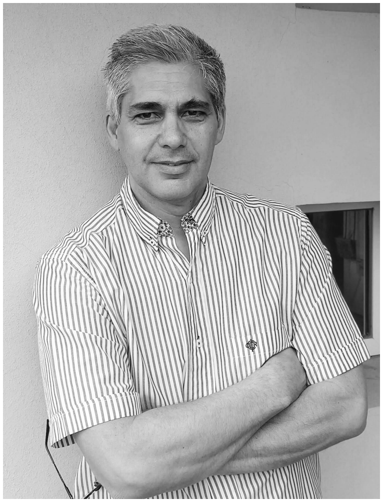
9th
INTERNATIONAL TOPICAL MEETING ON NEUTRON RADIOGRAPHY

CENTRO CULTURAL KIRCHNER

Sarmiento 151
Ciudad Autónoma de Buenos Aires
Argentina



Javier Santisteban
ITMNR-9 Chair

Welcome

On behalf of the Organizing Committee and the Scientific Program Committee, it is my pleasure to welcome you to ITMNR-9, the 9th International Meeting on Neutron Radiography, which is being held at the Centro Cultural Kirchner, Buenos Aires, Argentina.

Organized by the International Society for Neutron Radiography (ISNR), ITMNR-9 is the latest meeting in a highly successful series that started in Pembroke (Canada) thirty-two years ago, and continued in Yokosuka (Japan, 1995), Lucerne (Switzerland, 1998), Pennsylvania (USA, 2001), Garching (Germany, 2004), Kobe (Japan, 2008), Kingston (Canada, 2012) and Beijing (China, 2016).

Originally planned to be held in 2020, the organization of ITMNR-9 was delayed due to the COVID-19 pandemic which hugely impacted in our daily lives. After considering several options, the ISNR board decided that ITMNR should continue to be an in-person meeting where scientists, students and engineers could interact directly and learn about the latest advances on the application of neutron imaging techniques to an ever increasing number of problems in science and technology. With over 110 oral and poster presentations given by attendees from 15 countries, ITMNR-9 participants will surely return home with new ideas and collaborations.

This ITMNR, being the first ISNR conference to take place in Latin America, will contribute to expand the international neutron imaging community whilst helping to build a solid user base for ASTOR, a state-of-the-art cold-neutron imaging instrument being developed by the Argentine Neutron Beam Laboratory (LAHN) of the Atomic Energy Commission of Argentina for the multipurpose research reactor RA-10.

I would like to take the opportunity to thank our sponsors and funding institutions for helping to make ITMNR-9 a success.

Finally, I would like to give a special welcome and thank to our international delegates who make up over 80% of the attendees at ITMNR-9.

I hope that you will have a truly stimulating time at ITMNR-9 and that you will also find time to know and enjoy the great city that is Buenos Aires.

ITMNR-9 /

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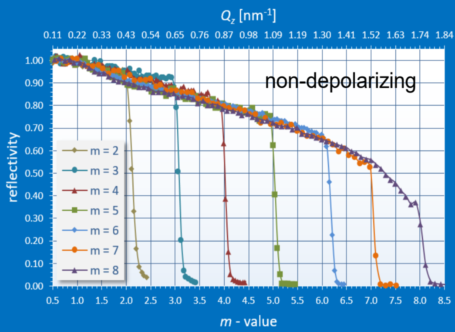
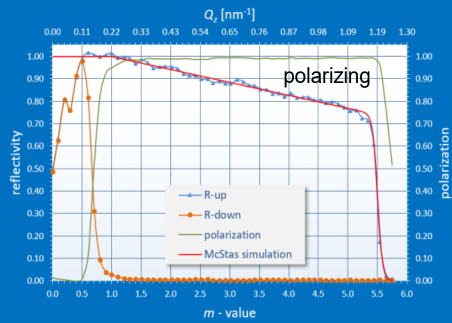




Supermirror at its best: high reflectivity – large angles of reflection


POWTEX @ FRM II

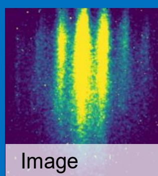

Insert @ ANSTO


BWFA for ODIN @ ESS

Complex elliptic guides made from glass, Al, or Cu


Nested mirror optics (not to scale)


Object



Image

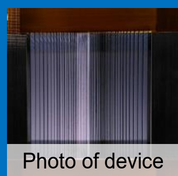
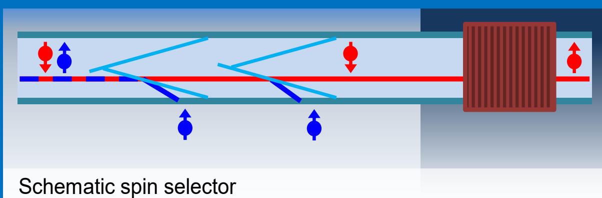
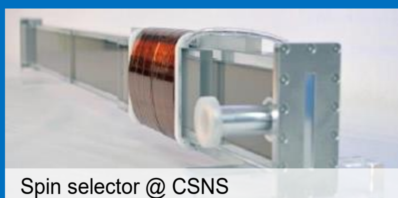


Photo of device

Imaging with nested mirror optics


Schematic spin selector


Spin selector @ CSNS

Spin selection: 2V-cavity combined with RF spin flipper

Swiss Quality for Excellence in Neutron Science

Amsterdam Scientific Instruments B.V. (ASI)

ASI designs and manufactures advanced detection systems based on hybrid pixel technology. Hybrid pixel detectors are very advantageous to detect weak signals, as they are intrinsically noise free. Furthermore, this technology allows to detect particles both in frame mode (with frame rates up to 2000 fps) and event mode (with a time resolution up to 260 ps).

