12th International Meeting of the Union for Compact Accelerator-driven Neutron Sources

UCANS12

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ABSTRACT BOOK

LIST OF ABSTRACTS

UCANS12

Keynote Talk

12th International Meeting of the Union for
Compact Accelerator-driven Neutron Sources

IAEA Activities in Support of Sustainable Utilization and Applications of Neutron Sources

Danas Ridikas

Physics Section, Division of Physical and Chemical Sciences, Department of Nuclear Sciences and Applications, International Atomic Energy Agency, Vienna International Centre, PO Box 100, A-1400 Vienna, Austria

E-mail: *d.ridikas@iaea.org*

Facilitation of development and promotion of nuclear applications for peaceful purposes and related capacity building are among the IAEA missions where Physics Section contributes most [1]. The relevant activities fall under the IAEA's program on nuclear science and cover three main thematic areas: research and applications with particle accelerators and neutron sources (incl. research reactors), nuclear instrumentation and capacity building, and controlled fusion research and technology development. As a result, the Section helps IAEA's Member States to advance their capabilities and progress in materials research, energy, environment, food, agriculture, medicine, cultural heritage, forensics, and some other fields with a direct socioeconomic impact. The Section also operates the Nuclear Science and Instrumentation Laboratory (NSIL) at Seibersdorf [2], located 40 km south of Vienna. The laboratory offers expertise, training and support in the effective utilization of nuclear instrumentation and analytical techniques in a broad range of applications, with a focus on mobile radiation monitoring, X-ray spectrometry, and neutron science.

This presentation will provide an overview on the status of neutron sources [3] worldwide and describe the IAEA program related to support of Member States in the area of their utilization and applications, including strategic and business planning for existing and planned facilities; organization of technical meetings, training workshops, proficiency tests and round robin exercises, coordinated research projects, peer review missions and expert advisory missions; development of guidance documents, technical publications and e-learning tools; and management of relevant portals and data bases. Finally in this presentation, the key challenges and opportunities in sustainable neutron source operation and utilization will be discussed. A new IAEA initiative on Neutrons for Nuclear Sciences and Applications (Neutrons4NA) will be also presented with an open call for cooperation and participation.

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New Directions for Compact Accelerator-Driven Neutron Sources at RIKEN: The RANS Platform

Takehiko R. Saito[1,2,3,4]

[1]Neutron Frontier Research Team, RIKEN Center for Advanced Photonics, RIKEN, Japan, [2]High Energy Nuclear Physics Laboratory, Pioneering Research Institute, RIKEN, Japan, [3]GSI Helmholtz Center for Heavy Ion Research, Germany,[4]Graduate School of Science and Engineering, Saitama University, Japan

E-mail: Takehiko.saito@riken.jp

RIKEN has been operating two compact accelerator-driven neutron sources, RANS and RANS-II, as platforms for neutron science and a wide range of application-oriented research. In 2025, the trailer-mounted compact accelerator-driven neutron source RANS-III successfully generated its first neutron beam [1], marking an important milestone toward the realization of a mobile neutron source. Since then, extensive developments have been underway to establish RANS-III as a practical tool for on-site neutron applications.

In April 2026, the former Neutron Beam Technology Team, which had led the development of the RANS project, was reorganized into a new framework consisting of the Neutron Frontier Research Team and the Neutron Operation Unit. Under this new structure, the Neutron Frontier Research Team is responsible for advancing neutron science and developing new applications, while the Neutron Operation Unit oversees facility operation, safety management, and user support. Close collaboration between these two organizations provides an integrated framework that enables both innovative research and reliable operation of the RANS platform.

To date, research using the RANS facilities has primarily focused on non-destructive inspection of civil infrastructure. Under the new organization, these activities will be further expanded together with the practical deployment of RANS-III. In addition, new research programs are being launched in semiconductor technologies, energy-related materials, biological and food sciences, and advanced materials. A key element of these future activities is the development of high-resolution neutron imaging based on the RANS platform. RIKEN has already demonstrated sub-micrometer transmission neutron imaging using novel neutron detectors [2–4]. Current developments are focused on further improving the neutron beam performance of the RANS facilities and integrating these advances with the imaging technology to realize practical micron-scale neutron imaging on a compact accelerator-driven neutron source.

This presentation will introduce the new research framework and future strategy for compact accelerator-driven neutron sources at RIKEN. Particular emphasis will be placed on the development of high-resolution neutron imaging and its potential scientific and industrial applications. The presentation will also discuss the future role of the RANS platform in expanding the capabilities and impact of compact accelerator-driven neutron sources across a broad range of research fields and real-world applications.

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Recent Progress in High-Current Li^{3+} Acceleration for Compact Neutron Sources at BNL

M. Okamura[1], A. Cannavo[1], M. Horana Gamage[1], S. Ikeda[1], T. Kanesue[1], S. Kondrashev[1], T. Sakabe[1], K. Takahashi[2]
[1]*Brookhaven National Laboratory, Upton, NY, USA*
[2]*Nagaoka University of Technology, Nagaoka, Japan*
E-mail: okamura@bnl.gov

Brookhaven National Laboratory (BNL) has been developing a compact accelerator-driven neutron source based on high-current heavy-ion beams for applications in nuclear physics, materials science, and boron neutron capture therapy (BNCT). Recent efforts have focused on demonstrating high-current acceleration in a radio-frequency quadrupole (RFQ) linac as a compact driver for intense neutron production.

Fig. 1. Interior view of the RFQ linac at BNL.

A significant milestone has been achieved with the acceleration of Li^{3+} ions to 300 keV/u at a peak current of 150 mA. Successful beam acceleration and capture demonstrate that the beam quality is suitable for injection into a subsequent drift-tube linac (DTL). Development of the DTL section is currently underway.

Two neutron production target concepts are under development: a liquid nitrogen cooled hydrogen target concept for low-repetition-rate pulsed operation, and a tape-driven plastic target for high-repetition-rate applications such as BNCT.

Future work includes DTL construction and high-power beam tests aimed at achieving neutron yields suitable for medical and materials science applications.

The presentation will also briefly introduce collaborative studies with Eötvös Loránd University and the HUN-REN Energy Research Centre in Hungary [1].

Work supported by Brookhaven Science Associates, LLC under Contract No. DE-SC0012704 with the U.S. Department of Energy.

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Emerging Needs and Current Status of High-Flux Fusion Neutron Sources for Fusion Energy Development

Jaeyoung Park

Energy/Matter Conversion Corporation (EMC2)

Abstract

The net-energy gain achieved at the National Ignition Facility in 2022 catalyzed a major shift in the fusion landscape, triggering multibillion-dollar public and private investment aimed at developing commercial fusion energy systems over the next decade. This accelerated development timeline highlights the role of a high-flux fusion neutron source in addressing recognized technical gaps in structural materials degradation and tritium-breeding blanket technologies. The relevance of this requirement is reflected in the U.S. Department of Energy's May 2026 funding solicitation dedicated to design studies for DT-fusion-based Volumetric Neutron Sources (VNS). This talk provides an overview of emerging needs for fusion-based neutron sources, alongside a discussion of concepts currently under development across the fusion community. By evaluating their respective technological approaches, this presentation aims to provide a deeper understanding of their capacity to deliver the fusion neutron flux and fluence required for commercial fusion development, factoring in the critical dependencies of continued progress in plasma science and other aspects of reactor operation.

Compact neutron systems for research & industry: progress to date within the cuteNESS initiative

Felix Fernandez-Alonso[1,2,3]

[1]*Centro de Física de Materiales – Materials Physics Center, Donostia - San Sebastian, 20018, Spain*
[2]*Donostia International Physics Center, DIPC, Donostia - San Sebastian, 20018, Spain*
[3]*IKERBASQUE, Basque Foundation for Science, Plaza Euskadi 5, Bilbao, 48009, Spain.*

E-mail: felix.fernandez@ehu.eus

This talk provides an overview of recent activities within the remit of the IKUR strategy* and its cutting edge Neutrionics for Science & Society (cuteNESS) initiative, involving the joint use & development of flagship facilities and compact neutron systems. In the former case, ongoing efforts include in-depth surveys of novel materials for energy applications and sustainability, using neutrons and computational materials modelling as our primary tools of inquiry. Beyond flagship facilities, cuteNESS has also been examining the yet-to-be-tapped prospect of in-house neutron provision for academia and industry, with an emphasis on capitalizing from the latest developments in compact systems. Scientific and technological demonstrators implemented to date include elemental analysis and imaging of construction materials, to support parallel activities at high-flux sources as well as the (much-needed) training and professional development of early-career researchers in our immediate surroundings. In a broader context, this work represents a necessary step for a detailed assessment of last-generation and emerging technologies for neutron production, always with a view to extending their realm of applicability to other areas of research where neutrons can make a substantive difference.

* ikur.euskadi.eus/en/neutriónica

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Invited Talk

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Current and Future Reactors at the University of Missouri: MURR and NextGen MURR

Paul F. Miceli[1], Thomas W. Heitmann[1,2], Christine Norman[3], Michael Hoehn[3], and John Brockman[2,4]
[1]Dept. of Physics and Astronomy, [2]MURR, [3]NextGen MURR, [4]Dept. of Chemistry
University of Missouri, Columbia, MO, USA

E-mail: micelip@missouri.edu

Since 1966, the University of Missouri has operated a light-water open-pool reactor, MURR, with its current power being 10 MW. It is the highest-power reactor on a university campus in North America. The reactor has been broadly impactful in producing critically important isotopes, transmutation doping and irradiations, as well as providing a powerful source for neutron science, including neutron scattering to study materials relevant to basic and applied sciences, nuclear activation analysis, archaeometry, and other important areas of science and technology. In recent years, medical isotope production has become an important driver for MURR as such isotopes have national significance. Because of the essential nature of medical isotopes, the university has initiated an effort to build a new 20 MW reactor, NextGen MURR, that will have higher capacity to produce medical isotopes as well as support a major neutron scattering facility of national importance for science and technology. The design study for NextGen MURR was recently completed by the Korean Atomic Energy Research Institute (KAERI) and Hyundai Engineering (HEC). This talk will discuss the current activities at MURR and our plans for NextGen MURR.

Update on HANARO Neutron Beam Instruments, Korea

Young-Soo Han
Korea Atomic Energy Research Institute KAERI, Korea

E-mail: yshan@kaeri.re.kr

HANARO is the only large multipurpose reactor in Korea. It has been operated for 30 years since its initial criticality in February of 1995 and the cold neutron source was installed in 2009. Currently, 5 thermal neutron instruments and 9 cold neutron instruments are operational. Until 2013, the operation of HANARO was successful, with the reactor running for an average of more than 160 days per year. As a result, the number of annual users of neutron beam facilities reached 687 in 2013. HANARO faced the first serious challenge in 2014 when the nation's nuclear regulator, the Nuclear Safety and Security Commission (NSSC), ordered KAERI to reinforce the outer walls of the reactor building in preparation for severe seismic events. The construction took more than 3 years, during which the fledging user community had to find out ways to access foreign neutron science facilities.

Although the reactor was officially back online since December 2017, the facility was facing another unprecedented challenge in the form of a unique regulation. Since July 2018, NSSC requires research reactor operators to report virtually all unplanned shutdown events to the Commission before approved to restart. As a result, from mid-2014 to 2020, HANARO had operated only for less than two months. Although there is still the regulation that hinder normal operations, 73 days had been operated in 2021, 92 days in 2022, and 63 days have been operated in 2023. Fortunately, thanks to the efforts of many people, the regulation was changed in September 2024. Accordingly, the HANARO was operated for 118 days in 2024 and 127 days in 2025. In addition, the number of users reached 586 in 2025, recovering to 85% of the historical peak level. One encouraging trend is the substantial increase in industrial usage of the facility. While industrial users accounted for only 5% of the total external user-days in 2013, this proportion increased to 17% during the 2023–2025 period. Furthermore, 41 papers utilizing the facility were published in 2025, corresponding to approximately 60% of the historical maximum number of publications. In terms of publication quality, remarkable progress has also been achieved. The average journal impact factor of publications utilizing the facility increased markedly from 3.8 during 2013–2015 to 12.1 during 2023–2025. These achievements are considered to be largely attributable to the growing number of high-quality publications produced by leading domestic researchers in the field of secondary batteries.

Fig. 1 Neutron scattering instruments in HANARO Hall(left) and Guide Hall(right).

State-of-the-Art High Power Proton Linacs for HiCANS

Holger Podlech[1,2], Martin Droba[1], Michael Händler[2], Klaus Kümpel[1], Oliver Meusel[1], Julius Storch[1], Chuan Zhang[1,2,3], Andreas Lehrach[4], Thomas Gutberlet[5] and Paul Zakalek[5]

[1]*Institute of Applied Physics (IAP), Goethe University Frankfurt, Germany*
[2]*Helmholtz Research Academy Hesse for FAIR (HFHF), Campus Frankfurt, Germany*
[3]*GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany*
[4]*Nuclear Physics Institute, Forschungszentrum Jülich, Germany*
[5]*Jülich Center for Neutron Science, Forschungszentrum Jülich, Germany*

E-mail: h.podlech@iap.uni-frankfurt.de

Compact High Current Accelerator-driven neutron sources (HiCANS) are an attractive alternative to the classical neutron sources of fission reactors and spallation sources to provide neutrons for almost all areas of natural science, engineering, cultural heritage, and medical applications.

These facilities require powerful accelerators. For most application, Linacs are the preferred choice because of the flexible pulse scheme and the possible high current and high duty factor operation. In addition, Linacs are scalable with respect to the final beam energy. The typical proton Linac consists of a proton source (ECR or volume source), a LEBT-section, a Radio-Frequency Quadrupole (RFQ) and a chain of drift tube cavities. All mentioned parts have their specific challenges, especially when operated with very high beam current (up to 100 mA) or high duty factor. This presentation addresses the main challenges and shows the development toward new HiCANS facilities with the goal of maximum reliability and performance.

Several projects will be presented using these technologies like the Frankfurt Neutron Source FRANZ [1] (2 MeV, 30 mA), MYRRHA [2] (600 MeV, 4 mA) and the High Brilliance Neutron Source HBS-I [3] (20 MeV, 100 mA).

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The 100 MeV Proton/Neutron Beam User Facility: Currents Status and Future Plans

Myung-Hwan Jung, Young Seok Hwang, Hyeok-Jung Kwon, Jae-Sang Lee,
Korea Multi-purpose Accelerator Complex, Korea Atomic Energy Research Institute, South Korea

E-mail: jungmh80@kaeri.re.kr

Since its commissioning in 2013, the 100 MeV proton accelerator at KOMAC has provided stable beam times for diverse research fields in semiconductors, aerospace, biotechnology, and nuclear physics. Notably, the facility achieved 40,000 hours of cumulative operation in May 2026. Lately, the semiconductor and aerospace sectors have seen an increase in demand for radiation effect testing. Assessing these radiation effects is critical; as semiconductor devices scale down, single-event effects (SEEs) caused by cosmic and atmospheric radiation pose severe threats to system reliability. Therefore, rigorous radiation hardness assurance is paramount. In response to this need, KOMAC constructed a high-energy atmospheric-like neutron beamline utilizing a beam dump, which entered operation in 2025. At the sample position, the neutron flux reaches approximately $1x10^5$ /cm^2-s for energies exceeding 10 MeV. The reliability of this beamline was recently confirmed via SRAM irradiation, which yielded FIT (Failure-in-Time) rates highly comparable to other international facilities. International semiconductor testing standards (e.g., JESD89B, ECSS) recommend 200 MeV-class energies, revealing limitations in the existing 100 MeV infrastructure. To address this restriction, we have formulated an upgrade plan to elevate the accelerator energy to 200 MeV, thereby expanding both proton and neutron beamlines for advanced semiconductor testing. This presentation introduces the current status of the 100 MeV facility and details the upcoming 200 MeV upgrade roadmap.

This work was supported by the KOMAC operation fund of KAERI, which is funded by the Korean government-MIST (Ministry of Science and ICT)

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Refurbishment and Repurposing of the Indiana University Low Energy Neutron Source

David Baxter, John Ostler, Tyler Sipla, Gerard Visser, and Scott W. Wissink
Indiana University Center for Exploration of Energy and Matter, Bloomington IN, USA
Daniel Loveless
Indiana University Center for Reliable and Trusted Electronics, Bloomington IN, USA

E-mail: baxterd@iu.edu

Indiana University's Low Energy Neutron Source (LENS) served as a model for CANS facilities since achieving first-beam in 2005. LENS used a 13 MeV proton linac and thin Be targets to provide both fast (~10 MeV) and thermal/cold neutron beams until the onset of the pandemic. LENS has not operated since 2020 due to a combination of limited demand and loss of support staff.

