**4th Joint RIKEN/HBS Workshop**

June 22-24, 2020, Forschungszentrum Jülich

The Japanese RIKEN Center for Advanced Photonics (RAP) and the Jülich Centre for Neutron Science (JCNS) will held their fourth joint workshop on compact accelerator-driven neutron sources (CANS) on June 22 – 24, 2020 as a special webinar due to the current travel restrictions world wide.

The workshop will tackle common research topics regarding the development of target, moderator and instrument systems for CANS at both institutes.

Access to participate in the webinar is given with the following web access

https://iffvc.fz-juelich.de/b/pau-5lb-t9m

The webinar takes part on June 22 – 24 each day from 9:00 – 12:00 CET. Presentations will be given on the following topics.

**Programme**

**Mo. June 22, 2020**

09:00 Dr. Y. Otake, Dr. T. Gutberlet Welcome RIKEN, Welcome JCNS

09:10 Dr. P. Zakalek Big Karl Experimental Area

09:30 Dr. U. Rücker Moderator-Reflector Assembly for HBS

09:50 Mr. T. Kobayashi Current status of RANS-II

10:10 Mr. K. SugiharaStudy on neutron field characteristics of p-Li neutron source RANS-II

by simulation with PHITS

10:20 Coffee break

10:40 Dr. A. Taketani Quantitative determination of thin water layer thickness distributed

on steel plate

11:00 Dr. K. Fujita Defect detection for bulk samples via neutron scattering imaging

11:20 Dr. T. Takanashi Exact CT reconstruction algorithm method and neutron imaging

11:40 General discussion of Day 1

12:00 End of Day 1

**Tu. June 23, 2020**

09:00 Dr. J. Li Monte Carlo simulation of neutron yield measurements for Be, V and

Ta targets

09:20 Dr. Z. Ma Considerations about guide configuration of the TOF diffractometer at

high brilliance source

09:40 Dr. T. Hosobata Success of focussing mirror development for J-PARC BL16

10:00 Dr. C. Iwamoto Development of high-resolution residual stress measurement method

via angle-dispersive neutron diffraction using a compact neutron

source RANS

10:20 Coffee break

10:40 Mr. M. Rimmler Proton beam multiplexer developments towards HBS

11:00 Dr. S. Ikeda Development of a 500MHz proton linear accelerator for transportable

compact neutron source, RANS-Ⅲ.

11:20 Dr. A. Mauerhofer HBS Project – Target activation and radiation safety

11:40 General Discussion of Day 2

12:00 End of Day 2

**We. June 24, 2020**

09:00 Prof. Y. Ikeda Design optimization and installation status of the RANS new target

station for cold neutron source

09:20 Mr. M. Strothmann Measurement of mesitylene moderator efficiency @COSY (FZJ)

09:40 Mr. A. Schwab Cold Moderator development for HBS

10:20 Dr. Y. Wakabayashi Exploitation of neutron applications with gamma-ray detection at