The TPX3CAM from ASI is a dedicated time-resolved event-driven 2D detector used for neutron imaging and neutron diffraction. ASI has partnered with LoskoVision GmbH to make use of smart real-time processing of neutron event data to allow high-resolution neutron imaging with scintillators. This new technology is beneficial to neutron scientists worldwide as it is a dramatic improvement from current technologies on the market. LoskoVision GmbH and ASI will present this technology at their booth during the conference. We are looking forward to seeing you there!

ITMNR-9 Scientific Freedom Policy Statement

ITMNR-9 shall observe the basic policy of non-discrimination and affirms the rights of scientists and engineers throughout the world to adhere or to associate with international scientific activity without restrictions based on nationality, race, colour, age, religion, political philosophy, ethnic origin, citizenship, language or gender.

Plenary Presentations

Neutron imaging insights into electrochemical devices for the energy transition

Pierre Boillat[1,2]

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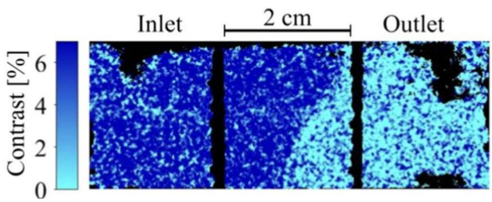
Electrochemistry can be considered the cornerstone of various technologies used for the de-carbonization of the world energy landscape, ranging from battery of fuel cell powered electric vehicles to electrolyzers used to produce hydrogen as a form of energy storage. In this context, a deep insight into the physico-chemical processes limiting the performance and durability of such devices is a key requisite for further optimizations in order to enable their large-scale deployment.

Besides some notable exceptions such as solid-state batteries, the hydrogen atom is found in virtually every electrochemical systems. This includes its presence in water, which plays a key role in fuel cells and electrolyzers, but also its presence in aqueous and organic electrolytes used for batteries and redox flow cells. The very particular interaction of neutrons with hydrogen opens a large field of opportunities to understand electrochemical systems through neutron imaging.

In the first part of this presentation, I will review the learnings obtained from more than 20 years of application of neutron imaging to electrochemical systems, at PSI and in other institutions. I will also illustrate how the applications to electrochemistry have been a significant driver for innovation not only for energy conversion devices, but also for the neutron imaging technology itself. In the second part, I will give an overview of the opportunities offered by advanced imaging modalities going beyond attenuation-based contrast. This will include in particular the development of spectroscopic neutron imaging, which exploits the significant inelastic component in neutron scattering of hydrogen.



Neutron imaging of the water (dark blue)/ice (light blue) distribution in fuel cell porous materials, based on the different inelastic interactions of hydrogen as a function of aggregate state [reproduced from M. Siegwart et al., *J. Electrochem. Soc.* **167**, 064510 (2020), Copyright 2020, The Authors]

The Neutron Imaging Instrument CONRAD – post-operational review

Nikolay Kardjilov[1], Ingo Manke[1], André Hilger[1], Tobias Arlt[1], Ralf Ziesche[1], Robert Bradbury[2], Henning Markötter[3], Robin Woracek[4], Markus Strobl[5], Wolfgang Treimer[6] and John Banhart[1,2]

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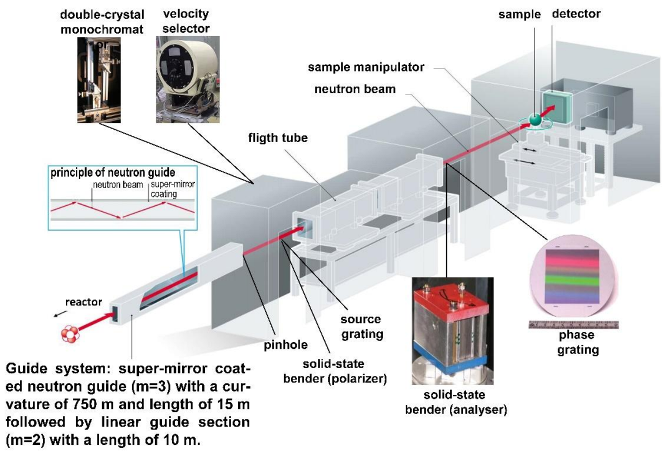
The neutron imaging instrument CONRAD was operated as a part of the user program of the research reactor BER-II at Helmholtz-Zentrum Berlin (HZB), Germany from 2005 to 2020. The instrument was designed to use the neutron flux from the cold source of the reactor, transported by a curved neutron guide. The cold neutron spectrum provided a great advantage in the use of different neutron optical components such as focusing lenses and guides, solid-state polarizers, monochromators and phase gratings. The flexible setup of the instrument allowed for implementation of new methods including wavelength-selective, dark-field, phase-contrast and imaging with polarized neutrons. In summary, these developments helped to attract a large number of scientists and industrial customers who were introduced to neutron imaging and subsequently contributed to the expansion of the neutron imaging community.



