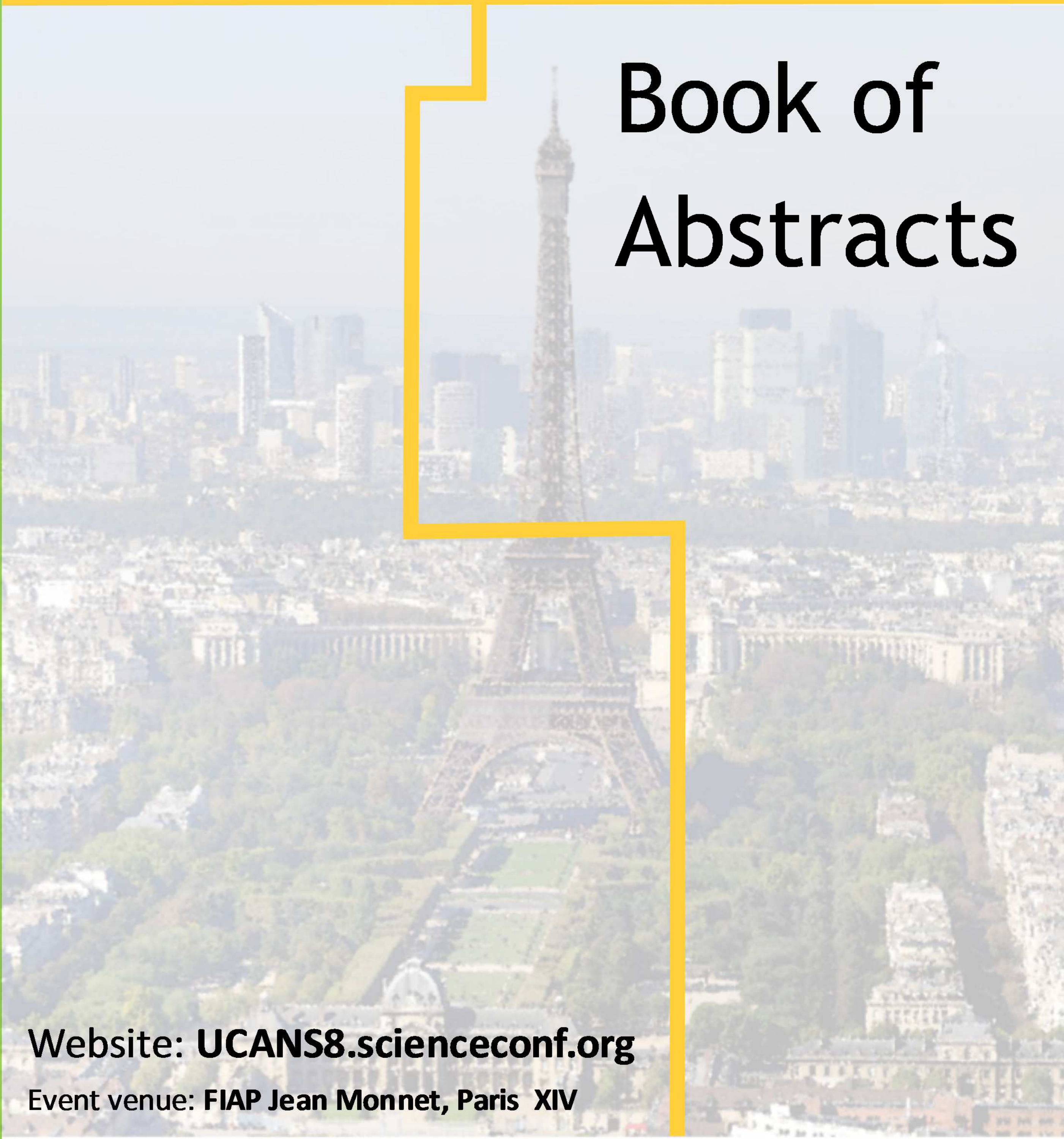
UNION FOR COMPACT ACCELERATOR-BASED NEUTRONS SOURCES

UCANS 8

PARIS

July 8-10th 2019



Book of Abstracts

Website: **UCANS8.scienceconf.org**

Event venue: **FIAP Jean Monnet, Paris XIV**

Monday July 8th - Morning

Plenary session

The development of Compact Neutron Sources

John Carpenter

Many smaller research reactors built as neutron sources before the year 2000 are being shut down. The activities that these supported are ending, which motivates their replacement with new facilities. Compact accelerator-based neutron sources under development are able to take up many of those activities.

This presentation will

- paints the background for these developments,
- summarizes the replacement technologies,
- relates recent work that supports them, and
- alludes to some of the new activities that they enable.

J. M. Carpenter, *"Development of Compact Neutron Sources."* ***Nature Reviews Physics*** **1**, published online 28 January 2019, pp.177-179. Issue date March 2019.

A Personal Reflection on Target Moderator Reflector Design Considerations for CANS Facilities

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Although a number of different nuclear reactions have been utilized in the design of CANS facilities, most such reactions are much less efficient in terms of neutrons produced per unit of energy deposited in the target. As with most neutron sources, maximizing the neutron intensity on the instruments is an important design consideration, and this involves a combination of target engineering and neutronic design and engineering of the moderators. The particular design challenges associated with this task for CANS facilities is, in many ways, quite distinct from the corresponding design task for larger scale facilities. In this talk, I will present an overview of the various choices that have been made throughout the world at CANS facilities and highlight the aspects of the design problem that are most distinct from those at spallation facilities.

Particle accelerators: a powerful tool for interdisciplinary research

Anne-Isabelle Etienvre

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Particle accelerators are powerful interdisciplinary tools, addressing key scientific and technological challenges, and answering to industrial needs. Besides their prominent role in nuclear and particle physics, accelerators are important actors for material science, energy, and health care. An overview of these applications will be given. The relevant technological developments will be presented, with a focus on compact accelerator neutron sources.

Low-dimensional moderators for high-power and compact sources

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We give a review of the research carried out at the European Spallation Source on low-dimensional moderators for high-power and compact sources. Such high-brightness moderators will serve all the instruments of the initial suite of ESS. The main physics principles, responsible for the higher efficiency in slow neutron production per fast neutron produced at the target, are related to the properties of the parahydrogen cross section, and to the response of the reflector. The optimization of such moderators is achieved by considering the layout of the facility and the beam extraction, and *flat* or *tube* moderators can be designed, in different geometrical configurations, depending on the number of instruments. In an accelerator-based compact source, such moderators can be designed in an even more efficient way than for high-power sources, taking advantage of the lower heat loads and of the more compact arrangement of the target-moderator system. In principle this gives more freedom in the optimization of the geometrical setup. Several promising design options have been explored for compact sources.

Progress of Neutron Sources and Opportunities for CANSs in China

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There are three grand national neutron sources in operation or in construction in China, including, China Spallation Neutron Source (CSNS) which got its first neutron beam in August, 2017, China Advanced Research Reactor (CARR) which got critical in 2011 and is expected to start operation in 2018, China Mianyang Research Reactor (CMRR) which started operation since 2013. The recent progress of the three grand neutron source of China will be introduced.
There are also several compact accelerator-driven neutron sources in operation or in construction in China, such as, the Compact Pulsed Hadron Source (CPHS) in Tsinghua University, the Peking University Neutron Imaging Facility (PKUNIFTY), the RFQ-based BNCT supported by CSNS, the electrostatic accelerator-based BNCT of NeuBoron, the intense neutron generator of Lanzhou University, the compact accelerator-driven neutron source and neutron radiography facility of China Academy of Engineering Physics, the compact-accelerator driven neutron source in Xi’an Jiaotong University, and so on. The progress of these CANSs will be presented.
The first seminar on compact accelerator-driven neutron sources in China was held in Tsinghua University, Beijing on January 19, 2019. The opportunities for CANSs in China will be discussed while the grand national neutron sources and the CANSs are coming with great progress in China.

Monday July 8th - Afternoon - Parallel sessions

Accelerator

Replacement of the primary electron beam accelerator at Hokkaido University neutron source facility

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The Hokkaido University neutron source facility (HUNS) which was an old facility completed in 1973, used an electron beam as the primary beam to generate neutrons. A 45 MeV electron linear accelerator had been used to generate the electron beam, but it used over 40 years operation and there were concerns about future maintenance and operation. So we decided to update the primary accelerator system. Although the choice between proton and electron was considered as the primary beam for neutron generation, electron beam accelerators were chosen as before due to the ability of short pulse drive and the expectation for stable and low-cost operation.
The new accelerator consists of two S-band klystrons, an electron gun, a pre-buncher, and two accelerator tubes. A block diagram of the new accelerator system is shown in fig.1. Among the components, one of the accelerator tubes, the electromagnets for electron beam control and the electron beam tube are remained old. The capabilities of the new accelerator are as follows; peak current: 250 mA (old acc.: 210 mA), beam energy: 32 MeV at 250 mA (old: 31.5 MeV at 210 mA), maximum pulse width: 4 □s (old: 3 □s), maximum repetition: 100 pps (old: 50 pps), beam power: 3.2 kW (old: 1.1 kW). After completion, it is expected to have about three times the intensity of old facilities.
The old accelerator was shut down at the last day of October 2017, then the replacement work was done within a year. There were some initial troubles, but the normal operation was started from the mid of February 2019. Now the new accelerator facility HUNS-2 is successfully operated with 50 pps repetition, which is the 1.5 times power toward the old HUNS.

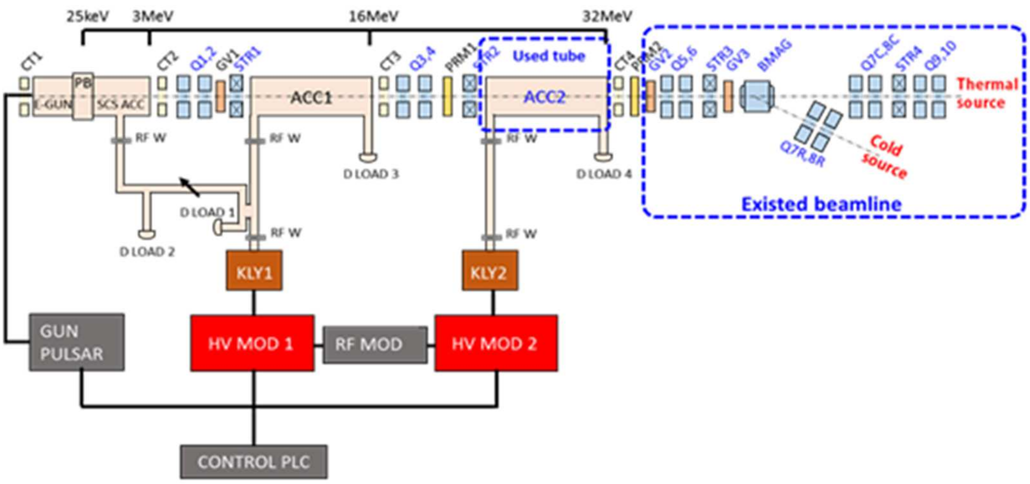

Figure 1: *Block diagram of replaced electron linear accelerator.*

Fast and Moderated DD and DT Neutron Sources and Applications

Dr. Charles Gary, Dr. Melvin Piestrup, Dr. David Williams, Dr. Craig Brown, Eugene Guan, Glenn Jones, Dr. Randy Urdahl, Dr. Jay Cremer

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Presented are fast (2.5 MeV DD and 14 MeV DT) fusion-based, Adelphi neutron generators and their applications, including Prompt Gamma Neutron Activation Analysis (PGNAA), radiographic imaging, cancer therapy and 14 MeV DT-based Associated Particle Imaging (API). The generators use a plasma ion source and acceleration voltages for the deuterium and/or tritium ions between 60 and 250 kV to produce total neutron outputs between 10^8 and 10^{11} neutrons per second. Thermal neutrons fluxes of over 10^7 neutron per second per square centimeter have been achieved with closely coupled moderators.

An e-linac based photoneutron source designed for various neutron applications

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With an 50 MeV e-linac, photoneutrons are produced via the e→γ→n process. The neutron yield could reach 5E13n/s when the average electron current is 0.5 mA bombarding on the tantulum target. As the electrons can be switched easily to different targets, four neutron converting targets are designed in this study to cover the various neutron applications. A thermal neutron convertor is designed for the thermal neutron imaging, which may play an important role in the turbine blade inspection. An epithermal neutorn convertor is designed for the middle and high-Z nuclides resonant analysis, by balancing the eV-keV neutron's yield and the energy resolution. Another epithermal neutron convetor is designed for the BNCT (boron neutron capture therapy) study. The estimated epithermal neutron flux could be larger than 1E8n/s when the photon's dose rate is as low as <2E-13 Gy cm^2/neutron. The cold neutron will also be produced with the fourth convertor, aiming at the research of braggedge detection for the residual stress analysis. Meanwhile, the energetic X-ray beam can induce intense positron flux inside the metal due to the pair-production process, as the result, the PIPA (photon induced positron analysis) can also be realized with this system. Such a facility was proposed by Tsinghua University and will be constructed in Yibin city, Sichuan Province, China. The method of involving the applications of four different radiations (electron, positron, X-ray and neutron) will be discussed in this presentation.

IPHI, a high intensity proton accelerator for neutron production

Nicolas Chauvin
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Over the last years, CEA-Saclay has been strongly involved in R&D activities dedicated to accelerated high intensity proton and deuteron beams. In particular, the high power proton injector IPHI has been designed, developed and build with the ultimate goal of accelerating a 100 mA continuous beam to 3 MeV. This machine is composed by a high intensity ECR ion source, a low energy beam line, a 352 MHz Radio-Frequency Quadrupole and a medium energy transport line equipped with diagnostics.
In 2016, the IPHI facility has been successfully commissioned with a low duty cycle (around 0.1 %) proton beam of 80 mA. After a technical shutdown, IPHI was restarted by the end of 2017. In October 2018, a beam power of 7.2 kW was reached.
Following this achievement, a neutron production setup based on a multi-kW Beryllium-based target and a polyethylene moderator was installed and successfully operated at 3 kW.
The current accelerator performances will be presented together with the plans for the near future.

Development of the radio frequency quadrupole proton linac for ESS-Bilbao

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The Radio Frequency Quadrupole (RFQ) linear accelerator for ESS-Bilbao is described. This device will complete ESS-Bilbao injection chain after the ion source and the LEBT. Fabrication and testing of the first segment are currently ongoing. The RFQ is a 4-vane structure, aimed to accelerate protons from 45 keV to 3.0 MeV and operating at a frequency of 352.2 MHz in pulsed mode (duty cycle up to 10%). Total length is about 3.1 meters and it is divided in 4 segments. Each segment is itself assembled from four components, named vanes, by using polymeric vacuum gaskets with no brazing among them. Notable aspects of the design are the constant mean aperture R0, vane radius ρ and thus ρ/R0 ratio and also uniform intervane voltage. Novel procedures for the design of the modulation and integrated beam dynamics and electromagnetic design have been developed for this task. In this paper, the complete design procedure and its results are presented, including beam dynamics, RF cavity design, field flatness and frequency tuning, cooling and thermo-mechanical design. Fabrication, assembly and testing of the first segment are also described.

Proton beam multiplexer developments for multi-target operation at the High Brilliance Source HBS

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The High Brilliance Source (HBS) project aims to develop a scalable Compact Acceleratordriven Neutron Source (CANS) enabling neutron fluxes at the corresponding instruments comparable to medium-flux fission-based research reactors. The full-fledged HBS facility features simultaneous operation of different neutron instruments which subdivide into three target stations each efficiently operated to supply different neutron energies. This will be realized by different proton beam timing schemes distributed to the target stations in order to obtain the optimal balance between wavelength bandwidth and resolution of the timeresolved neutron spectrum extracted from the thermal or cold neutron moderator according to the requirement of the experiment. For this reason a proton pulse distribution device, i.e. multiplexer, has to be developed that allows the spatial separation of two different subsequent proton pulses within less than 800 us. This contribution presents concepts on the realization of a multiplexer for a 70 MeV, 100 mA proton beam with 384 Hz, 96 Hz, 24 Hz pulse sequences and 2 % duty cycle as well as developments on a multiplexer device realized at 45 MeV proton energy, uA peak currents and an identical timing scheme.

Neutron scattering – Radiography

Bulk Texture Measurement Technique using Compact Neutron Source

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Neutron diffraction is a powerful probe to acquire the bulk averaged information for better bridging the microscopic crystal lattice with the macroscopic properties, in contrast with the X-ray and electron diffractions which are capable for investigating the surface/very limited local regions of polycrystalline materials. In Japan, the RIKEN compact accelerator-driven neutron source facility (RANS) has been developed to improve the instrumental accessibility of neutron diffraction experimental studies, which were mostly carried out on large-scale neutron source facilities. Here, our latest technical progress in RANS neutron diffraction bulk texture measurement will be reported. The comparable study between RANS and another large-scale neutron diffraction facility suggests that the high stereographic resolution realized through the proper fine division of neutron detector panel is valuable to improve the precision and reliability of texture measurement, together with the careful scattering intensity correction of neutron patterns.

CONSTRUCTION of SANS INSTRUMENT ib-SAS at COMPACT NEUTRON SOURCE (RANS), Tokyo.

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We report on the construction of time-of-flight small angle neutron scattering (TOF-SANS) at a compact neutron source. RIKEN, Japan has developed accelerator-driven compact neutron system, RANS (RIKEN Accelerator-driven compact neutron source) and neutron beam technology for these five years. It was relocated in Jul. 2015 and resumed operation in Jan. 2016. In order to regain the brilliance of incident neutron, an converging device, multi-pinhole collimator (5x5), was prepared to make a focus of neutron on the detector position (2m from sample). The covered q-region, where q is a wave number, is from 0.01 to 5 (A^{-1}) using small-angle and wide-angle detectors. The pulsed neutrons are generated by Be(p,n) reaction with hitting proton (7 MeV). A Be target is composed of beryllium (Be) thin plate of 0.3mm thickness and backing plate of vanadium (V) of 4.0 mm thickness. Cooling water is flowing in a titanium (Ti) cavity. The Be target is shielded with thick plates of lead, borated-polyethylene and iron (target station). Ibaraki university developed small-angle neutron scattering instrument (SANS) at the down stream of Be target station (Fig.1). The total length is about 3.6m from collation to detector position. Using a TOF method, a wide range of wave length from 1 A to 10 A is utilized for SANS measurement. As a two-dimensional detector, flat panel (2x2) (Hamamatsu photonics Co. Ltd.) are utilized. In this talk, we present SANS obtained for glassy carbon and concrete.

Acknowledgements

This work is supported by scientific funding A-STEP (Adaptable and Seamless Technology Transfer Program through Target-driven R&D, Industrial Needs Response Type) by Japan Science and Technology Agency (JST).