RANS and RANS-μ

10:20 Coffee break

10:40 Dr. J. Baggemann Cooling of high power targets

11:00 Mr. N. Ophoven Radiation induced material damage – Status quo of current

simulations of the Ta target

11:0 Dr. J. Li FLUKA and MCNP simulation benchmark for neutron yield

measurement

11:40 General Discussion of Day 3

12:00 End of Day 3, End of Workshop

**Participants RAP-RIKEN**

Dr. Yoshie Otake

Dr. Kunihiro Fujita

Mr. Takuya Hosobata

Dr. Shota Ikeda

Prof. Yujiro Ikeda

Dr. Chihiro Iwamoto

Dr. Tomohiro Kobayashi

Ms. Baolong Ma

Mr. K. Sugihara

Dr. Takaoki Takanashi

Dr. Atsushi Taketani

Dr. Yasuo Wakabayashi

Dr. Yutaka Yamagata

**Participants JCNS-HBS**

Prof. Dr. Thomas Brückel

Dr. Thomas Gutberlet

Ms. Qi Ding

Dr. Jiatong Li

Dr. Jingjing Li

Dr. Klaus Lieutenant

Dr. Zhanwen Ma

Dr. Eric Mauerhofer

Mr. Niklas Ophoven

Mr. Marius Rimmler

Dr. Ulrich Rücker

Mr. Alexander Schwab

Mr. Mathias Strothmann

Dr. Paul Zakalek

**Abstracts JCNS**

**Monte Carlo simulation of neutron yield measurements for Be, V and Ta targets**

Jingjing Li, Marius Rimmler, Jiatong Li, Eric Mauerhofer, Ulrich Rücker, Paul Zakalek, Thomas Gutberlet, Thomas Brückel

Jülich Centre for Neutron Science, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany

The High Brilliance Neutron Source (HBS) project was initiated at the Jülich Centre for Neutron Science of the Forschungszentrum Jülich (JCNS). It aims to develop a medium neutron source facility based on a linear accelerator, scalable up to 70 MeV proton energy and optimized to deliver high brilliance neutron beams to a variety of neutron instruments. To better understand the neutron yield of different materials at different energies of bombarding protons, measurements to determine the proton-induced neutron production were carried out at the accelerator facility Julic-Cyclotron at Forschungszentrum Jülich.

The experiment was set up with different targets (e.g. beryllium, vanadium and tantalum), which were surrounded by a polyethylene moderator. The neutron yield was indirectly determined by measuring the gamma radiation induced by thermal neutron capture in the moderator. The calibration was performed with an Am-Be neutron source to obtain the neutron gamma conversion rate. Corrections were made for escaping neutrons with the parameter of neutron escape ratio, which was calculated from Monte Carlo simulations.

The details of the simulations will be introduced at the workshop. The total neutron production compared with measurements, the neutron and gamma escape ratio and the spectrum as well as the neutron flux distribution will also be presented.

**Proton beam multiplexer developments towards HBS**

Marius Rimmler

Jülich Centre for Neutron Science, Forschungszentrum Jülich GmbH, 52425 Jülich

The High Brilliance neutron Source (HBS) project aims to develop a scalable Compact Accelerator-driven Neutron Source (CANS) enabling neutron fluxes at the corresponding instruments comparable to medium-flux fission-based research reactors. The full-edged 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 time-resolved 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. This presentation includes developments of a multiplexer test setup at the 45 MeV COSY injector JULIC in Jülich as well as concepts towards an implementation of such device into the final 70MeV HBS framework.

**Measurement of mesitylene moderator efficiency @COSY,FZJ**

Mathias Strothmann, Paul Zakalek, Johannes Baggemann, Robin Similon

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The organic compound mesitylene combines an easy handling and a high hydrogen density. These properties qualifies the substance to be used in cold moderator systems. The performance of a mesitylene based cold moderator system has been investigated during a beamtime at the COSY facility of Forschungszentrum Jülich, where a tantalum target irradiated by a 45 MeV pulsed proton beam has been used to produce neutrons in a (p,n)-reaction. The mesitylene moderator system, cooled by a coldfinger cryocooler to temperatures between 22K and 300K, moderated the neutrons to long wavelength up to 40 Å. These cold neutron spectra has been measured by a 3He detector system in time-of-flight mode. In this talk the experimental setup and results will be presented.