A complete refurbishment of LENS is currently underway. As part of the SCALE initiative, we secured funding to replace all the plumbing and electrical components, repair and upgrade the vacuum system, and drain, disassemble, rebuild, and refill the three klystrons with new insulating oil. The interlock, monitoring, and safety systems have also been modernized and brought into compliance with current standards. Separately, the ion source (used to extract protons from hydrogen gas) has been rebuilt and now meets its original design specs. All three klystrons can be ramped to full voltage, and tests of extracted RF power will begin soon.

The SCALE program[1] focuses on the design, testing, and workforce development associated with radiation-hardened (rad-hard) microelectronics. Engineers and technical support staff from LENS will work closely with members of the IU Center for Reliable and Trusted Electronics to bring LENS fully online and establish the facility as an integral part of the rad-hard microelectronic testing ecosystem over the next few years, including its use in student training. The talk will cover various lessons learned from this effort and describe our plans for the facility's future.

Activities of Compact Accelerator-driven Neutron Sources in Japan

Yoshiaki Kiyanagi[1],
[1] *Emeritus prof. Hokkaido University and J-NOP, Japan*

E-mail: yoshikiyanagi22@gmail.com

CANSs are used for scientific and industrial applications, and medical application in Japan. Both applications are expanding. Neutron sources used for the first case are shown in Fig. 1. The fluxes written are for imaging use. For the first application, there are two large neutron sources, JRR-3 and J-PARC/MLF. JRR-3 is a 20 MW research reactor and MLF (Material Life Science Experimental Facility) in J-PARC is a 1 MW spallation neutron source. As well known, in these facilities various kinds of neutron experiments have been performed and they are key facilities. As a medium class neutron source, there was Kyoto University Research Reactor in the Institute for Integrated Radiation and Nuclear Science (KURNS) but its operation ceased on 23 April 2026. Therefore, importance of the CANSs has increased. HUNS at Hokkaido University was renewed and powered up from 1 kW to 3 kW. AISTANS in Tsukuba has begun to use 2nd beam line for radiography. RANS at RIKEN has been equipped with two stationary accelerators and is developing a portable neutron source set on a trailer. KUANS in Kyoto University is used for education, too. Aomori QSC and KUANS Linac are used for imaging and irradiation and so on. Sumiju ATEX (SHI ATEX) is actively used for imaging and irradiation.

For medical application, there exist nine facilities for BNCT. Fig. 2 shows the facilities and their accelerator energy and current with used targets. For treatment, Southern Tohoku BNCT Center, Kansai BNCT Medical Center in Osaka Medical and Pharmaceutical University started insurance covered treatment. National Cancer Center and iBNCT are proceeding clinical trial. Edogawa Hospital and Shonan Kamakura General Hospital have begun treatment under Specified Clinical Research. Kyoto University neutron source was used for clinical trial and then has been used for physical research of BNCT. NUANS in Nagoya University is used for irradiation. Fujita Health University is constructing a new BNCT facility to cure a cancer sit in deep place.

In the presentation, recent trend of the CANS and information on each facility are explained for both applications in Japan.

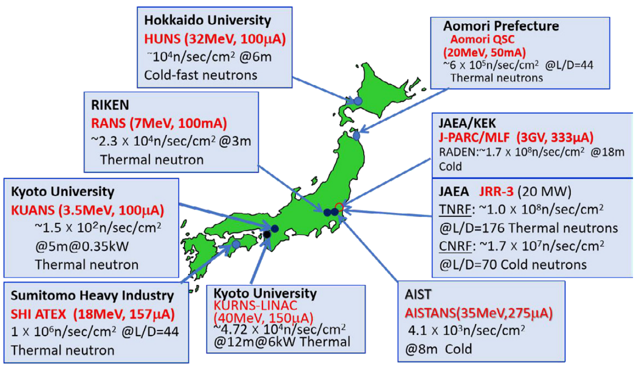

Fig. 1 Neutron sources for scientific and industrial applications.

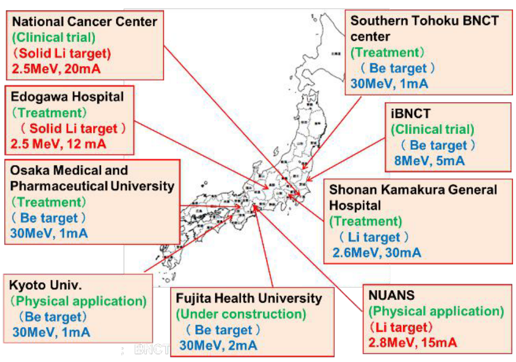

Fig. 2 BNCT facilities and relating CANSs.

Target and Neutronics Development for the Moderator Test Station at Oak Ridge National Laboratory

E. B. Iverson[1], K. C. Johns[1], A. V. Aleksandrov[1], G. P. Carden[1], V. Freudenberg[1], F. X. Gallmeier[1], K. B. Grammer[1], J. A. Watkins[1], A. S. Westover[1], and W. D. Willis[1]
[1]*Spallation Neutron Source, Oak Ridge National Laboratory, USA*

E-mail: iversoneb@ornl.gov

Oak Ridge National Laboratory operates the Spallation Neutron Source (SNS), providing high-intensity slow neutron beams for a variety of condensed matter, engineering, and basic physics applications with a 2 MW 1.3 GeV proton beam and a mercury target. The fast neutrons produced in the target must be efficiently moderated to low energies via moderators, sometimes called cold sources, which in turn are tailored to the specific needs and characteristics associated with given neutron instruments. A good moderator choice can improve instrument productivity by an order of magnitude, so innovative, efficient, and practical moderator designs are called for in the operation of the SNS facility as it stands, and through any future upgrades and expansions.

We describe a moderator test and development facility, the Moderator Test Station (MTS), now in the construction phase at the SNS. We will leverage the already-operational Beam Test Facility (BTF) at the Spallation Neutron Source (SNS) to provide a moderator neutronics test stand, where we will verify the anticipated performance gains expected from planned upgrades for the First Target Station as well as innovative moderator concepts central to the SNS Second Target Station (STS) project. These upgrades and concepts include high-brightness low-dimensional moderators like the tube moderator, intermediate temperature (i.e., 100 – 200 K) moderators such as ammonia, pelletized moderators, and moderators with extended lifetime against decoupler and poison burnup. The MTS will add various proton beam transport components, a neutron-producing target, a cryogenic moderator and gas handling system, a reflector-shielding assembly, and a neutron beamline to assess the performance of the moderator under test. This neutron beamline is a stand-alone instrument, optimized exclusively for moderator performance characterization, relying on advanced yet straightforward optical design, analyzers, and detectors.

This presentation will describe the Science Case for the Moderator Test Station, including the first moderators to be characterized and their potential benefits to SNS, the MTS design, and the project status, along with technical descriptions of the lithium target development effort and the radiation transport calculations performed in support of the project design.

Status of AISTANS: Facility, Measurements, and Promotion of Industrial Applications

Koichi Kino[1]

[1] *National Institute of Advanced Industrial Science and Technology (AIST), Japan*

E-mail: koichi.kino@aist.go.jp

The compact accelerator-driven neutron analytical facility AISTANS at the National Institute of Advanced Industrial Science and Technology (AIST) [1,2] successfully provided the first pulsed neutron beam from the 20 K solid methane moderator at its first neutron beamline in 2020. The first beamline is optimized for time-of-flight (TOF) measurements such as Bragg-edge imaging and TOF-type diffraction, using a short-pulse neutron beam from a decoupled moderator and a relatively long flight path of 8 m with supermirror guide tubes. In addition, the second beamline, which is optimized for neutron radiography and computed tomography (CT), became operational with a coupled solid methane moderator and a shorter flight path of approximately 4 m compared to the first beamline. These configurations provide sufficiently high neutron flux with a large field of view, which is required for radiography and CT imaging of industrial products. Complementary measurements—TOF-based diffraction and Bragg-edge imaging at the first beamline, and radiography and CT using an intense large-area neutron beam at the second beamline—are currently being performed. The diffraction method at AISTANS [3] is useful for obtaining crystal structural information, particularly for evaluating lightweight atoms or distinguishing atoms with similar mass numbers, which are difficult to analyze using X-ray diffraction. For Bragg-edge imaging, long-term tracking of the degradation of commercial lithium-ion batteries has been carried out [4]. In addition, studies on nondestructive imaging of crystals in bulk concrete are ongoing [5]. At the second beamline, a large-area neutron flat-panel detector (nFPD; 256 × 310 mm² active area, 200 µm pixel pitch, LiF/ZnS(Ag) scintillator) [6] is permanently installed just downstream of the sample position, approximately 4 m from the moderator. This setup enables ready-to-use neutron radiography and CT [7]. Various activities are being carried out to promote industrial applications of the AISTANS beamlines, including offering companies opportunities for trial measurements (both jointly and individually) and organizing webinar seminars.

In this presentation, the status of AISTANS will be reported from the perspectives of the facility, measurements, and promotion of industrial applications.

Part of this presentation is based on results obtained from a project, JPNP14014, commissioned by the New Energy and Industrial Technology Development Organization (NEDO). The author (K.K.) thanks all AISTANS project team members.

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Updates on nuclear data development in support of moderator and reflector design at the European Spallation Source

<u>José Ignacio Márquez Damián</u>[1], Douglas D. DiJulio[1], Thomas Kittelmann [2], and Günter Muhrer[1]
[1]*ESS Spallation Physics Group, Lund, Sweden,*
[2]*ESS Data Management and Scientific Computing Center, Copenhagen, Denmark*

E-mail: jose.marquez@ess.eu

Radiation transport simulations require accurate and complete nuclear data. In particular, for neutron moderator and reflector systems this translates into accurate scattering kernels that correctly model the interaction of low energy neutrons. To support this at the European Spallation Source there is a continuing effort to develop software tools and models to improve and extend thermal scattering kernels. In this talk we will present the latest updates on the topic that are relevant to the UCANS community, including the release of new thermal neutron scattering sublibraries in the ENDF/B [1] and JEFF [2] projects, and updates on the modeling of thermal scattering in NCrystal [3,4].

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Development of a Compact D-D Neutron Generator and Integrated Detection System for Industrial Non-Destructive Testing and Activation Analysis

Bongki Jung[1], Soobin Lim[1], and Dong Won Lee[2]
[1]Q-beam solution, Korea, [2]Korea Atomic Energy Research Institute (KAERI), Korea

E-mail: bkjung@qbeamsol.com

Compact accelerator-driven neutron sources (CANS) have attracted growing interest as versatile neutron facilities that can deliver beams of adjustable flux and energy spectrum at the point of use, offering a practical alternative to research reactors and large-scale spallation sources as access to reactor-based neutron beams becomes increasingly limited. Practical implementation, however, requires stable operation of the accelerator and target–moderator assembly, together with the radiation detection and data-analysis methods and the shielding and licensing framework, to be established as a single integrated system. To broaden the industrial utilization of neutron beams, we have adopted such an integrated approach, and we report recent progress on an accelerator-driven neutron platform for industrial non-destructive testing (NDT) and neutron activation analysis (NAA). A compact electrostatic D-D neutron generator has been developed with a compact deuterium ion source, a high-voltage feedthrough, and a titanium target. Thermal-fluid analysis and dedicated experiments were used to establish a stable plasma operating window, and remotely controlled operation achieved deuteron-beam extraction at up to 130 kV. A fast-neutron diagnostic system based on EJ-301 scintillator for yield measurement. Under the present test conditions, the measured neutron yield increased monotonically with accelerating voltage, reaching approximately 5.6 × 10^7 n/s at 100 kV. The analysis chain was evaluated separately by HPGe and $LaBr_3$ gamma-ray spectrometry, from which sample-dependent spectra and a characteristic prompt peak were identified. In parallel, detector-response libraries generated by MCNP simulation and multilayer-perceptron models are being investigated for radiation shielding and safety analysis.

The presentation will summarize the principal design and operational considerations of these systems (source–instrument integrated design, target heat management, moderation and collimation, detector response, and radiation licensing) and will show how such a compact platform can be adapted to different inspection and analysis requirements. Taken together, these developments define a staged pathway toward application-specific neutron systems for applications such as material recycling, metals and minerals processing, and security inspection.

Keywords: compact accelerator-driven neutron source; D-D neutron generator; neutron activation analysis; gamma-ray spectrometry; industrial non-destructive testing

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Development of a High-Flux Neutron Source for BNCT Using a Low-Energy Tandem Accelerator

Bong Hwan Hong, Chawon Park, Kyeong Min Kim, Won Taek Hwang, Minho Kim, Ho Namgoong, Donghyup Ha, Hyounggun Lee, Seungwoo Park
KIRAMS, Korea

E-mail: burnn@kirams.re.kr

Since 2019, the Korea Institute of Radiological and Medical Sciences has been developing a low-energy proton tandem accelerator as an accelerator-based neutron source for boron neutron capture therapy (BNCT). A tandem accelerator uses a single high-voltage terminal twice: negative ions are first accelerated toward the positively charged terminal, converted into positive ions by electron stripping, and then accelerated again away from the terminal.

In 2022, a 250 kV prototype tandem accelerator was fabricated, and stable extraction of a 500 keV, 6 mA proton beam was successfully demonstrated. In this system, H^- ions generated from a multicusp ion source are extracted at 30 keV and injected into the tandem accelerator. At the high-voltage terminal, an argon gas stripping system converts H^- ions into H^+ ions for the second acceleration stage. The argon gas is circulated inside the high-voltage deck using two turbomolecular pumps.

Based on the experience gained from the prototype system, a 1200 kV DC power supply using a Cockcroft–Walton multiplier has been developed, and a 1200 kV tandem accelerator has been constructed. The accelerator is currently under commissioning, with ongoing experiments to gradually increase the beam current. One of the major current issues is improving the stability of the DC high-voltage power supply, since the system shows vulnerability to transient discharges during beam acceleration. Research is also underway to reduce the overall length of the accelerator system.

To generate neutrons from 2.4 MeV low-energy protons, the $^7Li(p,n)^7Be$ reaction, which has a threshold energy of 1.882 MeV, will be used. For this purpose, a lithium deposition system was developed to deposit lithium onto a copper substrate, and lithium targets were fabricated. Figure 1 shows the developed tandem accelerator, the lithium deposition system, and the fabricated lithium target.

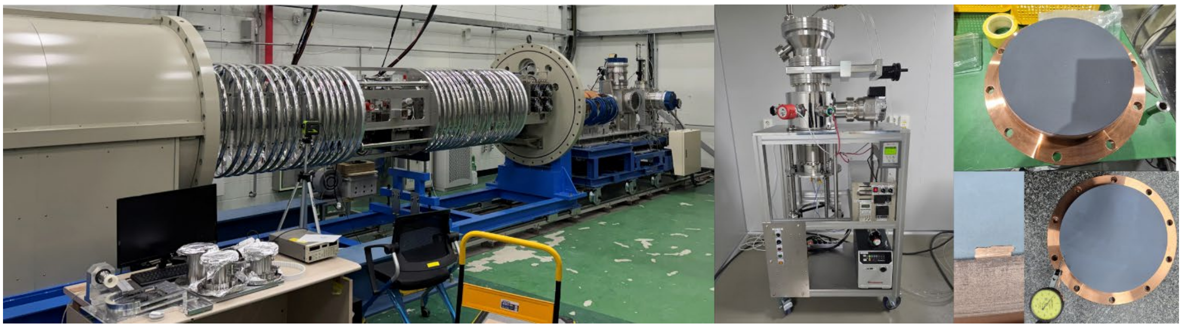

Fig. 1. Tandem accelerator(left), Lithium evaporation system(middle) and Lithium target(right)

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Efficient Stationary Liquid Lithium Targets for UCANS and BNCT Facilities.

F. Mezei and Ha Shuai, Mirrotron Ltd, Hungary
E-mail: ferenc.mezei@mirrotron.com

Liquid lithium has been successfully used as target for high power proton beams, for the purpose of neutron beam production. Liquid targets have crucial advantages compared to solid ones. In solids the crystal structure suffers strong mechanical damage by elastic collisions of the nuclei with the high energy protons and also by the accumulation of hydrogen atoms and molecules created by protons stopped in the target volume by energy losses without nuclear reaction with the Li nuclei. In a liquid target the displacement of the atoms by elastic collision with protons does not damage the atomic structure and the H atoms and H_2 molecules created by the slowed down protons can continuously leave the target as the result of fast diffusion to an upper surface of the target facing evacuated space. At high power proton beams the circulation of the liquid lithium target contained through a sizable cooling system outside the irradiated area offers a most advantageous solution for the evacuation of the deposited proton beam power. In the case of low power proton beams (typically below 50 - 100 kW), solid lithium targets hot rolled on a cooled metallic structure also offer a well working approach. However, since solid lithium has a moderate heat conductivity and is melting at 180.5 °C, thicker Li layers can easily melt on the proton irradiated surface, in spite of heavy cooling of their other side. The proton penetration in metals around proton energies < 3 MeV is in the range of 0.1 mm, which makes it impossible to place the Li target into a container behind a mechanically solid metallic wall. We propose cost-effective solutions taking advantage of the above favorable properties of liquid Li targets, without moving or circulating the liquid target material, also in cases where solid Li targets are currently used. On the one hand, we propose flat, fixed liquid containers with open top, offering a large free horizontal open liquid surface to the high vacuum volume of the proton accelerator and allowing the proton beam to hit directly this free Li surface from above, without going through any material window. This can happen e.g. in the vertical direction or at some convenient angle to it (typically < 70°). On the other hand, for proton beam energies larger than about 5 MeV, with the increased proton beam penetration capability in solid metals, one can also use nearly closed liquid Li containers with solid beam windows, e.g. for proton beam irradiation in the horizontal direction. In order to avoid accidental pressure difference between container and its accelerator environment, such a container must be safely kept at the level of pressure in the proton accelerator.