Layout of the CONRAD-2 instrument

Invited Presentations

iBeatles: Bragg Edge Imaging Software for the VENUS beamline at the Spallation Neutron Source

Jean C. Bilheux[1], Hassina Z. Bilheux[1]

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Large scale user facilities such as the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory (ORNL) are home of state-of-the-art beamlines that are optimized based on their scientific research portfolio. While some scientific communities are well-versed in using these beamlines, others require advanced software development efforts to process and understand the collected data. Neutron wavelength dependent imaging is a relatively new technique that offers unique contrast mechanisms to study both engineered and natural materials. Imaging beamlines notoriously produce large amount of data that is impossible to sort through unless appropriate software is developed. ORNL is currently building the VENUS imaging beamline which, as expected from an imaging facility, will produce large and complex amount of data. Hence, while the beamline is being constructed, meticulous attention is being paid to data acquisition, reduction, processing, and analysis as software is indispensable to the success of VENUS. The layout of the SNS SNAPbeamline, a high pressure diffractometer, allows it to be utilized as a time of flight (TOF) neutron imaging instrument. This access offers a unique opportunity to develop software tools such as iBeatles (Imaging Bragg Edge Analysis Tools for Engineering Structure) which is a user-friendly intuitive interface capable of fitting Bragg edges and back projecting the atomic spacing and strain onto the radiograph of the object under investigation. Other features include automated normalization and the ability to live-select a region of interest (ROI) while fitting the data to evaluate the size of the ROI based on signal-to-noise ratio (SNR).

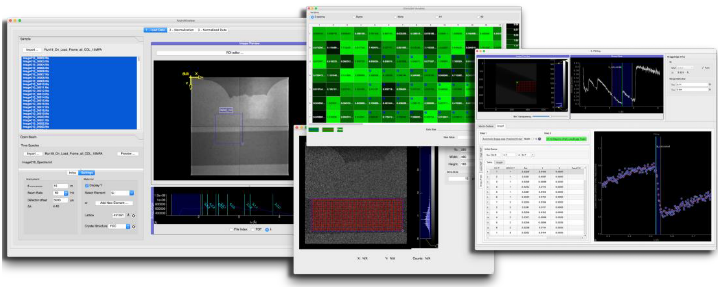

Figure caption. Screenshots of the iBeatles General User Interface.

The iBeatles software provides a unique platform to interact with data collected at VENUS shortly after measurements have been automatically reduced/corrected.

Neutron and X-ray imaging in concrete and geological systems

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[2] *Institut Laue-Langevin (ILL), Grenoble, France,*
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Porous media such as rocks and concrete are ubiquitous in a wide range of engineering applications impacting our everyday life. For example, concrete is the second most widely used substance on Earth after water. The macroscopic behavior of this broad class of materials depends on processes occurring at the micro-scale and their interactions. Full-field methods lend themselves as ideal non-destructive probing tools to explore their evolution across time.

Historically x-ray imaging has been the main approach to study their full-field response, but in numerous cases neutron imaging has proven essential to study processes, and notably the role played by hydrogen-rich substances, such as water, within them. Recent developments have pushed the spatio-temporal resolution of neutron imaging as well as allowed for the acquisition of truly concurrent x-ray tomographies. This combined use is uniquely powerful, thanks to the high complementarity of their contrast. It allows not only to study different aspects of coupled processes (e.g., the interdependence between the opening of cracks and water penetration) but even aids in the identification of the different phases comprising a sample, as highlighted in Fig. 1 .

This contribution will present an overview of recent developments in neutron imaging, including its combined use with x-ray imaging, and focusing on recent discoveries and future avenues for the study of concrete and geological systems.

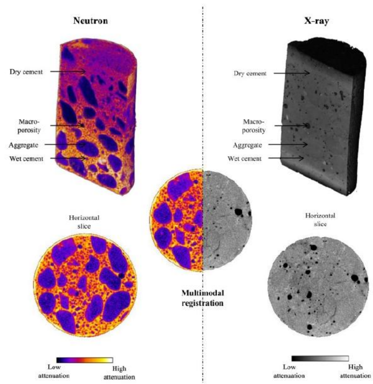

Fig. 1: Example of the unique complementarity of information provided by neutron and x-ray CT in the study of concrete.