**Radiation induced material damage** **- Status quo of current simulations of the Ta target**

Niklas Ophoven

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Jülich Centre for Neutron Science (JCNS-2), Forschungszentrum Jülich GmbH, 52425 Jülich

Materials which are exposed to a radiation field with particles of sufficient high kinetic energies suffer degradation processes and undergo changes in their micro- and macroscopic properties such as mechanical, thermal or electrical ones. The understanding of these radiation induced material damages is crucial both for the estimation of a target's lifetime as well as for safety aspects. This presentation aims to give a compact and clear overview about the current status of the radiation damage analysis of the tantalum target designated for the Jülich high-brilliance neutron source (HBS) based on the common displacements per atom (dpa) concept. After some few fundamental aspects in the very early beginning, the obtained results of SRIM and FLUKA simulations will be presented in a very concise and clear manner. Whereas previous SRIM simulations focus only on the proton damage, FLUKA simulations will mainly set the focus on the damage caused by the produced neutrons but also give a short overview about the contribution of all relevant particles during the hadronic collision cascade. Furthermore, the results of both Monte Carlo codes will be compared to each other and the meaning of the obtained dpa values will be discussed as well as a prospect for future work will be given.

**Considerations about guide configuration of the TOF diffractometer at high brilliance source**

Z. Ma, K. Lieutenant, J. Voigt

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A time of flight diffractometer for the study of the nanoscale and disordered materials samples with a high neutron flux is envisioned for the HBS. To transfer neutrons from moderator to sample over a long-distance effectively, several neutron guide systems, including a truly elliptical guide and ballistic guides with elliptical diverging and focusing sections were studied via Monte-Carlo simulation, varying the moderator to guide distance and the guide entry cross section. The neutron flux, spatial distribution, and divergence distribution and brilliance transfer ratio with different guide shape geometries were calculated and discussed. Simulation results indicate that a well-designed ballistic guide system can achieve a comparable neutron flux (96.3% of the true elliptical guide system) and brilliance transfer ratio compared to the true elliptical guide.

**Moderator-Reflector Assembly for HBS**

U. Rücker, P. Zakalek, J.Voigt, K. Lieutenant, J. Li, T. Cronert, T. Gutberlet, T. Brückel

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S. Böhm

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In a compact accelerator driven neutron source, the design of the moderator/reflector system is crucial to convert the fast neutrons produced at the compact target into a thermal or cold neutron cloud that can be extracted with a high brilliance. A quick moderation together with a small diffusion length in the thermal moderator is suitable to confine the thermal neutrons in a small space, yielding a high phase space density for extraction into a small space, e.g. to feed a neutron guide or a 1-dimensional cold neutron source.

On the other hand, a strong confinement of the neutron cloud inside the thermal moderator has an influence to the neutron pulse length, which is important for the resolution of time-of-flight instruments. Increased absorption or leakage may result into shorter pulses, while longer pulses intended to accumulate more thermal neutrons in a larger volume can be achieved by diluting the hydrogen rich thermal moderator material. Therefore, the moderator/reflector system has to be adapted to the desired pulse length and will be different at the different target stations of the HBS facility to serve the proper resolution for different instrument types.

**HBS Project – Target activation and radiation safety**

J. Baggemann, E. Mauerhofer, J. Li, P. Zakalek

Jülich Centre for Neutron Science, Forschungszentrum Jülich GmbH, 52425 Jülich

In a Compact Accelerator based Neutron Source (CANS) the irradiation of the target material with protons (or deuterons) and neutrons induced radioisotopes which activities must be considered during and after operation of the target for radiation safety issues. The activity produced by irradiation of a tantalum target with 70 MeV protons is presented together with the concept of the radiation shielding of the neutron source.

**Big Karl Experimental Area**

P. Zakalek1, J. Baggemann1, E. Mauerhofer1, U. Rücker1, J. Li1, J. Voigt1, K. Lieutenant1, T. Gutberlet1,   
M. Rimmler2, O. Felden2, R. Gebel2, R. Achten3, Y. Bessler3, R. Hanslik3, Th. Brückel1

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The High Brilliance neutron Source (HBS) project develops a compact accelerator-driven neutron source based on a tantalum target and a 70 MeV, 100 mA proton linear accelerator. The target / moderator / reflector (TMR) assembly is designed to withstand a power deposition of 100 kW at the target position and to direct the moderated neutrons in an efficient way to the instruments. It is therefore built in a very compact way but also allowing simultaneously a remote handling of the activated target and a way to access the core for maintenance and inspections.