A particularly great advantage of a solid window for the proton radiation before reaching the liquid Li volume is that neutrons can be also generated by nuclear reactions of protons with the window material at eventually higher rates for faster protons than it would happen in Li above 3 MeV proton energies. Such a favorable window material is beryllium. By choosing the thickness of the window adequately smaller than the position of the Bragg peak in this material, more neutrons will be generated before slowing down of the protons in the window than it would be generated in Li in this proton slowing down energy range. The high neutron generation efficiency of Li at relatively low proton energies will work efficiently around the Bragg-peak location designed to be situated in the liquid Li layer, behind the proton window. All protons that avoided nuclear reaction within the Be window will either generate neutrons or stop in the following liquid Li layer. This way the accumulation of hydrogen atoms and molecules will happen in the liquid Li, making the lifetime of the window longer. Hydrogen will evaporate from the system through a mandatory open surface of the Li container to evacuated space. As an illustration, for about 8 MeV proton beam energy the thickness of the solid Be window could be 5 mm and that of the liquid Li layer in the range of 1 – 3 mm.

Intense Epithermal Neutron Source Using Low-energy and High-power Proton LINAC for Boron Neutron Capture Therapy

Young-soon Bae[1]
[1]*DawonMedax, Korea*

E-mail: ysbae1@dawonmedax.com

Boron neutron capture therapy (BNCT) has been attractive radiation cancer therapy as a new radiation modality because it can selectively destroy cancer cells while sparing the healthy cells. Many experimental trials have demonstrated significant BNCT treatment efficacy using neutron beams from research reactors. Since nuclear reactor technology cannot be scaled to sites in hospitals, compact accelerator-based neutron sources as an affordable to many hospitals are under development around the world. DawonMedax (DM) established in 2015, a leading global total solution provider of an advanced in-hospital accelerator-based BNCT medical system developed a highly efficient neutron source using proton LINAC. The neutron source provides the highly efficient production of an epithermal neutron beam with an optimized neutron energy spectrum range of 0.1 ~ 10 keV with a 10-MeV and 20-kW proton beam from the LINAC, and the epithermal neutron flux is higher than 1 x 10^9 n/cm^{2}s at the irradiation port. Using neutron beam generated by LINAC accelerator, DM has initiated clinical trials for the treatment of recurrent malignant gliomas and recurrent head and neck cancer for the first time in Korea since December 2022 at the remote BNCT clinic located at Songdo, Incheon. This paper presents performance and characteristics of LINAC-driven neutron beam and brief status of clinical trials.

VITA^{TM} Accelerator based Neutron Sources: Applications and Results

Sergey Taskaev[1,2]
[1]*BINP, Russia,* [2]*NSU, Russia*

E-mail: taskaev@inp.nsk.su

The accelerator based neutron source VITA® is a facility that includes an electrostatic tandem accelerator of charged particles of an original design for obtaining stationary beam of protons or deuterons with an energy of 0.1 MeV to 2.3 MeV with current up to 10 mA, a thin lithium target for generating neutrons and set of neutron beam shaping assemblies [1]. The facility produces neutron beams in a wide range of energies: fast, supra-epithermal, epithermal, monoenergetic, thermal and cold. The facility is used to develop boron neutron capture therapy (BNCT), including the treatment of domestic cats and dogs with spontaneous tumors, testing new boron delivery drugs, and the development of dosimetry tools and methods [2]. We have opened the era of lithium neutron capture therapy, which brings a new quality – 100% delivery of the dose to tumor cells [3]. Considerable attention is paid to obtaining fundamental knowledge: measuring the yield of particles and the cross-section of nuclear reactions [4, 5]. The facility is used for radiation testing of boron carbide and steel samples for the ITER, optical cables for the Large Hadron Collider [6], neodymium magnets for a powerful linac, semiconductor photomultipliers, electronic components and devices, etc. The use of a thin lithium target makes the neutron source extremely bright, which can be used to build a neutron-neutron collider. As a first step towards the ambitious project, it is proposed to obtain a beam of cold (ultracold) neutrons and, using a sextupole magnet, repeat the Stern-Gerlach experiment and give it a correct description [7]. The next step could be the creation of a neutron-electron collider for the first time to directly study the neutron.
Two neutron sources VITA-II made for oncology clinics. The first source was delivered to China and has been used for several years to conduct clinical trials of BNCT, which allowed China to become the second country in the world to master the new method of treating malignant tumors. The second source has been delivered to an oncology center in Moscow, Russia, where clinical trials will soon begin, making Russia the fifth country in the world to master the new method of treating malignant tumors.
Experience gained from operating slightly different neutron sources has allowed the development of a third version VITA-III, which is distinguished by the use of a more compact gas stripper and the use of pre-decelaration instead of pre-acceleration of the injected ion beam. This will make it possible to obtain a parallel beam of protons and eliminate the need for a high-voltage platform, an isolating transformer, and a number of focusing devices.
The report describes the facilities, presents the results of the research conducted and declares plans.
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Development and Application of BNCT in China

Sheng Wang[1,2]
[1]*Xi'an Jiaotong University*, [2]*HBNCT Co., Ltd., China*

E-mail: shengwang@xjtu.edu.cn

Boron neutron capture therapy (BNCT) is a biologically targeted radiation therapy based on the selective accumulation of boron-10 in tumor cells and the subsequent $^{10}B(n,\alpha)^{7}Li$ reaction induced by neutron irradiation. The high-linear-energy-transfer particles generated in this reaction have ranges comparable to cellular dimensions, enabling selective tumor-cell destruction while reducing damage to surrounding normal tissues. Traditionally, BNCT was mainly dependent on reactor-based neutron sources, which limited its accessibility and clinical deployment. With the rapid development of compact accelerator technologies, accelerator-based BNCT (AB-BNCT) has emerged as a promising and more practical approach for hospital-based applications. In recent years, BNCT development in China has accelerated rapidly, supported by advances in accelerator-based neutron sources, high-power target systems, beam shaping assemblies, boron-containing pharmaceuticals, treatment planning, radiation dosimetry, and neutron monitoring. The transition from reactor-based facilities to compact accelerator-based systems has improved the accessibility, operational flexibility, and potential clinical deployment of BNCT. This talk will review the development and application of BNCT in China, with particular emphasis on the accelerator-based BNCT program jointly promoted by HBNCT Co., Ltd. and Xi'an Jiaotong University. The project integrates high-current proton accelerators, high-power and long-lifetime neutron-production targets, beam shaping assemblies and shielding systems, neutron detection, treatment planning, boron drug development, and system engineering. Particular attention will be given to the stable operation of compact proton accelerators, thermal management and irradiation resistance of solid lithium targets, optimization of epithermal-neutron beam quality, and the engineering integration of BNCT systems. The progress of system construction, biological experiments, medical evaluation, and clinical translation will also be discussed.

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GIF-SANS: A CANS-based SANS with High Neutron Current, Wide *Q* Range, and Low Noise

Meng Yuan[1], Weihang Hong[1], Xuewu Wang[1], and **Zhe Wang[1]**
[1]*Department of Engineering Physics, Tsinghua University, Beijing, China*

E-mail: zwang2017@mail.tsinghua.edu.cn

The GiF-SANS developed at the CPHS [1] (Tsinghua University, China) addresses the critical challenges of realizing high-performance SANS instrument based on CANS — achieving high neutron current, wide Q range, good resolution, and limited length. The key is to employ a novel nested multi-layer grazing-incidence neutron supermirror combined with a post-collimation aperture system, as illustrated in Fig. 1 [2]. This design achieves a significant gain in neutron flux, an extended Q_{min}, and a good resolution. The maximum neutron current at the sample exceeds 10^5 n/s under 8 kW proton beam operation, corresponding to two orders of magnitude gain relative to the pinhole optics. Two interchangeable detectors are equipped: a large-area ^{3}He linear position-sensitive detector for routine measurements, and a high-resolution neutron-sensitive microchannel plate detector to extend the Q_{min} down to ~10^{-3} Å^{-1}. By switching between focusing and pinhole optics, together with interchangeable detectors, GiF-SANS covers a broad Q-range from 2×10^{-3} to 0.7 Å^{-1}. The instrument has been fully validated through scattering experiments with standard samples.

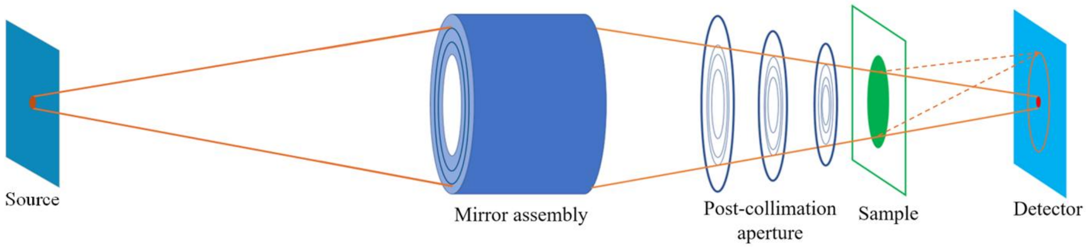

Fig. 1. Schematic configuration of the neutron optics of GIF-SANS.

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Prompt Gamma Imaging with Compton Cameras for Boron Neutron Capture Therapy

Shuai Ha[1,2], Ferenc Mezei[2], and Szabolcs Czifrus[3]
[1]*Eötvös Loránd University, Pázmány sétány 1/A, 1117 Budapest, Hungary*
[2]*Mirrotron Ltd, Konkoly-Thege Miklós út 29-33, 1121 Budapest, Hungary*
[3]*Institute of Nuclear Techniques of Budapest University of Technology and Economics, Műegyetem rkp. 3, 1111 Budapest, Hungary*

E-mail: shuai.ha@mirrotron.com

The development of compact accelerator-driven neutron sources has opened new opportunities for medical applications of neutrons, particularly accelerator-based boron neutron capture therapy (AB-BNCT). As AB-BNCT moves toward wider clinical implementation, reliable methods for treatment verification and dose monitoring become increasingly important. Prompt gamma rays produced during neutron capture reactions provide a potential means for real-time visualization of neutron-capture activity and indirect assessment of the delivered dose distribution. The challenge of imaging such gamma-ray emissions has stimulated interest in detector technologies originally developed in other fields.

Among these technologies, the Compton camera has attracted particular interest. Originally developed for gamma-ray astronomy to localize celestial gamma-ray sources without the use of mechanical collimators, the Compton camera has subsequently found applications in nuclear security, environmental monitoring, and medical physics owing to its high detection efficiency and imaging capability. More recently, Compton-camera imaging has emerged as a potential tool for real-time monitoring of BNCT.

In this work, the feasibility of using a Compton camera to image prompt gamma emissions during accelerator-based BNCT is investigated using Monte Carlo simulations. The study examines the capability of reconstructing the spatial distribution of gamma-ray-emitting regions and evaluates the influence of background radiation originating from surrounding healthy tissues. The results demonstrate that prompt gamma imaging can provide spatial information on boron-enriched tumor regions and, under favorable conditions, allows the discrimination of tumor structures separated by approximately 2 cm. However, gamma rays produced outside the target volume significantly degrade image quality and remain a major challenge for quantitative treatment monitoring. Within the studied scope, the prompt gamma distribution cannot be monitored for tumors with a size below $1\times1\times1$ cm^3. If the dimension of a single tumor is no smaller than $2\times2\times2$ cm^3, it is feasible to monitor the prompt gamma distribution to a certain extent. These results highlight both the potential and the current limitations of Compton-camera-based imaging for BNCT and indicate the need for improved background-rejection and reconstruction techniques to enable reliable clinical implementation.

UCANS12

Oral Talk

12th International Meeting of the Union for
Compact Accelerator-driven Neutron Sources

FETSMETS concept design performance and safety considerations

S Lilley, K Gelborova, P Morgan, A Chrysafi, S Gallimore, S, Jago

ISIS Spallation Neutron and Muon Source

At ISIS we are investigating the potential to use an existing compact accelerator for moderator testing and development. The Front End Test Stand (FETS) has been used to develop ion sources for ISIS and provides a 3 MeV H- ion beam with an average beam current of 6 mA at 10% duty factor. FETS has a pulse chopper which enables the proton pulse to be shaped and chopped to match a short pulse neutron source in pulse length, with a corresponding reduction in protons.

A project has been initiated to investigate adding a neutron target to FETS to create a Moderator Engineering Test Stand (FETS-METS) [1]. In order to do this a range of systems are needed including: a lithium target, a reflector, cryogenic systems for the cold moderators, diagnostics and safety systems.

The facility has been simulated using MCNP [2] coupled with McStas [3] to estimate the performance with a wide range of moderators and examine which moderator properties can be evaluated in a timely manner and which pulse length is suitable for different moderator studies.

The supporting safety calculations include MCNP simulations coupled with FISPACT [4] calculations for both neutron and proton activation with automated analysis of shutdown dose rate & radioactive waste levels at different decay times. In addition, initial FESTIM [5] calculations have been performed for tritium migration in the target showing the potential impact of a titanium layer on the lithium target on tritium retention.

In this work we will describe the potential long and short pulse performance, impact of proton beam size, target design considerations such as nuclear heating and gas production. We will also describe neutron and proton activation calculations including tritium production and the impact on maintenance and radioactive waste.

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Monte Carlo Simulation-based Neutron Target Design for KOMAC 200 MeV Proton Accelerator Upgrade

Gyuhaeng Jo[1], Junsik Kim[2], Seung-Hyun Lee[1], Sang-Pil Yun[1], Dong-Hwan Kim[1], SeokHo Moon[1], Sungbin Park[1], Han-Sung Kim[1], and **Hyeok-Jung Kwon[1]**
[1]*Korea Multi-purpose Accelerator Complex, Korea Atomic Energy Research Institute, 181, Mirae-ro, Gyeongju-si, Gyeongsangbuk-do, Republic of Korea*
[2]*Department of Nuclear Engineering, Seoul National University, 1, Gwanak-ro, Gwanak-gu, Seoul, Republic of Korea*

E-mail: hjkwon@kaeri.re.kr

KOMAC 100 MeV proton accelerator, which has been in operation since 2013, is scheduled to be upgraded to 200 MeV. One primary objective of this upgrade is to establish a beamline for evaluating the effects of cosmic rays and terrestrial neutrons incident on semiconductor components and materials. Therefore, by referring to the specifications of overseas neutron research facilities based on proton accelerators, Monte Carlo simulations were conducted to characterize the neutron flux and energy spectrum generated by collision between the metal target and the upgraded proton beam to develop a blueprint for the 200 MeV neutron target system.

Through these simulations, it was confirmed that, if the proton beam current and duty are maintained after the 200 MeV upgrade, the terrestrial neutron beamline at the KOMAC proton accelerator with aluminum and tungsten targets will be able to achieve a similar fast neutron flux, which is over 10 MeV, to the existing facilities.

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Preparation and Characterization of a Series of Targets for Monoenergetic Neutron Reference Radiation Fields

QIAO Zhaopeng [1], ZHANG Ke, LIU Liye, YU Weiyue, CHEN Faguo, LI Deyuan
China Institute for Radiation Protection, Taiyuan 030006, Shanxi, China

E-mail: qiaozhaopeng@126.com

Monoenergetic neutron radiation fields serve as core benchmark conditions for neutron metrology, detector calibration and nuclear data research. The China Institute for Radiation Protection is constructing an accelerator facility to generate monoenergetic neutrons ranging from 2 keV to 19 MeV, which requires scandium (Sc), lithium (Li) and deuterium (D) targets.