Molecular Spectroscopy at ISIS – Synergies & Opportunities with Medium & Compact Neutron Sources

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A number of joint ventures between the Molecular Spectroscopy Group at the ISIS Facility [1] and projects to develop next-generation medium & compact neutron sources have been reported in earlier editions of UCANS and other related international events [2]. In this talk, we provide an overview of more recent progress, capitalising upon new developments primarily on the VESUVIO [3] and TOSCA [4] spectrometers, and involving the extensive use of more agile & responsive beam-access mechanisms relative to traditional routes [5]. In particular, we describe the full implementation of broadband neutron-transmission techniques on VESUVIO+, from fractions of a meV to tens of eV. This new capability has been used with success in a number of situations of relevance to the UCANS community, including: the quantitative assessment of nuclear-spin-isomer concentrations in our hydrogen moderators, as part of the ongoing TS1 Project [6]; or its concurrent use with neutronresonance-capture analysis for high-throughput materials research [7]. The number of applications & associated scientific community exploiting these new capabilities continues to grow, oftentimes in unforeseen directions. A particularly exciting area of increasing interest relates to the combined use of Xpress access [5] on VESUVIO+ [3] & on the upgraded TOSCA [4] along with computational materials modelling [8], in order to establish the spectroscopic response of materials of relevance to neutronics, neutron-source development, and other nuclear-physics applications, as superbly illustrated in Ref. [9]. This presentation also addresses how these emerging science & instrumentation programmes have been underpinned by a strong educational & training component in both experimental & computational methodologies, primarily aimed at early-career researchers and newcomers to the field. In closing, we also explore how these recent developments may also provide a much-needed platform for a number of yet-to-be-tapped synergies & opportunities for collaborative work across the present and envisaged ecosystem of neutron sources in Europe and beyond [10].

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Study of a collimation method as a nondestructive diagnostic technique by NPGA for salt distribution in concrete structures at RANS

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To meet strong demand for realizing an effective diagnostics tool to diagnose salt distribution in concrete infrastructures, we have started a research and development of a new technique using a neutron-captured prompt gamma ray (NPGA) at the RIKEN accelerator-driven compact neutron source (RANS) [1]. So far, we have confirmed that RANS provides a suitable neutron beam to detect small enough amounts of Cl in salt within the marginal concentration of around 1.2 kg/m^3 to involve steel corrosion, by performing experiments using mortar bricks of 4x4x4cm^3 with different chloride ion concentration in the range from 0.36 to 5.1 kg/m^3 including chloride of 23 to 330 mg by applying NPGA [2, 3]. Concerning salt depth profile in concrete, which has been addressed as a critical important information associated with corrosion start of steel bar, we have proposed two methods to derive the depth profile in concrete as follows; the first one utilizes a difference in the intensity ratio of two different energies of gamma-rays of interest, which is depending on the depth where the neutron capture reaction takes place inside the concrete; and the second is called the collimator method that measure gamma -rays coming through a collimator of the detector [4].

In the collimator method, a detection sensitivity of gamma -ray due to salt with respect to depth in concrete has been studied by a simulation with a simplified geometry of salt containing concrete with realistic size. By taking neutron beam injection to the concrete object, neutron transport, and then prompt gamma -ray production into accounts, we have derived fractions for □-ray sensitivity of interest for every layers of 50 mm thick up to 150 mm depth. Based on the fraction for layer of different depth, a salt depth profile has been derived when the calculated fraction for □-ray sensitivity is applied as a correction factor.

Highlighting the collimator method, we present feasibility of the methods to estimate the depth profile of salt distribution in concrete.

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Combining fast neutron radiography with positron emission particle tracking in a tumbling mill system

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Understanding the behavior of flow within dynamic systems is important to optimize the required outputs from such active systems. Non-destructive methods offer a significant advantage since the system may be preserved over multiple studies. We present the first dual measurements of the steady-state flow of material within a laboratory scale tumbling mill system which combine observables obtained from fast neutron radiography (FNR) and positron emission particle tracking (PEPT). FNR measurements were made using the CV28 Isochronous cyclotron at the Physikalisch-Technishe Bundesanstalt, Braunschweig, Germany, and PEPT measurements were made using a Siemens HR++ PET scanner at PEPT Cape Town laboratories, iThemba LABS, South Africa. We offer comment on the usefulness of combining a 2D transmission technique (FNR) with a 3D emission technique (PEPT) to validate existing numerical models of flow conditions within the system of interest

Design and Construction of Imaging beamline at Nagoya University Neutron Source (NUANS BL2)

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The electrostatic accelerator-driven neutron source was designed and constructed at Nagoya University. There are two neutron target stations, BL1 is using epithermal neutron for study of BNCT engineering, and BL2 is thermal neutron for multi-purpose such as neutron imaging and detector development.
Dynamitron accelerates the proton beam up to 2.8MeV and the maximum average current is 15mA, which is DC beam. We designed to be able to use the proton beam up to 1.5mA in BL2, because of the cost and the area space capacity. Be foil of 40 um thickness is using for neutron emission target, and polyethylene is using for thermal neutron moderator material in BL2. The first neutron beam is emitted in July 2017, and the neutron intensity is raised with the proton beam tuning. The thermal neutron measurement port is set at the 50 cm position from the moderator. Since this distance is shorter than that of the other compact neutron sources, higher intensity neutron beam can be obtained. The neutron beam size is 10 x 10 cm and it is suitable for neutron imaging. A $ZnS/^{6}LiF$ scintillator and a cooled CCD camera system is using for the neutron imaging. We will report the design concept and the current status of the NUANS BL2.

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Status report on development of a compact D-D neutron generator and fast neutron detection/imaging capabilities at ETH/PSI

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In recent years a custom compact D-D fast neutron generator has been under development in Switzerland at the Paul Scherrer Institute (PSI) in collaboration with ETH Zurich. Its main intended use is imaging, and its most important feature is the small emitting spot (~2 mm) which keeps source-induced imaging blur low. A purpose-designed plastic scintillator array was developed in parallel in order to perform computed tomography [1]. The source was recently upgraded to have a rotating beam target, increasing the total neutron output to ~3×10^7 neutrons/s, which is ~5x more than what was achieved with the previous non-rotating target, [2]. Ongoing source upgrades include changing from an RF to microwave driven ion source, which is hoped to allow higher voltage operation and neutron output.
The neutron source is used in particular as a tool for development of neutron detectors in general, and energy-selective imaging in particular, by taking advantage of the angle dependent and quasi-mono-energetic nature of the D-D reaction. The range of energies available with our source is roughly 2.2 to 2.8 MeV. By combining measurements at different energies, it is possible to gain information about the elemental content of a sample. Basic tests of this principle were successful [3] and ongoing efforts include more test sample materials and more complex/realistic geometries.
The detector development includes the aim of scalable gamma-blind radiation detectors with imaging capabilities. The operating principle is wavelength shifting fibers embedded in a ZnS(Ag)+epoxy mixture. Fundamental tests of this detector type were successful, and the concept is planned to be applied to spent nuclear fuel characterization. Ongoing work includes coupling this composite material to a CCD camera to get a 2D distribution of events. It is additionally being explored if detecting coincidences between perpendicularly arranged fibers, using a Silicon photomultiplier, can be used for imaging purposes.
An overview of these source, energy-selective, and detector activities using fast neutrons will be presented, including the latest results and an outlook of future work.

[1] R. Adams, R. Zboray, and H. M. Prasser, “A novel fast-neutron tomography system based on a plastic scintillator array and a compact D-D neutron generator,” Appl. Radiat. Isot., vol. 107, pp. 1–7, 2016.
[2] H. Kromer, R. Adams, B. Soubelet, R. Zboray, and H. M. Prasser, “Thermal analysis, design, and testing of a rotating beam target for a compact D-D fast neutron generator,” Appl. Radiat. Isot., vol. 145, pp. 47–54, 2019.
[3] B. Soubelet, R. Adams, H. Kromer, R. Zboray, and H. M. Prasser, “Feasibility study of using a compact deuterium-deuterium (D-D) neutron generator for energy-selective transmission tomography,” Radiat. Phys. Chem., vol. 156, pp. 292-299, 2019.

Magnified imaging by cold neutrons using refractive optics

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The modulating sextupole magnetic lens is a powerful device for making use of precious neutrons generated with a compact neutron sources. It can focus wide wavelength range of neutrons in pulsed neutron beams. The focusing is realized by modulating the focusing strength synchronized with their TOF information. The refraction lens has no material that may scatter neutrons in the bore and the straightforward optical axis eases its mechanical alignment compared with the mirror devices, whose angle error of the downstream axis is twice as much as the angle alignment error. The simple focusing principle of the refraction lens is suitable for the neutron imaging with neutrons. A series of trial imaging experiments is under going at HUNS at Hokkaido Univ[1]. The status will be presented.

[1] Iwashita, Y., Fuwa, Y., Ishida, T. and Kino, K. “Magnified Neutron Imaging with Modulating Permanent Magnet Sextupole Lens”, Proc. Int. Conf. Neutron Optics (NOP2017) 22 011008-1-7 (2018).

Target

Development of a regenerated Beryllium target and a thermal test facility for Compact Accelerator-based Neutron Sources

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The possibility to use compact accelerators coupled to high current ion-sources for the production of intense low energy proton or deuteron beams has recently motivated many research teams to develop accelerator based neutrons sources for several purposes, including Neutron Capture Therapy (NCT). The NCT needs a high flux about 10^9 n/(cm^{2}s) of epi-thermal neutrons (E < 10 keV) at the tumor site. Up to now, the NCT required neutron flux was mainly produced by nuclear reactors. However, the production of such neutron field is now possible using proton or deuteron beams on specific targets able to stand a high power (~15-30 kW) on a small area (~10 cm²). This specific target design, materials and supports, has to cope with extreme physical constraints.

The LPSC team has conceived an original solution formed by a thin (8 µm) rotating beryllium target deposited on a graphite wheel and coupled with a beryllium sputtering device for periodic ^{9}Be layer restoration. By means of ^{9}Be(d,n)^{10}B nuclear reaction, this target irradiated by a 10-20 mA deuteron (1.45 MeV) beam should produce the required neutron field.

In order to validate simulations done of the neutron flux production and the Beryllium target thermal capabilities, we built a 30 cm diameter rotating Beryllium target prototype and a compact thermal electron beam line able to produce a power of 3kW on a 1 cm² surface.

The ^{9}Be target design and the thermal test facility will be presented showing the first thermal results at 3kW/cm^2.

Target Concept for the High Brilliance Neutron Source

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In the framework of the HBS Project, a large national neutron facility is currently conceived. Several target stations are foreseen, sequentially supplied by proton pulses from a single accelerator. Each of the target stations is supposed to be operated with an average power of 100 kW.

The elevated power levels require special care when designing the target assemblies. The high brilliance of such a source results from the density of the neutron flux inside the moderator, which requires a small neutron production volume, thus a compact target moderator assembly.
For non-spallation systems, this is achieved on the one hand by the small interaction length of the accelerated protons inside the target, which is in the order of some millimeters and on the other hand by a small beam spot.

As a consequence, the whole beam power is deposited inside a small volume, which requires highly efficient heat removal techniques.
Concepts to handle the high temperatures and thermal stresses will be presented, in order to permit a HBS target to be operated with a peak beam current of 100 mA with 70 MeV proton beam energy and a duty factor of 1.4 %, resulting in a thermal load of 100 kW in average.

Internally-cooled target design to achieve high power density in a CANS target

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Within the framework of the HBS Project, a pulsed compact accelerator driven neutron source [CANS] is being developed as user facility. The neutron production takes place by nuclear reactions at 70 MeV below the spallation threshold energy with a time averaged proton current of 100 mA inside the target which is one of the key components of the source. The use of the low energy regime has advantages e.g. by enabling a holistic optimization of the neutron production chain for each instrument and thereby increasing the portion of usable neutrons but the low energy reduces the neutron yield and the target thickness, too. Thus, the high proton flux is necessary in order to compensate for the limited yield and enable the development of a competitive thermal neutron source. The high proton flux at low energy causes several difficulties for the development of a dedicated target which endanger the target integrity. Previous investigations indicate that hydrogen embrittlement and mechanical stresses due to temperature gradients are the dominant challenges. For the actual realization of these goals two target designs are proposed within the HBS project. The internally-cooled target is one of them. The combination of the materials choice and the target dimensions together with an innovative micro channel coolant design promises a reliable operation at a maximum power density together with an efficient primary neutron production originating from a small volume. Simulations suggest that the internally-cooled target can be operated at the envisaged parameters. The manufacturing method is tested and the fabrication of the target is initiated. First experimental test of the targets stability are scheduled within the next month.

A solid Beryllium target for SONATE

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We will report on the development of a new solid Beryllium target for neutron production. This multi-kW target designed for a compact accelerator-driven neutron source shall eventually be used for the SONATE project.
The concept and the design of the target will be presented and the first beam performances will be shown. The first prototype of the target has been tested on the IPHI accelerator. The target has been operated at an average power of 3kW for more than 50 hours corresponding to an integrated fluence higher than 50mA.hours. The maximum power density on the target was 650W/cm². The accelerator was operated in pulsed mode with a peak power of 60kW (E_p = 3MeV, I_{peak} = 20mA).

Recent developments of Hot Isostatic Pressing diffusion bonding technologies to enhance cooling efficiency and reliability of proton beam targets and dumps at CERN

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In the upcoming years, upgrade of CERN fixed proton target facilities (n_TOF neutron spallation target and Super Proton Synchrotron (SPS) internal beam dump) and design of novel ones (Beam Dump Facility (BDF)) will require to adapt to future the higher beam energies and deposited beam power.
The target/dump materials, when directly cooled with liquid coolants, suffer erosion-corrosion from the fluid, hence shielding such as coatings or claddings are widely employed. Since new beam energies, protective layers ensuring thermal exchange between the coolant and the target and a sound contact with the target during the whole device lifetime are mandatory. Previous studies at CERN combined with experience from neutron spallation sources facilities raised the interest on claddings applied by means of Hot Isostatic Pressing (HIP) assisted diffusion bonding.
This work presents an outlook on the investigations carried out for two facilities: a) for BDF, the application of Ta based claddings (1.5 mm thick) diffusion bonded to the refractory metals target material to prevent erosioncorrosion and b) for the new SPS dump, the diffusion bonding between the Cu based cooling plate and embedded stainless steel cooling pipes to improve cooling efficiency. Several downscaled prototypes with representative geometries of the final application were fabricated and subsequently characterized. The microstructural, mechanical and thermal properties of the diffusion bonded interfaces as well as the involved materials (W, Mo, Ta alloys for BDF; Cu alloys and stainless steels for SPS dump) after the HIP cycles were assessed. In both cases, high quality interfaces have been achieved, therefore raising HIP as a trustful technique.
Moreover, further optimization and understanding of the technique was sought. Additional prototypes were built to assess the potential use of new materials (new Ta alloys and new Cu alloys), the use

of different HIP cycle parameters (temperatures and time) and HIP interfacial aids (interlayer materials). The prototype preparation procedures and characterization results will be presented, together with the application of these results to beam facing prototypes. Additionally, open points and potential issues based on the upscaling to full scale targets will be formulated.

DIFFUSION BONDED Be NEUTRON TARGET USING 8MeV PROTON BEAM

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The development of the high intensity compact neutron source is mainly conducted by using accelerators for medical purposes. Recently, a lot of compact neutron sources have been developed, and most of them are for boron neutron capture therapy (BNCT). Compared with the common accelerators used for industries, accelerators for BNCT have to accelerate a 100 times larger current of charged particles because of the low conversion efficiency of neutron moderators. To attain a reliable target for the BNCT neutron source, two obstacles have to be overcome; radiation damage (blistering) and the heat issue. We introduce diffusion bonding method aiming to make defect free Be neutron target and 1MPa latent heat water-cooling system. We also install beam expansion optics using quadrupole and octupole magnets to reduce charge density.
Our facility operates more than three years from the commissioning period and we report the recent situation as following.
-Diffusion bonding method was applied to the solid neutron target of Be with latent heat cooling system
-Amount of integrated coulomb value of protons implanted to the Be target is nearly 3000C now
-Amount of neutron dose rate was measured
-Developed laser reflection microscope (LRM) method is applying to observe neutron target condition (especially radiation damage) through viewport with a few meters working distance
-Direct observation of the surface of the Be target was done during the period of improving nearly target vacuum and residual radiation conditions
From these evidences, we conclude our neutron target already produces neutrons capable to treat nearly 500 patients of malignant melanoma.

Tuning of target / moderator / reflector unit for optimized instrumentation at compact accelerator driven neutron sources

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Neutron scattering instruments require specific bandwidths and timing structures according to the experimental resolution conditions. Recent developments of compact accelerator based pulsed neutron sources (CANS) enable an individual optimization of the neutron energy spectrum and pulse timing to feed every instrument with a suitable phase space volume. This is an advantage compared to today's reactor or spallation sources where all instruments are fed by a single common thermal or cold moderator.

In CANS neutrons are produced by the interaction of protons in the 10 to 100 MeV range with a suitable target. This target is embedded in a thermal moderator which is surrounded by a reflector. This increases the thermal neutron flux in the moderator also affecting the neutron dynamics and therefore the pulse structure. Extraction channels inside the moderator and reflector direct the neutrons to the instruments. One dimensional cryogenic moderators can be inserted into the extraction channels and serve just one instrument each. The target / moderator / reflector unit (TMR) is optimized to fulfill the specific requirements of the individual neutron instruments.

We will present the possibility to optimize the neutron spectra and the timing structure for some selected neutron scattering instruments and show the flexibility a CANS offers.

Real-time neutron beam monitor with single moderator spectrometers

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A step forward in the field of neutron spectrometry was given, in recent years, by the introduction of single-moderator spectrometers. These devices succeeded in the difficult challenge of condensing the functionality of a Bonner Spheres Spectrometer into a single moderator, embedding multiple thermal neutron detectors. To meet the measurement needs of different types of neutron producing installations, two geometries were developed: the spherical one for isotropic measurements (SP2 device), and the cylindrical one for directional measurements (CYSP device). As the internal thermal neutron sensors are simultaneously acquired, these devices are suited to operate as real-time beam monitors with spectrometric capabilities. This communication will explain the operating principles, characterization and performances of these instruments, with special emphasis on a practical design that was demonstrated already in the Italian Neutron Experimental Station (INES) at the ISIS spallation source. Relevant aspects such as the choice of the internal detectors, the measures to enhance the neutron-to-photon discrimination capability and the spectrum unfolding will be explained in details.

The obtained results demonstrate that routine quality assurance of neutron beamlines can be performed using a real-time neutron spectrometer responding to all spectral components from thermal to GeV.

[1] R. Bedogni, J.M. Gómez-Ros, K. Alikaniotis, G. Pagano, M. Pillon, A. Pietropaolo. Nucl. Instr. Meth. A 927, 151 (2019).
[2] R. Bedogni, D. Bortot, B. Buonomo, A. Esposito, J. M. Gómez-Ros, M. V. Introini, G. Mazzitelli, M. Moraleda, A. Pola, A. M. Romero, Rad. Prot. Dos. **170** (1-4), 326 (2016).
[3] R. Bedogni, J.M. Gómez-Ros, A. Pola, D. Bortot, A. Gentile, M.V. Introini, B. Buonomo, M. Lorenzoli, M. Mazzitelli, D. Sacco, Nucl. Instr. Meth. A **782**, 35 (2015).