In order to test all components and the whole TMR, we are currently designing a TMR prototype at the JULIC cyclotron which operates at 45 MeV proton energy with a beam current of up to 10 µA and an adjustable pulse structure. The setup allows to test the TMR for its expected nucleonic performance and to validate the MCNP simulation. With an expected neutron yield of the tantalum target in the order of 1011 n/s, the operation of basic instruments like e.g. a reflectometer, a SANS or a PGNAA instrument can be envisioned.

During the workshop, I will show the TMR prototype concept as well as the plans we have for the Big Karl experimental area in which the TMR prototype is being build.

**Cooling of high power targets**

J. Baggemann, P. Zakalek, P-E. Doege, E. Mauerhofer, U. Rücker, J. Li, T. Gutberlet, T. Brückel

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In recent years, the interest in compact, accelerator-driven neutron sources (CANS) has increased worldwide, especially with regard to the increasing shutdown of existing fission-based neutron sources. The focus of interest is shifting more and more from low-flux university scale CANS to powerful high-flux CANS that have the potential to replace current national neutron sources.

One of the key components on the way from compact low flux neutron sources to compact high flux neutron sources is the neutron target. Unique requirements are placed on the target, consisting of low ion energies in the range of 70 MeV at high ion fluxes up to 100 mA, maximal neutron yield and minimal surface area. These requirements lead among other things to extreme thermal power densities and stresses within the target and therefore the heat dissipation of the target can become a bottleneck for the entire facility in terms of power and reliability.

Currently, different approaches to cool the target are being investigated in the different CANS projects, e.g. liquid targets or high temperature targets. The JÜLICH HBS project focuses on a solid target with an adjusted micro channel structure. Theoretical considerations and simulations indicate a possible power density above 1000 W/cm² at a total power of 100 kW, experimental proofs are currently being prepared. The fluid dynamics and structural mechanics simulations of of the target were performed with the commercial ANSYS software. The simulations for the target cooling will be presented at the workshop.

**A compact solid methane moderator system for the Jülich High Brilliance Neutron Source (HBS) prototype**

A. Schwab, J. Baggemann, P. Zakalek, U. Rücker, J. Li, T. Gutberlet, T. Brückel

Jülich Centre for Neutron Science, Forschungszentrum Jülich GmbH, 52425 Jülich

During the last year two cryogenic moderators for the Jülich High Brilliance Neutron Source (HBS) project were tested at the COSY facility at the Jülich Research Centre. Time-of-flight spectra were measured for solid mesitylene at different temperatures (24 K to 300 K) and liquid hydrogen for different ortho-para-ratios (25% to approx. 100% p-H2)

An attempt to increase the cold neutron brilliance exists in lowering the temperature of the moderating material even below 20 K, a commonly used minimum temperature for solid cryogenic moderator materials.

At temperatures below 20 K and corresponding energies, energy transfer mostly takes place by excitations of vibrational and rotational movements of the lattice molecules. Therefore, an effective cryogenic moderator has to allow sufficient low-energy modes.

Solid methane shows a phase change below approximately 21 K from phase I to phase II, which leads to a change of free molecular rotations to three-fourths of hindered rotations. Due to energy transfer by inducing librational movements of the hindered molecules even down to low temperatures, methane in phase II is one of the most effective candidates for increasing the cold neutron brilliance.

Simulations on different methane thicknesses and geometries were performed to find an effective way of dimensioning the phase II methane moderator to maximize cold neutron brightness while keeping the moderator vessel as compact as possible. Using a reentrant hole for extracting cold neutrons from the center of the moderator volume, as suggested in literature, didn’t prove profitable.

A preliminary design for a new cryogenic system for using solid methane at an HBS prototype is currently being carried out. Besides different measures to keep the heat load onto the cold moderator as low as possible, one also has to examine possible dangers in using solid methane being irradiated for extended periods of time while at the same time keeping those periods of time as long as possible.