To fabricate a series of high-performance Sc, Li, LiF and TiD targets, we conducted four main studies. Firstly, the target thickness was optimized. The Monte Carlo method was used to simulate the neutron generation. The correlation between proton incident energy, target areal density, film thickness, and neutron fluence as well as the full width at half maximum of the neutron energy spectrum was analyzed to determine the optimal areal density range. Secondly, four types of targets were fabricated, and the optimal preparation scheme for each was summarized. In particular, three techniques, namely magnetron sputtering (MS), resistance heating evaporation (RH) and electron beam evaporation (EB), were applied and compared for LiF target preparation. Thirdly, we systematically characterized the thin films in terms of thickness, areal density, surface morphology and chemical composition. Fourthly, a irradiation test was performed. A RH prepared LiF target was irradiated by proton beams on the 2×3 MV tandem accelerator at Sichuan University. The resulting neutron fluence and energy spectrum were measured and analyzed.

The results indicate that the Sc target fabricated via MS without glove box protection suffers from severe carbon and oxygen contamination. To mitigate this issue, we plan to raise the base vacuum level prior to deposition. For LiF targets, the deposition rate of MS is one order of magnitude lower than that of EB and RH. Nevertheless, the resulting films possess a notably higher areal density. During EB deposition of LiF, the source material tends to agglomerate and discolor owing to localized high temperatures. Irradiation tests on the LiF target prepared by RH demonstrate that it can produce a monoenergetic neutron field, whose characteristics are in good agreement with simulation results. Additionally, we attempted to fabricate lithium targets, though LiF targets are more widely adopted for monoenergetic neutron production. Finally, qualified TiD targets were successfully fabricated via a two-step process: titanium films were first deposited by MS, and the coated samples were subsequently kept in a high-temperature deuterium atmosphere.

In summary, we have successfully fabricated a range of Sc, Li, LiF and TiD targets dedicated to monoenergetic neutron production. Follow-up systematic irradiation experiments will be performed to assess target performance and refine fabrication techniques. The outcomes lay a technical foundation for constructing a high-purity monoenergetic neutron reference radiation field.

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Neutron Phase-Space Cooling for an Intense Very-Cold Neutron Source

Yun Chang Shin[1],
[1]*Independent Researcher, South Korea,*

E-mail: graser@gmail.com

Very-cold neutrons (VCNs) are neutrons with energies below 1 meV. Despite their low kinetic energies, VCNs possess sufficient velocities to form well-defined beams. The realization of intense VCN beams with high phase-space density would enable transformative advances across a broad range of scientific disciplines. However, conventional cold neutron moderators are fundamentally limited by the absence of low-energy excitation modes capable of efficiently thermalizing neutrons into the VCN regime.

In this work, we investigate the role of collective excitations in neutron phase-space cooling by determining effective neutron spectral temperatures associated with discrete excitation modes. This approach yields a clear physical picture of the mechanisms governing neutron moderation toward the VCN regime. Our analysis identifies the solid methane-argon (CH_4-Ar) system in the glassy phase as a promising candidate moderator for VCN production [1]. By virtue of its high density of low-energy excitations in the rotational mode and the large neutron scattering cross section of hydrogen, this system offers a viable pathway toward generating the intense VCN beams required for next-generation neutron research. Furthermore, this study establishes a systematic framework for identifying and designing advanced moderator materials optimized for future VCN sources.

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Development of A Quasi-Monoenergetic Neutron Beamline for the 30~50 MeV Energy Range

Xiaobo Li[1], **Sumin Wei**[1], **Zhe Wang**[1], **Bin Ji**[1], **Shizhong An**[1], **Fengping Guan**[1]
[1] *China Institute of Atomic Energy, Xinzhen, Fangshan, Beijing, China*
E-mail: lixiaobo@ciae.ac.cn

Due to the growing demand for high-energy neutrons in irradiation effect studies and neutron measurements—driven by advances in space exploration, medical treatment, and high-energy physics[1-4]—a quasi-monoenergetic neutron beamline in the 30–50 MeV range, based on a 50 MeV proton cyclotron, is currently under construction. This study focuses on the design of the beamline, particularly the target chamber and collimator. A comprehensive comparison of the thermodynamic and nuclear properties of lithium and beryllium was conducted. Lithium was selected as the target material due to its better performance in generating a distinct quasi-monoenergetic neutron peak. Parametric simulations of lithium thickness were carried out, considering both neutron generation efficiency and spectral quality[5-8]; the results reveal how the height and width of the quasi-monoenergetic peak change with thickness. The energy loss of incident protons caused by the titanium film and argon gas was estimated to provide a reference for the mechanical design of the target chamber. The variation of neutron spectra and fluxes at different distances from the target, as well as for collimators of different lengths, was evaluated. Based on neutron flux and the ratio of the quasi-monoenergetic peak, the collimator length was determined to be 2 m. This work provides a data reference for the construction and operation of the quasi-monoenergetic neutron beamline. The quasi-monoenergetic neutron beamline has now been completed and acceptance-tested, achieving a neutron flux on the order of 10^4 n/(cm^2·s) at the exit.

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Toward Developing an Electron Linac-Based Neutron Source for Bragg Edge Imaging at PAL

Mahdi Bakhtiari, Nam-Suk Jung, and **Hee-Seock Lee**
Pohang Accelerator Laboratory (PAL), POSTECH, Pohang, South Korea
E-mail: lee@postech.ac.kr

Compact Accelerator Neutron Sources (CANS) offer a promising and accessible alternative to conventional reactor and spallation-based neutron facilities for material characterization [1]. CANS provide near-user, small-scale platforms capable of supporting Bragg edge imaging, a nondestructive technique for mapping texture orientation, phase volume fraction, and crystallite size of structural materials. In Korea, this technique based on accelerator-driven neutron sources has not yet been established, motivating the present work at the Pohang Accelerator Laboratory (PAL).

This project utilizes the dedicated 70 MeV electron linear accelerator (e-Labs) at PAL, which operates at a repetition rate of ~60 Hz with an average beam current of 18 nA. A neutron time-of-flight (TOF) measurement facility has been constructed, featuring a tungsten target (5×5×1.75 cm^3), a target-to-detector distance of 26.5 m.

Fast photoneutron production yields from the tungsten target were successfully measured using a liquid organic scintillator (EJ-301) with pulse-shape discrimination (PSD) for neutron-gamma separation. The measured neutron intensity was 0.98 ± 0.01 n/s in the energy range $1.4 < E_n < 12.6$ MeV, at an electron charge of 346 ± 9 pC. Measured yields were compared against Monte Carlo predictions from PHITS-3.28 [2] and FLUKA 4-3.0 [3]. While both codes showed good agreement at lower neutron energies, they underestimated the data above 4 MeV. PHITS calculations incorporating the TENDL-2019 [4] and JENDL-5.0 [5] nuclear data libraries showed improved agreement with experiment.

The feasibility of cold neutron production was demonstrated using a polyethylene (PE) moderator at both room temperature (296 K) and cryogenic temperature (87 K, cooled with liquid nitrogen). Cold neutrons were detected using a LiI(Eu) scintillator. The integrated cold neutron flux ($4 < E_n < 16$ meV) increased by a factor of 1.2 when the moderator was cooled to 87 K, confirming the effectiveness of a cooled PE moderator for cold neutron enhancement.

A Bragg edge transmission imaging was performed at the Hokkaido University Neutron Source (HUNS) in Japan to verify the imaging methodology. Samples of 304 austenitic stainless steel were irradiated using a GEM-type 2D detector. Neutron transmission spectra were analyzed. Crystallite size, texture, and phase volume fractions were successfully extracted and validated against Electron Backscatter Diffraction (EBSD) measurements, confirming that crystallite size increases with annealing temperature [6]. This work establishes the foundational steps toward a fully operational electron linac-driven neutron source at PAL for Bragg edge imaging-based material characterization in Korea

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HUNS is back: renovation and recent experiments at the Hokkaido University Neutron Source facility

<u>Hirotaka Sato</u>[1], Hiroki Nagakura[1], Ko-ichi Sato[1], and Takashi Kamiyama[1]
[1]*Hokkaido University, Japan*

E-mail: h.sato@eng.hokudai.ac.jp

The Hokkaido University Neutron Source, HUNS, facility is based on pulsed cold/thermal/fast neutron sources driven by 32 MeV-100 μA-3.2 kW electron linear accelerator with 4 μs-100 Hz electron pulses [1]. The old accelerator and the facility building were constructed in 1973, the new accelerator was installed in 2018, and the new electron transport tubes were installed in 2020. In 2024-2025, the facility building was renovated as shown in Figure 1. In this presentation, the renovation status of the HUNS facility building is reported. In addition, during the renovation, our neutron experimental activities were helped by Japanese neutron facilities, such as J-PARC MLF, AISTANS (CANS), SHI-ATEX (CANS) and KURNS-LINAC (CANS). Such support experimental activities are also reported.

After completing the renovation (the end of July 2025), RF was input at 20 Hz on 14th October 2025. However, since the vacuum level near the electron gun rose from 10^{-8} Pa to 10^{-6} Pa, we confirmed that the aging was required. On 7th November 2025, the neutron production was confirmed under 8% power condition of the electron accelerator. On 8th December 2025, a neutron beam experiment was restarted under 40% power condition of the electron accelerator. In May 2026, the power of the electron accelerator reached 60% owing to the aging. Such restarted accelerator operation status is reported in this presentation.

Various neutron experiments were conducted at HUNS after the facility building renovation. For example, three crystalline phase imaging of ferrite-austenite-martensite steel was achieved by wavelength-resolved cold/thermal neutron transmission imaging with triple Bragg-edges analysis method. The energy-dependent neutron transmission data of various neutron shielding materials were measured from cold to epithermal neutron energy range. The non-destructive crystal structure and elemental composition analyses of cultural heritage materials were carried out. The Bragg-edge imaging of additive manufacturing samples was conducted. The fast neutron irradiation experiments were conducted for astrophysics, radiation biology, semiconductor and structural materials. In this presentation, we report recent experiments performed at HUNS after the renovation.

Figure 1. Renovation of the HUNS facility building.

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Experimental Validation of Neutron Reflection Power by Nano-sized Graphene Plate via. Coherent Scattering of Cold Neutrons Extracted through a Slit Collimator at RANS

Y. Ikeda[1], K. Saruta[2], Y. Kawamura[1*], M. Teshigawara[2*], K. Muramatsu[3], K. Sutani[3], K. Kimijima[3], M. Fukuzumi[4], Y. Noda[5], S. Koizumi[5], D. Kuwahara[1], A. Muneem[1]and Y. Otake[1],

[1]RIKEN, [2]J-PARC Center, [3]INCUBATION ALLIANCE INC.,
[4]Hyogo Prefectural Institute of Technology, [5]Ibaraki Univ

Corresponding author Y. Ikeda: E-mail yujiro.ikeda@riken.jp

To meet strong demand for high intensity cold neutrons in material science, we have proposed an intensifier of low energy neutrons using reflector material of graphene which has been developed incorporating HIP technology [1]. Although supreme scattering characteristics of the graphene in terms of its high total cross section via. coherent scattering and small angle neutron scattering strength, have already been experimentally confirmed by comparing with those of nano-diamond [2], importance has been addressed to show directly the neutron intensification power with a large size graphene materials layer. Thus, we have carried out experimental confirmation of performance with the plate type graphene in terms of high reflection power under a configuration with a short flight path of 1.5 m between the full surface of the cold neutron moderator at RANS and the graphene plate scatterer, where a slit collimator with small gap of 7 mm was installed in between in order to extract incident neutrons onto the graphene plate. This experimental set up was designed to increase gain in event rates at the GEM (Gas Electron Multiplier) detector positioned in forward direction after the scatterer. Given a relatively poor signal to noise ratio, this scheme associated with the slab geometry of RANS, enabled measurements of energy and angle dependent scattering characteristics in forward direction, from 0 to 10 deg with respect to incident proton direction of RANS. Along with graphene, measurements were carried out on graphite, Al, Fe and polyethylene (PE) for comparison. Even though energy and angle resolutions are poor due to the short flight path and rather broad space incident neutron distribution, we have successfully observed clear differences in scattering strength between graphene and other materials. In neutron energy range less than 1 meV, and at an angle range from 3 to 6 deg., graphene exhibited scattering intensity larger by a factor of 3 than that of graphite, and higher by a factor of 20 than these of Al, Fe and PE.

In this paper, along with the new slit collimator set-up concept, we report results for the effective angle dependent increase of scattered neutrons from graphene plate as a function of plate inclination with respect to extracted neutron beam direction. Discussion is to be also given on possible design of the neutron intensifier incorporating graphene materials.

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Unified Multi-Foil Activation Analysis for Dome Characterizing Domestic Accelerator-Based Compact Fast Neutron Sources

Soobin Lim[1], Jooyub Lee[2], Junsik Kim[2], Geehyun Kim[2], Kyung-Jae Chung[2], Jeong-Jeung Dang[3]*
[1]*Q-Beam Solution Inc., Daejeon*
[2]*Seoul National University, Seoul*
[3]*Korea Institute of Energy Technology, Naju*

E-mail: jjdang@kentech.ac.kr

Reliable use of compact accelerator-driven neutron source facilities for fusion-relevant irradiation studies requires quantitative characterization of neutron flux and spectral characteristics at the irradiation position. Because source geometry, shielding, detector accessibility, and local background conditions vary among facilities, direct detector-based measurements may not provide a consistent basis for cross-facility comparison. Therefore, this work employed multi-foil neutron activation analysis (NAA), in which activation foils record integral neutron-field information through induced radioactivity and are analyzed by gamma-ray spectrometry. Multi-foil NAA was conducted at three neutron-source facilities using several activation foils selected according to the expected neutron-energy range, flux level, irradiation geometry, activation cross sections, product half-lives, and gamma-counting feasibility. Candidate materials included In, Ni, Al, Co, Fe, Nb, and Bi. The measured gamma-ray activities were used to derive reaction rates and evaluate the neutron-field characteristics at each irradiation position. The results provide a common experimental basis for comparing compact neutron source facilities and assessing their applicability to fusion-relevant irradiation studies.

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Development of Novel Polyethylene Composite with High-concentration LiF for Neutron Shielding

Naoyuki Kitamura, Takeshi Ikeda, and Tetsuyuki Nakamura
Daico MFG Co., Ltd.

E-mail: n_kitamura@daico.co.jp

In various neutron-utilizing facilities, particularly neutron capture therapy facilities, resin materials dispersed with thermal neutron-shielding inorganic substances (such as LiF, B_4C) [1] or sintered ceramics composed of these substances are widely used. We have been developing the latter – specifically, fluoride ceramic materials – with the aim of effectively shielding thermal neutrons [2]. On the other hand, while the former (resin materials) can also shield fast neutrons and is widely used. Resin materials containing high concentrations of LiF or B_4C for effective thermal neutron shielding have not been commercialized. This is because the uniform mixing of powder inorganic materials into resin remains difficult. This research aims to develop a polyethylene composite material containing a high concentration of LiF via a novel process analogous to ceramic firing.

In this study, nano-sized LiF and polyethylene particles were used as starting materials. We fabricated a composite by uniformly mixing the raw material powders – comprising about 1 μm LiF powder and polyethylene (PE) nanoparticles smaller than 100 nm – and subsequently heating the mixture at moderate temperatures to soften the resin, thereby binding the powders together. Uni-axial pressure applied before or during the heating process. Polyethylene composites were successfully prepared in the range of 50-90 wt% LiF. Fig. 1 shows a photograph of 75 wt% LiF:PE composites prepared by this process. The bulk density of the fired body was approximately 95% at LiF concentrations of 80 wt% or less, and the flexural strength was confirmed to be 10-20 MPa, which is equivalent to that of ordinary polyethylene. At LiF concentrations above 80 wt%, both bulk density and flexural strength tended to decrease with increasing LiF content. Moreover, the composite with an intermediate concentration of 75 wt% LiF could be subjected to bending and film processing using reheating.

Fig.1 Photograph of 75wt%LiF:PE composites (220mm square-11mmt).