Tuesday July 9th – Morning

Plenary session

RIKEN Accelerator-driven compact neutron systems

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RIKEN Accelerator-driven compact neutron source, RANS, has been operated since 2013 [1]. There are two major goals of RANS research and development. One is to establish a new compact low energy neutron system of floor-standing type for industrial use. Another goal is to invent a novel transportable compact neutron system for the preventive maintenance of large scale construction such as a bridge. The low energy transmission imaging [2], neutron diffractometer [3], small angle scattering instruments [4], fast neutron transmission imaging [5], fast neutron reflected imaging [6], neutron induced prompt gamma-ray analysis [7] and neutron activation analysis are available with RANS. To solve the lack of nuclear data to develop compact neutron sources, we have created new function which gives neutron spectrum from the 9Be +p reaction with protons of energy below 12MeV[8]. For further compact neutron system, RANS-II are now ready to generate neutrons in the RANS experimental hall with individual shielding system [9]. The novel proton accelerator tube and 500 MHz solid state high-frequency amplifier for RANS-III, of a transportable neutron system [10], are now ready to be developed in RIKEN.

[1] Y.Otake, "A Compact Proton Linac Neutron Source at RIKEN", “Applications of Laser-Driven Particle Acceleration” eds. Paul Bolton, Katia Parodi, Jörg Schreiber, June 5 (2018) Chapter 19 pp.291-314CRC Press [2] Atsushi Taketani, et al. "Visualization of water in corroded region of painted steels at a compact neutron source" ISIJ International vol.57 N.1 (2017) pp.155-161

[3] Y. Ikeda, et al "Prospect for application of compact accelerator-based neutron source to neutron engineering diffraction", Nucl. Instr. Meth. A 833(2016)pp 61-67

[4] S.Koizumi, et al. “A Variety of Small-angle Neutron Scattering Instruments Available in Tokyo Area, Japan — Complimentary Use of Accelerator and Reactor—” JPS Conf. Proc. 25, 011004 (2019)

[5] Y.Seki et al. “Fast neutron transmission imaging of the interior of large-scale concrete structures using a newly developed pixel-type detector", Nucl Inst. Methods Phys Res A 870 (2017) pp. 148-155

[6] Y. Ikeda, et al. "Nondestructive measurement for water and voids in concrete with compact neutron source", Plasma and Fusion Research Vol.13(2018) pp.2406005-1-5

[7] Y. Wakabayashi, et al. “ A Study on the Non-Destructive Detection of Salt in Concrete Using Neutron-Captured Prompt-Gamma Rays at RANS”, Plasma and Fusion Research, Vol.13, 2404052 (2018)

[8] Yasuo Wakabayashi et al. "A function to provide neutron spectrum produced from the 9Be + p reaction with protons of energy below 12 MeV", J. Nucl. Sci. Technol. Vol. 55 (2018) pp.859-867

[9] T.Kobayashi et al. "Development of accelerator-driven transportable neutron source for non-destructive inspection of concrete construct", 2017 IEEE Nucl. Sci. Symp. and Med. Imag. Cof. Atlanta, USA Oct.(2017) [10] N.Hayashizaki et al. Patent 2011-086494

Instrumentation on CANS Vs other facilities

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Recent technical improvements in the accelerator and target technology coupled with the concept of compact moderator open the possibility to conceive efficient neutron source for imaging and neutron scattering. Low power tests and McStas simulations show that instruments installed on such a source may have similar performances than similar ones available on medium flux research reactors [1]. Considering the high flexibility of a compact source design, its low cost compared to a research reactor and the raising price of efficient instruments, we have now to consider the option of conceiving a source fully adapted to a dedicated single instrument or at least a family of similar instruments having similar source requirements. In that case, the broad band request of the users may be solved by putting in place a large network of small specialized CANS but each one involved in a strong collaboration process with the other ones.

[1] F. Ott et al. Performances on Neutron Scattering Spectrometers on a Compact Neutron Source, ICANS XXII, IOP Conf. Series: Journal of Physics: Conf. Series 1021 (2018) 012007

Development of a Sealed Lithium Target for Nagoya BNCT System

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An accelerator based neutron source for boron neutron capture therapy (BNCT) is currently under development in Nagoya University. The neutron source employs a DC accelerator and lithium (Li) target. Li is a suitable target material to generate low energy neutrons through the $^{7}Li(p,n)^{7}Be$ reaction. On the other hand, lithium as a target material has several difficulties in properties such as low melting point, high chemical activities, and ^{7}Be production. For resolving those issues, we have devised and produced a sealed Li target with an efficient water cooling channel. The sealed Li target is a structure in which thin Li is set on a metal base plate and covered by a thin metal foil to confine Li and ^{7}Be. The base plate has cooling channels with V-shaped staggered rib structure to remove the heat load by the proton beam.
Figure 1 shows the temperature rise (Delta T) at the surface of the base plates depending on the heat load in the case of straight simple channel and rib channel. The rib structure has the effect of inducing turbulence in the cooling channel, which was able to improve the heat removal performance about twice that of the straight channel.
We made a small lithium target for the proton beam irradiation test. When the heat load of the proton beam on the target is 4.0 MW/m^2, the temperature of the target was less than 120 degrees which is much lower than the melting point of Li. In addition, the irradiation experiment confirmed that the Ti foil was not damaged.
These results indicate that the proposed sealed Li target is reliable as a target of our neutron source.

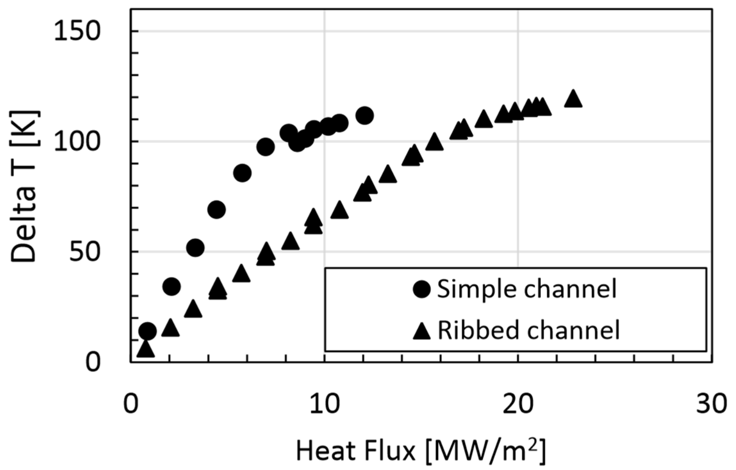

Figure 1 *Temperature on the target surface to the heat load*

A 50 kW Liquid-Lithium Target for BNCT and Material-Science Applications

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A compact Liquid Lithium Target (LiLiT) has been operating at SARAF for several years with beam power of several kW (1.9-2.5 MeV, up to 2 mA). This neutron source was used for nuclear astrophysics research and was decommissioned about two years ago due to an internal oil leak in the heat exchanger. An upgraded model was considered to expand possible applications to boron neutron capture therapy (BNCT) and material-science studies.

The improved version has been designed to sustain 50 kW beam power to provide sufficient neutron flux required for clinical BNCT application (up to 2.5 MeV, 20 mA). The new model has a 50 mm wide lithium jet to enable dissipation of the higher beam power and an improved heat exchanger to remove the power to a secondary cooling loop. A new annular linear induction electro-magnetic pump (ALIP) is being designed and built to provide the required lithium flow rate. Other mechanical improvements facilitate the maintenance of the system and the robustness of operation. Radiological risks due to the 7Be produced in the reaction are reduced by using an integral lead shielding of the lithium reservoir. An integral neutron moderator is being designed to adjust the neutron energy to the spectrum best suited to BNCT.

A low power (6 kW) model of the new design with a narrower nozzle (18 mm wide) and the old rotating-magnets electro-magnetic pump is operating at SARAF to support the ongoing astrophysics and nuclear research program [1,2]. The upgraded LiLiT model will require an accelerator (e.g. radio-frequency quadrupole) of appropriate energy and intensity. The design features of the new system will be presented.

[1] I. Mardor, O. Aviv, M. Avrigeanu, D. Berkovits, A. Dahan, T. Dickel, I. Eliyahu, M. Gai, I. Gavish-Segev, S. Halfon, M. Hass, T. Hirsh, B. Kaiser, D. Kijel, A. Kreisel, Y. Mishnayot, I. Mukul, B. Ohayon, M. Paul, A. Perry, H. Rahangdale, J. Rodnizki, G. Ron, R. Sasson-Zukran, A. Shor, I. Silverman, M. Tessler, S. Vaintraub, and L. Weissman, “The Soreq Applied Research Accelerator Facility (SARAF): Overview, research programs and future plans,” The European Physical Journal A, vol. 54, no. 5, p. 91, (2018)
[2] M. Paul, M. Tessler, M. Friedman, S. Halfon, T. Palchan, L. Weissman, A. Arenshtam, D. Berkovits, Y. Eisen, I. Eliahu, G. Feinberg, D. Kijel, A. Kreisel, I. Mardor, G. Shimel, A. Shor, and I. Silverman, “Reactions along the Astrophysical s-Process Path and Prospects for Neutron Radiotherapy with the Liquid-Lithium Target (LiLiT) at the Soreq Applied Research Accelerator Facility (SARAF),” Accepted for publication in European Physical Journal A, (2019)

Tuesday July 9th – Afternoon

Parallel sessions

Isotope and nuclear data

Nuclear data evaluation of neutron-induced reactions on Pu isotopes

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In order to reduce the uncertainties in the design and operation of accelerator-driven systems (ADSs), accurate nuclear data for neutron-induced reactions on Pu isotopes below 150 MeV are required. To meet this requirement, all cross sections, angular distributions, energy spectra, double differential cross sections of neutron, proton, deuteron, triton, helium3 and alpha emissions and the number of neutron per fission for n+Pu reactions are consistently calculated and analyzed by theoretical nuclear models in the energy range of $E_n \leq 150$ MeV. The theoretical models include the optical model, the distorted wave Born approximation theory, the Hauser-Feshbach theory, the fission model, the evaporation model, the exciton model and the intranuclear cascade model. The calculated results reproduce the experimental data well, and the variation tendency of reaction cross sections related to the target mass numbers is obtained, which is important in the prediction of neutron-actinides reactions with insufficient experimental data.

Nucleon scattering analysis for tungsten isotopes by a regional dispersive optical potential

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Tungsten isotopes are important structural material and are thought to be similar to fissionproduct and actinide nuclei, therefore nuclear data of tungsten isotopes play an important role in not only geophysics and astrophysics but also nuclear engineering applications. These data are related to determination of the age and origin of the earth, moon and chondrules. Also these data are used in high-temperature nuclear-energy systems. However there are still significant differences between existing w-isotopes evaluations in different evaluated nuclear data libraries. Therefore the improvement of evaluated scattering cross sections and reduction of their uncertainties for neutron induced reactions on w-isotopes is an important goal that should initiate new theoretical studies. A regional dispersive coupled channels optical-model potential based on a new rotor model is derived for tungsten and neighboring isotopes from 100keV to 200MeV. Excellent agreement with experimental data is obtained for total cross sections for $^{182,183,184,186}W$, ^{178}Hf, and ^{181}Ta nuclei in the whole energy range. Nucleon elastic/inelastic scattering angular distributions and analyzing powers are also in good agreement with measurements. Meanwhile the effect of nuclear volume conservation is checked for the calculation of total cross section, angular distribution and analyzing power. The results show that this potential works well for almost all the nucleon scattering data for tungsten isotopes and the adjacent nuclei of tungsten, and the present results are better than those data in other evaluated data libraries.

Moderators

A proto-type cold neutron source at RANS and applications using it

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The RIKEN accelerator-driven neutron source (RANS) is a compact neutron source which aims to widely spread the use of neutron beams in the industrial field. A cold neutron source is being developed for RANS to provide a lower energy range of neutrons for applications such as small angle scattering, reflectometry and Bragg-edge measurements. We plan to employ methyl benzene derivatives as the moderator material for its non-explosive characteristics and rather long maintenance cycle. Calculations were done using "PHITS", a beam transporting simulation software based on Monte Carlo code for several types of moderator systems. Mesitylene, a mixture of mesitylene and m-Xylene, were considered as the moderator material. For calculations using mesitylene, several types of scattering kernels based on different models were applied. The scattering kernel was provided by Dr. Granada and Dr. Abe. The performance estimation, pre-moderator and moderator thickness optimization calculations were done. The reflecting system was also considered, and pulse width was calculated for coupled, decoupled and poison type reflecting system. The optimum thickness was calculated to be 3 - 4 cm for the polyethylene and 3.5 cm for the mesitylene. The pulse characteristics for mesitylene moderators is expected to be rather relaxed than solid methane moderators with a lower energy spectrum.

An installation experiment was operated using a prototype moderator unit at RANS and the wavelength spectrum, pulse width was measured for both types of moderators. The moderator material was sealed in an aluminum cavity and cooled to 20K. 3 cm of polyethylene was set just before the moderator as the pre-moderator. Both the moderator and pre-moderator were surrounded by graphite reflectors. The dimensions of the mesitylene inside the cavity were 100 mm x 100 mm x 2.5 mm. We measured the TOF spectrum of the mesitylene moderator 5 m apart from the moderator surface.

A neutron focusing test using an ellipsoidal mirror was operated to estimate the performance of an focusing-SANS instrument. A Bragg edge measurement test was also operated and showed rather promising results for a steel sample.

Deuterated clathrate hydrates for neutron moderation and reflection in future high-flux sources of very cold neutrons

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Fully deuterated clathrate hydrates are a promising class of materials for diffuse neutron reflection and for moderation to much lower energies than current cold neutron sources. The required low temperatures naturally meet the relaxed radiative heat-load conditions of CANS which opens a window to enhance performances of novel neutron sources. The inclusion compounds are available with a variety of weakly neutron absorbing guest molecules. Due to their large unit cells they offer better diffusion properties than common reflector materials within a much larger cold-neutron wavelength range up to 2 nm (Clathrate Structure II) or 2.4 nm (CS I). There, they outperform not only graphite or beryllium, possessing much smaller Bragg cut-offs and larger absorption, but also the best imaginable nanostructured materials. In addition, local modes of the guest molecules offer incoherent inelastic scattering channels able to remove kinetic energy stepwise from the neutron, unsuppressed due to low density of phonon states at low energies and kinematic restrictions by dispersion relations. Inelastic magnetic scattering in fully deuterated O2-clathrate hydrate has recently been identified as a promising moderator material. It possesses an experimentally established non-dispersive inelastic neutron scattering signal with 0.4 meV energy transfer due to

the zero-field splitting of molecular oxygen. Based on calculated cross sections for magnetic neutron scattering and a stationary neutron transport equation for an infinite, homogeneous medium with Maxwellian neutron sources, strong cooling effects are to be expected, requiring only ordinary liquid-helium temperatures, no external magnetic field and no neutron polarisation. An experimental program has been started at the ILL to measure S(q,ω) in absolute units not only for this material but also for other clathrate hydrates to investigate the strength of various molecular rotational and local translational modes. The goal is to establish a data base for a realistic modelling of moderator/reflector geometries in novel neutron sources.

Directional reflection of Cold Neutrons using Nanodiamond Particles for Compact Neutron Sources

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Nanodiamond Particles (NDP) are new candidates for neutron reflection. They have a large scattering and low absorption cross-section for low-energy neutrons. Very Cold Neutrons (VCN) are reflected in NDP with large scattering angles while Cold Neutrons (CN) have a quasi-specular reflection at small incident angles. A new scattering process has been added in Geant4 in order to examine the directional reflection of CN in an extraction beam made of NDP layers. Impurities in NDP are responsible for the up-scattered neutrons, especially hydrogen which has a high scattering cross-section. Other impurities are also considered in Geant4 in order to produce a more accurate model of NDP scattering. The new scattering process was used to model possible configurations of target-moderator-reflector in compact sources.A typical beam of 13 MeV proton striking a Beryllium target was chosen. Parahydrogen is placed as a cold moderator in order to produce CN. NDP are placed around the extraction beam for scattering the CN toward the exit of the beam. The results show that CN exiting the extraction beam can be increased thanks to the implemented NDP layer.

Cryostat for the provision of liquid hydrogen with variable ortho-para-ratio for a low-dimensional cold neutron moderator

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A significant contribution to the enhancement of the neutron brilliance achievable with Compact Accelerator-driven Neutron Sources (CANS) can be made by an optimized cold moderator design. When using liquid para-H2 as the moderating medium, the concept of lowdimensional cold moderators can be employed to increase the neutron brightness (as currently foreseen at the European Spallation Source ESS). Para-H2 shows a drop in the scattering cross section by about one order of magnitude around 30 meV, resulting in large deviation between the mean free paths of thermal and cold neutrons. Taking advantage of this effect, the cold moderator geometry can be optimized to allow the intake of thermal neutrons through a relatively large envelope surface and then extracting them in an efficient way towards the neutron guides. One drawback of this solution is the lack of thermalization of the cold neutrons. In the context of the HBS (High Brilliance Source) project, efforts are made to overcome this problem by increasing the scattering cross section of the H2 in a defined way. The idea is to admix small amounts of ortho-H2, which maintains its large scattering cross section in the region below 30 meV. Like this, the neutron spectrum can be shifted towards lower energies and adjusted for the needs of the respective instrument. In a cooperation between TU Dresden and FZ Jülich, an experimental setup has been created to proof the feasibility of this concept. The main component of the experimental setup is a LHecooled flow cryostat that enables the separate condensation of a para-H2 and a normal-H2 flow and a subsequent mixing of the two in precise proportions. The resulting LH2 mixture at 17 – 20 K is fed into a small cold moderator vessel (approx. 200 ml). In this work, the current status of the setup is presented. The construction and commissioning of the mixing cryostat have been completed and first test runs show that different ortho-para-H2 mixtures can be produced. In the near future, the system will be ready for measurements at a neutron source.

Slab geometry type cold neutron moderator development based on neutronic study for Riken Accelerator-driven compact Neutron Source (RANS)

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Cold neutrons are important in neutron scattering investigation for material science because they have high resolutions to be detected. However, cold neutron sources are usually available at large neutron facilities, such as spallation neutron sources and reactor neutron sources. Recent advanced accelerator technology dramatically increases available neutrons, especially for compact type accelerator-driven neutron source. RANS [1] is an accelerator-based pulse neutron facility based on the ^{9}Be(p,n)^{9}B reaction [2] in a beryllium target with 7 MeV proton injection. Currently, we focus on a coupled mesitylene cold moderator (20K) with polyethylene pre-moderator (room temperature) based on slab geometry from the view point of safety, stability, handling convenience, high radiation resistance, etc. [3]. So far, we have optimized the thickness of pre-moderator and mesitylene to get highest cold neutron flux by using a Monte Carlo simulation code, PHITS [4]. In this study, we considered a realistic configuration of moderator with thin aluminum vessel wall and vacuum layer.

The lateral size of moderator is about 100 x 100 mm^2, and size of neutron beam extraction hole is 75 x 75 mm^2. The cold neutron performance at 1 m or 2 m from the target is characterized. As a result, so far, the optimized thickness of polyethylene and mesitylene are about 4 cm and 3 cm, respectively. Along with the thickness of moderator, optimization study on material and geometry of reflector, neutron brightness, neutron pulse characteristics, etc., is underway as parameters.