Neutron transmission of mosaic crystals and oligo-crystalline materials

Florencia Malamud[1,2], Javier Roberto Santisteban[2], Yan Gao[3], Takenao Shinohara[4], Kenichi Oikawa[4], Anton Tremsin[5], Markus Stobl[1]

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The wavelength-resolved neutron transmission spectrum of imperfect single crystals (mosaic crystals) contains a series of dips in intensity at specific neutron wavelengths, as a result of the neutrons removed from the beam due to Bragg reflections. The position, width, and depth of those dips depend on the material, the crystal orientation, and the degree of perfection of the single crystal. We have developed a Rietveld-type full-pattern analysis of wavelength resolved neutron transmission imaging experiments on mosaic crystals that allows precise and simple determination of lattice parameters, mosaicity, extinction factors, and crystal orientation. The method allows rapid investigation of the spatial variation of such microstructural features of mosaic crystals across macroscopic specimens with < 1 mm resolution, and it was applied to study several naturally occurring and man-made objects. Here we present an application of this method to characterize non-destructively important properties of nickel-based superalloys, and their spatial distribution across macroscopic specimens. From a TOF neutron imaging experiments recorded with an MCP detector, we have quantified the lattice parameters and misfit parameter of the two composing phases, γ and γ', together with their misorientations, with an effective spatial resolution of ~500 µm x 500 µm. For this, we have extended the theoretical model designed for mosaic crystals, to include the analysis of oligo-crystals, e.g., specimens composed by a small number of crystals.

Time-of-flight frame overlap Bragg edge imaging

Matteo Busi[1], Jan Capek[1], Efthymios Polatidis[1], Jan Hovind[1], Pierre Boillat[1], and Markus Strobl[1]

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Neutron Bragg edge imaging enables spatially resolved studies of crystalline features through the exploitation and analysis of Bragg edges in the transmission spectra recorded in each pixel of an imaging detector. Studies with high spectral resolutions, as is required e.g. for high-resolution strain mapping, and with large wavelength ranges have been largely reserved to pulsed neutron sources. This is due to the fact, that the efficiency for high wavelength resolution measurements is significantly higher at short pulse sources. At continuous sources a large fraction of the available neutrons must be sacrificed in order to achieve high wavelength resolution for a relevant bandwidth e.g. through a chopper system. Here we introduce a pulse overlap transmission imaging technique, which is suited to increase the available flux of high wavelength resolution time-of-flight neutron Bragg edge imaging at continuous neutron sources about an order of magnitude. Proof-of-principle measurements utilizing a chopper with a fourfold repeated random slit distribution of eight slits were performed at the thermal neutron instrument POLDI of the Applied Materials Group at the SINQ neutron source of Paul Scherrer Institut in Switzerland. It is demonstrated, that disentanglement of the overlapping pulses is achieved with the correlation theorem for signal processing. Thus, the Bragg edge pattern can be reconstructed from the strongly overlapping Bragg edge spectra recorded and the results demonstrate the feasibility of the technique.

In situ Neutron Radiography on the Mixing Behavior in a Flow-type Reactor during Supercritical Hydrothermal Synthesis

Seiichi Takami[1], Ken-ichi Sugioka[2#], Masaki Kubo[2], Takao Tsukada[2], Katsumi Sugimoto[3], Nobuyuki Takenaka[3], Naoya Odaira[4], Daisuke Ito[4], and Yasushi Saito[4]

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We have synthesized metal oxide nanoparticles by mixing a stream of an aqueous reactant solution with another stream of supercritical water at a T-shaped junction in a flow-type reactor. We found that the size of synthesized nanoparticles was affected by the direction of the streams at the T-shaped junction. However, observing the mixing process was difficult because the nanoparticles were synthesized in a thick-walled stainless-steel tubular flow reactor operated above the critical point of water (374°C and 22.1 MPa).

To observe the mixing process, we performed neutron radiography. Under typical pressure conditions (25 MPa), the metal salt solution at room temperature had a high water density (~25°C, 1.0 g/cm^3) while supercritical water had a low water density (~400°C, ~0.2 g/cm^3) and we expected the difference in water density can be visualized by neutron radiography.

By using the experimental apparatus shown in Fig. 1a, we obtained the radiography images (Fig. 1b) at the T-shaped junction where room temperature water and supercritical water were mixed. Based on the images, we evaluated averaged density of water in the flow channel around the T-shaped junction (Fig. 1c). We also obtained computed tomography images and performed numerical simulation to understand how the streams were mixed. We believe that these approaches, together with experiments, are effective tools to understand and predict the mixing in a tubular reactor and contribute to the production of desired nanoparticles.

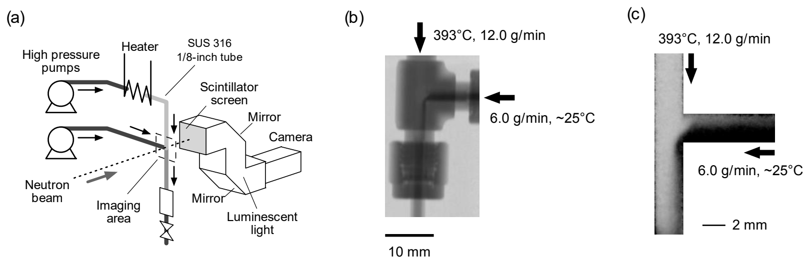

Figure 1 (a) Schematic diagram of the experimental apparatus, (b) neutron radiography image of the T-shaped junction, and (c) the averaged density of water in the flow channel.