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Development of High-LET Neutron Irradiation Platforms for Next-Generation Mutation Breeding

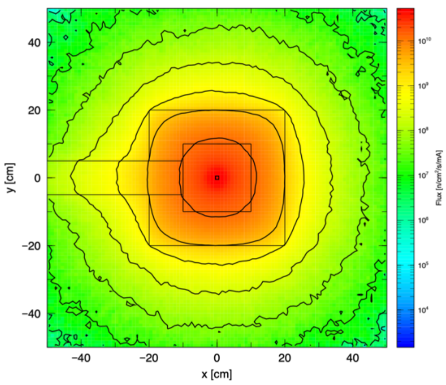
May Sweet[1], Kenji Mishima[2], Hiroyuki Uno[3], Randa Permanda[1], Daspute Abhijit Arun[1], Norio Kikuchi[1]

1 Quantum Flowers & Foods Co., Ltd., QFF Tokyo Head Office

Seven Bldg. 7F, 3-7-14 Nihonbashiningyo-cho, Chuo-ku, Tokyo 103-0013, Japan,

2 RCNP, The university of Osaka, 10-1 Mihogaoka, Ibaraki, Osaka, 567-0047, Japan, 3 SHI-ATEX Co., Ltd, 1501 Imazaike, Saijo City, Ehime Prefecture 799-1393, Japan

Fast neutron (FN) irradiation is a promising novel approach for breeding based on mutagenesis. The FN irradiation results in high-LET recoil particles that can induce large-scale genomic variations, including deletions, inversions, and translocations, as well as structural rearrangements that are difficult to achieve using conventional photon-based mutagenesis methods. Although previous studies [1] have investigated dose-LET distributions for spallation sources such as J-PARC BL10 and basic compact accelerator-driven neutron source (CANS) models such as KUANS, it's necessary to develop a well-defined procedure framework for frequent high-throughput biological applications. This study presents a controlled irradiation protocol that used the 18 MeV proton-driven ^{9}Be (p,n) reaction at the SHI-ATEX cyclotron [2] in both the thermal and FN beamline configurations. In contrast to conventional experimental methods [3], we developed a method to optimize the neutron flux for the FN around a 1 MeV neutron energy range. The narrow spectral focus of our method allows the dose (Gy) delivered at these energies to directly correlate with a high-LET recoil-proton field at 20-70 keV/um and thus with increased double-strand break induction, with minimized non-mutagenic side effects. The integration of Monte Carlo dose calculations and experimental dosimetry enabled us to determine uniform irradiation conditions for seeds, live plants, and microbial suspensions. It showed the potential of a standard FN irradiation framework for mutation breeding. Furthermore, this approach enables new applications for UCANS with compact accelerator-driven neutron sources, broadening research and development.



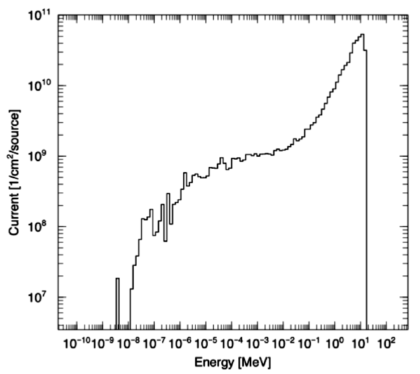


Fig. 1. Flux distribution mapping for standardized irradiation of targeted biological samples.

Fig. 2. Neutron energy spectrum 18 MeV, ^{9}Be (p,n) the around 1 MeV peak optimizes high-LET recoil proton production for precise mutation induction.

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Activation Experiment with Neutron Beam Produced by 30 MeV Proton Bombardment of Beryllium

Dal-Ho Moon[1], Sung-Chul Yang[1], Tae-Yung Song[1], and Jong Chul Lee[2]
[1]*Nuclear Physics Application Research Division, Korea Atomic Energy Research Institute, Daejeon 34057, Republic of Korea,* [2]*Accelerator and Radioisotope Development Team, Korea Atomic Energy Research Institute, Jungeup 56212, Republic of Korea*

E-mail: dhmoon@kaeri.re.kr

A neutron activation experiment was performed using neutrons generated by the irradiation of a Be target with 30 MeV protons from the RFT-30 cyclotron at the Advanced Radiation Technology Institute (ARTI). The neutron energy spectrum and beam intensity were determined using an unfolding method. The unfolding analysis was performed using activation data measured with Al, Fe, Co, Nb, Ta, and Au foils. The neutron-induced reaction cross sections for the target materials were measured based on the obtained neutron flux. The activities of the reaction products were determined using a High-purity germanium (HPGe) detector. The measured cross sections were compared with available experimental data reported in the literature, as well as with evaluated nuclear data from TENDL library. These results contribute to the validation of nuclear reaction models and the improvement of neutron cross section data for accelerator based neutron applications.

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RECENT STATUS OF A NEUTRON EXPERIMENTAL SYSTEM AT THE RAON HEAVY ION ACCELERATOR

Cheolmin Ham[1], Geonhee Oh[1], Seong Jae Pyeun[1], Sinchul Kang[1], CheongSoo Lee[1], Changwook Son[1], Kwang-Bok Lee[1], Sangjin Lee[1], Dong Geon Kim[1], Minsik Kwag[1], Jae Cheon Kim[1], Mi Jung Kim[1], EunHee Kim[1], Jinho Lee[1], Young-Ouk Lee[1,2], and Kyoungho Tshoo[1]

[1] *Institute for Rare Isotope Science, Institute for Basic Science, Daejeon, Republic of Korea,*
[2]*Korea Atomic Energy Research Institute, Daejeon 34057, Republic of Korea*

E-mail: cmham@ibs.re.kr

RAON (Rare isotope Accelerator complex for ON-line experiments) is a heavy ion accelerator facility in South Korea designed to provide both stable and rare isotope beams ranging from protons to uranium ions over a wide energy range. Various ion beams, from proton to lead, are generated by the Electron Cyclotron Resonance (ECR) ion source. These beams are accelerated by the Superconducting LINAC 3 (SCL3) and delivered to several experimental systems, including the Nuclear Data Production System (NDPS), which is dedicated to neutron production and nuclear data measurements.

Nuclear Data Production System (NDPS) [1,2] is a neutron experimental device that generates neutron beams up to 100 MeV using ion beams from SCL3. Although NDPS is designed to provide pulsed beams for future Time-of-Flight measurements, current operations use continuous beams for neutron production. Neutrons are transported through a 4-m collimator to an adjustable 5–50 m flight path in the experimental area. NDPS supports two neutron production modes: quasi-monoenergetic neutrons generated by proton beams on thin ^{nat}Li targets, and white neutrons produced by heavy-ion irradiation of thick targets. In 2024, 16 MeV/u ^{40}Ar beams were successfully used to produce neutrons via the ^{40}Ar + ^{12}C reaction, and the resulting spectra were measured using EJ-301 scintillators, activation foils, and He-3 Bonner Spheres. Originally intended for neutron-induced cross-section measurements above 20 MeV, NDPS also supports shielding studies, semiconductor damage testing, neutron imaging, materials analysis, and biomedical research. As a key component of the RAON accelerator, NDPS is expected to enable advanced nuclear data measurements as well as a broad range of neutron science and applications.

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High Intensity D-T Neutron Source KylinLight- I and Its Applications

Wen Wang*, Qi Yang, Wen Wang, FDS Consortium
International Academy of Neutron Science, Chongqing, China, 401331

E-mail: wen.wang_g@fds.org.cn

Neutron sources are the important experimental platform for the R&D of advanced nuclear energy systems and nuclear technology application, especially for the development for Boron Neutron Capture Therapy (BNCT) and fusion systems.

FDS Consortium has developed a series of neutron sources for different applications, such as the Mini Neutron Generator (MINEG), Small Neutron Generator (SNEG), Compact Neutron Source (CONEG), High intensity neutron source (KylinLight) and Volumetric Neutron Source (VNEG).

Among them, MINEG, with a minimum diameter of 26mm, features long service life, heat resistance, and strong anti-vibration performance. Its pulse timing is adjustable and has been widely used in neutron logging, industrial material analysis, and security inspections. SNEG is a D-D/D-T neutron source featuring with high neutron yield, compact design, and mobility. Its main body occupies an area of less than 1 m^2, with a D-D source strength of 10^{10} n/s and a D-T source strength of 10^{12} n/s. Due to its small size and portability, the SNEG neutron source is highly suitable for on-site calibration of detectors. CONEG is a cyclotron-based neutron source with an intensity exceeding 10^{14} n/s. It is primarily designed for neutronics and shielding validation in advanced nuclear energy systems, as well as for neutron therapy and isotope production. VNEG is a Field-Reversed Configuration (FRC) fusion neutron source with a neutron flux higher than 10^{15} $n \cdot cm^{-2} \cdot s^{-1}$, it is an optimal platform for research on tritium breeding blankets of fusion reactors and material irradiation testing.

KylinLight is a high-intensity deuterium-tritium (D-T) fusion neutron generator. The program consists of two phases: KylinLight-I and KylinLight-II.

KylinLight-I is designed for steady-state operation with a neutron yield up to 10^{13} n/s. The facility has been constructed in Chongqing, with a practical D-T neutron yield reaching 1.3×10^{13} n/s. Its main components include a high-voltage power supply, high-intensity ion source, low-energy beam transport line, accelerating tube, high-energy beam transport system, and high-power rotating tritium target. Its superior performance is supported by three core technologies: (1) High-efficiency beam transport technology, which ensures stable extraction and transmission of high-current deuterium beams. (2) A large, ultra-high-speed rotating target that can stably operate high rotation speed to solve the problem of ultra-high heat flux density. (3) The large-area tritium-titanium target with high tritium content, which is a key component for achieving a high production rate and strong current of neutron sources.

KylinLight-II will be built as a neutron source facility cluster, aiming to establish the first neutron science facility with ultra-high neutron flux and continuously adjustable neutron energy spectra of China. The design and development of key components for KylinLight-II are still in progress.

A series of applications can be performed on KylinLight neutron source. Especially with the development of Boron Neutron Capture Therapy (BNCT), research on the biological effects of neutron radiation for animal experiments has become increasingly essential. KylinLight can also provide multiple types of neutron spectra including fusion-like spectra, acting as a crucial experimental platform for fusion-related technical verification, radiation damage mechanism research, and advanced reactor technology validation. That specifically includes neutronics performance test of reactor components, shielding performance and activation experiments of materials, validation benchmark experiment for fast and epithermal neutrons shielding and collimation, etc.

FDS provides an open platform that invites global research and applications in neutron source and fusion technology.

Status of The Neutron Salt-meter RANS-μ for Non-destructive Measurement of Chloride Ion Concentration to Concrete Bridge Inspection Use

Yasuo Wakabayashi[1,2], Tomonori Fukuchi[1,2], Yujiro Ikeda[1], Masato Takamura[1], Masakazu Muroyama[1], Tsunekazu Ide[1], Masahiro Yoshikawa[1], Yoshie Otake[1,2], and Ryuutarou Ooishi[1,3]
[1]Rans View Corporation, Japan, [2]RIKEN, Japan, [3]Oriental Shiraishi, Japan

E-mail: yasuo.wakabayashi@ransview.co.jp

As it has been reported that bridges collapsed and many serious damages occurred due to chloride attack of concrete structures all over the world, strong demands have been addressed to urgent requirement of a non-destructive on-site measuring techniques which can measure the chloride ion concentration in concrete structures distributed from the surface to steel bar.

To meet them, we have developed a portable type of neutron salt-meter, RANS-μ, combining with a ^{252}Cf neutron source and a prompt gamma neutron activation analysis (PGNAA).

RANS-μ has been developed through the examination at outdoor test fields and at concrete bridges in common use as national highway from effectiveness of non-destructive way point of view, and by confirmation of the results of chloride ion concentration with data obtained by conventional methods like a concrete core sampling. Eventually, the performance of RANS-μ was demonstrated that "the lower detection limit is below 1.0kg/m^3 of the chloride ion concentration to know the marginal concentration of 1.2kg/m^3 at which steel corrosion starts", "it can measure the chloride ion concentration in 3 depth every 3 cm from concrete surface", "it can measure in 15 minutes to 1 hour in total measuring time", "it has around 50 kg of total weight", and "it can be installed on the bucket of inspection vehicle".[1]

Rans View Corporation was established in April 2023 to diagnose concrete bridges using RANS-μ. Up to March 2026, the 143 bridges and their many parts such as piers and main girders have been measured from Hokkaido in the north to Okinawa in the south in Japan. We have continued the advanced development of the RANS-μ system such as ease of handling, miniaturization and weight reduction, and gamma-ray detection sensitivity. In addition, the large-scale measurement of 50 bridges was conducted to demonstrate the performance of RANS-μ and to study the situation of chloride attack due to sea salt spray and spreading anti-icing agent at multiple locations on a single bridge, which was not possible with conventional methods.

We report on the status and results of RANS-μ, highlighting specific detector system developments in terms of sensitivity and compactness and the large-scale measurement.

A part of this research was carried out as “Research and development of salt-meter with neutron source for on-site nondestructive inspection of bridge structure”, the commissioned research of “Tohoku Regional Development Bureau” under technology research and development system of "The Committee on Advanced Road Technology" established by MLIT, Japan. A part of this work was also supported by the Ministry of Land, Infrastructure, Transport and Tourism's SBIR Phase 3 Fund Project. A part of this measurement was supported by Dia Nippon Engineering Consultants Co., Ltd., PACIFIC CONSULTANTS CO., LTD., and FUKUYAMA CONSULTANTS CO., LTD.

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Development of A Compact 10^9 n/s-Class D–D Neutron Generator System Based on an ECR Ion Source

Sung-Ryul Huh[1], Jong-Gab Jo[1], Tae-Seong Kim[1], Kihyun Lee[1], and Dae-Sik Chang[1]
[1]*Korea Atomic Energy Research Institute, Republic of Korea*

E-mail: srhuh7@kaeri.re.kr

The Korea Atomic Energy Research Institute (KAERI) is developing a compact 10^9 neutrons/sec-class deuterium–deuterium (D–D) neutron generator designed to deliver 2.45 MeV monoenergetic neutrons for applications such as cargo screening, explosives detection, neutron activation analysis, and nuclear data research. The neutron generator comprises an electron cyclotron resonance (ECR) plasma source, a four-electrode extraction/acceleration system, and a target, and is designed to meet a beam energy of 60 keV, a beam current of 50 mA, and a neutron yield of $\geq 10^9$ n/s, under stable continuous-wave (CW) operation. The plasma source is a compact permanent-magnet ECR whose plasma chamber has an inner diameter and length of 10 cm each. Microwaves at 2.45 GHz are coupled into the plasma with input power up to 1.5 kW through a four-step ridged waveguide for impedance matching and robust plasma generation [1]. The magnetic field, produced by three NdFeB ring magnets and two iron yokes and optimized with OPERA3D, sustains the resonance condition ($B_{ECR} < B < 1.3\, B_{ECR}$) over about 70% of the chamber length for efficient electron heating, while the stray field is suppressed near the extraction region to preserve beam quality. The plasma source is biased to high voltage for beam extraction/acceleration by employing a high-voltage DC break that electrically isolates it from the grounded microwave power generator, so that the target remains at ground potential and the neutron irradiation point can be placed close to the target for maximum usable flux [1]. The deuteron beam is extracted and accelerated by a four-electrode extraction/acceleration system optimized with IGUN simulations. Its electrode geometry and voltages are tuned to balance beam current, emittance, and transmission efficiency and to set the final beam energy, providing operational flexibility while minimizing beam losses. In initial tests, the ion source ran stably for one hour at a 50 mA hydrogen beam current under CW conditions; from the measured parameters and reaction cross-sections, the corresponding D–D neutron yield is estimated at approximately 10^9 n/s. Ongoing work targets operation with deuterium beams, regulatory licensing, improved thermal management of the drive-in target, and the introduction of advanced diagnostics. This presentation reports the present development status of the neutron generator.

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Development of a Neutron Imaging Instrument for the HBS-I

Richard Wagner[1], Jochen Fenske[1], and Richi Kumar[1]
[1]*Helmholtz Zentrum Hereon, Germany*
E-mail: Richard.wagner@hereon.de

High-Current Accelerator-driven neutron sources (HiCANS) have the potential to become an important component of the ongoing transformation of the neutron research landscape. By delivering high-brilliance beams with low radiation background and fully flexible pulse structures, they enable new experimental capabilities and improved user accessibility.

One such project is the High Brilliance Neutron Source Phase I (HBS-I) [1], a proposed HiCANS user facility to be realized at Forschungszentrum Jülich (FZJ) in collaboration with Helmholtz-Zentrum Hereon. The project has been included in the national shortlist of nine priority research infrastructures by the German Federal Ministry of Research, Technology and Space.

The planned instrument suite for HBS-I includes a neutron imaging station [2] (see Fig.1 for a possible layout), that is designed to address a broad range of key applications. Neutron imaging is a powerful non-destructive technique for investigating objects that enables the investigation of objects and materials across diverse research fields, including energy storage systems, engineering components, and cultural heritage artifacts

The HBS-I concept allows for different pulse structures and the use of neutrons in the thermal, cold or even bi-spectral region. Different design options will be simulated using a McStas-model of the instrument with the current HBS-I source model. We will present the conceptual designs, simulation results, and expected performance characteristics of the imaging instrument.