**FLUKA and MCNP simulation benchmark for neutron yield measurement**

Jiatong Li, Jingjing Li, Eric Mauerhofer, Marius Rimmler, Ulrich Rücker, Paul Zakalek, Thomas Gutberlet, Thomas Brückel

Jülich Centre for Neutron Science, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany

The High Brilliance Neutron Source (HBS) project was initiated at the Jülich Centre for Neutron Science of the Forschungszentrum Jülich (JCNS). In the framework of this project the neutron emission induced by irradiation of beryllium, vanadium and tantalum targets irradiated with protons of various energies (22-42 MeV) were measured at the accelerator facility Julic-Cyclotron at Forschungszentrum Jülich.

Simulations of the neutron emission were carried out first with the MCNP code. In this work, we report on the simulations of the neutron emission using the FLUKA code. The results are compared to those obtained with the MCNP code and to the experimental data.

**Abstracts RAP**

**Current status of RANS-II**

Tomohiro Kobayashi1\*, Shota Ikeda1, Yoshie Otake1, Yujiro Ikeda1, Noriyosu Hayashizaki2

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RANS-II (RIKEN Accelerator-driven compact Neutron Source II) is a prototype of a transportable compact accelerator neutron source, which we will test diagnostics of infrastructures and material analyses. 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 started neutron emission in 2019 summer at a dedicated shelter constructed in RANS experimental hall. 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 concrete surface. The pulsed 2.45 GHz microwave ECR ion source and the 2.49 MeV RFQ-LINAC are in operation tests with neutron emission, which started after all the systems were relocated to the RANS-II shelter. So far, proton current of 1.4 mA with a pulse width of 300 usec was measured at the target. When it was operated at the designed duty factor (3 %), a time averaged proton current was 42 uA. The lithium target with a cooling system, the target station with shielding, and HEBT are in the stage of final adjustment.

**Study on neutron field characteristics of p-Li neutron source RANS-II**

**by simulation with PHITS**

K. Sugihara1, T. Kobayashi1, S. Ikeda1, K. Fujita1, Y. Ikeda1,2 and Y. Otake1

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*2. J-PARC Center, Japan Atomic Energy Agency, Japan*

RANS-II (RIKEN Accelerator-driven compact Neutron Source II), which produces neutrons via the 7Li(p,n)7Be reaction with 2.49 MeV proton incident on thin Li deposited in a Cu substrate, has been under commisioning as reported in the acompanied presentation by Kobayashi. As a variety of experiments, e.g., non-destructive detection of structural imaging for infrastructures, are planned to be carried out with use RANS-II, we have started studies on neutron characteristics in terms of 1) dose rate distribution around the RANS-II target station which is placed in a rather small area surrounded by mainly concrete, 2) neutron beam profiles from the p-Li target station with collimators. Those information are requested importantly in preparation of experiments. PHITS (Particle and Heavy Ion Transport code System) is applied to simulate neutron fields in the experimental space including the target station shielding. Nuclear data library of ENDF/B-VII.1 is used to calculate neutron generation by the p-Li reaction. JENDL-4.0 is used for neutron and gamma-ray transportations. In the calculations, model geometries are made by taking dimensions of available CAD data for the experimetal hall and the target station.

In general, althogh the compact target station structures reduce radiation leakage as designed, results show that there are considerable amount of neutron and gamma-ray dose distributed throughout the experimental hall. Concerning the background in the hall, major source are scattered neutrons by the building walls. Neutron beam which is extracted through the opening in the forward direction from the p-Li target, could be controled by placing appropriate collimators. An outline is to be presented for the optimization of beam extraction with parameters in terms of collimator sizes and their materials. Also, critical steps are addressd as important issues to be done in coming several months.

