Code System (PHITS) is a comprehensive Monte Carlo particle transport simulation tool used to model the transport and interactions of particles such as neutrons, photons, ions, and electrons. In this case study, PHITS version 3.34 was employed to generate detailed radiation dose maps for a teletherapy bunker housing a Cobalt-60 source with an activity of 2000 mCi, as well as for selected surrounding areas. The simulation involved meticulously defining the geometry, source parameters, and tally setup to accurately assess radiation exposure levels in targeted zones. Simulation results were then compared with empirical measurements obtained from dose mapping operations. The application of PHITS in this study enabled the prediction and evaluation of radiation exposure levels, providing essential insights for minimizing the risk of ionizing radiation exposure and enhancing radiation safety protocols.

Particle Bombardment on Liquid Metal Plasma Facing Components

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Liquid metal has been actively investigated for the possibility to be plasma facing components (PFCs) in a next step magnetic confinement fusion (MCF) device [1]. In such a device, nuclear fusion occurs at which all fuels are in the plasma phase. Subsequently, high energetic particles bombard on PFCs, so that their melting are unavoidable if they are initially in the solid phase. Routine maintenance is required. This is the case unless PFCs in the liquid phase is used, so that the replenishment mechanism is required for healing the PFCs instead. However, liquid metal interacting with high energetic particles still insists. These particles are the substances and the products from nuclear fusion.

This presentation aims to present the use of PHITS [2, 3] to study the interactions between low melting point liquid metals, for examples lithium (Li), tin (Sn), tin-lithium (SnLi) alloy, and various particles found in an MCF device, for examples hydrogen isotope nucleus ($H^+/D^+/T^+$), alpha particle (He^{2+}), neutron, electron. The studies using PHITS help in designing the liquid metal circulation in terms of the operational management, understanding the source and sink actions, and so on.

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Design of Si-TlBr Compton Camera Geometry using PHITS for Measuring Prompt Gamma-rays in BNCT

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Boron neutron capture therapy (BNCT) is a radiotherapy technology that selectively kills tumor cells via the $^{10}B(n, \alpha)^{7}Li$ reactions. The in-vivo dose of BNCT depends on the number of $^{10}B(n, \alpha)^{7}Li$ reactions in the tumor, which is determined by the local ^{10}B concentration distribution and thermal neutron flux intensity. Non-invasive determination of in-vivo dose is an ongoing challenge. A promising solution is measuring and localizing the 478 keV prompt gamma-rays emitted from $^{10}B(n, \alpha)^{7}Li$ using gamma-ray imaging devices such as Compton cameras. However, the strong neutron and photon background in clinical BNCT environments complicates accurate detection and localization using general-purpose Compton cameras [1]. This study focuses on designing a BNCT-specialized Si-TlBr semiconductor Compton camera using PHITS code [2]. The Compton camera detects incident photons through coincidence events between two detectors: a scatterer and an absorber. Calculating these events using conventional PHITS tallies is challenging. To address this, we utilized the *T-Deposit* tally with a *Counter* function to specify deposition events for detection efficiency calculations and a User-defined tally to extract spatial and energetic data for determining angular resolution. The optimal thicknesses of the Si scatterer and TlBr absorber were identified by maximizing a figure of merit that combines detection efficiency and angular resolution for monoenergetic 478 keV photons. Future work will include further optimization using neutron source-based simulations and image reconstruction analyses.

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Exposure Calculation for a Worker with Contaminated Hair

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The hair of a worker using unsealed radioisotope ^{131}Iwas found to be contaminated. To establish an appropriate safety management method, a rapid dose evaluation was performed using the PHITS[1] (Particle and Heavy Ion Transport code System) software. A simplified head model was created, and the total radioactivity of the contaminated hair was back-calculated based on dose rate measurement results. The measured dose rate was 750 μSv/h, corresponding to a total calculated radioactivity of 0.49 MBq.

The absorbed doses to the lens and scalp were then calculated and compared with regulatory dose limits. Accounting for the 8-day half-life of ^{131}I, the absorbed dose rates to the eye and skin were determined to be 3.56 μGy/h and 5.08 μGy/h, respectively. The cumulative doses over 30 days were calculated as 7.12 μGy and 10.16 μGy, respectively. These values comply with the dose limits of 150 mSv/year for the lens and 500 mSv/year for the skin.