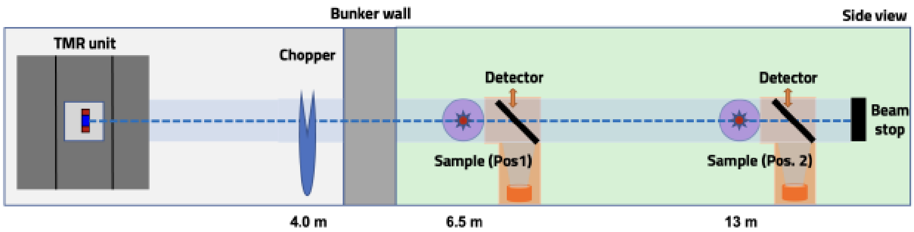

Figure 1: Sketch of a possible design of the imaging instrument for the HBS-I

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Preliminary Evaluation of Reduced-Flux Thermal and Fast-Neutron Imaging for Compact Neutron Source Applications

Myungkook Moon[1], Bongki Jung[2] and Jongyul Kim[1]
[1]KAERI, Korea, [2]Qbeam Solution, Korea,

E-mail: moonmk@kaeri.re.kr

Compact accelerator-driven neutron sources are attractive for practical neutron imaging, but their available neutron flux is typically lower than that of reactor-based facilities. In this study, preliminary imaging tests were performed to evaluate neutron beam conditions relevant to compact neutron source applications. At the ENF beam port of the HANARO research reactor, high-density polyethylene plates were installed upstream of the beam aperture to reduce the neutron beam intensity. The measured beam attenuation decreased with increasing HDPE thickness, reaching approximately 0.44 at 25 mm and 0.37 at 30 mm. Neutron radiographs were obtained under reduced-flux conditions to assess exposure-time requirements and image visibility.Fast-neutron radiography was also tested at the 30 MeV cyclotron-based neutron facility in Jeongeup, with a neutron source strength of approximately 10^{12}–10^{13} n/s. Cable and connector samples were imaged to examine the visibility of internal metallic and hydrogenous structures. These results provide preliminary guidance for designing CANS-based neutron imaging systems, including source intensity, collimation, detector selection, and exposure optimization.

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Poster

12th International Meeting of the Union for
Compact Accelerator-driven Neutron Sources

High epithermal neutron source driven RF LINAC for BNCT (Boron Neutron Capture Therapy)

Jae Eun Han[1], Woong Hee Kim[1], Ihyeon Kim[1] , Sung Yun Kim[1], Dong Soo Kim[1] and Young Soon Bae[1]
[1]*Dawon Medax, Korea,*

E-mail: jehan1@dawonmedax.com

BNCT (Boron Neutron Capture Therapy), one of the radiation treatments, is required high efficiency epithermal neutron flux. In this paper, as the most compact and the most radiation safety, Proton beam accelerator for RF Linear accelerator type has developed as neutron source. Proton beams having 20 kW of beam power and 10 MeV of beam energy collide with beryllium target and then it produces fast neutron by (p,n) nuclear reaction. To produce high efficiency epithermal neutron flux, moderator design and experimental verification was done. RF LINAC benefits from low energy and high current which has strong advantages of no long life radioactive materials in moderator structure & quick access to accelerator tunnel after the operation. Finally, patient examined epithermal neutron flux of $1X10^9$ n/(sec cm^2) during 20 minutes, glioblastoma clinical trial of phase 2 was finished.

Development of a Proton ECR Ion Source for an Accelerator-Driven Neutron Source

Hayato Okubo[1], Yushi Masuoka[2], Issei Yamauchi[2], Hideaki Yamauchi[2], Sosuke Kikuchi[3], Shouta Ikeda[3], Noriyosu Hayashizaki[3], Shuai Ha[4], Kazumasa Takahashi[1]

[1]Nagaoka University of Technology, Japan, [2]TIME Co., Japan
[3]Institute of Science Tokyo, Japan, [4]ELTE University Budapest and Mirrotron Ltd, Hungary

E-mail: s233104@stn.nagaokaut.ac.jp

A proton Electron Cyclotron Resonance (ECR) ion source has been developed for application to an accelerator-driven neutron source. ECR ion sources are expected to be suitable for accelerator injectors because they can generate high-current and low-emittance ion beams [1]. Stable production of high-current proton beams is essential for efficient neutron generation. In this study, optimization of the extraction electrode system and beam extraction conditions was carried out to improve the beam performance of the ECR ion source.

The extraction electrode parameters, including the electrode position and extraction gap, were systematically adjusted to optimize the plasma extraction condition. As a result of the electrode tuning, a stable proton beam current of approximately 25 mA was successfully obtained. Beam current characteristics were evaluated using a Faraday cup measurement system.

In addition, charge state analysis of the extracted ion beam was conducted using a magnetic analysis system in order to evaluate the ion species generated in the plasma. The relationship between the extraction conditions and the charge state distribution was investigated, and it was confirmed that proton components were dominant under the optimized operating conditions.

These results demonstrate that optimization of the extraction electrode configuration is effective for improving both beam intensity and beam quality of the ECR ion source for accelerator-driven neutron source applications.

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Experimental Investigation on Electron Beam Melting Additive Manufacturing and Lightweight Design of a Pure Copper RFQ Accelerating Cavity

Jia-meng Li, Fan-Xi Zhang, Ya-Ru Wang, and Zhen-chao Liu
Department of Nuclear Science and Technology, School of Energy and Power Engineering, Xi'an Jiaotong University, Xi'an, Shaanxi, 710049, China

The radio frequency quadrupole (RFQ) accelerator is the core component of compact linear accelerators. Its central four-vane electrode assembly is conventionally fabricated by furnace brazing, after which shape distortions caused by residual stress release necessitate multiple time-consuming and inefficient post-weld heat treatment steps, resulting in a complex manufacturing process and high cost. Additive manufacturing (AM) offers a revolutionary approach for the design and fabrication of accelerator components. This study focuses on the additive manufacturing method and lightweight design of an RFQ accelerating cavity, aiming to explore the feasibility of reducing accelerator weight, lowering fabrication cost, and achieving fully monolithic printing.

Using electron beam melting (EBM) with high-electrical-conductivity and high-thermal-conductivity pure copper, a 1/6-scale prototype of a 162.5 MHz RFQ accelerating cavity with a lightweight design was monolithically fabricated. While maintaining the mechanical strength of the electrode structure and the radio frequency (RF) performance, the material usage in non-critical regions was significantly reduced, achieving a total weight reduction of 34.89%. By optimizing the printing process parameters, the final as-built component exhibited an average geometric deviation of 0.35% at non-tip regions, a relative density of 99.4%, and an electrical conductivity of 93.38% IACS. After preliminary abrasive flow machining, the internal surface roughness was reduced to 3.178 μm. Measured with a vector network analyzer, the electromagnetic field frequency of the RFQ prototype was 163.77 MHz, yielding a relative error of 0.003% compared with the CST simulation value of 163.72 MHz. The measured mode separation between the quadrupole mode and the nearest dipole mode was approximately 6.82 MHz, which satisfies the requirement for stable RFQ operation.

This study systematically integrates additive manufacturing with lightweight design for RFQ accelerating cavity components. Additive manufacturing enables the fabrication of complex structures that are difficult to realize using conventional techniques. In future work, water cooling channels and tuners will be incorporated to adjust the cavity's resonant frequency, thereby further improving the beam performance of the accelerator. This work provides a novel solution for the future development of more compact, more efficient, and more economical particle accelerators.

Mechanical and Electronic System Design of a Large-Aperture Capacitive Pick-up Type Bunch Shape Monitor for Nonrelativistic Ion Beams

Changsun Na[1] , Geunwoo Kim[1], Donghyun Kwak[2] · Moses Chung[1]
[1]DANE, POSTECH, Korea [2]KAERI, Korea

E-mail: moses@postech.ac.kr[1]

Accurate measurement of the longitudinal bunch shape is crucial for beam dynamics studies and optimization in modern accelerators. In this study, a large-aperture capacitive pick-up type bunch shape monitor (CPU-BSM) was designed to accommodate large beam sizes. Based on simulated CPU-BSM signals, an electronic and control system was developed for diagnostic signal readout. Furthermore, essential data processing procedures, including post-processing, integration, frequency analysis, and signal reconstruction, were implemented and verified. This system is highly applicable to RAON beam diagnostics, serving as a complementary tool alongside broadband pickups, FFCs, and BPMs. Future work will focus on developing a CPU-BSM-based tomography algorithm to reconstruct the longitudinal (z, δ) phase space from the measured bunch profile projections.

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Simulation Study of Virtual Pepper-Pot Method for Low Energy Proton Beams

Jiyoung Choi[1], Emre Cosgun[2], Bokkyun Shin[3], Chang-Kyu Sung[3], and Moses Chung[1*]

[1]POSTECH, Korea, [2]KEK, Japan, [3]PAL, Korea

E-mail: moses@postech.ac.kr*

The Virtual Pepper-Pot (VPP) method enables reconstruction of the 4-dimensional (4D) transverse phase space from slit-based beam measurements without using a physical Pepper-Pot (PP) mask. Compared with the conventional PP method, the VPP method can provide improved applicability by enhancing image resolution. In this study, simulation-based investigations of VPP reconstruction were performed under low-energy proton beam conditions relevant to the Korea Multi-purpose Accelerator Complex (KOMAC) Beam Test Stand (BTS). During the reconstruction process, sensitivity of reconstructed beam parameters to the number of macroparticles was observed. To investigate the origin of these discrepancies, systematic studies were conducted under various numerical and reconstruction conditions. The reconstructed beam parameters were compared with reference beam distributions to evaluate the reconstruction accuracy and numerical robustness of the VPP method. Furthermore, this study outlines experimental plans to conduct VPP measurements under various beam conditions.

Design of Magnetic Field Measurement Device for A Miniaturized New Type of H_2^+ High-intensity Cyclotron and Research on Magnetic Field Shimming

Fei Wang, Jinrong Lu, Shizhong An,Xinyu Chen, Tianjian Bian, Jiansheng Xing,Xiaobo Li, Yuanhao Liu, Pengfei Zhu, Jie Liu, Cong Wu, Fengping Guan, Sumin Wei, Bin Ji
China Institute of Atomic Energy, Beijing 102413

E-mail:wangfei@ciae.ac.cn

A miniaturized new type of H_2^+ high-intensity cyclotron is currently under construction at the China Institute of Atomic Energy (CIAE). This device will lay a technical foundation for the future development of large-scale scientific facilities based on 10 mA/10 MW high-current cyclotrons for advanced nuclear energy and spent fuel processing. Among them, high-precision magnet design and magnetic process technology are important technical foundations for high-current accelerators, and it is necessary to conduct research on multi-physical field simulation technologies including temperature field, electromagnetic field and structure, mechanics, etc. After completing the design and processing of high-precision magnets, we designed a fully automated magnetic field measurement device applying the Hall effect method, using high-strength and high-wear-resistant synthetic materials G10 and PEEK, optimizing the power drive components, reducing the weight of the device, and shortening the measurement cycle through the refined design of the magnetic field measurement process. The installation accuracy of the entire set of equipment reaches ± 0.03 mm, and the installation accuracy of the insert strips is as high as ± 0.02 mm. And a new set of padding positioning fixtures was designed based on the optimized padding scheme. The padding accuracy was improved to ± 0.02 mm. Eventually, by using the magnetic field measurement device and the padding fixture, four magnetic field measurements and three high-precision padding were carried out, successfully completing the magnetic field measurement work of the miniaturized new H_2^+ high-intensity cyclotron and achieving good results. The isochronicity goal of the integral sliding phase not exceeding ± 10° has been achieved, meeting the physical design requirements of the miniaturized new type H_2^+ high-intensity cyclotron.

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Physical Design Study of The Main Magnet For The CIAE 30 MeV Cyclotron

JinRong Lu, TianJian Bian, FengPing Guan, and ShiZhong An
China Institute of Atomic Energy, Beijing 102413

E-mail: Dongnanrong@proton.me

Small-scale, high-current cyclotrons have demonstrated profound potential across frontier fundamental science, advanced energy systems, and national defense nuclear technologies. Currently, these facilities are widely utilized in key domains such as neutron radiography, boron neutron capture therapy (BNCT), advanced nuclear energy R&D, nuclear material irradiation testing, and medical radioisotope production. To address the growing demand within nuclear medicine for both radioisotope synthesis and BNCT neutron sources, a 30 MeV cyclotron is currently under development at the China Institute of Atomic Energy (CIAE), designed to extract a beam with a rated power exceeding 30 kW. This paper details the critical design challenges and corresponding solutions in the computational analysis of the main magnet, which employs a structural scheme featuring deep valleys and straight-edged sectors. The required isochronous magnetic field is established via an axial shimming method, and the field distribution has been optimized using the numerical simulation software OPERA-3D to enhance the acceleration efficiency. Furthermore, deformation simulations and mechanical optimizations were conducted. Without compromising the overall magnetic performance, the structural deformation of the 32-ton, 2.45-meter-diameter main magnet was successfully constrained within strict engineering tolerances.

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Coupled EPOCH-FLUKA Simulation for Laser-Driven Neutron Sources

ROUPEC C.[1], DORNER R.V.[1,2] and MÜLLER M.J.[1]
[1]Emerald-Horizon AG, R&D Department, Graz, Austria, [2]Graz University of Technology, IEP, Graz, Austria

E-mail: roupec@emerald-horizon.com

Neutron sources are important for a wide range of applications, ranging from material investigations to medical treatments. Depending on the use-case in question, neutron sources require a significant commitment regarding facility size and operational costs. Reactor based solutions are next to unfeasible in the current age and even typical accelerator sources usually require a dedicated building.

In recent years, laser driven acceleration schemes have become popular. Depending on the acceleration mechanism it is possible to accelerate electrons [1] or ions [2] using laser-plasma interactions utilizing high-intensity (>10^{18} W/cm^2), ultra-short-pulse light sources. With innovative technologies such as diode-pumping and chirped pulse amplification (CPA) [3], field gradients in the range of TV/m are feasible in a spatially compact envelope.

Currently, the main focus of the scientific development is focused on electron, proton, deuteron or ion acceleration. However, generated particles can be used for conversion to neutrons via nuclear interactions. Protons and deuterons are the prime candidates at the moment for compact solutions but using electrons for generating neutrons via Bremsstrahlung is also possible.

As a first step in the development of a compact, laser-driven neutron source, a simulation pipeline from the laser-plasma interaction to the neutron generation was implemented using the particle-in-a-cell (PIC) code EPOCH [5] and the Monte-Carlo based particle transport code FLUKA [6-7]. In particular, the output of EPOCH is post-processed, such that the laser accelerated ions can be imported using a modified SOURCE user routine in FLUKA.

For the simulation, the laser-plasma interaction assumes a pulse-energy in the Joule range with a duration below 100fs. The acceleration method is target-normal sheath acceleration (TNSA) from a thin foil target. In this scheme the laser pre-pulse fully ionizes the foil. When the main pulse reaches the plasma, electrons are accelerated at 90° to the back surface of the target. The electric field between the cloud of electrons and the near unaffected nuclei leads to an acceleration of protons (or ions) present either from hydrogen in the material or contaminations on the surface.

The PIC code calculates a pico-second time-span based on the initial conditions, laser pulse and the electromagnetic interactions between the particles until the protons reach their final energy. The phase-space information for all particles is imported into FLUKA, where they further propagate towards the converter target. Finally, neutrons are scored and the spectrum and angular distribution are evaluated.

This setup will be used to facilitate the target development of the laser and the converter target and to develop the ion optics, moderator and shielding of a L-CANS.

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Thermal Response and Lifetime Evolution of a Solid Lithium Target Under High-Power Proton Beams in AB-BNCT

Zheng Han, Sheng Wang
Department of Nuclear Science and Technology, School of Energy and Power Engineering, Xi'an Jiaotong University, Xi'an, Shaanxi, 710049, China

In accelerator-based BNCT (AB-BNCT) systems, fixed solid-state lithium targets exposed to high-power proton beams often suffer from localized overheating, lithium-layer thinning, and irradiation-induced damage. These effects reduce neutron yield and shorten target lifetime. To mitigate these issues, this study examined the thermal response and lifetime behavior of a lithium target operated with an octupole-magnet beam-flattening scheme. With a 2.8 MeV, 35 kW proton beam, the beam profile, target surface temperature, and outlet epithermal neutron flux were measured and online-calibrated. Using the calibrated data, the work systematically evaluated neutron-yield degradation versus accumulated irradiation charge and analyzed the associated target degradation mechanisms. The results indicate that the target design provides adequate cooling over a large area, achieving a flow maldistribution coefficient of 2.52%. With octupole-based beam uniformization and a cooling-water flow rate of 42 L/min, the outlet epithermal neutron flux remained above 50% of its initial value even after the accumulated charge exceeded 1500 mAh. Overall, the findings show that combining beam uniformization with high-flow-rate cooling is essential to extend the service life of fixed lithium targets.