**Quantitative determination of thin water layer thickness　distributed on steel plate**

A.Taketani, T. Takanashi, Y. Ikeda, Y.Wakabayashi, T. Hashiguchi, and Y.Otake

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Steel is very wodely used material in society supporting our daily life. Howevere, it is degraded by corrosion, which is caused by oxidation-reduction reaction with small quantity of water, order of micron meter thickness. We have been tried to observing with neutron imaging method utilizing RANS. In order to evaluatting measuring thin water thickness quantatively, we stick solid hydrocarbon film, which emulate water beahavior to thermal neutron, on steel plate, and measure theraml neutron trasnmisstion. Stacks of 0.3 um water equivalent(WEq) thick mylars and 11um Weq thick Polyimide and mylar film on the 6mm steel sample were used.

**Defect detection for bulk samples via neutron scattering imaging**

Kunihiro Fujita, Chihiro Iwamoto, Takaoki Takanashi, Yoshie Otake

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We have developed an imaging technique using neutron scattering for nondestructive detection of defects in infrastructure such as bridge cables and composite floor slabs of road bridges. The information in the bulk samples composed of concrete and/or iron can be obtained by irradiating with a fast neutron beam having high penetrating power and measuring the neutrons scattered and emitted from the sample. Using the developed system, we investigated the feasibility of the defect detection such as water erosion and voids caused by wire breakage, which lead to the breakage of bridge cables. Monte Carlo simulations using Geant4 have revealed that the water and the voids with the thickness of smaller than 1 cm can be detected by using the collimated parallel beam. The experiment was performed at RANS to detect the dummy defects inserted in the bridge cable. As a result, the experimental data well agree with the simulation data, and it was shown that water and void of 7 mm could be detected. We have also developed a system for detecting voids inside a composite floor slab of road bridges due to poor initial construction. From the simulation work, it was found that a void with a thickness of 3 mm could be detected by using the methods of beam collimating and beam scanning across the void.

**Exact CT reconstruction algorithm method and neutron imaging**

Takaoki Takanashi1, Shigeho Noda2, Masaru Tamura3 and Yoshie Otake1

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2 Image Processing Research Team, RIKEN Center for Advanced Photonics, RIKEN

3 Technology and Development Team for Mouse Phenotype Analysis, RIKEN BioResource Research Center, RIKEN

The computed tomographic (CT) images are generated by image reconstruction of transmission images using quantum beams containing X-rays, visible light, and neutrons taken from multiple directions. Taking the transmission images and image reconstruction in CT corresponds to the mathematical operation of Radon transform and its inverse. The Radon transform is expressed as an integral formula, and guarantees a one-to-one correspondence between a set of projection images and a tomographic image when the pixels are infinitesimally small. However, in an actual apparatus, the size of pixels and the number of projections are finite. In order to reflect this, the Radon transform is discretized, though it has been known that this one-to-one correspondence is broken in the process of discretization. Further, the Radon transform discretized in this way becomes a multi-dimensional simultaneous linear equations in which the number of independent equations for unknowns is insufficient. For this reason, when performing image reconstruction using approximate solution based on the iterative calculation, the problem that trap to the local minimum (pseudo) solutions are arises. This destruction of one-to-one correspondence reduces the quantitativeness of the tomographic images.

Therefore, we invented an algorithm to generate the exact solution of the discretized Radon transformation. As a result, the geometric indeterminacy that the conventional discretization method has is eliminated, and the one-to-one correspondence is restored. In this talk, we will show that applying this method to neutron CT data taken by RANS has yielded more quantitative tomographic images.