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COMPARISON OF NEUTRON CHARACTERISTICS OF COLD NEUTRON MODERATORS IN THE COMPOSITION OF THE TARGET STATION FOR CNS «DARIA»

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The DARIA compact neutron source is projected based on a proton accelerator with an energy of up to 13 MeV and a beryllium target. The studies (Ref. 1) of neutron emission spectra and design of neutron target station is show neutron yield is ~0,11% per 1 proton (Ep=10MeV). According to the calculations, the average neutron energy is 2 MeV, which is consistent with the data presented in the EXFOR library and in other studies (Ref. 2). Therefore, the key task is to choose the characteristics of the moderator: material, shape, temperature, combination. Difference variants of optimizations of the neutron target station will be presented. The following moderators are considered: water, beryllium, heavy water, para-hydrogen, mesitylene. Optimization calculations were carried out for a specific instrument for neutron research of a substance.

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Detection

Measurement methods of Single Event Upset cross section depending on neutron energy for diffusion of soft error test using compact accelerator-driven neutron source

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The research of the soft error by cosmic ray derived neutrons is rapidly increasing recently due to the miniaturized semiconductor but the relationship between neutron energy and soft error rate is not sufficiently clarified. Because there is no method to detect the neutron energy that caused the soft error, the SEU (Single Event Upset) cross section has been measured using a monochromatic neutron source that generates neutrons of specific energy. Therefore, it was difficult to measure the SEU cross section over a wide energy range. Hence, we devised a new method that enables us to measure SEU cross sections depending on neutron energy, and succeeded to measure the SEU cross sections with high resolution over about 3 orders energy range. It is assumed that soft error tests using the compact accelerator-driven neutron source will spread by this data.

Hybrid boron-10 gaseous detector for slow and fast neutron simultaneous detection

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The hybrid position-sensitive neutron detector with active 10B-layer filled with Ar+20%CO2 has been constructed [1,2]. It also permits measuring time-of-flight. The detector is used on the source based at the linear accelerator. Recording two pairs of pulse heights, produced in two gas gaps by 7Li and 4He nuclei between the anode and two cathodes, gives a possibility to determine both X and Y neutron coordinates. A significant difference in pulse heights for slow and fast (several MeV) neutrons was observed [3]. It has been found that the pulse heights depend on the fast neutron energy. By changing the beam energy, the position of the spectrum maximum in the pulse height

versus the limiting neutron energy from one of the four electron channels is obtained as shown in Fig.1.

Using the found properties a compact detector is being developed to measure slow and fast neutrons. In contrast to scintillation detectors, the presented detectors (1) have a very low sensitivity (< 10-7) to other types of radiation including g-rays, (2) weakly distort neutron field due to small scattering and absorption in gas, aluminum and silicium of which detector consists. We estimated that 10B 3m-layer detector would have the efficiency 3x10-2 for thermal neutrons and 3x10-6 for fast (MeV) neutrons [3]. Thus, such detector will be capable to operate in powerful flux of fast neutrons. In order to increase the detector efficiency one can implement multiple 10B layers.

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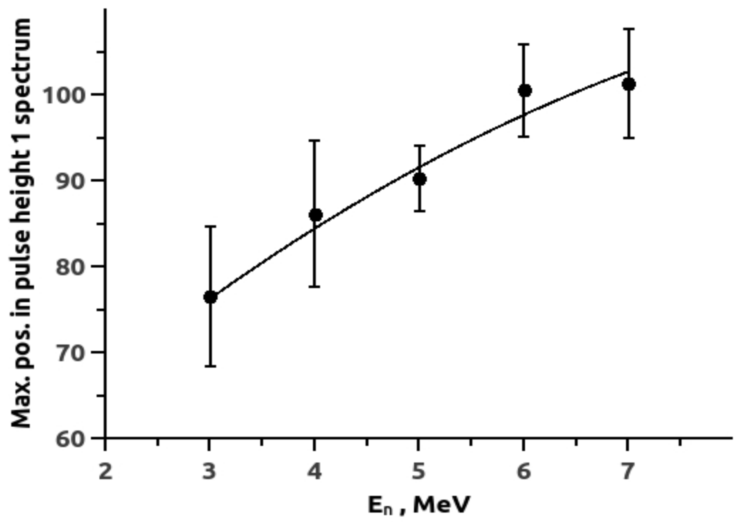

Figure 1: *Position of spectrum maximum in the pulse height versus the limiting neutron energy.*

Fast neutron spectroscopy, Targets and Moderators for Compact Accelerator Neutron Sources

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The spectroscopy and angular distribution of the neutron field produced at the target level is one of the important information to take into account for designing the moderators adapted to the different applications.

We have developed a new spectrometer based on the 3D nuclear recoils produced by the fast neutrons called MIMAC-FastN. This new directional detector opens the possibility to describe the neutron energy distribution with their angular distribution discriminating the neutron-diffused contribution.

We will show the different neutron spectra produced by the ^{9}Be(d (1.45 MeV), n) ^{10}B nuclear reaction adapted to AB-BNCT (Accelerator Based-Neutron Capture Therapies).

We have designed and developed two original solutions for ^{9}Be and ^{7}Li targets that can be coupled to existing accelerators. The ^{7}Li liquid target will be rapidly shown.

To validate the concept of our targets, thermal tests are performed at the LPSC with an electron beam facility of 20 keV (I = 150 mA on 1 cm^{2}) producing the same power density (3kW/cm^{2}) that required for a high neutron flux production (see Muraz's contribution).

An original moderator designed for the Beryllium target for AB-NCT applications will be shown.

The research of a Boron-lined Honeycomb Convertor based neutron detector

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Boron-lined gaseous detectors play the important role as the ^{3}He alternative detectors in the neutron scattering and homeland security. However, due to the short range of alpha particle or ^{7}Li nucleus, the large S/V (surface area vs volume) ratio is the necessity for achieving a high intrinsic neutron detection efficiency. Most of the researchers thus place tremendous anode wires inside the detector's sensitive volume to multiply the ionized electrons after the $^{10}B(n,\alpha)^{7}Li$ reaction. Unfortunately, these designs inevitably complicate the manufacturing process and deteriorate the operation robustness of the detector. In this research, a boronlined honeycomb convertor based neutron detector (BHCND) is proposed to address these problems. A new process, the migration of electrons driven by an electric field from their birth places near the $^{10}B(n,\alpha)^{7}Li$ reaction points to a outside electron multiplier, is introduced. This design has been confirmed by the pre-research and showed the simplified manufacturing process and a better operation robustness, as well the ~mm scale spatial resolution for the neutron detection. It also has a directional neutron sensitivity and the good capability of suppressing cross-talk neutrons, which can suppress the background neutrons by 10 times and improve the S/B (signal vs background) ratio of the detection system significantly. It is a promising new-designed detector that may replace the ^{3}He counter in the area of neutron scattering.

Completion in the ITU-T's standardization of Soft Error Test of network equipment using Compact Accelerator-driven Neutron Sources

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The establishment of international standard for measures against soft errors in network equipment was completed at ITU-T(the International Telecommunication Union, Telecommunication Standardization Sector) in November 2018. This International Standard consists of five Recommendations and one Supplement. A soft error is a temporary bit error (memory bit inversion) in a semiconductor device that can be recovered by restarting the semiconductor device or overwriting correct data. Even though soft errors can cause a serious impact such as system down or malfunction, it is difficult to reproduce the event and identify the cause since it will be recovered by restarting or overwriting correct data. Therefore, this international standard defines a test method for reproducing soft errors using a compact accelerator-driven neutron source. And, in the Recommendations, reliability requirements of the network equipment are defined, and the quality evaluation method is also shown. The concept of the reliability requirement and the concrete evaluation method using the small accelerator-driven neutron source will be presented.

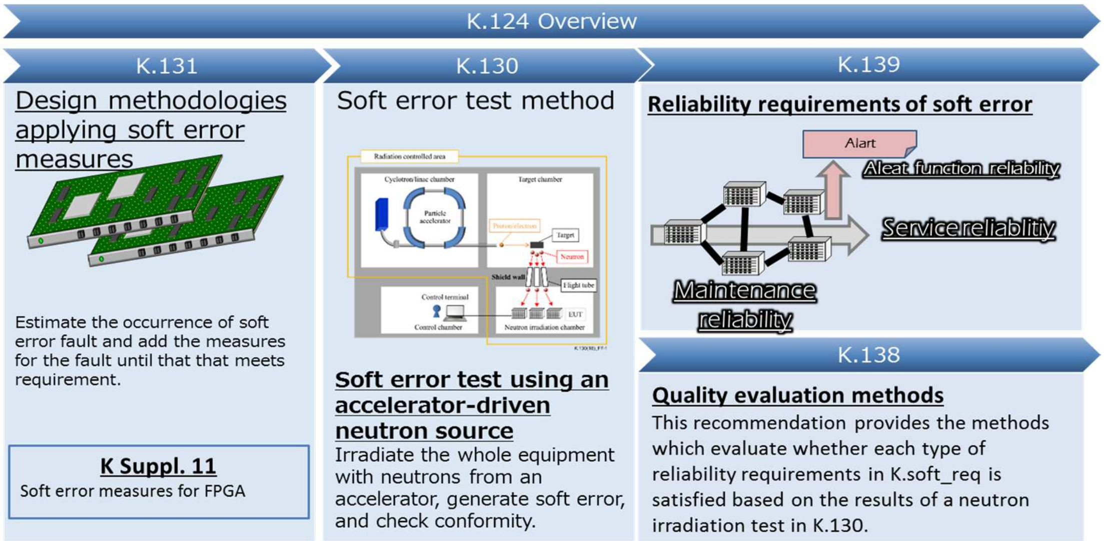

Figure 1: *Overview of the standardization of the soft error*[1] [2] [3] [4] [5] [6]

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Energy and Flux Measurement of Monochromatic Fast Neutrons with Cs_2LiYCl_6:Ce (CLYC) Detectors

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Since 2017, a monochromatic neutron source based on a 1.7 MV tandem accelerator is in operation to provide external users with a quasi mono-energetic neutron beam at the Korea Multi-purpose Accelerator Complex (KOMAC) of Korea Atomic Energy Research Institute. In the facility, fast neutrons are generated by bombarding a proton beam on a lithium fluoride (LiF) target via the charge exchange reaction ^{7}Li(p,n)^{7}Be. The kinetic energy of neutron is uniquely defined by the scattering angle and the incident proton energy, while the experimental cross section for the neutron production is well reported in the literature [1] for the proton energy range of interest. For the neutron beam characterization, the energy and flux of generated fast neutrons were measured with a 1.5 inch Cs_2LiYCl_6:Ce (CLYC:Ce) scintillators attached with Hamamatsu photomultiplier tube, R6231-100, employing pulseshape discrimination (PSD) techniques for n-γ separation. Detector outputs fed directly a fast waveform digitizer operated at the sampling rate of 1 GS/s without any pre-processing electronics, subsequently recorded data was processed by using off-line analysis code for digital signal processing. Unlike a typical PSD technique, three integrating gates (two for PSD and one for energy) were applied to improve PSD performance while maintaining the energy resolution. The detectors were calibrated with standard gamma-ray sources, and the energy resolution was found to be equal to or less than 5% at 1332 keV. The neutron energy was measured for the incident proton energy between 2.0 to 2.8 MeV, and the detectors were calibrated accordingly. In the presentation, we present the specifications of the neutron facility and the experiments for determining the energy and flux of emitted neutrons, subsequently describe the experimentally obtained results in comparison with theoretical calculations.

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Medical applications

e_LiBANS project: thermal and epithermal neutron sources based on a medical-type electron Linac

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The E_LIBANS project (INFN, CSN 5) aims at producing neutron facilities for diverse interdisciplinary irradiation purposes among which pre-clinical research for BNCT. After the successful setting up and characterization of the thermal neutron source based on a medical LINAC a similar apparatus for epithermal neutrons is under development. Both structures are based on an Elekta Precise SL 18 MV, installed in a dedicated bunker at the Physics Department of Turin University. In both cases the linac head is coupled with a photoconverter-moderator system which deploys the (γ, n) photonuclear reaction on a thick lead target to convert the bremsstrahlung photons of the linac beam into a neutron field. Suitable materials and geometries are chosen to slow down neutrons to the wanted energy and to reduce the gamma contamination and the residual fast-neutrons component in the irradiation cavity. Relying on two specifically designed photocoverter+moderator assemblies, nearly pure

thermal or epithermal fields were achieved. This contribution will describe the numerical design of these fields and the experimental measurements performed for their spectrometric characterization.

Simulation and Design of electron accelerator-based photoneutron source for BNCT

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Electron accelerator-based photoneutron source for Boron Neutron Capture Therapy (BNCT) has been considered as an alternative neutron source in recent studies. This study focuses on designing optimized target and BSA (Beam Shaping Assembly) system for a photoneutron source based on the electron accelerator. It also discussed the methods of filtering the high-energy gamma-rays followed by neutron production in (e, γ) and (γ, n) reaction.

In order to maximize the epithermal neutron flux and optimize BSA system to satisfy the IAEA recommended criteria, MCNP5 Monte Carlo code has been employed to simulate this system. Cylindrical tungsten (radius=2cm, length=5cm) is chosen to be the target, which makes neutron yield reach 5×10^{13}n/s based on a 50 MeV/25kW electron accelerator. BSA system, consists of moderators, reflectors, filters and collimators, is mainly designed to slow down fast neutrons generated by photoneutron source and filter undesired photons. To avoid the forward photons, the direction of desired neutron beam is perpendicular to that of the incident electrons. Heavy water is chosen to get more epithermal neutrons and Bismuth with thickness of 30 cm is applied to moderate extra fast neutrons and filter majority of photons.

Reflectors and collimators are 'wrappers' of the BSA system. Tungsten is suitable material to be suggested to reflect neutrons and focus the flux at the exit of this system.

Through BSA system, the desired epithermal neutron flux is about 2.77×10^{8} n/cm^2/s, Φ_{th}/Φ_{epi} is 1.3×10^{-3}, much better than the IAEA recommended criteria. D_{γ}/Φ_{epi} has been reduced to 1.29×10^{-13} Gy cm^2/n and D_{fast}/Φ_{epi} is about 6.33×10^{-13} Gy cm^2/n. The results of this study indicates the possibility to design such a photoneutron source to treat patients in hospital conveniently. And cooling system for the target material has been dicussed. Due to the high power of the electron accelerator, water will be chosen as an effective coolant to remove the heat deposited in the target.

Neutron beam performance of iBNCT as the linac-based neutron source for BNCT in University of Tsukuba

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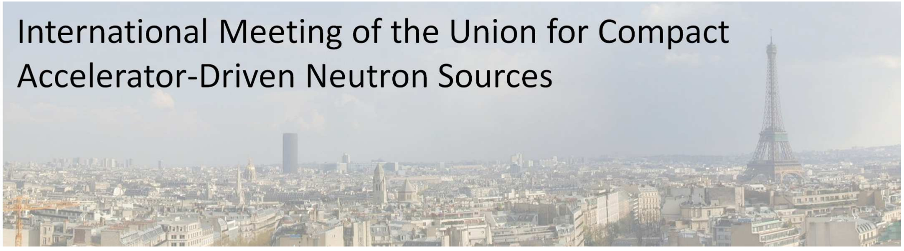
A collaboration team headed by the University of Tsukuba is being developed iBNCT as the compact linac-base neutron source for boron neutron capture therapy (BNCT) [1]. The accelerator of the

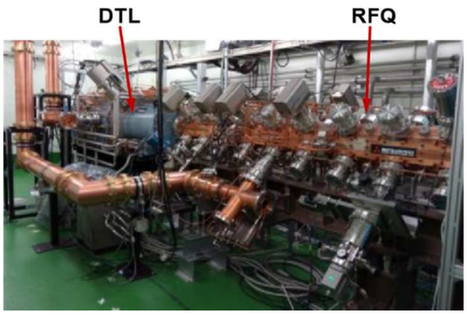


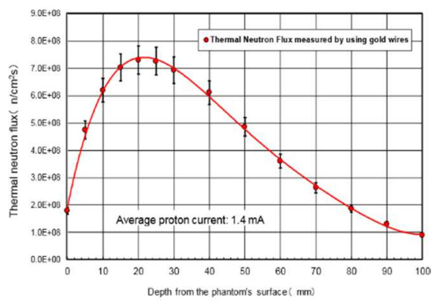
iBNCT has adopted an RFQ and a DLT type linac and accelerates protons to 8 MeV. Fig.1-(a) shows the linac of iBNCT. The linac has been designed to deal with the average current of 5 mA or more. Regarding the target material, beryllium has adopted. The iBNCT has completed the construction in 2016 and is being improved to increase neutron intensity. To implement clinical studies using the device in the near future, we are carrying out the characteristic measurement of the neutron beam generating from the iBNCT. To confirm the applicability of the neutron beam to actual treatment of BNCT, neutron irradiation experiments with a rectangular water phantom were performed. In the experiments, two-dimensional distribution for both of thermal neutron flux and gamma-ray dose were measured. For the measurement of the thermal neutron flux, gold wires were set inside the phantom where was set in front of the beam aperture and neutron beam was irradiated.

Fig.1-(b) shows the distributions for the thermal neutron flux on the beam axis in the phantom, when the linac is operated with an average current of 1.4 mA. The maximum flux was 7.3×10^{8} (n/cm^2/s) at 20 mm depth from the surface of the phantom. Base on the measurement results, we also estimated the applicability of the device to BNCT clinical study. The results proved that the device can administering the prescribed dose of approximately 55 Gy-Eq for tumor. And the irradiation time was approximately 48 min when the linac was operated with the average current of 1.4 mA. And we evaluated that the durability of the beryllium targat. The results indicated that the beryllium target had already generated neutron fluences sufficient to treat more than 700 patients and the neutron intensity has not yet reduced at all.

At the beginning of 2019, iBNCT started the operation with an average current of 2.8 mA. We continue to improve further the device and carry out the characteristic measurements. Based on these, we plan to implement clinical studies in the near future.

[1] H. Kumada et al., Development of LINAC-Based Neutron Source for Boron Neutron Capture Therapy in University of Tsukuba, *Plasma and Fusion Reserch*, **13**, 2406006, 1-6, (2018)





(a) **(b)**

Figure 1: *The linac of the iBNCT (a) and thermal neutron flux distributions on the beam axis in the phantom (b)*

Wednesday July 10th – Morning

Plenary session

The High Brilliance Neutron Source (HBS) Project

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Neutron scattering has proven to be one of the most powerful methods for studying structure and dynamics of condensed matter on atomic length and time scales. It is essential to understand processes, phenomena and functionalities in a wide range of materials. Accelerator driven neutron sources with high brilliance neutron provision are an attractive option as older research reactors are fading out. The Jülich Centre for Neutron Science is developing a compact accelerator driven high-brilliance neutron source to offer access for science and industry to neutrons in form of a medium-flux, but high-brilliance neutron facility. The High-Brilliance Neutron Source (HBS) will consist of a high current proton accelerator, compact neutron production and moderator system and optimized neutron extraction and transport for thermal and cold neutrons. The project will allow construction of a scalable neutron source ranging from a university-based neutron laboratory [1] to a full-fledged user facility [2, 3] with open access and service. We will describe the currents status of the project, the requirements for the accelerator, the next steps, milestones and the vision for the future use of neutrons at universities and research institutes.