Neutron imaging of lithium batteries

Ralf F. Ziesche[1], Nikolay Kardjilov[1], Ingo Manke[1], Tobias Arlt[2], Henning Markötter[3], Alessandro Tengattini[4,5], Lukas Helfen[5], Anton S. Tremsin[6], Winfried Kockelmann[7], Dan J. L. Brett[8,9], Paul R. Shearing[8,9] and John Banhart[1,2]

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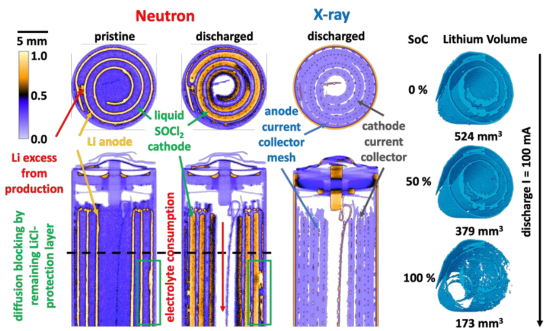
Increasingly demanding applications of batteries mandate an improved understanding of the performance, degradation and failure of both materials and devices. Today's researchers have a large portfolio of microscopy, spectroscopy, and diffraction tools at their disposal. The increasing trend towards *multi-modal* and *in-situ* or *operando* characterization provides an opportunity to probe the highly correlated physio-chemical phenomena associated with battery operation and degradation. In the recent years, neutron imaging has made large strides to catch up with complementary X-ray imaging techniques in terms of resolution and acquisition rate and now plays an essential role for device and materials characterization within the pantheon of battery analysis tools. Given the high sensitivity for lithium and the liquid electrolyte, neutron methods are especially suited for lithium battery studies. Recent improvements of neutron imaging instruments and techniques make neutron imaging an even stronger tool for directly probing Li batteries in 2D, 3D and 4D, the fourth dimension being either time or energy. All of that provides a platform for studying dynamic and structural process with a high local resolution making neutron imaging to a rising investigation tool in battery research. An overview of the latest neutron battery research will be presented, providing a deep insight into dynamic, multi-dimensional, complementary neutron imaging and structural analyses. The main challenges for neutron imaging of Li batteries will be outlined and the future development of methods and their potential and significance for future battery research discussed.



Dynamic Li diffusion from the Li-metal anode to the liquid thionyl chloride cathode of a Li|$SOCl_2$ ER14505M cell discharged with 100 mA as orthogonal slices from 4D neutron CT and post-mortem X-ray CT data, alongside the quantified lithium anode depletion.

Classical ghost imaging with neutrons

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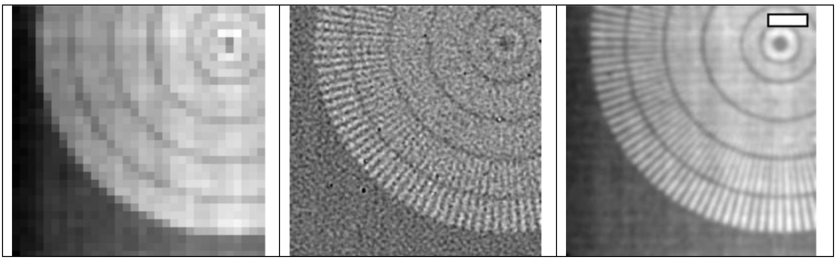
Ghost imaging (GI) is a new paradigm in imaging that originated from quantum optics based on the position, or momentum, correlation of entangled photons. Classical variants of GI emerged within a decade based on patterned illuminations. Here the image of an object is computed based on the correlation of measurements in two arms of an experiment. In one arm, the illumination pattern is recorded; in the other arm, the total interaction of this patterned illumination with the object is measured. We demonstrate classical GI using the polyenergetic reactor source of thermal neutrons on the Dingo beamline at the OPAL reactor in Sydney, Australia. Such a proof-of-concept opens up the potential for several further applications. Neutron GI can be beneficial for dose reduction and resolution enhancement; it also enables imaging with a single-pixel sensor (or bucket detector) meaning position resolution can be incorporated into a variety of existing neutron instruments.

Here we explore the principle of resolution enhancement by employing a variant of GI where each pixel of a detector is regarded as an independent bucket detector; a ghost image is then computed for each pixel. This parallel form of neutron ghost imaging can significantly increase spatial resolution as demonstrated in the figure. Further applications and extensions of our neutron GI protocol will also be discussed. These include neutron ghost tomography, darkfield neutron ghost imaging, and isotope-resolved colour neutron ghost imaging via prompt-gamma-ray bucket detection.