**Focusing Mirror for Neutron Reflectometry**

Takuya Hosobata1, Norifumi L. Yamada2, Masahiro Hino3, Hisao Yoshinaga3, Fumiya Nemoto2,  
Koichiro Hori2, 4, Toshihide Kawai1, Yutaka Yamagata1, Masahiro Takeda1 and Shin Takeda1

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We have successfully realized a functional neutron-focusing supermirror that converges a beam of cold neutrons to a tiny spot. The main originality of our neutron-focusing supermirror is in the material of the substrate; we chose aluminum alloy covered with Ni-P plating. This plating is an amorphous metal that can be polished to realize sub-nanometer surface roughness, which is a prerequisite for depositing neutron supermirrors. The plating can be applied to any premachined bulk metal; hence, curved surface for focusing is much easier to realize compared to conventional brittle substrates made of glass or silicon. Based on this concept, we have been developing neutron-focusing supermirrors for a neutron reflectometer named SOFIA, located at beamline No. 16 in Materials and Life Science Research Facility of Japan Proton Accelerator Research Complex (BL16 in J-PARC/MLF). Neutron reflectometers provide depthwise structural information of thin films, and SOFIA especially excels in measuring layered samples with buried interfaces. To enhance SOFIA’s performance, a focusing supermirror was expected to illuminate small samples with greater neutron intensity. The first two mirrors we developed proved the feasibility of the concept [1-2], but they were insufficient for practical use, mainly due to two reasons. First, the form accuracy of the elliptic surface was insufficient: we failed to remove the waviness on the elliptic surface, which broadened the focus spot. Second, the reflectivity of the supermirror was non-uniform, due to the position dependent variation of the surface roughness. In this work, we have successfully solved both of these problems and developed the neutron-focusing supermirror, which satisfied the requirements for SOFIA[3]. The mirror is now permanently installed in the beamline and is open to the users of SOFIA.

*[1] S. Takeda et al., Optics Express, Vol. 24, Issue 12, pp. 12478-88 (2016).*

*[2] T. Hosobata et al., Optics Express, Vol. 25, Issue 17, pp. 20012-24 (2017).*

*[3] T. Hosobata et al., Optics Express, Vol. 27, Issue 19, pp. 26807-20 (2019).*

**Development of high-resolution residual stress measurement method via angle-dispersive neutron diffraction using a compact neutron source RANS**

Chihiro Iwamoto1, Yoshimasa Ikeda1, Masato Takamura1, Yoshie Otake1, Hiroshi Suzuki2, Pingguang Xu2, Tomoyuki Hakoyama3, Ryunosuke Kakuta4, Masayuki Kumagai5, Akira Otsuki6

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3Department of Mechanical Engineering, Gifu University

4College of Industrial Technology, Nihon University

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6University of Lorraine

We are developing a method of angle-dispersive neutron diffraction using a compact neutron source RANS to measure residual stress. Higher signal-to-noise ratio by improving the position resolution enables us to extract accurately the residual stress by measuring the peak shift of the diffracted neutrons. A feasibility study of the angle-dispersive neutron diffraction at RANS beam line has been performed with a monochromator of Silicon single crystal. The monochromator was installed at about 1 m downstream from the exit of the target station. A monochromatic neutron beam with the peak in the energy range between 20 meV and 40 meV was obtainded. The monochromatic neutron beam irradiated a sample of IF steel. As a result, a position resolution of 18 mm with a full width at half maximum was obtained by measuring the diffraction peak from 211 crystal plane of IF steel. The position resolution corresponds to a resolution of 2.5 % in the lattice space spectrum. As future plan, we are planning to achieve the resolution of 0.5 % in the lattice space spectrum by optimizing an angular spread of the neutron beam using a solar collimator.

**Development of a 500MHz proton linear accelerator for transportable compact neutron source, RANS-Ⅲ.**

S. Ikeda1, Y. Otake1, Y. Ikeda1, T. Kobayashi1, N. Hayashizaki2

1, Neutron Beam Technology Team, RIKEN Center for Advanced Photonics, RIKEN

2, Laboratory for Nuclear Reactors, Tokyo Institute of Technology

In infrastructural diagnostics by a compact neutron source, it is essential to make the neutron source system lighters and smaller. In order to make a lighter RFQ linac for a transportable compact neutron source RANS-Ⅲ, we have developed a 500 MHz RFQ linac which mainly consists of three components. Since the resonance frequency of the cavity is chosen as 500 MHz, the cavity diameter and the weight are lower than in a conventional four-vane type RFQ linac.