[1] E. Mauerhofer et al., Conceptual Design Report NOVA ERA, Schriften des Forschungszentrum Jülich, General, Vol.7 (2017)
[2] U. Rücker et al., The Jülich high-brilliance neutron source project, Eur. Phys. J. Plus, 131, 19 (2016)
[3] J. Voigt et al., Spectrometers for compact neutron sources, Nucl. Instr. Meth. A, 884, 59 (2018)

LvB project: progress and early instrumentation concepts

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The compact neutron source project LvB is lead and will be operated by Mirrotron Ltd. The project is supported by a major grant of structural funds for development of regional industry. After the completion of the building on a green field in the city of Martonvasar, at 40 min drive or 30 min train ride from Budapest, the tedious EU public procurement process for a 2.5 MeV, 20 mA peak current pulsed proton accelerator with 5 % duty factor has been technically accomplished. The offers do not fully exhaust the budget for accelerator and a further tender for an afterburner is being prepared in order to reach 5 MeV final proton energy. The facility will be alternatively used for delivering 2.5 MeV proton beam for epithermal neutron production for hadron cancer therapy, and for 5 MeV proton beam for moderated bi-spectral cold-thermal neutron beam and fast neutron beam production in different beam bundle directions. The primary industrial goal of the LvB compact neutron source is to test on site components, primarily neutron supermirrors both for product development and production quality control as part of the manufacturing activities at Mirrotron Ltd. For this purpose, a reflectometer without moving parts is being planned (grant application in 2019), making use of the pulsed character of the source with variable long pulse lengths and pulse rates of about of 1 ms and 20 Hz, respectively. It will be primarily used for the observation of supermirror reflectivity profiles. The early installation of a boron capture therapy beam line is another priority, it is pursued in collaboration with a venture investment agency, in view of the high risks and high return potentials of investing in healthcare. Following the successful example of RANS in serving a broad industrial community, LvB also will provide neutron beams of different parameters for various industrial applications beyond the in-house needs. For this purpose both the provision of un-instrumented beam lines and of beam-time on a number of neutron instruments is considered. The cold and thermal neutron beams will be available for neutron radiography and tomography, neutron reflectometry, small angle scattering, prompt gamma activation analyses and neutron diffractometry for phase analysis, texture studies and strain scanning. At all of these instruments, the scope is to study the high intensity features of the scattered neutron spectra, often with good resolution (for example shifts of Bragg peaks for strain studies). High-resolution capability will be achieved by superposing a fast, random beam modulation on the basic pulsed time structure of the long pulse neutron generation, and observing the correlation between detector counting rate fluctuations in time with the random beam modulation. By the doubly time modulated neutron delivery pattern, low and high time resolution information will be simultaneously delivered by the instruments.

Characterization of Neutron Beam Applications

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(on behalf of the Fundamentals Working Group of the Japanese Society for Neutron Science)

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[c]Institute for Integrated Radiation and Nuclear Science, Kyoto University, Japan

As compact accelerator-driven neutron sources become commonly recognized and widespread for practical use, the need for comparing and discussing the performance of neutron sources and their suitability for individual applications is increasing. General-purpose large facilities have a common need to more accurately optimize the instrumentation and to optimally allocate resources. An effort to formulate the characterization of neutron beam applications is being paid in the Fundamentals Working Group of the Japanese Society for Neutron Science. The formalism may be used as an evaluation standard to estimate possible benefit in advance. We report the present status of the development of formalism and sketch the strategy to apply it for networking of neutron sources in Japan.

Instrumentation for small and large CANS

U. Rücker[a*], P. Zakalek[a], J. Voigt[a], E. Mauerhofer[a], S. Böhm[b],

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The scalable concept of Compact Accelerator-based Neutron Sources (CANS) allows to build pulsed neutron sources for neutron scattering and neutron analytics between some 100 W (NOVA ERA, university size source [1]) and 100 kW (medium flux HBS [2]) average ion beam power. The instrumentation has to be adapted to the source, as flux, shielding requirements, and background conditions vary with the power level.

In this presentation, I would like to show the design and approximate performance of some workhorse instruments (e.g. SANS, powder diffractometer, PGNAA analysis) as well as inelastic scattering instruments for both extremes of the source layout.

[1] E. Mauerhofer et al., Conceptual Design Report NOVA ERA, Schriften des Forschungszentrums Jülich, Allgemeines / General, Vol. **7** (Jülich, 2017)
[2] U. Rücker et al., The Jülich high-brilliance neutron source project, Eur. Phys. J. Plus **131**, 19 (2016)

Studies on reflector materials for cold neutrons

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Neutron scattering techniques and neutron applications in general are powerful and well established tools for research in science and technology. However the tremendous potential of neutrons as a probe of matter or as a research object by itself is limited by the relatively low flux intensity of the neutron sources, as compared with photon sources. In addition, the different processes (production, slowing-down) and devices (moderators, transport systems, collimators, energy-selectors, detectors, etc.) reduce by several orders of magnitude the actual neutron intensity that eventually conveys the experimental information of interest. One of the research lines devoted to reduce part of those loses has been oriented to the search for efficient reflector materials, that may improve the efficiency of guiding surfaces or the actual reflection of neutrons on a containment walls to minimize their leakage. A large body of work has been done in the past, particularly concerning the interaction of slow neutrons with diamond nanoparticles. It has been demonstrated the high reflectivity of this material for UCN and VCN, and proposed that such capacity extends at higher neutron energies, thus bridging the reflectivity gap in the neutron spectrum [1, 2]. In this work we present calculations aimed at evaluating the performance of other materials that seem to behave as very efficient reflector for neutrons over the CN range, as compared with diamond nanoparticles.

[1] E.V. Lychagin *et al*., Nuclear Instruments and Methods in Physics Research **A 611** (2009) 302–305 [2] V. Nesvizhevsky *et al*., Carbon **130** (2018) 799e805

Wednesday July 10th – Afternoon

Round Table

Invited

I. Swainson (AIEA), J.L. Martinez (ESFRI), Y. Kiyanagi (CANS in Japan)

IAEA activities in accelerator-based neutron production

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The IAEA Physics Section's activities include covers fusion, instrumentation and the applications of both research reactors and research accelerators. Several activities concerning neutron production, moderation and detection have been run in recent years or are on-going. For example, we recently concluded a 4-year Coordinated Research Project on advanced cold moderators for materials research that included developments for both accelerator and reactor neutron sources. We are also in the process of building a neutron science laboratory at our Seibersdorf laboratories for education and training purposes using D-D and D-T generators.
In the last two years, we have run Technical Meetings on neutron detectors and cold moderators, and will host another during November 4–7, 2019 on non-spallation, accelerator based neutron production. This meeting is being held due to the decline in the number of research reactors available for neutron beam methods as well as recent developments in both accelerators and target technologies. It will examine the classes of accelerators available to fill the gap, and how they may be optimized to tasks such as neutron scattering, imaging, BNCT, and cross-section measurements. Interested parties can contact us for details of the nomination process.

Plenary session

Laser driven neutron sources

Short-Pulse Laser-Driven Moderated Neutron Source

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Los Alamos National Laboratory (LANL) and collaborators have pioneered a novel short duration yet extremely intense neutron source using the short-pulse laser at LANL's Trident laser facility [1-5]. The Trident laser facility was until it's closure in 2016 one of the most intense and powerful short-pulse lasers in the world, providing a very high contrast laser pulse of ~600 fs in duration, ~80 J energy with a wavelength of 1053 nm. The laser beam can be concentrated to a peak intensity up to 10^{21} W/cm^2, that, when interacting with a sub-micron ultrathin CD (or CD_2) foil target, drives a high-energy deuteron beam. That intense beam converts into a neutron flux in a beryllium target that acts as catcher of deuterons and converter of deuterons to neutrons. The Trident laser-driven neutron source featured high intensity and directionality, ~10^{10} fast neutrons per shot in a ~1 sr cone and with an extremely short neutron pulse of <1 ns in time. The source has been already used effectively towards the development of a new generation of active interrogation concepts to detect clandestine nuclear material [6]. In order to enable other applications, such as nuclear resonance spectroscopy for isotopic identification of (irradiated) nuclear fuel [7], temperature measurement in shock–driven dynamic material experiments [8], and pulsed neutron diffraction and scattering, we have developed a bright moderated short-pulse laser-driven neutron source. Beryllium and high density polyethylene were used to realize this aim. The single pulse moderated neutron source was fully characterized in its energy spectral components by a set of neutron time-of-flight detectors, including the fast neutron component (~1 MeV-~50 MeV) coming from the neutron production, as well as the epithermal, thermal, and cold (few meV) components subsequent to the moderation of the neutrons. The presentation reports and discusses the measured features of the moderated single-pulse neutron source that we have just demonstrated and preliminary results in the detection of nuclear resonances with a view towards spectroscopy.
Moreover, the presentation compares the laser-driven short pulse neutron source with the spallation neutron source at the LANSCE facility, and the prospects of such novel laser-driven compact neutron sources based on available or proposed laser systems for medium and large scale neutron user facilities. The precedence of high-powered lasers in rugged environments for military or industrial (e.g. welding) applications may even provide a pathway to mobile compact short-pulse neutron sources.

[1] Roth, M. et al., PRL 110 044802 (2013).
[2] Fernández, J. C., et al. Physics of Plasmas 24.5 (2017): 056702.
[4] Vogel, S. C., et al. Neutron News 29.2 (2018): 32-36.
[5] Favalli, A., et al. Scientific Reports 9.1 (2019): 2004.
[6] Favalli, A., et al. report LA-UR-14-28697, IEEE Nuclear Symposium (Seattle, WA, USA, 2014).
[7] Roth, Markus, et al. report LA-UR-17-23190. Los Alamos National Lab, (Los Alamos, NM, USA, 2017). [8] Yuan, V. et al., PRL 94, 125504 (2005).

Photo-neutron production in laser driven proton neutron sources

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Laser driven neutron sources represent a possible route to compact neutron sources which can be tailored to the needs of different neutron analysis techniques in particular they provide a means of potentially producing very high brightness neutron sources. Laser driven neutron sources have been the focus of increased interest in recent years as developments in Laser power mean the neutron production rate and neutron energies required are now accessible. There are several different options for laser driven neutrons sources depending on the desired energy range and intensities such as laser driven protons [1], laser driven photons/xrays leading to photo neutrons [2] and laser driven fusion neutrons [3].
As with any neutron source the efficiency at which the initially generated neutrons can be turned to "useful neutrons" depends on the, target, reflector and moderating assembly. Traditional reflector materials such as Lead and Beryllium have relatively low energy thresholds for (gamma, n) and the relatively high fraction of photons produced by laser driven sources mean that many extra neutrons may be produced through this method.
In this work we briefly outline the main components and physics of a laser driven proton neutron source, then examine photo neutron production in different reflector materials. We examine if these photo neutrons can be useful neutrons for different types of neutron analysis techniques.
We simulate, using MCNP [4], a simple laser driven neutron source with a pitcher catcher style target (based on the work in [5]), reflector and moderator assembly as well as the start of a simple neutron instrument. We investigate the sensitivity of photo neutron production to the energy of the laser driven protons, the reflector material and reflector size.
Additionally we consider if heavy water as a pre moderator or moderator could also generate significant additional photo-neutrons. Deuterium also has a low energy photo-neutron threshold (1.8 MeV) and hence this could also be a source of additional useful neutrons. As expected photo-neutrons can boost the neutron production however these neutrons may not be useful depending particularly if time of flight energy resolution is required.
We conclude with a broader look at the consequences of enhanced photo neutron production and include engineering, safety and waste management considerations.

[1] S. Kar *et al*, New Journal of Physics, 18, 053002, (2016)
[2] I. Pomerantz *et al*, Physical Review Letters, 113, 184801 (2014)
[3] M. Roth *et al*, Physical Review Letters, 110, 044802 (2013)
[4] J.T. Goorley, et al., "Initial MCNP6 Release Overview - MCNP6 version 1.0", LA-UR-13-22934 (2013).
[5] C. M. Brenner *et al*, PPCF, **58** 014039, (2016)

CANS Projects

Newly constructed compact accelerator-based neutron facility at AIST

Koichi Kinoa*, Takeshi Fujiwaraa,b, Michihiro Furusakaa,b, Noriyosu Hayashizakia,b,c, Hidetoshi Katoa,b, Ryunosuke Kurodaa,b, Koji Michishioa,b, Takemi Murogab, Hiroshi Ogawaa,b, Brian E. O'Rourkea,b, Nagayasu Oshimaa,b, Daisuke Satoha,b, Norihiro Seia,b, Tamao Shishidob, Ryoichi Suzukia,b, Masahito Tanakaa,b, Hiroyuki Toyokawaa,b, Akira Watazua,b

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We have just constructed a compact accelerator-based neutron facility at the National Institute of Advanced Industrial Science and Technology (AIST) in Japan. This facility is aimed at development of structural materials of transportation vehicles for weight reduction. The Bragg edge imaging is promising for this purpose and this facility was optimized for this technique. Figure 1 shows an overview of this facility. We use an electron linear accelerator with a beam pulse width of 10 μs in maximum, a repetition rate of 100 Hz in maximum and a maximum beam power of 10 kW. As a neutron moderator, we adopted a decoupled solid methane for a short pulse width neutron beam, which is required for the Bragg edge imaging. Moreover, super mirror guide tubes were set along the beamline to increase neutron flux at a sample position, which is about 8 m from the moderator. In this presentation, we will introduce this new facility and show the current status.

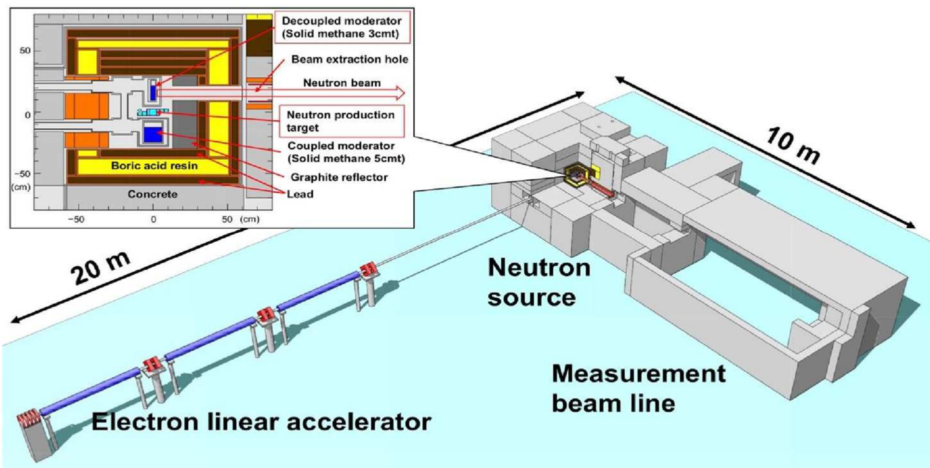

Figure 1: *Overview of the compact accelerator-based neutron facility at AIST [1].*

[1] K. Kino *et al*., Nuclear Inst. and Methods in Physics Research, A 927 (2019) 407–418.

This presentation is based on results obtained from a project commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

Neutron-related Activities and Future Plan at KOMAC

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At Korea Multi-purpose Accelerator Complex (KOMAC), a 100-MeV high power proton linac has been used for proton beam irradiation services for various applications and research programs including material science, bio-medical science, semiconductor applications as well as nuclear physics and basic science since commissioning of the machine in 2013. Currently, one beam line for 20 MeV beam and three beam lines for 100 MeV beam are available for user service. In addition to the applications with direct irradiation of proton beam to specimen, we are going to expand the utilization of the facility to secondary beams such as isotope beam (Li-8 for beta-detected NMR) and pulsed neutron. For pulsed fast neutron utilization, especially for terrestrial neutron-induced soft errors in semiconductors or various detector research for space applications, we carried out basic study to characterize the neutron beam from 100-MeV linac beam dump. From a preliminary study, the neutron yields of about 2.5E13 pps can be obtained on the tungsten target with the average beam power of 1 kW. At present, we provide pilot services to users from semiconductor industry with neutron generated at beam dump, made of copper. Also, for quasi-monochromatic neutron source based on a 1.7 MV tandem accelerator is under development at KOMAC. To generate quasmonoenergetic neutron, we use 7Li(p, n)7Be reaction with a target made of LiF thin film deposited on aluminum substrate. This neutron source will be used for detector test and nuclear data and as a platform for neutron-related research. To extend our neutron-related capabilities and meet various neutron user requirements, we plan to construct new building for secondary beam utilization in near future. KOMAC facility overview along with on-going activities and neutron-related future plan will be given in this presentation.

Acknowledgements: This work has been supported through KOMAC (Korea Multi-purpose Accelerator Complex) operation fund of KAERI by MSIT (Ministry of Science and ICT).

From micro- to macro-sources:
The Lund Broad-band Neutron Facility

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Nathaly De La Rosa[a], Markus Kristensson[a], Per Kristiansson[a], Nicholai Mauritzson[a],
Francesco Messi[a], Charlotta Nilsson[a], Jan Pallon[a], Emil Rofors[a]

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Neutrons of all energies are important probes of matter and are crucial to an increasingly number of applications in both scientific and industrial fields. For many novel developments, a dedicated facility offering easy and affordable access to neutrons is a vital prerequisite.

The Lund Broad-band Neutron Facility (LBNF) has been designed with such use cases and a low barrier-of-entry in mind. Hosted by Lund University (LU) and operated by the Neutronics Group, the LBNF provides well-established and user-focused infrastructure, expertise in nuclear physics and detection techniques and access to neutrons from both neutron-emitting radioactive sources and accelerator-based neutron sources.

Each of the neutron production methods comes with distinct characteristics that make it ideally suitable for specific applications. Source-based continuous neutron beams provide stable fluxes of typically 106 neutrons per second for response [1] and/or attenuation measurements [2] as well as long-term irradiation measurements for dosimeter testing. Using a technique called "tagging" and the infrastructure present at the LBNF, it is even possible to study attenuation and detector responses as function of the neutron energy even with standard radioactive sources [3,4].

The accelerator-based pulsed neutron beams, on the other hand, enable variable fluxes controlled by the beam current for time-of-flight measurements. The existing Pelletron-based accelerator facility has recently been upgraded with an eye on re-purposing for the production of neutrons and is foreseen to be able to deliver fluxes of up to 1011 neutrons per second in the near future. Until then, a d-t neutron generator provides turn-key operation and neutron fluxes of up to 108 neutrons per second.

By providing its users with this variety of low-cost options for neutron sources, an optimal configuration can be determined on a case-by-case basis thus significantly reducing the barrier of entry. Furthermore, such a facility located at a University provides an ideal site for the education of the next generation of neutron scientists.

In this contribution, the LBNF will be presented together with an overview over the results so far obtained there and the plans for future projects.

[1] Issa, Khaplanov, Hall-Wilton, Llamas, Riktor, Brattheim & Perrey, "Characterization of thermal neutron beam monitors", *Phys. Rev. Accel. Beams*, **20**, 092801 (2017). link. doi.