Example of resolution enhancement from a 32 x 32 pixel array (Left) to a 256 x 256 pixel array (Centre) through parallelised neutron GI; this used 1716 illumination patterns and bucket-measurement pairs. (Right) Ground truth image of the resolution star (2.0mm scale bar).

High-resolution neutron imaging for hydrogen characterization in irradiated zirconium cladding

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Zirconium alloys are used as fuel cladding in nuclear reactors due to their excellent combination of mechanical properties and low neutron cross section. It is of high importance that these components maintain their integrity during their lifetime. Although during operation in the reactor, the claddings are subject to aging mechanisms, like radiation and water corrosion. Hydrogen is the corrosion product formed where part of it is released into the reactor environment, and the other part diffuses into the metal cladding. As hydrogen has very limited solubility in zirconium alloys, hydrides are formed when the solid solubility is exceeded. The mechanical properties of zirconium cladding are strongly influence by hydrides leading to a decrease of fracture toughness and ductility. The amount of hydrides, as well their orientation with respect to mechanical loading also plays an important role for the spent fuel integrity after unloading, handling and transportation for dry storage facilities. As hydrogen/hydrides can often have a non-uniform distribution due to the high mobility of hydrogen interstitial atoms, the risk to the nuclear fuel rod integrity can significantly be raised. In this context, the hydrogen quantification and the evaluation of its distribution in the cladding is of high importance.

High-resolution neutron imaging, using PSI Neutron Microscope detector, has become an excellent non-destructive tool providing a hydrogen quantification in un- and irradiated nuclear fuel claddings, with a sub-10 µm resolution and sub-10 wppm sensitivity to hydrogen. In this respect, neutron imaging has allowed unique investigations of hydrogen in highly radioactive fuel cladding sections after service in nuclear power plants.

Neutron imaging applications in cultural heritage at ISIS

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Scientific investigations and archaeometric studies have played a major role in the field of archaeology, especially with regard to materials that have been transformed through human activity, like metals. In this talk, I will give an overview of how neutron imaging can be useful to improve our knowledge of ancient manufacturing processes of metals, their technological evolution over the centuries, and how they degrade over time.

Neutron imaging techniques are used to shed light on the inner structure of composite materials and their manufacturing techniques, but also can be used for elemental investigations. In addition, the combined use of X-rays and neutrons provides additional element-dependent information which is fundamental in case of multi-phase objects.

The talk will cover several case studies carried out at the ISIS Neutron and Muon Source, spanning from Roman coins to Egyptian artefacts.

Oral Presentations

Scintillation screens for Imaging with Neutrons. What do I need to know?

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Neutron imaging detectors based on a light-sensitive camera, which observes the emitted light from a scintillator screen have become a standard tool at many facilities. Meanwhile, there are systems available for very large field-of-view (FOV), very high spatial resolution, high frame rate and those for sophisticated new methods (like centroiding or "event-mode"-imaging). Each of them has specific requirements in particular related to the scintillator screen - one of the key components.

Clearly, the two most relevant specifications of the scintillation screens are the light output and the resolution, but to fully evaluate the performance of the screen also the "signal to noise ratio", the light attenuation and the neutron capture efficiency should be taken into account.

Here we will give an overview of the different type of scintillation screens and their advantages and disadvantages in the use of different applications or beamline surrounding.

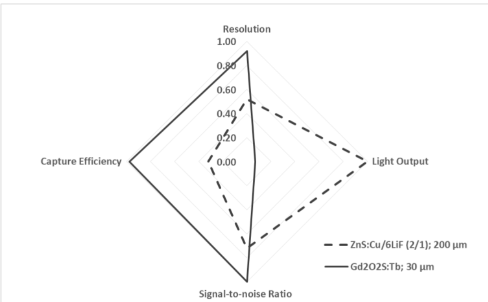

Fig. 1: Comparison of the different features of the most used scintillation screens within a net diagram (measured at Neutra (PSI)).

High spatial resolution neutron imaging based on CMOS image sensors

Martín Pérez[1,2], José Lipovetzky[1,2,3], Eduardo Martínez[1,3], Osiris Inti Abbate[2], Fabricio Alcalde Bessia[1,3], Miguel Sofo Haro[1,2,3], Julio Marín[1,2], Fernando Ariel Sánchez[1,2], Juan Longhino[1,2], Mariano Gómez Berisso[1,2,3], Juan Jerónimo Blostein[1,3]