A Study on the Effect of Magnetron Sputtered Tantalum Coatings on the Corrosion Resistance of Cooling Water Channels in BNCT Target Systems

Yaru Wang, Sheng Wang
Department of Nuclear Science and Technology, School of Energy and Power Engineering, Xi'an Jiaotong University, Xi'an, Shaanxi, 710049, China

During AB-BNCT operation, hydrogen peroxide (H_2O_2) generated by cooling-water radiolysis can significantly accelerate corrosion of copper (Cu) cooling channels in target systems, thereby compromising structural reliability. To address this issue, tantalum (Ta) coatings with different thicknesses were deposited on Cu substrates by magnetron sputtering, and their corrosion behavior in a simulated radiolysis cooling-water environment containing H_2O_2 was systematically investigated. Immersion corrosion tests were carried out in H_2O_2 solution, while surface morphology, structural characteristics, and chemical states before and after corrosion were characterized by SEM, XRD, XPS, and ICP-OES. The effects of Ta coating thickness on surface stability, localized corrosion, and Cu ion release were then evaluated. The results show that the sputtered Ta coatings form continuous protective layers on Cu substrates and markedly enhance corrosion resistance in H_2O_2-containing environments. Compared with bare Cu, Ta-coated samples exhibit a more intact surface morphology, weaker localized corrosion, and lower Cu dissolution after corrosion. The improved protection is mainly attributed to the physical barrier effect of the Ta coating and the chemical stability of the Ta-oxide-rich surface layer. However, although increasing coating thickness further improves corrosion resistance, it also introduces additional interfacial thermal resistance, which may adversely affect heat transfer. Overall, an appropriately designed Ta coating thickness can achieve a desirable balance between corrosion protection and heat-transfer performance, providing a feasible surface-engineering strategy for cooling channels in AB-BNCT target systems.

Ta–W Nanoscale Multilayered Hydrogen Diffusion Layers for High-Power BNCT Neutron Targets: Microstructure, Hydrogen Embrittlement Resistance, and Irradiation Performance

Fanxi Zhang , Sheng Wang
Department of Nuclear Science and Technology, School of Energy and Power Engineering, Xi'an Jiaotong University, Xi'an, Shaanxi, 710049, China

Boron neutron capture therapy (BNCT) requires neutron source targets with high stability and long-term reliability. However, conventional single-material targets are generally unable to simultaneously achieve high neutron yield, resistance to hydrogen-induced degradation, and effective thermal management, which limits the further development of high-power BNCT neutron sources. In this work, Ta–W nanolayered multilayers were fabricated by high-frequency pulsed magnetron sputtering and proposed as hydrogen diffusion interlayers for lithium targets used in BNCT neutron sources. The influence of sputtering parameters, including target power and substrate bias voltage, on the film structure and properties was systematically studied. The microstructure, phase composition, chemical state, surface morphology, residual stress, and interfacial characteristics were examined using SEM, XRD, XPS, LSCM, and TEM. In addition, SRIM and PHITS simulations were performed to evaluate proton transport, proton range, and irradiation damage behavior in Ta–W multilayers with different structural configurations and thicknesses. The results indicate that the Ta–W nanolayered multilayers exhibit a compact and uniform morphology, together with strong interfacial bonding to the copper substrate. Increasing Ta target power promotes the transformation from metastable β-Ta to stable α-Ta and improves film crystallinity. Meanwhile, an optimized negative substrate bias of −120 V effectively reduces surface roughness and residual stress through ion bombardment. The alternating Ta–W architecture provides a combined protection mechanism, in which W enhances structural stability and irradiation resistance, while Ta contributes to hydrogen blocking and surface passivation. Simulation results further show that the multilayer structure disperses proton energy deposition, suppresses irradiation damage, and limits proton penetration. Therefore, optimized Ta–W nanolayered multilayers are promising hydrogen-resistant interlayers for BNCT lithium targets.

Growth Behavior of Tantalum Hydrogen Diffusion Layers on Surface-Modified Copper Substrates for Target Systems of Accelerator-Driven Neutron Source

Yupeng Xie[1], Fanxi Zhang[1], Yaru Wang[1], **Sheng Wang[1,2]**
[1]Xi'an Jiaotong University, [2]HBNCT Co., Ltd., China

E-mail: shengwang@xjtu.edu.cn

Accelerator-driven neutron source target systems require long-term stability under high-power proton irradiation. In lithium-based targets, residual protons may penetrate into the copper substrate, leading to hydrogen accumulation, blistering, embrittlement, and eventual target failure. Introducing a tantalum (Ta) hydrogen diffusion layer between the lithium layer and copper substrate is an effective strategy to promote hydrogen diffusion and suppress hydrogen-induced damage. However, the stable deposition of micrometer-scale Ta layers remains challenging because residual stress accumulated during magnetron sputtering can cause cracking, peeling, and interfacial failure. In this study, copper substrate surface modification was investigated as a key strategy to regulate the growth behavior of Ta hydrogen diffusion layers. Electrolytic oxidation, Al_2O_3 sandblasting, and nanosecond laser ablation were employed to construct controllable micro/nanostructures on copper substrates prior to Ta deposition. The modified Cu surfaces provided abundant nucleation sites, restricted the long-range migration of sputtered Ta atoms, improved interfacial mechanical interlocking, and promoted stress relaxation during film growth. The effects of copper surface morphology on Ta nucleation, grain evolution, crystal orientation, phase transformation, and residual stress were systematically analyzed. The results demonstrate that appropriate surface modification of copper substrates can significantly improve the uniformity, adhesion, and mechanical stability of micrometer-scale Ta layers. By regulating the substrate-induced growth behavior, stable Ta hydrogen diffusion layers can be achieved while effectively suppressing cracking and delamination. This work provides a practical surface-engineering approach for fabricating high-performance hydrogen diffusion layers and improving the reliability and lifetime of accelerator neutron source target systems.

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Neutron Monitoring Using a PSD System for Semiconductor Atmospheric Radiation Effect Testing at KOMAC

Yong Seok Hwang[1], Gi-Wan Jeon[1], Gwang-il Jung[1], In-Mok Yang[1] and Myung-Hwan Jung[1]
[1]*Korea Atomic Energy Research Institute, S. Korea*

E-mail: hys@kaeri.re.kr

Driven by the increasing demand for atmospheric radiation effect assessment in the semiconductor industry, a Pulse Shape Discrimination (PSD) system has been implemented at the 100 MeV proton accelerator facility (KOMAC). As semiconductor devices become more highly integrated, they are increasingly susceptible to soft errors induced by high-energy cosmic radiation. To address this challenge, the facility aims to replicate atmospheric neutron fields above 10 MeV and to provide real-time monitoring of the neutron flux entering the target room during irradiation tests.

The monitoring system employs an EJ-276D plastic scintillator coupled with a high-speed CAEN DT5730 digitizer, enabling high-resolution waveform acquisition. Rather than measuring radiation dose directly, the PSD system complements conventional dosimetry by distinguishing neutrons from gamma rays, thereby allowing selective neutron monitoring in mixed radiation environments. For energy characterization, calibration was performed using standard gamma-ray sources to establish a reliable energy scale in MeVee (MeV electron equivalent).

System performance was validated with an Am-Be neutron source, yielding a Figure of Merit (FoM) of 1.02. This result demonstrates clear and reliable separation between neutron and gamma-ray signals. Overall, the study confirms the feasibility of PSD-based high-energy neutron monitoring in neutron facilities, providing a solid technical foundation for optimizing beam dosimetry, enhancing radiation safety, and supporting accelerated semiconductor radiation testing.

Characterization of RFT-30 Neutron Source Using Multi-Sample Neutron Activation Analysis

Junsik Kim[1], Joo Yub Lee[1], Soobin Lim[2], Jeong-jeung Dang[3], and **Kyoung-Jae Chung[1]**
[1] Seoul National University, Korea, [2] Q-beam Solution Inc, Korea, [3]KENTECH, Korea

E-mail: jkjlsh1@snu.ac.kr

At the Advanced Radiation Technology Institute (ARTI), the RFT-30 cyclotron provides a 30 MeV proton beam with an average current of 10 μA for neutron production via irradiation of a thick beryllium target [1]. Despite the broad utilization of this source, its neutron energy spectrum has not yet been fully characterized [2,3]. In this work, multi-sample neutron activation analysis (NAA) was applied to characterize the neutron spectrum of the RFT-30 neutron source. The neutron energy spectrum was reconstructed using GRAVEL unfolding algorithm based on the measured activities and response functions of each sample. The reconstructed energy spectrum was validated by comparing the measured activities with recalculated activities from the unfolded spectrum.

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Continuous Neutron Spectroscopy up to 30 MeV using Diamond Detector via GRAVEL-Based Spectrum Unfolding

Gyeongjin Choi[1], Jaehyo Kim[1], Ill-hyuk Han[1] and Kyoung-Jae Chung[1]
[1]*Department of Energy System Engineering, Seoul National University, Seoul 08826, Republic of Korea*

E-mail: jkjlsh1@snu.ac.kr

Diamond detectors have been widely considered for neutron diagnostics in large-scale fusion devices such as ITER due to their energy discrimination capability for 14 MeV monoenergetic DT neutrons[1], thermal stability under high-temperature conditions, and low gamma sensitivity. In particular, diamond detectors exhibit high radiation tolerance, making them suitable for high energy and high flux neutron environments such as the accelerator-based Jeongeup Target-Moderator-Reflector-Shielding (TMRS) neutron irradiation facility with continuous neutron sources up to 30 MeV[2]. However, in continuous neutron fields, $^{12}C(n,\alpha)^{9}Be$ peaks—used as indicators of monoenergetic neutron energy—are not clearly observed, making it difficult to analyze neutron energy distributions solely from the pulse height spectrum. To investigate the applicability of neutron spectroscopy in continuous neutron fields, neutron spectrum unfolding was performed. A Geant4-based diamond detector model with the FTFP_BERT_HP physics list[3] was used to generate the detector response matrix. The simulation was validated through comparison with experimental results obtained using the Korea Research Institute of Standards and Science (KRISS) DT neutron generator. Subsequently, irradiation experiments were conducted at the Jeongeup TMRS neutron irradiation facility using a continuous neutron source with energies. GRAVEL algorithm-based neutron spectrum unfolding was then performed using the measured pulse height spectra. The results demonstrated the detector response characteristics and the feasibility of applying diamond detectors to continuous neutron fields in high energy and high flux neutron environments.

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High-fidelity Monte Carlo simulation method and virtual experimental study of neutron scattering spectrometer background

Liangsheng Huang[1,2], Wei Luo[1,2], Fei Shen[1,2], Bin Zhou[1,2], Yu Zheng[1,2] and Tianjiao Liang[1,2*]
[1] *Institute of High Energy Physics, Chinese Academy of Science(CAS), Beijing 100049, China*
[2] *Spallation Neutron Source Science Center, Dongguan 523803, China*
* E-mail of corresponding author: lshuang@ihep.ac.cn, liangtj@ihep.ac.cn

Abstracts: Neutron scattering spectrometer is a key device to explore the microstructure and dynamics of matter, and the background noise directly affects its performance. Due to the complexity of the background source of the spectrometer, the difficulty of accurate tracing by traditional debugging methods, and the limitation that the background is not included in the simulation framework as a dynamic variable in the existing virtual experiments, this paper intends to carry out high-fidelity Monte Carlo simulation method and virtual experiment research on the background of neutron scattering spectrometer. Through refined modeling, realistic expression of physical processes, lossless data transfer among multiple Monte Carlo software, and variance reduction methods to ensure accuracy, a comprehensive and accurate analysis of the background sources will be carried out, and the general laws of background sources will be mastered. In-depth research on the manifestation of the spectrometer background in scattering data and understanding the dynamic change laws of the background will promote the evolution of background subtraction methods from traditional 'constant subtraction' to 'variable subtraction'. This background simulation method was applied to the background analysis of the CSNS high-energy direct geometry spectrometer (HD), and achieved good results. The background virtual experiment has also been initially carried out in HD. The implementation of these tasks will provide methodological support for the low-background design optimization of the CSNS-II spectrometer and the improvement of scattering data quality.

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Preliminary study on performance of light-guiding scintillator for fast neutron imaging based on Geant4 simulations

Hanna Lee[1,2] , Pilsoo Lee[1,2*], Soobin Lim[3] , Gyeongjin Choi[4], Bongki Jung[3] , Kyoung-Jae Chung[4], Dong Won Lee[2]

[1]*University of Science & Technology, Republic of Korea*
[2] *Korea Atomic Energy Research Institute, Republic of Korea*
[3]*Q-Beam Solution Inc., Republic of Korea*
[4]*Seoul National University, Republic of Korea*

*E-mail: pilsoolee@kaeri.re.kr

Fast neutron imaging has emerged as a powerful non-destructive testing technique, offering unprecedented penetration capabilities for inspecting thick, high-Z (high-atomic-number) materials where conventional X-rays or thermal neutrons fail.

To systematically optimize this imaging modality, this study establishes a comprehensive Geant4 Monte Carlo simulation framework tailored to evaluate the imaging performance of a neutron radiography setup.

This model faithfully replicates the realistic experimental environment by incorporating the specific neutron energy spectrum from the compact accelerator-based neutron source at the Korea Atomic Energy Research Institute (KAERI) in Jeongeup, which is driven by the 30-MeV cyclotron. To quantify spatial resolution and system modulation, a virtual tungsten edge phantom was introduced, allowing for a rigorous assessment of how various physical and geometrical parameters of the instrumental components impact image degradation.

This simulation extends beyond basic characterization to provide a comparative analysis between advanced light-guiding scintillators and conventional ordinary scintillators, revealing the quantitative trade-offs in light collection efficiency and spatial blurring.

The preliminary findings discussed in this presentation offer key design guidelines for next-generation fast neutron imaging systems.

Acknowledgement

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Elemental identification using multi-dimensional synergy diagram based on multi-energy neutron and X-ray combination imaging

Yuka Yamaguchi[1], Hirotaka Sato[1], and Takashi Kamiyama[1]
[1]*Hokkaido University, Japan*

E-mail: yamaguchi.yuka.q2@elms.hokudai.ac.jp

Compact electron accelerator-driven neutron sources, such as HUNS (Hokkaido University Neutron Sources), can provide both broad-energy neutrons and X-rays from a single source. Non-destructive elemental identification using neutron and X-ray combination imaging utilizes a "synergy diagram" based on the ratio of radiation attenuation. This ratio corresponds to the total cross-section ratio, representing an inherent property of the element, and is also independent of density and thickness. However, uniquely identifying elements with similar cross-section ratios remains challenging. To overcome this issue, we propose an elemental identification method using a "multidimensional synergy diagram", which contains increased cross-section ratio parameters by combining multi-energy neutrons and X-rays, enhancing identification capabilities.
In this study, we verified the effectiveness of this method through simulation calculation. We constructed a multidimensional cross-section database covering 52 elements, spanning from two to four dimensions by combining the total cross-section ratios of thermal (25 meV), epithermal (0.5 eV-10 keV), and fast (1 MeV) neutrons with X-rays (150 keV). To demonstrate the proposed "multidimensional synergy diagram" method, we selected nine elements including those with similar cross-section ratios between 25-meV thermal neutrons and 150-keV X-rays (Fig. 1) and simulated their radiation transmission at each energy using the particle transport simulation code, PHITS. The resulting three-dimensional synergy diagram (Fig. 2) successfully separated the elements that are difficult to distinguish in Figure 1, confirming that multidimensional synergy diagrams enhance identification capabilities.
Elemental identification was performed by deriving the inner product of the multidimensional vectors between the radiation attenuation ratio data and the cross-section ratio database, identifying elements with values closest to 1. While $_{41}$Nb was incorrectly identified in the two-dimensional analysis, it was successfully identified in the four-dimensional analysis utilizing three energy regions of neutron and X-ray. Overall, eight out of the tested nine elements were correctly identified, confirming that the multidimensional synergy diagram is an advanced tool for robust elemental identification.

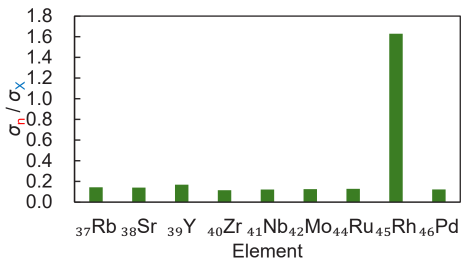

Fig.1. Total cross-section ratios between thermal neutrons and X-rays for each element.

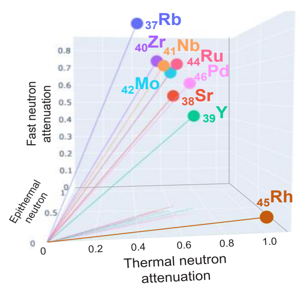

Fig.2. 3D synergy diagram of thermal, epithermal, and fast neutrons.