[2] DiJulio, Cooper-Jensen, Perrey, Fissum, Rofors, Scherzinger & Bentley, "A polyethylene-B4C based concrete for enhanced neutron shielding at neutron research facilities", *"NIM A"*, **859**, 41 - 46 (2017). link. doi. [3] Scherzinger, Al Jebali, Annand, Fissum, Hall-Wilton, Kanaki, Lundin, Nilsson, Perrey, Rosborg & Svensson, "The light-yield response of a NE-213 liquid-scintillator detector measured using 2-6 MeV tagged neutrons ", *"NIM A"*, **840**, 121 - 127 (2016). link. doi.

[4] Scherzinger, Al Jebali, Annand, Bala, Fissum, Hall-Wilton, Hamilton, Mauritzson, Messi, Perrey & Rofors, "Tagging fast neutrons from a ^{252}Cf fission-fragment source", *"Applied Radiation and Isotopes"*, **128(C)**, 270 - 274 (2017). link. doi.

The Legnaro fast-neutron facility NePIR

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NEPIR (Neutron and Proton Irradiation facility) is a project of a new irradiation facility at INFN Legnaro National Laboratories (LNL) in Italy. This contribution focuses on the most recent progress of the project, that is in an advanced design phase and partially funded.
The facility will exploit the LNL 30-70 MeV, high current proton cyclotron of the SPES project to feed two different compact neutron sources in order to generate high flux neutron beams with different energy spectra. The first will produce a quasi mono-energetic neutron beam, with a controllable energy peak in the 30-70 MeV range; the calculated flux at maximum energy and maximum current (10 microA, limited by radioprotection regulations) is 4.5x10^5 n/cm2/s, at a test point 3 m downstream. This versatile tool will be an important addition to the park of research infrastructures for national and European research.
The second converter, ANEM (Atmospheric Neutron EMulator) will produce fast (E > 1 MeV) neutrons, with an energy distribution similar to that of neutrons naturally present at sea-level (atmospheric neutrons), generated by the interaction of energetic cosmic rays with the Earth atmosphere; the maximum expected flux, 4 m downstream of the source, is 3x10^6 n/cm2/s. This will be used to study atmospheric neutron-induced Single Event Effects in electronic devices and systems. Using additional moderator panels, the ANEM white spectrum can be shaped to resemble that of other environments (eg. surface of Mars).

Russian initiative on compact neutron source DARIA

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The world's leading neutron research centers are currently developing a new generation of neutron sources for the needs of condensed matter physics. Compact sources are designed to replace the morally obsolete small- and medium-power research reactors and open up the possibilities for creating a neutron scattering laboratory in any organization. Such a source initially loses several orders of neutron flux as compared to a large accelerator-type source; however, a significant part of this odds can be recouped by increasing the capture aperture and deep instrument optimization, including adaptation of the accelerator, target and moderator parameters to the needs of a particular instrument located at the source.
On a wave of worldwide interest to the compact neutron sources we present he Russian compact source initiative – DARIA (Dedicated to Academic Research and Industrial Applications) project. Formulated is a general approach to the creation of a neutron scattering instrument on a compact source, on its basis the appearance of the required accelerator and target assembly is described. Using the example of several methods - diffraction, spectroscopy, reflectometry, small-angle scattering and SESANS - experimental schemes for the implementation of neutron scattering methods were proposed, a number of optical devices were calculated, the use of which will allow the most efficient use of the generated neutron flux.
For a powder diffractometer, the use of two interchangeable moderators with a thermal and cold spectrum maximum is proposed. This will allow the instrument to have two operation modes with an optimal flux at a given resolution, differing in the choice of the operating wavelength band and providing high-quality measurements for investigations of both crystalline and magnetic structures.
To implement the neutron spectroscopy method on a compact source, the time-of-flight technique in reverse geometry was chosen. Its use allows you to create a so-called excitation observer in (q, E)-

space is an effective tool for the analysis of inelastic, quasi-elastic and elastic scattering, providing a quick and comprehensive study of the dynamics.
Of the three methods chosen, small-angle scattering is most demanding on the luminosity of the source, since it has the most stringent requirements for the collimation of the beam used. The possibility of implementing the method in focusing geometry is considered for SANS and neutron reflectometry.
The results of this work will be underpinned to the conceptual design project of a compact neutron source as a laboratory of neutron scattering research methods.
This work is supported by the Russian Science Foundation (RScF) under grant No. 19-12-00363.

The SONATE project, a French CANS for Materials Sciences Research

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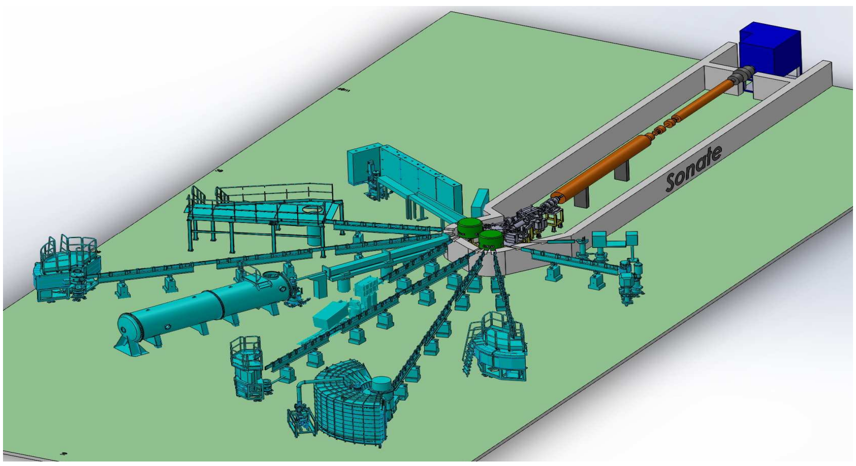
The reactor Orphée at the CEA Saclay has been serving the French neutron scattering community for 38 years. The reactor will however stop operation in 2019. The Laboratoire Léon Brillouin has been operating up to 24 neutron scattering instruments. The reactor was also serving other purposes such as industrial radiography, silicon doping and irradiatio. We are considering replacing the reactor neutron source with a compact accelerator-based source which would serve an instrumental suite of about 10 instruments. The instruments would be split into low resolution instruments (SANS, reflectivity, imaging, spin-echo) and higher resolution instruments (powder diffraction, Direct Time-of-flight spectroscopy, Indirect geometry spectroscopy). Our reference design “SONATE” is based on a proton accelerator operating at an energy in the range 20-29 MeV. The accelerator would serve 2 target stations. The first one operating at 20Hz with 2ms long pulses serving low resolution instruments and the second one operating at 100Hz, 200µs long pulses serving higher resolution instruments. The 2 operation modes would be interlaced. The peak current on the target is aimed at 100mA with an average power on the target on the order of 50-80kW. Numerical Monte-Carlo simulations show that we may expect instrument performances equivalent to the current instruments around Orphée or ISIS.
The first phase of the project is “IPHI – Neutron” which is using a 3MeV proton accelerator which can achieve peak currents up to 60mA. Our aim is to validate our simulations and be able to extrapolate the actual instruments performances which can be expected on SONATE. We will show the first scattering results obtained on this source.



UppCANs: Bringing neutrons to the users

Max Wolff
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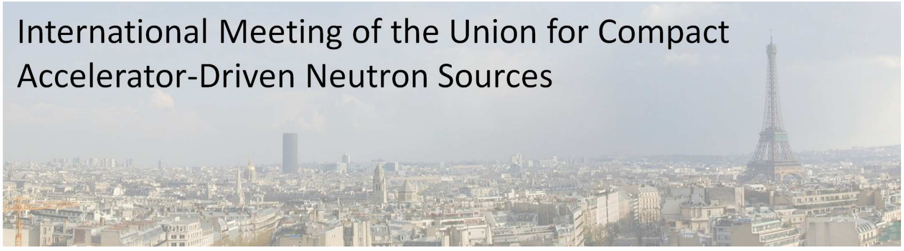
Neutrons provide unique and essential tools for research across many disciplines ranging from basic sciences of materials, biology and chemistry to engineering and studies of heritage artefacts. The present neutron facilities are currently decreasing in number. This overall shortage will not be compensated by ESS offering the best available brilliance but a limited total number of beam days.
Ultra-compact accelerator driven neutron sources (UCANS) can provide small facilities and enable easy accessibility by bringing neutron instruments close to the users. These use modest energy protons (~18 MeV) that impact on a light target. This allows an extremely compact design of the moderators. The small size and optimised source design provide good brilliance at reasonable cost. Dedicated instrumentation can compete in performance with current small to medium size facilities and complement high brilliance sources in an ideal way.
I will present a project for UppCANs in Uppsala. When built, this would provide neutrons for 5 to 7 beam ports and offer a broad range of modern capabilities allowing the existing community to both complete straightforward measurements and prepare to exploit world leading instruments elsewhere. In addition UppCANs will provide neutrons at a lower cost for experimental methods that are very relevant for industry, in particular, imaging, doping and activation analysis and the ready accessibility will encourage use in newer domains such as medical and environmental sciences and heritage studies.



Poster session 1

P1.1 Using Light to see Neutrons: a new 2D detector with high resolution.

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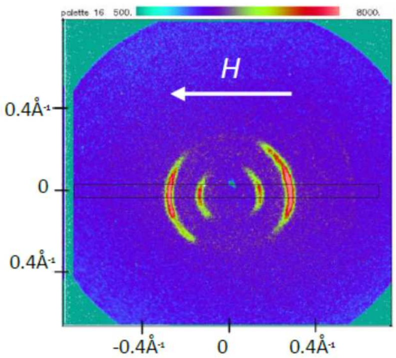
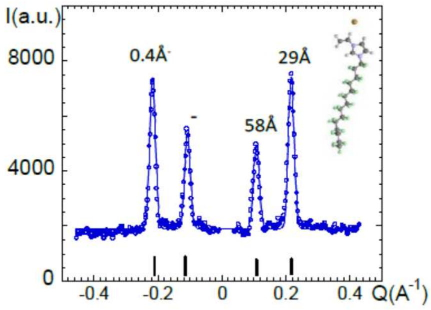
The evolution of light sensors enjoyed unprecedented growth in the last 20 years. This evolution is such that the camera of a smartphone can be used for Raman spectroscopy [1] or to detect atrial fibrillation in medicals. We will illustrate how these recent advances in light sensors revolutionize the observation in physics. Today the technology is sufficiently powerful to be exploited quantitatively in neutron spectrometry for the study of both elastic or inelastic scattering (time of flight). The two-dimensional high resolution neutron detector, called Barotron [2] (from the name of the inventor) is derived from this technology [3].

With a basis of 250 000 pixels, a resolution of 16 bits for each pixel, a very low detection limit (<< 1 / cm2 / s), a high dynamic (16 bit) and an excellent spatial resolution (0.5 * 0.5mm2), the Barotron performances compete the best current two-dimensional gas detectors. This new technology presents the huge advantage of being constantly upgraded by replacing the sensor. This development opens a new generation of high-performance neutron detectors, versatile and adapted to new spallation sources for an ever more precise characterization of the properties of the samples. We will give some examples of exploitation of the high resolution detector including imaging, diffraction or SANS.





Left figure: 2D-neutron pattern (without correction, smoothing or binning) recorded on Barotron detector enlightening the structure of a room temperature ionic liquid (RTIL). The layered organization and its ability to align along a magnetic field horizontal direction) are evidenced by the azimuthal distribution of the intensity centered along the field direction. Raw 2D pattern obtained without correction, smoothing or binning. With the courtesy of P. Judeinstein.

(1) A. Sences et al, ACS Photonics, 2014, 1, 17-26; D. Gallegos et al, Lab chip, 2013, 13,2124-2132, D. Pile Nature Photonis, 8 (2014) 168.
(2) P. Baroni, L. Noirez; Am. J. of Appl. Phys. 2014; Brevet n° 0502379, 24/03/2005 PCTE.
(3) P. Baroni, L. Noirez, New developments for 2D High Resolution Neutron Scattering Experiments. Application case and experimental evidences from crystals to polymer science." Neutron News 18 (2007) 17, ibid USING LIGHT TO SEE NEUTRONS AND ACCESSING THE 2D HIGH RESOLUTION: A
NEW PULSE FOR NEUTRON SCATTERING, AMERICAN JOURNAL OF APPLIED SCIENCES 11 (9): 1558-1565, 2014.

P1.2 Scalable Neutron Imaging Systems at Compact Sources

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Neutron imaging offers unique features under many perspectives qualifying it as prime candidate for instrumentation at compact neutron sources. The peculiar characteristics of neutrons, i.e., cross sections and magnetic moment, allows for results that are directly comparable but, in particular, complementary to all-pervasive X-ray imaging.
Technically, the range for possible installations is vast; this likewise holds for price, sophistication and potential use. As a most simple example, some basic neutron imaging is possible at rather small sources yielding only low neutron flux, just demanding state-of-theart detection systems (very high sensitivity, long exposure enabled).
At the other end of the scale and taking full advantage of a most versatile compact source with several independent target stations, one can conceive of unparalleled opportunities for dynamic neutron tomography with crossed neutron beams with high time resolution, which is principally not accessible at any other type neutron source. The moderators can be optimized for particular wavelengths and dedicated imaging tasks. The other way round, imaging setups allow for the detailed characterization, in particular concerning flux distribution and divergence, of emanating neutron beams and thus for efficient facility development and validation of numerical simulation tools.
Advantageous educational aspects are a direct consequence of these manifold possibilities: students can easily become acquainted to neutron-based instrumentation, make their first steps and can almost immediately obtain useful results with basic imaging of small-sized objects.
Quality Assurance topics can be claimed to lie at a center of gravity for relevant investigations in industry: neutrons deliver especially valuable results for connection between parts, comprising welding, soldering/brazing and, in particular, adhesive bonding. Further examples include humidity distributions in building materials, inclusions in metals ranging from impurities in old casts to process optimization in metallurgy for novel high-performance metal-based compounds.
As a new topic, relevant characteristics of specimen produced by additive manufacturing are favorably investigated with neutron imaging. The reliable detection of explosives and the correct application of lubricants are already certified studies. In parallel to increasing possibilities at larger and more complex, still compact, neutron sources, preparatory experiments can be performed before applying for beam time at high power neutron facilities with optimized set-ups. The development of novel methods at dedicated small sources featuring multiple targets and moderators offers an open-ended avenue. On a motivational account, no other neutron-based technique has the same potential to draw public interest. Unexpected images of familiar as well as of unknown objects like deciphering the internal make-up of, e.g., ancient sacred statues are considered as interesting by most people. This offers a unique way to demonstrate to the common tax payer as well as to funding agencies the high potential and manifold usefulness of neutron-based techniques starting at flux levels as low as 1000 n/cm^{2}s.

P1.3 SCATTERING KERNEL AND NEUTRON TRANSPORT PROPERTIES OF NANODIAMOND PARTICLES AT SLOW NEUTRON ENERGIES

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Nanoparticles are of great interest nowadays for science and technology. In particular, it has been shown that nanodiamonds could be efficient reflectors for very cold and ultra cold neutrons [1]. However, it is not clear what could be this material efficiency as reflector for neutron energies above 10^{-4} eV, although it was estimated that a high purity material (free from hydrogen contamination) could be of interest even beyond that energy [2]. We developed a scattering kernel and generated cross section libraries for bulk diamond and powders of nanodiamond, over the thermal and cold neutron energy ranges. The calculated cross sections are in very good agreement with recent experimental data [3]. The scattering kernel, including small angle scattering effects, was implemented in the Monte Carlo program OpenMC [4], and this tool was used to study the reflective properties of nanodiamond powder.

[1] V.V. Nesvizhevsky et al., Nuclear Instruments and Methods in Physics Research **A 595** (2008) 631–636
[2] V.V. Nesvizhevsky et al., Carbon **130** (2018) 799e805
[3] M. Teshigawara et al., Nuclear Instruments and Methods in Physics Research **A 929** (2019) 113-120. [4] P.K. Romano and Forget, B., Annals of Nuclear Energy **51** (2013): 274-281.

P1.4 Assembly Techniques for Segmented Neutron-focusing Supermirrors

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Neutron-focusing supermirrors are supermirrors on precise curved surfaces, which intensify cold neutrons at samples or detectors in neutron instruments. Such focusing mirrors are greatly beneficial to compact sources, not only because of their flux limitation, but also for their customizability: e.g. focusing mirrors can be designed to fit their moderators. To improve the availability of neutron-focusing mirrors, we have been developing metallic substrates for supermirrors, using amorphous Ni-P plating [1-2]. The plating allows smooth surfaces with sub-nanometer roughness—which is a prerequisite for sputtering supermirrors—on free-form machined metal substrates. This gives us much more freedom in structural design compared to conventional materials such as silicon and glass; hence, supermirrors can be designed to be assembled, to form a large mirror for high-gain focusing. In this presentation, we will introduce techniques for precise assembly of such supermirrors, with two examples: an elliptic supermirror with two segments designed for a neutron reflectometer (SOFIA@BL16 in J-PARC/MLF) and an ellipsoidal mirror currently under development for neutron resonance spin echo spectrometers (VIN ROSE@BL06 in JPARC/MLF).

[1] T. Hosobata et al., Development of precision elliptic neutron-focusing supermirror, *Optics Express* **25** (17) (2017).
[2] T. Hosobata et al., Precision Mechanical Design of 900 mm Long Ellipsoidal Neutron-focusing Supermirror for VIN ROSE at J-PARC/MLF, *JPS Conf. Proc.* **22**, 011010 (2018).

P1.5 Neutron beam generated by high intensity laser pulse

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We use two dimensional particle-in-cell simulations to study ion acceleration from a thin target irradiated by ultra-intense laser pulse. When the target is shaped initially in the transverse direction to match the laser intensity profile, the target can be uniformly accelerated for a longer time compared to a usual flat target. Undesirable plasma heating is effectively suppressed. The final energy spectrum of the accelerated ion beam in the acceleration region is improved and collimated quasi-monoenergetic ion beam can be obtained. The collimated ion beam irradiates on converter material and produced intense collimated neutrons, by selected materials such as deuteron or lithium with rather strong neutron production mechanisms. An integrated Laser-Ion-Neutron analysis is given and the neutron spectrum is discussed.