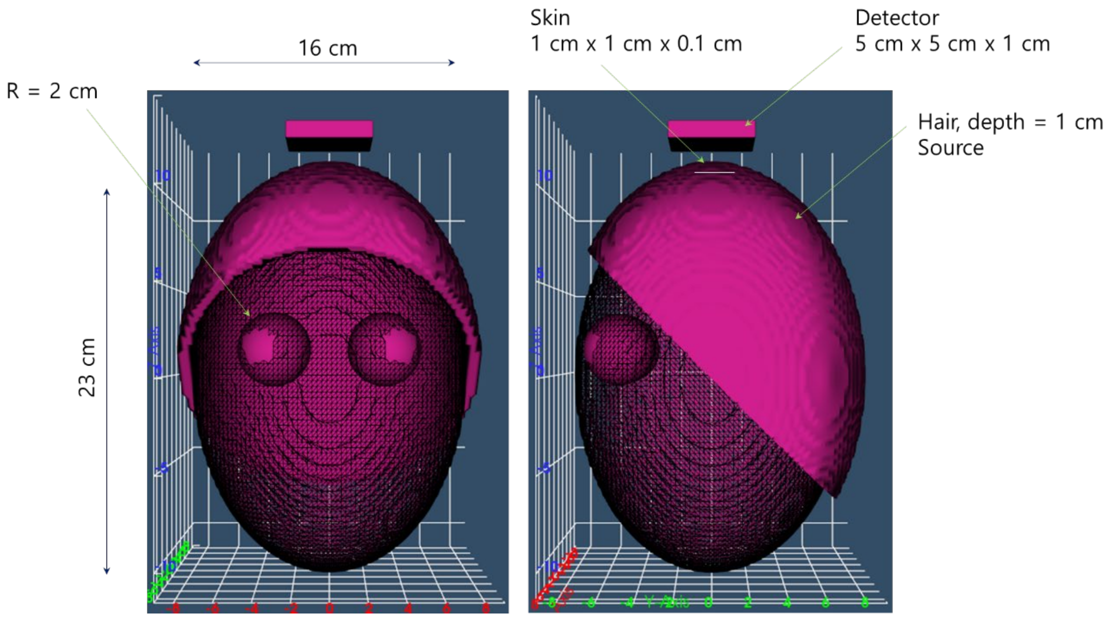

Fig. 1 Schematic diagram of a simplified head model

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Feasibility Study of Radiation Shielding Capability and Ion-Matter Interaction Parameters of Common South African Building Bricks Using PHITS Monte Carlo Code

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***Presenter:** S. F. Olukotun

Abstract

In South Africa, most building constructions utilize readily available bricks from local hardware stores, with detailed information on their physical dimensions, mechanical properties, durability, weather resistance, thermal and acoustic properties, fire resistance, aesthetics, and price. However,
their nuclear radiation shielding capabilities and ion-matter interaction characteristics, such as range and nuclear and electronic stopping powers, remain largely unexplored. This study aims to bridge this gap by providing a comprehensive analysis of these parameters, focusing on their potential application in nuclear radiation shielding and nuclear waste containment.

With the growing importance of radiation safety in nuclear applications, there is a pressing need for cost-effective, accessible shielding materials. This study will determine the elemental composition of common South African building bricks using ICP-MS, which will serve as an input data for simulations using the PHITS Monte Carlo code. The analysis will assess the bricks' radiation shielding capabilities, heavy ion range, and stopping powers when exposed to ions at varying energy levels. The findings will have significant implications for radiation protection in South Africa, where nuclear technologies are expanding, by identifying locally available, cost-effective shielding materials.

In conclusion, this research will provide crucial data on the nuclear radiation shielding potential of common building bricks, supporting informed decision-making for policymakers, engineers, and radiation safety professionals. This data will enhance the sustainability and cost-effectiveness of radiation shielding strategies and promote safe, responsible nuclear technology use in the region.

Neutronics Progress in Conceptual Design of the Self-Cooled Lithium-Lead SCYLLA Blanket for a Spherical Tokamak

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Over the last few years, Kyoto Fusioneering (KF) has been developing its capability in advanced blanket design, focusing its efforts on the development of its own innovative concept known as SCYLLA (Self-Cooled Yuryo Lithium-Lead Advanced), a self-cooled lithium-lead type blanket using silicon carbide composite (SiCf/SiC) as a structural material. The structural design of this blanket requires energy deposit distribution data as input for thermal fluid analysis codes, as well as tritium production distribution data to optimize tritium generation efficiency, and these data were calculated by using PHITS. The 3D model cut into one-eighth and the radial 1D profile of energy deposit are shown in Fig. 1 and Fig. 2 respectively. In this presentation, we report on these neutron analysis results and how this information has been utilized in the design.