Development of a Neutron-Based Nondestructive Analysis Method for Measuring the Internal Temperature of In-Vehicle Lithium-Ion Batteries at AISTANS

Koichi Kino[1], Takeshi Fujiwara[1], Tatsunori Shibuya[1], Brian E. O'Rourke[1], Takashi Utsunomiya[2], and Kiyoshi Oji[3]
[1]*National Institute of Advanced Industrial Science and Technology (AIST), Japan,*
[2]*Hiroshima University, Japan,*
[3]*Mazda Motor Corporation, Japan*

E-mail: koichi.kino@aist.go.jp

The performance of lithium-ion batteries (LIBs) is strongly influenced by temperature [1]. At low temperatures (below approximately 0 °C), the capacity of LIBs decreases compared with that at ambient conditions. In addition, lithium dendrites preferentially form on the electrode surface, which can lead to internal short circuits. At elevated temperatures (e.g., 60 °C), the degradation of LIBs is significantly accelerated, resulting in a reduced service life. These temperature-dependent effects are particularly crucial for in-vehicle LIBs, as battery performance must be maintained at a sufficiently high level under diverse operation conditions. Furthermore, during operation, heat is generated within the LIB due to high-current charge-discharge processes. Consequently, accurate measurement of the internal temperature is essential for the development of high performance in-vehicle LIBs. A non-destructive method is highly desirable, since the insertion of sensors such as thermocouples into commercial LIB cells is technically difficult and time-consuming, especially in the rapid product development.

In this study, we focus on neutron Bragg-edge imaging as a non-destructive technique for proving the internal temperature of in-vehicle LIBs. The underlying principle of this method is based on the measurement of the lattice parameter along the c-axis of graphite crystals in the negative electrode. Graphite exhibits a layered structure composed of graphene sheets, which are held together by van der Waals interactions. As a result, the lattice spacing along the c-axis is sensitive to temperature variations [2], enabling temperature estimation through precise determination of the c-axis lattice parameter. Diffraction and Bragg-edge measurements were carried out using an in-vehicle LIB cell (200 × 230 mm^2 in area and 10 mm in thickness) at the compact accelerator-driven neutron analytical facility AISTANS [3]. The measurements exploited the operational flexibility of this compact accelerator-based neutron source (CANS) for the development of advanced diagnostic methodologies. The sample was subjected to controlled cooling and heating over a temperature range of -15 to +60 °C to evaluate changes of the lattice parameter. In parallel, we are developing a computed tomography-based approach to enable spatially resolved temperature measurements within in-vehicle LIBs.

In this presentation, the progress of this study will be reported, with particular emphasis on the diffraction and Bragg-edge measurements performed at AISTANS.

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Design and Validation of a Fast-Neutron Camera for Non-Destructive Testing of Tungsten Divertor Targets

Soobin Lim[1], Pilsoo Lee[2], Hanna Lee[2], Kyung Jin Choi[3], Bongki Jung[1], Kyoung-Jae Chung[3]
[1]*Q-Beam Solution Inc., Daejeon*
[2]*Korea Atomic Energy Research Institute, Daejeon*
[3]*Seoul National University, Seoul*

E-mail: lsb9012@qbeamsol.com

In this study, a fast-neutron camera system was designed and evaluated for non-destructive testing of tungsten divertor targets. First, A 30 MeV proton cyclotron-based accelerator-driven neutron source was first characterized experimentally using activation foils of Al, Nb, Co, and Fe. The neutron energy spectrum was unfolded based on the GRAVEL algorithm, and the resulting neutron spectrum was used as the source term for imaging-system design and simulation.

The proposed fast-neutron camera consists of a collimator array, a plastic scintillator, and a multi-channel photodetector module. Geant4 simulations were performed with a tungsten monoblock divertor geometry to evaluate neutron transmission image formation, spatial resolution, and defect detectability. Preliminary neutron imaging experiments were also conducted to assess the feasibility of defect-sensitive imaging under the designed system configuration.

The results indicate that fast-neutron imaging can provide volumetric information for high-density tungsten divertor components and can serve as a complementary NDT technique for detecting internal and interfacial defects that are difficult to access using conventional inspection methods. This work supports the further development of neutron-camera-based inspection systems for fusion-component qualification and maintenance.

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Development of a Compact High Yield Neutron Generator

Sun Ho Kim[1], Seok Kwan Lee[2], Dae Sik Chang[1], Jung Tae Jin[1], Doo Hee Chang[1], Tae Sung Kim[1], Jong Gab Jo[1], Ki Hyun Lee[1], Bong Ki Jung[1], and Sung Ryul Huh[1]
[1]KAERI, Korea, [2]JAVACUUM, Korea

E-mail: shkim95@kaeri.re.kr

A compact high-yield fast neutron generator based on the deuteron-deuteron (DD) fusion reaction has been successfully developed. The main objective of the development was to design a compact and transportable system capable of continuously generating 2.45 MeV fast neutrons with a yield exceeding 10^{10} n/s. To achieve this, the system incorporates a compact 2.45 GHz Electron Cyclotron Resonance (ECR) ion source designed to extract a high-current deuteron beam of up to 50 mA, and a high-voltage acceleration system operating at 200 kV. A high-load target assembly was also developed to withstand a 10 kW beam thermal load while maintaining the surface temperature below 200 degree of Celsius through an optimized cooling configuration. The comprehensive performance tests demonstrated that the developed neutron generator reached a maximum neutron emission rate of 1.02×10^{10} n/s, which was verified using a Modified Long Counter (MLC) calibrated against a standard DD neutron source. The neutron energy spectrum measured with a calibrated CLYC detector clearly confirmed the characteristic peak of DD fusion neutrons at 2.45 MeV with a resolution of 0.16 MeV. The system also exhibited high operational stability, maintaining neutron output fluctuations within ±5%, monitored continuously via a ^{3}He counter. Remarkably, the core head of the generator is highly compact, featuring a total volume of just 0.09m^3 and a weight of 146 kg. An integrated remote control and monitoring platform was also successfully implemented using the EPICS framework to ensure safe operations from outside the shielding room. The high mobility and competitive production cost of this domestic system will be able to offer prominent advantages for on-site applications in Korea.

Acknowledgement
This work was supported by the Civil-Military Technology Cooperation Program, Korea.

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Deduction of the absolute value of neutron energy-dependent single event upset (SEU) cross-section from SEU rate trend measured by different polyenergetic neutron spectra

Tomoki Sebe[1], **Hirotaka Sato**[1], Hidenori Iwashita[1,2], Ryu Kiuchi[2], Yuji Sunada[2], Yoshiharu Hiroshima[2], Takashi Kamiyama[1], Michihiro Furusaka[1], and Yoshiaki Kiyanagi[1]
[1]Hokkaido University, Japan, [2]NTT, Japan

E-mail: h.sato@eng.hokudai.ac.jp

The neutron energy-dependent single event upset (SEU) cross-section, $\sigma_{\mathrm{SEU}}(E)$, of a semiconductor device is crucial for estimating the SEU rate in space, on Earth and on other planets. Current methods rely on quasi-monoenergetic neutron beams, or a time-of-flight (TOF) method with an intense short-pulsed neutron source which is suitable only for ultrafast circuit systems. Obtaining $\sigma_{\mathrm{SEU}}(E)$ using a polyenergetic neutron beam from a compact low-power accelerator simplifies the process, eliminating the need for multiple monoenergetic sources or high-intensity short-pulsed sources with ultrafast circuits. To address this, we developed a simple method that derives the absolute value of $\sigma_{\mathrm{SEU}}(E)$ from SEU rate trend (SERT) measured by different polyenergetic neutron spectra. SERTs for various semiconductor devices were measured using various neutron production target materials at the compact 18 MeV proton cyclotron-driven neutron beam facility at SHI-ATEX Co., Ltd. in Japan. The Fitting SERT (F-SERT) analysis, which fits the calculated SERT to the experimental one, provided the absolute value of $\sigma_{\mathrm{SEU}}(E)$ data over the fast neutron energy range, and the results were consistent with traditional methods, as shown in Figure 1. Thus, $\sigma_{\mathrm{SEU}}(E)$ can be easily deduced with a compact polyenergetic neutron source, except for the energy region above 20 MeV that can be reached by the accelerator used.

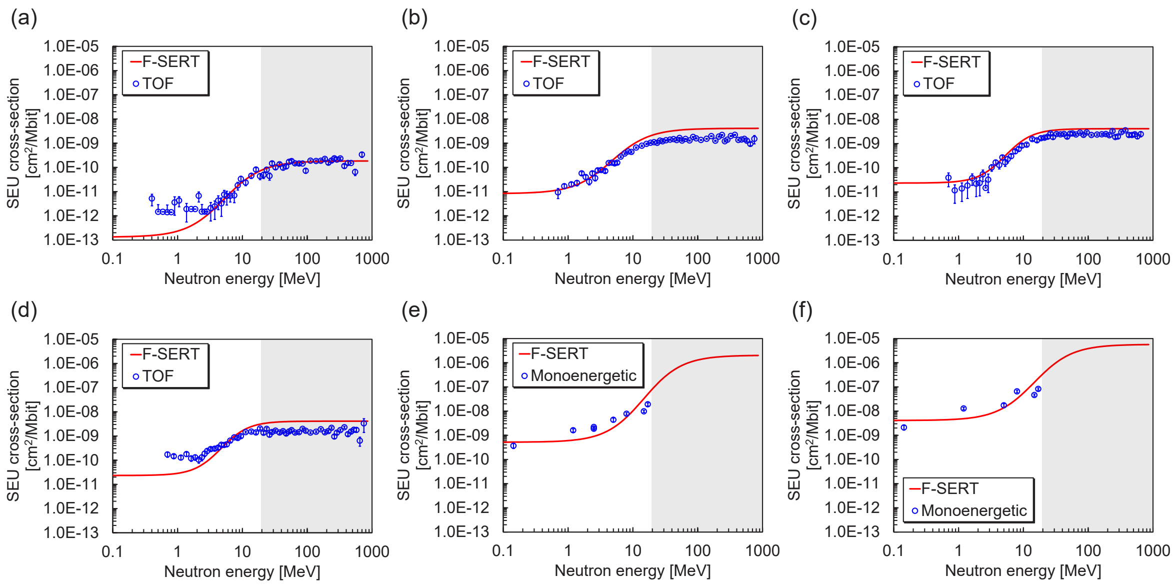

Figure 1: Obtained results of $\sigma_{\mathrm{SEU}}(E)$ using the F-SERT method, and measurement results of $\sigma_{\mathrm{SEU}}(E)$ using the TOF method or the monoenergetic neutron irradiation method. (a) FPGA 14 nm. (b) FPGA 28 nm. (c) FPGA 40 nm. (d) FPGA 55 nm. (e) SRAM 40 nm. (f) SRAM 65 nm.

Current Status of RANS Facilities

T. Kobayashi[1,2], T. Takanashi[1,2], S. Imajo[1,2], H. Kusano[1,2], A. Muneem[1,2], Y. Okuno[1,2], M. Mizuta[2], Y. Wakabayashi[2], T. Fukuchi[2], Y. Nakayama[2], T. Hashiguchi[2], Y. Ikeda[2], Y. Otake[2] and T. Saito[2]
[1]*Neutron Operation Unit, RAP, RIKEN, Japan*
[2]*Neutron Frontier Research Team, RAP, RIKEN, Japan*

E-mail: t-koba@riken.jp

We have been developing the RIKEN Accelerator-driven compact Neutron Systems (RANS) since 2011. RANS-I consists of 7 MeV proton LINAC (425MHz RFQ+DTL coupled) and a beryllium target with a room temperature polyethylene moderator and a helium-cooled mesitylene moderator. For the RANS-II (200MHz RFQ), the proton energy was lowered to 2.5 MeV to reduce the total weight of the system especially accelerator and shielding. At the same time, we have developed a method to make measurements with a smaller number of neutrons produced. RANS-II is currently used as a stationary compact neutron source.

Based on the measurement technique, accelerator technology, and shielding parameters obtained from RANS-II, we are now developing RANS-III for field measurements on a trailer. Social infrastructure in Japan, such as bridges, was intensively developed during 60s and 70s and is now exhibiting noticeable aging and deterioration. To achieve "preventive maintenance" for these structures, implementing new non-destructive measurement technologies on-site has become an urgent priority. We have been developing RANS-III, a transportable compact neutron source system, to maximize the unique characteristics of neutrons, which offer high penetration capability and exceptional sensitivity to elements like hydrogen and chlorine. Alongside the development of a lightweight, compact proton accelerator system, we have also advanced a degradation visualization technique using a novel scattering imaging method that enables safe, on-site measurement of structural deterioration. The permanent-magnet ECR ion source and the 500 MHz proton linac system were successfully integrated into a dedicated vehicle (a 40-foot wing semi-trailer), and accelerator operation tests were conducted inside the trailer. Additionally, the construction of a dedicated facility for neutron generation experiments was completed. Starting in early 2025, preparations were made for neutron generation tests and actual sample measurements with the system mounted on the trailer inside the facility. Following approval of the application to amend the radiation controlled area in 2025 autumn, test irradiation of the pulsed proton beam was performed with the lithium (Li) target loaded, resulting in the successful generation of neutrons.

This presentation will report on neutron generation with RANS-III and other developments achieved with RANS-I and II.

Recent Developments of 2.5 and 14.8 MeV Mono-energetic Neutron Fields at KRISS

Joong Hyun Kim, Jungho Kim, Hyeonseo Park, and Young Soo Yoon
Korea Research Institute of Standards and Science, Korea,

E-mail: ysy@kriss.re.kr

The Korea Research Institute of Standards and Science has established the national measurement standards for neutron dose equivalent, neutron fluence, and neutron emission rate. To extend national standardization capabilities into the fast neutron, an electrostatic accelerator was recently commissioned. By bombarding TiD and TiT targets, the facility now generates 2.5 MeV and 14.8 MeV mono-energetic neutron fields.

The neutron fluences are characterized using a calibrated Bonner sphere system and a long counter detector. This presentation will provide an overview of the neutron standard facilities and irradiation services at KRISS, and discuss the characterization, fluence measurement results, and future applications.

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Development of a Thermal-Hydraulic Correlation for Coolant Flow Path Optimization in Beam Dump Cooling System Design

Myungho Kim[1*], Hyoseong Gwon[1], and Mu-Young Ahn[1]
[1]*KFE, Korea*

*E-mail: mhkim@kfe.re.kr

A beam dump is a critical device used in high-energy physics experiments and particle accelerator facilities to safely stop and absorb high-energy particle beams. Under high-energy beam operation, a significant amount of beam power is deposited over a limited surface area. This makes the cooling system the main design constraint, rather than the structure itself. To distribute this heat load over a larger area and reduce the peak heat flux, the high-energy beam dump is usually designed as a conical structure cooled by water flowing through an interlayer channel as adopted for the IFMIF-DONES. The performance of such a configuration is governed primarily by the height of this coolant flow path: a narrow channel raises the heat transfer coefficient but increases both the pressure drop and the risk of flow-induced erosion, whereas an excessively wide channel wastes pumping margin and enlarges the device. Recent developments in high-power accelerator beam dumps indicate a clear trend toward single-phase water cooling concepts with sufficient subcooling margins to prevent the onset of nucleate boiling and critical heat flux under MW-class continuous-wave beam operation [1–3]. As beam power density increases, the design perspective has expanded into a thermo-hydrodynamic and thermo-mechanical optimization problem that requires simultaneously satisfying wall temperature limitations, pressure drop, thermal stress, and fatigue, alongside heat removal [4,5]. This study identifies the governing thermal-hydraulic parameters and the design criteria they impose and, on this basis, proposes a correlation that determines the coolant flow path height as a function of the local thermal-hydraulic conditions.

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Beam Optics Simulation of an Aperture-Scalable Extraction System for a Compact ECR Ion Source Neutron Generator

Tae-Seong Kim, Kihyun Lee, Jong Gab Jo, and Sung-Ryul Huh

Korea Atomic Energy Research Institute, Korea

E-mail: tskim@kaeri.re.kr

A compact DD neutron generator based on a 2.45 GHz electron cyclotron resonance (ECR) ion source has been developed at the Korea Atomic Energy Research Institute (KAERI) [1]. Through iterative simulation and experimental studies on various ion source extraction structures, a four electrodes extraction system with a single circular aperture has been finalized, and stable beam extraction at 60 kV/50 mA has been achieved. In this study, a scalable design concept is proposed, in which the neutron yield can be widely adjusted by changing only the extraction aperture size while the ion source, extraction structure, extraction voltage, and plasma discharge condition are kept unchanged. This approach allows the same platform to be readily reconfigured in either direction depending on the operating requirements, extending not only to low-yield applications such as a compact DT neutron generator but also to higher yields once the shielding capacity is upgraded in the future. As a representative case, beam-optics simulation results obtained with the IBSimu code [2] are presented, comparing the extracted beam performance for different reduced aperture sizes and targeting a beam condition of 60 kV/1 mA consistent with the currently available shielding facility.

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