P1.6 Study on Moderation Properties of Cold Mesitylene using KUANS

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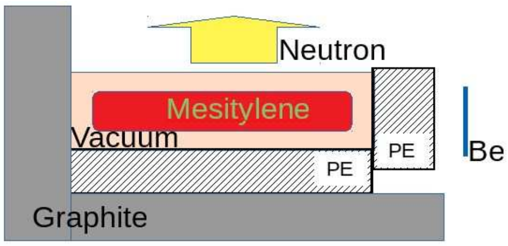
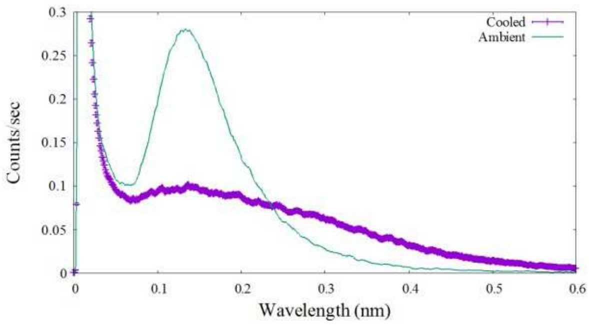
KUANS is a compact proton accelerator based neutron source, having a 3.5MeV-accelerator, a Be-target, and an ambient polyethylene moderator. Since the proton beam is pulsed with the width of about 60μs and hence the emitted neutron is also pulsed, trhen the time of glight (TOF) method is used to determine the wavelength of neutrons. Since the moderator is made of polyethylene in room temperature, wavelength spectrum of the moderated neutron decreases rapidly for longer wavelength then thermal peak at about 0.13 nm.
In the present study, we installed a cold moderator system consisting of ambient polyethylene and mesitylene contained in a cryostat. The schematic view of the system is shown in Fig. 1. In the

figure, neutrons are emitted from the Be foil bombarded by the proton beam and enter polyethylene pre-moderator (PE) with the thickness of 30mm. The dimension of the mesitylene container is 90x90x20 mm3. After pre-moderated, neutrons go into the mesitylene, cooled and emitted toward the experimental area. The backside of the mesitylene moderator, there is another PE and the whole system is surrounded by the Graphite reflector. The neutron wavelength spectrum from the moderator is shown in Fig.2. The solid line (green) represents that for mesitylene in the room temperature, and the cross marks with error bars (purple) is for 15K-mesitylene. Although the peak intensity at about 0.13nm is lowered, neutron intensity for the cooled mesitylene is higher in the longer wavelength than 0.23nm. Especially, the intensity is 5 times higher over 0.4nm. The Fig. 1 Neutron wavelength spectrum from the results will be compared with the simulation mesitylene moderator.
results, and the moderation properties of cooled mesitylene will be discussed.





(left) Cold moderator system for KUANS. *(right) Neutron wavelength spectrum from the mesitylene moderator.*

P1.7 The Application of Ti/Pd Film Coatings in Neutron Tube

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Ti film coating is a common hydrogen absorbing material, which is mainly applied in the target system of neutron tube. Due to the high diffusion rate and absorption ability for H2, thin film coating of palladium was proposed firstly to be added onto the Ti film. With the covering of Pd film, the service life of Ti film coating can be extended and the H2 pumping speed can be enhanced. Ti/Pd film coatings were deposited on the surface of oxygen free copper substrate by DC magnetron sputtering equipment. The surface topographies of Ti-Pd films were obtained and analyzed by scanning electron microscope(SEM) and atomic force microscope(AFM). Xray photoelectron spectroscopy(XPS) and X-ray diffraction(XRD) were used for chemical compositions analysis of Ti-Pd films. Chemical adsorption device was used to test the hydrogen adsorption properties of Ti-Pd films at the operating temperature of neutron tube.

P1.8 First-principles investigation hydrogen interaction with defects in Ti-H system

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In the D-D neutron generator, titanium(Ti) target plays the role of deuterium storage and has an important influence on the performance of the generator. Therefore, the titanium targets are susceptible to hydrogen embrittlement. In the design of new deuterium storage target materials and hydrogen embrittlement resistant alloys, it is necessary to understand the interaction between deuterium and titanium in order to better optimize the material properties ,and further improve the efficiency of the D-D neutron generator. In this study, the interaction between deuterium and titanium and the stability of Ti-H system are investigated from first principles. The interaction and nucleation phenomena of various defects in Ti and hydrogen are systematically revealed and discussed, which provides theoretical guidance and basis for the selection of target material for next neutron generator.

[1] Xu Q , Ven A V D . First-principles investigation of metal-hydride phase stability: The Ti-H system[J]. Physical Review B, 2007, 76(6).
[2] Han X L , Wang Q , Sun D L, et al. First-principles study of the effect of hydrogen on the Ti self-diffusion characteristics in the alpha Ti－H system[J]. Scripta Materialia, 2007, 56(1):77-80.

P1.9 High Power Beam Dump for SARAF Phase II

Ilan Eliyahu [a*], Sergey Vaintraub [a], Alex Arenshtam [a], Eli Shvero [a], Ofir Ozery [a], Mantefardo Alpha [a], Ron Raz [a], Tal Zaharoni [a], Daniel Moreno [a], Moshe Bukai [a], Eli .Barami [a], Arik Kreisel [a]

The Soreq Applied Research Accelerator Facility (SARAF) is a proton/deuteron RF superconducting linear accelerator. Phase I has already been completed and allows acceleration of 1 mA CW, 4 MeV proton beams and a low duty cycle acceleration of 5 MeV deuterons. Phase II of the project is under way and includes the development of the accelerator to its final specifications: energy of 40MeV proton/deuteron, and a current of up to 5mA. A beam dump will be required for the commissioning stage and daily operations.

The beam dump must be designed to stop a beam with a maximum power of 200 kW. To avoid radiation damage and improve heat transfer, we suggest a design concept of a liquid metal target, based on our prior experience with the liquid lithium target (LiLiT) at SARAF. The suggested liquid metal target is a Ga-In metal alloy with a melting point of ~15oC, designed to absorb a beam of 200 kW. This liquid metal is used in other applications for dissipating concentrated heat loads such as thermal interfaces for microprocessors, reactors and heat exchangers. The proposed beam dump design is based on a high-velocity windowless gallium-indium jet which absorbs the beam power and generates a stable 5 mm-thick film flowing at a velocity of up to 1 l/s onto a concave supporting wall. The gallium-indium loop is made of SS316 and includes: a heat exchanger (gallium oil), an electromagnetic pump, a target chamber with a nozzle and various diagnostic elements.

The design principles and various considerations (such as neutron yield, activation, etc.) related to the beam dump will be presented.

[1] S Halfon, S.; Arenshtam, A.; Kijel, D.; Paul, M.; Berkovits, D.; Eliyahu, I.; Feinberg, G.; Friedman, M.; Hazenshprung, N.; Mardor, I.; Nagler, A.; Shimel, G.; Tessler, M. & Silverman, I. (2013). High-power liquid-lithium jet target for neutron production, Review of Scientific Instruments 84 : 123507

[2] K.A. Narh, V/P. Dwivedi, J.M. Grow, A Stana and W.Y. Shih, "The Effect of liquid Ga on the strenghths of stainless steel and thermoplastics" Journal of Material Sciences 33 (1998) 329-337.

P1.10 Preliminary radiation shielding design for HBS

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The High Brilliance Neutron Source (HBS) project was launched at the Jülich Centre for Neutron Science of the Forschungszentrum Jülich (JCNS). The aim of this project is to provide a compact, accelerator-driven high brilliance neutron source that can be efficiently extracted into an optimized neutron transport system. To meet this requirement, a novel type of neutron facility based on a proton accelerator with dedicated target and moderator solutions for specific experimental requirements was proposed by JCNS.
The neutron yield in the HBS design is generated by a proton-pulsed beam with energy of 70 MeV, which impinges on a tantalum target. Therefore such a compact neutron source facility has a broad spectrum of neutron energy, from thermal neutrons to fast neutrons, with energy up to about 70 MeV. The Target-Moderator-Reflector (TMR) unit of the HBS is designed to maximize the thermal neutron production while the neutron and gamma shield of the TMR unit is configured so that the dose rates outside the station are below the limits specified by the authorities.
A multi-layer shielding concept with selective materials is taken into account. Borated polyethylene is selected for moderation of fast neutrons (hydrogen) and absorption of thermal/epithermal neutrons (boron). Lead is chosen to shield high energy prompt gamma rays and delayed gamma rays induced by neutron reactions as well as to moderate the fast neutrons. In addition barite concrete walls are positioned to a certain distance from the shielded neutron source to further reduce the neutron/gamma dose rate. Radiation dose rates are estimated for source operation and after the shutdown of the source considering the residual dose rate from activation products.
The Monte Carlo simulation of particle transport and neutron/gamma dose rate distribution was performed with the MCNP6 code. The US evaluated nuclear data library ENDF/B-VII and the TALYS-based evaluated nuclear data library TENDL-2017 were used to provide the cross section data of proton, neutron and gamma. The detailed simulation and optimization of the preliminary radiation shielding design for the HBS project will be presented in this paper.

P1.11 Development of new small-angle neutron scattering geometry with ring-shaped collimated beam for compact neutron source

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Small-angle neutron scattering (SANS), which is a method to obtain the large structure information of a sample, is expected to play a significant role not only in large but also in compact neutron facilities. This is because it does not require high spatial and energy resolutions relatively compared to other diffractometers. However, the incident neutron flux of the compact neutron source can still be very low, making it difficult to measure the scattered neutron with the typical SANS geometry such as a pinhole geometry.

A SANS geometry with a ring-shaped collimated beam is developed to conduct experiments at very low flux neutron source facilities. Figure 1 shows the schematic diagram of this geometry. The ring-shaped collimated beam is produced using three ring-shaped slits. By setting the point detector to be at the ring center line, scattered angle (2θ) is geometrically decided using the radius of incident neutron beam and the distance between the sample and detector. By applying time of flight method, the scattered neutron energy is obtained. The scattered neutron angle and energy enable us to measure the momentum transfer of scattered neutrons. The main benefit of employing this geometry is that the scattered neutron flux is high on the ring center line. This is due to the scattered neutrons from each part of the sample overlapping on the ring center line. This geometry also allows us to use the 3He point detector, which has higher counting ratio and is less sensitive against gamma ray compared with a typical two dimensional scintillation detector. Since the detection area of the detector is limited by the detector window, it can be easy to reduce the noise from the environment.

In this presentation, we will discuss the detailed concept and set up of this geometry and the preliminary results of our experiment at Kyoto University Accelerator-based Neutron Source (KUANS) [1].

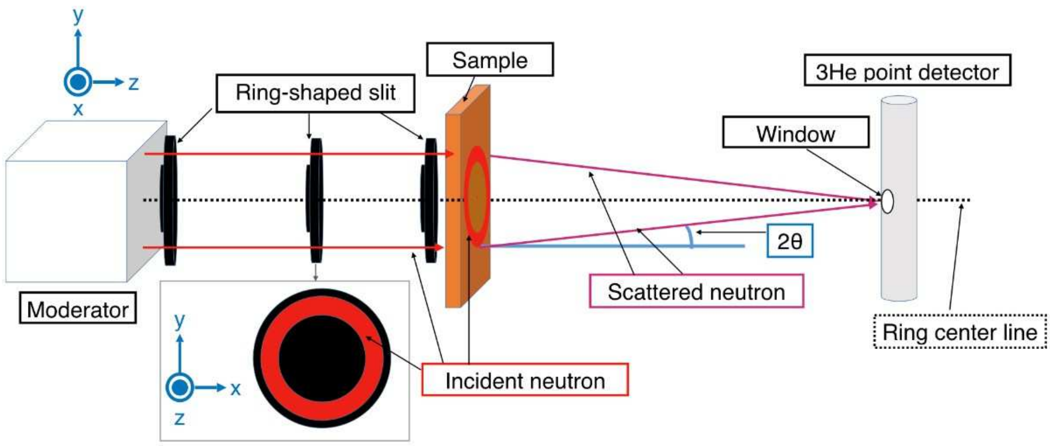

Figure 1: Schematic diagram of small-angle neutron scattering geometry with ring-shaped collimated beam

[1] Tasaki, S., et al. "Properties and Possible Applications of Kyoto University Accelerator Based Neutron Source (KUANS)." Physics Procedia 60 (2014): 181-185.

P1.12 Linear scan CT with fast neutron for large-scale, long-straight reinforced concrete members nondestructive inspection

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Computed tomography (CT) is able to generate 3D images and display the inner defects of the specimen. Fast neutrons have strong penetrating ability and sensitivity to light elements, especially hydrogen. Fast neutron CT is an effective nondestructive inspection technology for detecting the internal spatial structure of the large-scale, long-straight concrete members with steel bar. Sometimes, the large-scale reinforced concrete members can't be rotated, and the rotating of the neutron source and detector is also difficult. So the linear scan mode, translating the neutron source and detector array along longitude of reinforced concrete members synchronously, is considered. This study applies Monte Carlo method to simulate the fast neutron CT linear scan system. Some simulation experiments with different scan step and different flare angle are realized. Algebraic reconstruction techniques are realized for fast neutron linear scan CT. The results show that the algebraic reconstruction technique class can generate high quality image in linear scan CT.

[1] Zboray R , Adams R , Kis Z . Fast neutron radiography and tomography at a 10 MW research reactor beamline[J]. Applied Radiation and Isotopes, 2016:S0969804316303670.
[2] Yan M , Hu H , Otake Y , et al. Improved adaptive genetic algorithm with sparsity constraint applied to thermal neutron CT reconstruction of two phase flow[J]. Measurement Science and Technology, 2018.

P1.13 Development of a Neutron Spectrum Measurement Method for Steady-state Neutron Sources

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There are several methods to measure neutron energy spectra, for example, the time-offlight (TOF) method and the Bonner-Ball detector method. We newly developed a simple method to

measure neutron intensities at several energy points at once with the combined use of resonance cross sections of various metal foils and an X-ray imaging plate (IP).
We used a set of irradiation samples combined metal foils, which transfer radioactivity distribution to IP, with a step wedge of the same metal. The reaction probability at a specific energy is determined by transmission and activation at resonance absorption energy of the metal. The metals selected are Dy, In, Au, Er, Mn, Cu, etc. Irradiation experiments were performed at two different beamlines, vertical (Case-1) and horizontal (Case-2), in SHI-ATEX in Japan. Firstly, the radioactivity distribution is transferred to the IP, the generated image data are analyzed, and then the neutron fluxes at the metal foils absorption resonances can be calculated with high accuracy. Furthermore, neutron fluxes at plural different energies can be determined by using plural metal elements having different resonance energies. Thereby, a neutron energy spectrum can be roughly obtained.
It was found that the neutron spectrum of the irradiation field calculated by the Monte Carlo particle transport calculation code PHITS is relatively consistent with the experimental result at the vertical beamline, but differed by about 1.5 times particularly in thermal neutron region at the horizontal beamline (Fig.1). We will consider effect of deterioration of the moderator to explain this discrepancy. We confirmed usefulness and feasibility of the metal foil IP transfer method for neutron energy spectrum measurement at the steady state neutron sources.

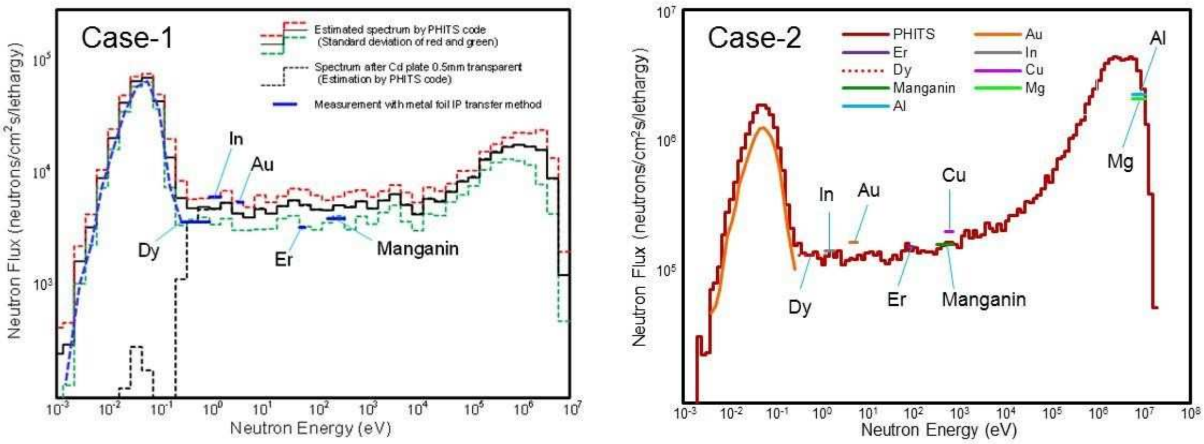

Figure 1: *Comparison of Metal Foil IP Transfer Results and Simulation (PHITS) Results.*

P1.14 Nuclear data Calculation and Analysis for n+^{64}Zn and p+^{7}Li Reactions

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Zinc is structural material nucleus that plays an important role in nuclear technology . All cross sections, angular distributions, energy spectra and double differential cross sections of neutron, proton, deuteron, triton, ^{3}He, and alpha particle emission for n+^{64}Zn reactions are consistently calculated using nuclear theoretical models. The optical model, pre-equilibrium and equilibrium reaction theories, the distorted wave Born approximation theory, the intranuclear cascade model are used. The calculated results are compared with the new experimental data and the evaluated data from JEFF-3.2 and JENDL-4.0.The ^{7}Li(p, n) ^{7}Be reaction is a relatively prolific source of neutrons for proton bombarding energies in the region of 4 MeV.The contribution from direct nuclear reaction for ^{7}Li(p, n) ^{7}Be reaction are calculated using distorted wave Born approximation theory.The statistical theory of light nucleus reactions will be used in the future.

P1.15 The study of the possibility of using Ti/Co bilayers to improve polarizing supermirrors

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The polarizing supermirrors are the basic optical elements of neutron polarizers and analyzers. The polarizing supermirrors are made by alternating ferromagnetic and nonmagnetic metal layers with a low neutron optical contrast for one of the spin components. A non-magnetic oxide layer formed in air on the surface of a polarizing coating sets up a barrier for spin-down neutrons and noticeably decreases the polarizing efficiency for cold and ultracold neutrons. A new method for suppressing the undesirable reflection of spin-down neutron by using «well/barrier» bilayers has been suggested in Ref.[1]. The Ti/Co bilayers may play the role of such antireflective coatings.
The paper presents the results of studies of polarizing mirrors with upper Ti/Co bilayers. The parameters of Ti/Co bilayers were determined by neutron and X-ray reflectometry. The exprements on suppression of reflection of neutrons with the undesired spin from polarizing mirrors were carried out at the V6 instrument at Helmholtz-Zentrum Berlin. The experimental results show a decrease in the reflection of spin-down neutrons from samples with antireflection metal/oxide bilayers in the q-region below 0.05 nm-1.

The work was supported by the Federal target program of Ministry of Education and Science of Russian Federation (project No.RFMEFI60717X0194).

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P1.16 Towards Axisymmetric and Focusing Neutron Analyzers to Enable Efficient Powder Neutron Diffractometers

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Compact laboratory-based neutron sources and small research reactors are indispensable, for example, for in-situ characterization during materials synthesis or when samples cannot be transported to other facilities. However, relatively low neutron fluxes severely limit applications of some otherwise very useful techniques of materials characterization such as powder and stress-strain diffraction. These techniques perform very well at high-flux neutron research facilities but cannot be used effectively with small sources unless instruments are adopted and optimized. Therefore, we are developing polychromatic cold and thermal neutron diffractometers based on novel analyzers. Polychromatic incident beam allows for multiplexing analyzer crystals in order to cover relatively large solid angles. Specifically, we optimized axisymmetric PG analyzers inspired by the very first neutron-diffraction experiment by Mitchell and Powers [1]. In addition, we are adopting bent single-crystal wafers following the developments of the so-called “thickness focusing” [3,4]. The combination of the polychromatic beam [5] and focusing geometry allows increasing both the signal rate and resolution. The proposed instruments will have much higher throughput than existing instruments and thus enable diffractometers at compact neutron sources.