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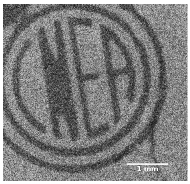
We present two novel high spatial resolution neutron detection techniques based on CMOS image sensors. Firstly, we introduce a thermal neutron detector implemented with an image sensor and a conversion layer made of sodium gadolinium fluoride nanoparticles. In this case, the images are obtained by the detection of electrons emitted by the Gd present in the conversion layer. A production method of calibration patterns made on neutron-absorbing materials by optical lithography and chemical etching is also detailed. These patterns were employed to evaluate the performance of the implemented detection technique. After experiments performed at the RA6 Nuclear Research Reactor (Bariloche, Argentina) we have obtained the first neutron images. The achieved intrinsic spatial resolution is better than 15 micrometers. This upper bound is comparable with that of the best neutron position-sensitive detectors available nowadays. The developed neutron detection technique was tested in neutron imaging experiments and has potential applications in diverse experimental techniques based on the use of neutron beams. Secondly, we present a neutron radiography method in which the images are obtained through the activation of an Indium foil, and the subsequent off-line detection of the electrons emitted by beta decay. This detection method has been designed for the acquisition of thermal and epithermal neutron images at mixed beams with a high gamma flux. It can be used to study highly radioactive samples placed into research reactor pools, for example nuclear fuel and structural components of nuclear reactors. Measurements performed in the RA6 reactor, confirm the capability of the proposed technique.



Neutron image of a calibration pattern consisting of an institutional logo of the National Atomic Energy Commission of Argentina (CNEA) of 4 mm diameter. The image was obtained after an irradiation at the RA6 reactor with a CMOS image sensor covered with sodium gadolinium fluoride nanoparticles. The image of the CNEA logo is produced by the "neutron shadow" generated in the zones of the sensor covered with the cadmium present in the calibration pattern.

New Measurements on Borated Neutron Imaging Screens at BNC Budapest

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The most commonly used screens for neutron imaging consist of 6LiF+ZnS. This type of screen yields the highest light output per detected neutron. For high resolution, gadolinium-oxisulfide (Gadox) screens are employed, which have a much higher detection efficiency, but a light output so much lower than for LiF+ZnS that measurements are often limited by photon statistics. Screens using boron as neutron sensitive material have not been very successful in the past until a new preparation method was introduced recently that combines light output 5-6 times higher than Gadox with detection efficiency larger than LiF+ZnS. Previous measurements were performed at FRM II, Garching, and ILL, Grenoble, which already matched a Gadox screen in resolution, but still contained too many large grains. The talk will report about the most recent measurements of new borated screens produced with improved milling process at the NORMA facility at BNC Budapest , in comparison to a high resolution Gadox screen.

Development of an areal density imaging for boron and other elements

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We developed a method to obtain the areal density distribution of boron, which has a large neutron cross section, by means of an energy resolved neutron imaging. Commonly in a measurement of elements with very high neutron sensitivity, the quantitative measurement becomes more difficult with the amount of element due to the neutron self-shielding effect. To avoid this effect, an energy-resolved method using known cross section data was attempted, and a quantitative imaging of such elements was demonstrated at the Materials and Life Science Experimental Facility of J-PARC.

This presentation introduces a measurement of melted simulated-fuel assemblies obtained in the research of the Fukushima Daiichi Nuclear Power Plant after the severe accident. This effort is to investigate the behavior of boron from control rods during melting processes. The neutron energy dependence of the cross section of boron, being inversely proportional to the square root of neutron energy in the wide range, is quite different from those of other materials contained in the simulated fuel assemblies. Energy-dependent neutron transmission rates of the samples were measured by a neutron imaging detector, and were analyzed to obtained the areal density of boron at each position. In the same manner we tried to derive the areal density distributions of other materials having relatively low sensitivities.

Multimodal Imaging using Neutrons and Gammas at the NECTAR Instrument

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Radiography and tomography using X-rays, gamma-rays, and neutrons have found usage in wide-ranging scientific applications. Because each imaging mode usually is sensitive to specific materials, it is critical to choose the optimal tool for an investigation, depending upon the problem at hand. However, having the capability to characterize samples using different probes simultaneously, indisputably enhances the investigation capabilities. Taking this idea forward, a combination of thermal and fast neutron along with gamma-ray imaging was developed at the NECTAR instrument of FRM II. The NECTAR instrument provides access to fission neutrons which are suitable for non-destructive inspection of large and dense objects. With the production of fission neutrons, gamma rays are produced as by-products and unconverted thermal neutrons are present in the background. While difficult to shield, it is possible to utilize the gamma-rays for imaging by using gamma-sensitive scintillator screens in place of the neutron scintillators, viewed by the same camera. Similarly, the thermal neutrons in the beam can also be utilized for imaging at the instrument. In the present work, a method was developed to perform multimodal imaging combining neutron and gamma-ray imaging, by simply changing the combination of scintillator and filter used. A combination of different modes of imaging allows differentiation of a wide range of materials, which a single probe often fails to do. This multi-mode imaging technique will be discussed using proof of concept experiments and some practical examples will be demonstrated in this talk.

Wavelength-Resolved Neutron Imaging: Revealing Hydrogen Dynamics and Physico-Chemical Changes in Battery Electrolytes

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Fast charging is essential in portable and transport applications of lithium-ion batteries (LIB). However, high power inputs induce temperature variations causing electrolyte stress, degradation, and polymerization, which impose safety risks and greatly reduce overall performance. Understanding the electrolyte behavior requires non-invasive techniques sensitive to the electrolyte composition, i.e., organic solvents.