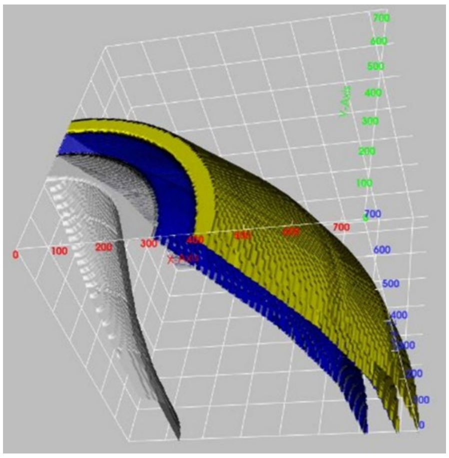

Fig1. The 3D model cut into one-eighth

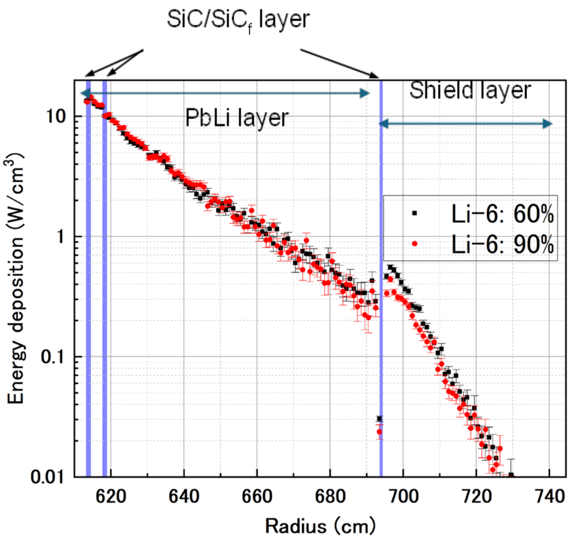

Fig2. The radial 1D profile of energy deposit for PHITS

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Monte Carlo Simulation Based Dose Calculation for Varian 2100 CD Linac: A Comparative Study with Clinical Algorithms in Homogeneous and Heterogeneous Media.

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Purpose: The main objective of the study was to validate the Monte Carlo (MC) dose calculation for a Varian 2100CD linac and subsequently compared it with commercially availble AAA and Acuros (AXB) algorithms used in Eclipse Treatment Planing System (Varian Palo Alto). This study has been investigated the impact of MC simulation for homogeneous and inhomogeneous dose calculation in radiotherapy.

Methods and Materials: The Electron Gamma Shower (EGSnrc) Monte Carlo user codes were performed for photon beam simulations. The linac treatment head geometry for 6MV photon energy was designed by using BEAMnrc. The central axis (PDD) and lateral dose profile (Profile) have been simulated with DOSXYZnrc simulation code with a rectilinear voxel dimension of 1 x 1 x 0.25 cm and 1 x 0.2 x 1 cm respectively for 10 and 20 cm^2 field. The calculation grid size has been used as 0.25 cm for all calculations in Eclipse at homogeneous and inhomogenous virtual phantom. Each data has been calculated individually with AAA and AXB algorithm. Water has been used as homogeneous and Air, Lung and Bone have been used as inhomogenous medium. A wide ranges of full width half maximum (FWHM) and energies have been simulated to match with calculation data. A gamma index criteria of 3%/3mm to 1%/1mm have been used to evaluate all the matched data.

Results: The design of Varian 2100CD linac has been valided with spectrum energy of 6.4 MV and FWHM of 0.35 cm. In homogeneous media the average gamma pass rate of PDD for 3%/3mm, 2%/2mm and 1%/1mm were 100% for all criteria and in the case of beam profile for 3%/3mm, 2%/2mm were 100%, 95.2% respectively. In inhomogeneos media (i.e, Air, lung medium) AAA calculation and simulated data showed larger deviation of gamma pass rate, 75.5% and 89.5% respectively with 3%/3mm while in same gamma criteria the AXB calculation in air and lung medium and simulated data showed deviation of gamma pass rate 86.9% and 100% respectively. In case of lung medium AXB and MC simulated data demonstrate good agreement. In bone medium there are no significant differences found in AAA, AXB and MC simulation for 3%/3mm gamma index.

Conclusion: The PDD and beam profile were calculated using MC simulation code found good agreement with measure data in homogeneous medium. In inhomogeneous medium AAA have poor calculation acuracy in air and lung medium compare to AXB and MC.

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Study of INC model for alpha inelastic scattering at 230 MeV/u

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The Intranuclear Cascade (INC) model has been improved for calculating alpha induced reaction. Alpha inelastic reaction is dominant for the alpha incident reaction, so that its cross section must be calculated accurately. However, it is difficult to optimize the inelastic reaction and fragmentation reaction for all fragment channel in parallel. Therefore, in this study, we focus on the inelastic reaction only and calculate the cross section for alpha particles using the break-up model having dependency of target mass density. For the double differential cross sections for the alpha particle at incident energy of 230 MeV/u on ^{27}Al at 15°, figure 1 shows the calculation result by improved INC model compared with experimental data and calculation results using INCL model[1] and JQMD model in PHITS[2]. As a result, the best agreements are obtained in the results by improved INC model.

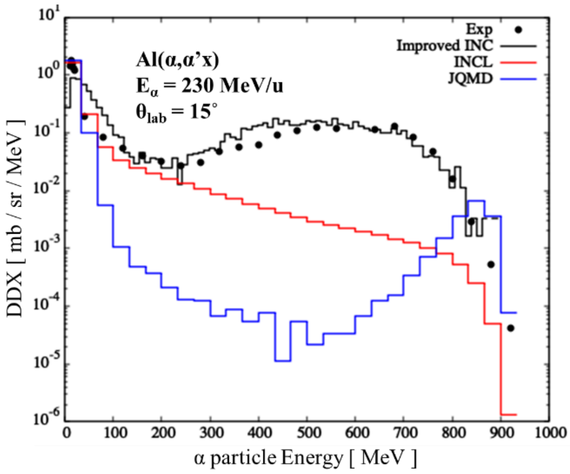

Fig. 1 DDX spectra of alpha calculated by improved INC model(black line), INCL model(red line) and JQMD model(green line) on ^{27}Al at 230 MeV/u at 15° with the experimental results (dots)

References

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