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Poster session 2

P2.1 A study of 4-dimensional point neutron source based on the (e,n) reaction

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The TOF (time of flight) technology asks for a short pulse width to reduce the flight distance while keeping a good enough energy resolution of neutrons. To conduct the MeV neutron resonant analysis, the pulse width should be as small as nanosecond or even smaller. In this research, the (e,n) based research is carried to investigate the possibility of realizing a 4-dimensional (xyzt) point fast neutron source. With the high energy electrons of 100 MeV electrons, the interaction between the energetic electrons and target nuclei was researched [1]. The virtual photons induced (e,n) reaction can help realize a point neutron source. Geant4 was used to simulate the properties of the neutron source, in which a 100 MeV electron beam hits into a <1 mm tantalum target. The results show that the RMS (root-mean-square) of the neutron generation is 0.5072 mm in x/y plane and the time duration brings by neutron-electron converting target is 0.3767 ns, indicating that only 10 m is needed for 0.1% energy resolution at 1 MeV, which is adequate for light-element fast neutron resonance analysis in limited space. The neutron yield is 1.3702E-4n/e-, meaning that if the accelerator work at the 2kW operating power, the neutron flux can be 1.346E10 n/sr·s, which is enough for neutron imaging in short distance. Meanwhile, only 2.18% of the electron energy is deposited in the thick target, reducing the burden of the cooling system compared with other photoneutron sources.

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P2.2 High-power TR-24 cyclotron-based p-n convertor cooled by submerged orifice jet.

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The TR-24 cyclotron provides protons with variable energies up to 24 MeV and 0.3 mA beam current. For such parameters, the p+Be source reaction on thick Be target can produce a white-spectrum neutron field, En ≤ 22 MeV with an intensity of 5×10^{12} n/s/sr.

Due to Gaussian-like profile of a cyclotron beam spot on the target (FWHM ≤ 15 mm), the heat density up-to 4 kW/cm^2 resulting in overall heat load of 7.2 kW needs to be removed from the beryllium target of proton-neutron convertor. Due to inverse square dependence of the neutron flux density on source-to-sample distance, the dimensions of cooling assembly are to be minimized to use high flux density option at the vicinity of the target. Taking advantages in dimensions and high cooling effectiveness, various types of orifice nozzles were considered and tested to form a submerged impingement jets in cooling arrangement of static Be target.

Using ANSYS simulation of forced conventional flow, the fluid pressure in stagnation zone and the velocity in jet stream and along shear layer for different nozzle types were compared. As a result, the sharp-edge orifice was selected as the optimal solution. A mockup of the target setup was manufactured to verify experimentally the ANSYS simulation and to determine the parameters of boiling mode of cooling. Considering similar empirical data on water wettability (contact angle) of the aluminum and beryllium surfaces, Al – instead of Be discs were utilized in the pilot experiments to facilitate a set of thermocouples inside the target, irradiated by proton beam at different current/beam spot. Heat transfer experiments with water flow were carried out at jet velocities up to maximum available rate of 2 l/s and a system pressure of 1.1 MPa. Constant jet temperature of 200°C was ensured by a cooling unit.

Experimental data have a) confirmed the ANSYS simulation of transfer characteristics below the onset of boiling point (130°C) and b) provided original data regarding the boiling and in particular the behavior of critical heat flux regime. Measured steady-state heat fluxes ranged from 2.5 to 4 kW/cm^2

exceed several times the typical value of 0.5 kW/cm^2 for contemporary p+Be neutron generators usually operating with single-phase flow cooling of fixed Be targets.

The heat fluxes of proton beam removed effectively from TR-24 p-n convertor target by submerged orifice jet cooling correspond to the fast-neutron flux up to 2x10^{12}n/cm^2/s, the highest value for irradiation purposes until now. Target station with the open area at forward direction is developed to provide the irradiation under non-perturbed arrangement of different samples and associated hardware. Remotely controlled manipulators of irradiated components are being developed to ensure basic operation in the large induced activity ranging up to Sv/h. The methods to minimize the blistering effect on the target during operation are under investigation.

P2.3 Development of neutron-focusing mirrors at Compact Pulsed Hadron Source

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The relatively low flux is the major barrier to the development of neutron scattering instruments at compact accelerator-driver neutron sources. As one of the most promising neutron optical devices to enhance neutron intensity, neutron-focusing mirrors are under intensive research. They are free of chromatic aberrations, allow for compact instrumental design and can increase neutron intensity by over one order of magnitude. Here, we report the design and test of a nested neutron-focusing supermirror system developed for the small-angle neutron scattering instrument at Compact Pulsed Hadron Source. This system contains two shell conical mirrors whose interior surfaces are coated with m=2 Ni/Ti supermirrors. Built up by such nested structure, a large effective collecting area can be realized to advance the neutron scattering instruments at compact sources.

P2.4 Reconstruction on fast neutron CT for concrete structure inspection with a pixel-type detector by applying linear scanning method

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Concrete structure has been widely used in bridges and highways, however, its performance will be deteriorated after long term serving or suffering disaster. Since fast neutron has strong transmission ability and is sensitive to water content in the concrete structure, it can provide an effective probe to inspect the inner structure of concrete with non-destructive way. Thus, we propose a fast neutron imaging and reconstruction system of 3D CT for concrete structure inspection with Riken accelerator-driven compact neutron source (RANS) using a fast neutron pixel-type detector, which has 8× 8 pixels. To improve the space resolution on the reconstructed image, a rotation + linear scanning method is devised and is used to collect the projection data from experiment or calculation. In this paper, reconstruction for a concrete object containing both iron bars and acrylic bars for simulation of water has been conducted. As a result, 3D image is reconstructed with resolution of 1 cm by the sparse reconstruction algorithm.

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P2.5 Development of accelerator-driven neutron source RANS-II

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RIKEN[1], Tokyo Institute of Technology[2]

RANS-II (RIKEN Accelerator-driven compact Neutron Source II) is a prototype of a transportable compact accelerator neutron source, which will be used for diagnostics of infrastructures and for a portable analysis station of materials. RANS-II aims to confirm the performance of accelerator, target, shielding, chiller and instrumentation for measurement. The design of the system started in 2016 and it is in the last stage of the construction. Lithium was chosen as a target material for neutron production via the 7Li(p,n)7Be reaction, and the incident proton energy was determined to be 2.49 MeV. Angular dependent neutron spectra at the Li target was calculated by the PHITS Monte Carlo particle transport code with ENDF/B-VII.0, which exhibits a neutron flux peak around 600 keV with a maximum energy of about 800 keV. The total neutron flux (100 uA of incident proton) at 1 m distance from the target is estimated to be about 1E5 cm-2 sec-1. This number suggests that the neutron transmission or reflection imaging technique could be applicable for up to 300 mm thickness in concrete. The pulsed 2.45 GHz microwave ECR ion source and the 2.49 MeV RFQ-LINAC are in operation tests for confirmation of design parameters. So far, proton current of 3 mA at a pulse peak was measured at the end of the RFQ with a low duty (0.09 %) operation. If it is operated at the designed value (3 % duty), a time averaged current will be 90 uA. The lithium target with a cooling system, the target station with shielding, and HEBT are very close to complete. High-duty (~3 %) operation with neutron emission will start after all the systems are relocated to the room dedicated to RANS-II.

P2.6 Research and Development of a High Counting Rate 3He Position Sensitive Detector System

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Neutron scattering experiments are indispensable in the structural analysis of various forms of condensed matter and in the development of advanced materials. A 3He gas detector [1], which is the most frequently used apparatus in the neutron experiments, is the best neutron detector available; however, the 3He gas detector is low counting rate, less than 20 kcps (count per second). In this research, we are developing to increase the counting rate of a 3He gas position sensitive detector (PSD), and a maximum counting rate of 535 kcps has been obtained. Even if the usage range is approximately 200 kcps, the PSD with a high counting rate of 10 times that of an ordinary one has been completed.

P2.7 Compact neutron source for BNCT in Nagoya University

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The neutron source in Nagoya is based on a Dynamitron from IBA accelerating protons up to 2.8 MeV. Bombarding with high intensity an innovative shield Li-target neutrons are produced using the 7Li(p,n)7Be threshold reaction. This has the advantage of neutron spectra with maximum energies of less than 1MeV, that is much lower than those obtained by Be-targets or as for the uranium fission spectrum, relevant for BNCT at nuclear reactors. The slowing down of the neutrons to about 10 keV that is needed to treat a deep-seated tumor, is related with less loss of neutrons during the process, less activation of the moderator and therefore less challenges for radiation protection issues.
Construction of an accelerator-driven compact neutron source had completed in Nagoya University for engineering studies of engineering study of BNCT, which has another beam line for applications to fundamental physics and furthermore engineering study. The neutron source is based on a proton Dynamitron accelerator (2.8MeV, 15mA) and Li target system. Bombarding with high intensity proton beam an innovative shield Li-target, neutrons are produced using the 7Li(p,n)7Be threshold reaction. This has the advantage of neutron spectra with maximum energies of less than 1MeV, that is much lower than those obtained by Be-targets or as for the uranium fission spectrum, relevant for BNCT at nuclear reactors. The slowing down of the neutrons less than 10 keV that is needed to treat a deep-seated tumor, is related with less loss of neutrons during the process, less activation of the moderator and therefore less challenges for radiation protection issues. In the new type of Li target, a thin lithium plate is sealed between a cooling base plate and a thin metal foil to confine
the liquid Li and Be-7 Be-7 は蒸気ですか。Vapor は無くても良い？ and we will establish an easy and safety maintenance work. A compact BSA (beam shaping assembly) as a BNCT neutron source corresponding to the new Li target had constructed and evaluated its performance as a .
By using this neutron source, we had performed several “In vitro” tests.

P2.8 THERMAL NEUTRON INTENSITY MEASUREMENT WITH FISSION CHAMBER IN CURRENT, PULSED and CAMPBELLING MODES.

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In thermal nuclear reactors, most of the power is generated by thermal neutron induced fission. Therefore, fission chambers with targets that responds directly to slow neutrons are of great interest for thermal neutron flux measurements due to relatively low sensitivity to gamma radiation. However, the extreme conditions associated with experiments at very low cross section demand highly possible thermal neutron flux, leading often to substantial design changes. In this paper we report design of a fission chamber for wide range (from 10 to 10^{12} n/cm^{2}sec) measurement of thermal neutron flux. Test experiments were performed at the first beam of IBR2M pulsed reactor using digital pulse processing (DPP) technique with modern waveform digitizers (WFD). The neutron pulses detected by the fission chamber in each burst (5 Hz repetition rate) of the reactor were digitized and recorded to PC memory for further on-line and off-line analysis. New method is suggested to make link between the pulse counting, the current mode and the Campbell technique.

P2.9 Comparison of the two possible geometries for the SANS instruments at the compact neutron source

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Compact neutron sources have relatively low neutron flux which leads to additional requirements for the instrument optimization. Even low resolution instruments like SANS and reflectometers need special attention. In this work we make a comparison of two possible geometries for the SANS instruments.
First option is the classic long pin-hole machine. Second option is focusing instruments based on the elliptic mirrors. These two configurations are tested against each other in terms of flux for different parts of Q-range. The influence of the finger type low dimensional moderator on the results is discussed.
Obtained results will be used during the design study of the Russian compact neutron source DARIA.

P2.10 Moderator Testing Station at the Budapest Research Reactor

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A new in-beam moderator testing station is currently being designed at the Budapest Research Reactor (BRR), to be deployed on a beam port with direct view of the reactor core. Transmission and reflection/scattering properties of the investigated moderator material will be measured by means of dedicated energy sensitive pinhole imaging equipment. The effects of moderator material, physical conditions, moderator cell and environment geometry (reflecting bodies and beam extraction voids) will be explored. The moderator cell is placed in a cryostat specially designed to allow placement of various size and shape containers in the vicinity of beryllium reflectors.
The cryostat with the investigated moderator is placed at the beam port, outside the reactor shielding wall, and two imaging lines are installed, one in transmission (horizontal, radial) and another in scattering configuration, including full sets of mask, chopper, evacuated beam tubes, detector, shielding and beam dump.
The first component of the imaging equipment is a mask with the source pinhole. It contains both gamma and neutron shielding material: steel, copper, tungsten, lead and boron-rich polymer, in sufficient amount to provide clear image in a wide neutron energy range. A small diameter, high speed chopper with a narrow slit provides the time structure for time-of-flight measurements. It also contains steel and enriched boron absorber. Due to space limitations relatively short flight length is available, which in turn allows for wide bandwidth in spite of the high repetition rate. A 2D detector with time stamped data acquisition allows energy sensitive divergence mapping. The detector is designed to achieve high neutron intensity tolerance, high count rate and reasonably good resolution.

P2.11 Implementation of Supermirror physics with Deterministic transport in MCNP6

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Beamlines for cold and thermal neutrons instruments use low-roughness multilayered-films called supermirrors, which have the characteristic to reflect neutrons below a critical angle. Calculations related to the design of these guides are often made with optics codes like MCSTAS, sometimes in combination with particle transport physics codes like MCNP or Geant4 , and more recently, supermirrors physics implemented in MCNPX . We have ported this physics into MCNP6, and also expanded its capabilities by implementing deterministic transport through the guides, and allowing the use of Deterministic Transports Spheres (DXTRAN). The results have been compared to existing work with positive results. The work performed enables integrated source-to-sample Monte Carlo particle transport calculations, representing a very powerful tool for guide shielding design and noise reduction in both compact sources and larger facilities.

P2.12 ESS-Bilbao in kind contribution to ESS

F. Sordo[1,2,a], on behalf of ESS-Bilbao team

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ESS-Bilbao is a public consortium between the local Government of Basque Country and the Central Goverment of Spain that has been nominated to channel the Spanish in kind contribution to European Spallation Source (ESS) construction project.

Between 2014 and 2016, ESS-Bilbao was selected as in kind partner for components in all the scientific areas of ESS (Accelerator, Target and Instruments). The contribution includes critical components like the Medium Beam Energy Transport (Accelerator), the Spallation Target system (Target) and a Backscattering instrument (MIRACLES instrument).

The aim of this presentation is to given overview of ESS-Bilbao in kind contribution activities, focusing on the status of the main components.

P2.13 Study of Neutron-generating Target for Transportable Acceleratordriven Neutron Source Using Low Energy Proton Beams

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Now, elevated roads, bridges and tunnels face the problem of deterioration and there is a growing demand for non-destructive testing of these outdoor construction [1]. Neutron is identified as a suitable probe for this work by its sensitivity to light nuclei and high penetration power. The neutron-generating target using low energy proton beam injection plays an important role in the system of the Transportable Accelerator-driven Neutron Source (TANS) which is designed for outdoor work. In this study, metal lithium was chosen as the target material by its high neutron yield [2]. With the purpose of minimizing the neutron loss and achieving efficient target cooling, the edge cooling system, whose copper substrate is with side-flow coolant water, was adopted in the target structure. And to protect copper substrate from the negative effect caused by incident proton, a vanadium interlayer was inserted between thin lithium film and copper substrate. For implementing the design, proton effect on target structural materials has been analyzed from perspectives of hydrogen diffusion and irradiation damage. Temperature of this target under proton beam was estimated using software COMSOL Multiphysics and experiment of the cooling structure was conducted to verify the simulation accuracy. Based on the Monte Carlo code, PHITS [3], the spectrum of forward neutron was calculated by taking the whole target structure into account. It was compared with those of other structure models with back cooling configurations to evaluate neutron loss. Lastly, the study of reaction products' residual radioactivity in this target with designed structure was done. The results showed that the designed target has feasibility to make TANS of long-life and safety in operation.

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P2.14 Laser based neutron sources

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In recent years the demand for small sized neutron sources has grown immensely, which is caused by several factors. On one side, as technology advances, structures become more complex and an in situ diagnostic is required that promises a sensitivity to small material variations while maintaining a high transmission range. On the other side, safety is a great concern in our days and at great transshipment points many containers move from country to country without the possibility to identify fissile materials or certain explosives.

Neutrons are able to solve both problems as they are capable of penetrating deep into samples since they do not interact electromagnetically and they are highly sensitive to variations in the isotopic mass number inside the probed object. This can not only be used to identify materials but also to trace them back to their origin since isotopic compositions vary strongly depending on geographic composition.
While conventional neutron sources are large in size, expensive and produce strong background radiation with large pulse widths, it is more desirable for this purpose to have additional sources, that are smaller, transportable with short pulse lengths and which require less shielding.

With laser based neutron sources this advantage can be achieved and with the current development of lasers, the amount of neutrons per pulse is increasing drastically as well as the repetition rate of the upcoming laser systems all over the world. This will soon lead to a point where laser based neutron sources will become a serious competition to existing sources because they provide capabilities and opportunities where conventional sources have their limits.

P2.15 Commissioning of the 13-MeV proton and cold neutron beam at CPHS: status report on accelerator and neutron activities at Tsinghua University

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The Compact Pulsed Hadron Source (CPHS) Project that was launched in September 2009 at Tsinghua University has reached final commissioning stage in conjunction with ongoing activities to fulfill the eventual design goal of a ~1013 n/s epithermal-to-cold neutron yield for education, instrumentation development, and industrial applications. The first 13-MeV proton beam and the first cold neutron beam with solid methane moderator had been achieved in January 2019. Here, we report the latest progress on the commissioning of 13-MeV proton and cold neutron beam of CPHS, and relative accelerator and neutron activities along with CPHS at Tsinghua University.

P2.16 Commissioning of a High Yield Gas Target DT Neutron Generator for Driven Subcritical Assembly Medical Isotope Production

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Phoenix has designed and built a high yield neutron generator that will drive a subcritical assembly developed by SHINE Medical Technologies to produce the medical radioisotope molybdenum-99, which is used in tens of thousands of medical imaging procedures daily around the globe. The isotope production system employs an accelerator-driven, low-enriched uranium (LEU) solution in a sub-critical geometry optimized for high-efficiency isotope production (including iodine-131 and xenon-133). Neutrons produced by deuterium-tritium fusion reactions in the Phoenix accelerator target, driving fission in the subcritical LEU solution. DT neutrons from the Phoenix device are created in the center of the subcritical assembly. The chamber itself is a cylinder with a height of 100 cm and radius of 5 cm. The chamber is surrounded by a proprietary neutron multiplication region. A 3rd generation prototype is currently undergoing commissioning at SHINE's facility in Janesville, WI and has demonstrated neutron yields greater than 4×10^{11} n/s using the DD fusion reaction. Measured DD neutron yields via multiple techniques including detectors and activation foils will be presented. Modeled and measured neutron flux profiles will be compared. First operation of a Phoenix gas target neutron source with tritium gas is expected in June 2019, with total neutron yields exceeding 3×10^{13} DT n/s expected. Measured DT neutron yields and flux profiles will be presented, and this data will be compared to models. Phoenix expects to deliver 8 neutron generators with yields of 5×10^{13} DT n/s each in 2020-2021 to SHINE's molybdenum-99 production facility. Target solution chemistry has been selected; target geometry has been optimized and prototyped. ^{99}Mo separation at >97% efficiency has been demonstrated, and commercially viable doses of Tc-99m have been produced. A construction permit for the isotope production facility was issued by the US Nuclear Regulatory Commission in February 2016, the first of its kind since 1960. Construction of the facility began in May 2019, and commercial production of Mo-99 is anticipated to commence in 2021.