First, by beam tracking simulation software, we designed the cell parameters of the 500 MHz RFQ linac which can accelerate a proton beam from 30 keV to 2.49 MeV. Using three-dimensional electromagnetic simulation software and Multiphysics simulation software, we optimized the cavity design of the 500 MHz RFQ linac, and investigated the thermal properties of the cavity with the cooling channel.

The 500 MHz RFQ cavity was fabricated according to the designed cavity parameters. A resonance frequency of the RFQ cavity were carried out with a network-analyzer, and tuned to 499.99 MHz by inserting eight tuners. In the presentation we will discuss the design and the frequency tuning results.

**Design optimization and installation status of the RANS new target station for cold neutron source**

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A program of RANS new target station, the reformation of RANS, has been conducted since last year to expand sciences cases as well as applications with cold neutrons at RANS. The reformation program aimed at primarily to provide high intensity cold neutrons in energy range less than 10 meV down to 0.1 meV. To start the program, several guidelines were identified as follows; 1) redesign in the central 400 mm3 core region, 2) keeping or increasing thermal neutron intensity along with orders of magnitude increase of cold neutrons, 3) no change in the outer dimensions of previous RANS assembly structure. As major structural changes in the central target/moderator /reflector (TMR) region, we have devised a retrievable system by taking the slab geometry into account, which enables smooth installation of a cryogenic cold moderator system and also other moderator systems with specific materials/geometry arrangements, and elimination of labor for removal of heavy shielding blocks above the neutron production target each time. We call this scheme as plug system. In addition to those design principles, we have payed attention to realize possible neutron beam extraction to 23 deg. and 90 deg. angles with respect to proton beam injection direction in the future.

Mesitylene was chosen as the moderator material because it has excellent properties appropriate to provide modest cold neutrons, being stable chemically and easy to be handled, although the neutroninc performance is not exciting comparing to solid methane. Extensive optimization studies on TMR have been carried out to design the best performance in terms of cold neutron intensity with parameters of moderator thickness, pre-moderator (polyethylene; PE), and mesitylene thickness assuming a realistic vessel configuration and extraction hole dimensions. The optimization was also done for the geometrical increase of the reflectors. The effects on the replacement of some parts of borated PE with PE in the forward region were investigated. The results for the cold neutrons to be provided to the user are to be shown with reformed TMR along with partially modified shielding structures. The estimated gain factors for cold and thermal neutron fluxes are presented by comparing those in the previous RNAS TMR configuration with the PE moderator.

Lastly、the progress of the reformation work are reported by illustrating re-construction the plug structure and shielding. Also the cold moderator system under installation is shown with a schematic drawing and pictures. A time-line for the acceptance and performance tests are to be mentioned.

**Exploitation of neutron applications with gamma-ray detection**

**at RANS and RANS-**

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Nowadays, there are increasing demands for non-pre-processing methods to analyze the elemental contents in substances with large bulk such as concrete structures and industrial wastes. Especially, since non-destructive method for measuring the chloride ion concentration in concrete structures with a depth profile from the surface to steel bar are strongly required, we have started a development of a new technique using a prompt gamma neutron activation analysis (PGNAA) at the RIKEN accelerator-driven compact neutron source (RANS). Along with the accelerator the base technique, we have started development of a technique with californium-252 neutron source, named as RANS-. In parallel to PGA, the neutron activation analysis technique (NAA) has been available as a basic measurement tool at RANS, to meet general wide needs for elemental analyses for many materials.

We will present current status of techniques using gamma-ray detection, both PGA and NAA at RANS. In particular, a progress in development of the method PGA for chloride detection with depth profile in concrete is to be highlighted. A conceptual RANS- program based on PGNAA is to be introduced as a new exploitation of future RANS applications.