In this work, we applied time-of-flight neutron imaging (ToF-NI) to identify aggregation and concentration changes in battery electrolytes due to temperature gradients. The resulting wavelength-resolved transmission images incorporate the unique footprint of ^{1}H in various solvents, based on which organic molecules can be identified as seen in Fig.1. This technique is particularly suited for *in-situ* experiments on LIB electrolytes, and our findings bridge the gap between neutron imaging and spectroscopy methods.

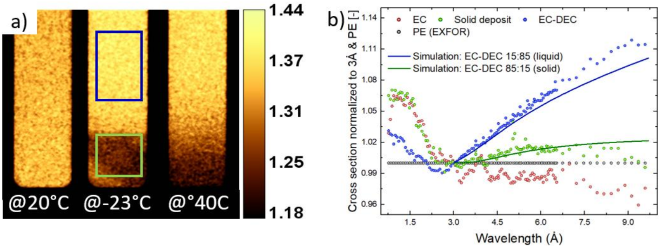

Figure 1. a) Identification of partial solidification in ethylene carbonate (EC) and diethyl carbonate (DEC) at a 1:1 v/v ratio. b) Calculated ^{1}H total attenuation cross section normalized to polyethylene. The long wavelength range (λ>3Å) contain information about the dynamic characteristics of a molecule. The simulations (solid blue and green lines) confirm the change of concentration ratio in the sample.

Strain and Microstructure Distributions around a Fatigue Crack Tip by Neutron Bragg-edge Imaging and Diffraction

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Fatigue damage is known as one of the major concerns in maintaining the integrity of large-scale engineering components. The nonlinear strain/stress distribution around a fatigue crack tip has a great impact to understand the fatigue and crack growth behavior of engineering component. We consider that it is possible to reveal local variations in strain and microstructure around a fatigue crack tip throughout the thickness of the material by using the non-destructive Bragg-edge imaging and diffraction probes.

To investigate the influence of austenitic (γ) and ferritic (α) phases on the changes in the strain and microstructure of steels during cyclic fatigue, we selected a typical single austenite stainless steel SUS304 (100% γ) and a duplex stainless steel SUS329J4L (approximately 50% γ, 50% α). The fatigue tests on the compact-tension samples were conducted with a servo-hydraulic fatigue testing machine. The 6 mm thick samples were subjected to constant amplitude loading until a crack of 25 mm was developed in SUS304 after 2.9×10^5 cycles or in SUS329J4L after 3.9×10^5 cycles. The pulsed Bragg-edge imaging experiment on the fatigued samples was performed at BL22 RADEN in MLF/J-PARC. The time-of-flight neutron diffraction strain mapping was performed at BL19 TAKUMI in MLF/J-PARC.

Two-dimensional maps of inhomogeneous residual strain and microstructure for the samples, which had been under different fatigue loading conditions, were determined by Bragg-edge spectral analysis. The obtained Bragg-edge imaging results were quantitatively compared with those determined by diffraction. Surface strains measured by digital image correlation during the fatigue tests will also be presented.

Digital Radial Radiography on Radioactive Waste Packages Using Fission Neutrons

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The non-destructive characterization of radioactive waste packages prior to intermediate or final disposal makes high demands on accuracy and precision on their radioactive inventory to comply with all regulations but avoiding too conservative assumptions to minimize virtual activities in disposals. The preferred measuring technique applied is (transmission corrected) segmented gamma-scanning but also passive neutron counting and active neutron interrogation are applied. Previous investigations at NECTAR at the FRM-2 demonstrated the applicability of fission neutron radiography and tomography on a 280-l barrel containing radioactive waste as additional inspection method. The main drawbacks of the presented tomographic measurements were the long inspection time and, chiefly, the large size of the object requiring stitching of 12 or more images per radiography to cover its full dimension. Applying the largest field-of-view possible at NECTAR comes along with a large beam divergence. A deconvolution based on extensive calibration measurements requires the application of iterative reconstruction procedures, both being time-consuming.

As the required spatial resolution in these investigations is about 1 cm, a simplified tomographic measurement mode, the Digital Radial Radiography (DRR), is applied, where only transmission measurements through the axis of rotation for a number of angular positions on 360° are performed. As this drastically reduces the information available to reconstruct the distribution of the cross-sections in the barrel additional a-priori information and image processing tools are applied.

The evaluation of the data is based on the Bayes-theorem using Marcov-Chain-Monte-Carlo (MCMC). The method and its applicability on simulated and measured data is presented.

Preliminary Optical Design of CUPI^{2}D, the Future Cold Neutron Imaging Beamline at the Spallation Neutron Source Second Target Station

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CUPI^{2}D (Complex, Unique and Powerful Imaging Instrument for Dynamics) is the neutron imaging beamline, among the eight instruments selected, to be built within the Second Target Station project (STS) at the Spallation Neutron Source, Oak Ridge National Laboratory. It is designed for a broad range of applications that require length scales that expand from angstrom to micrometer, and time scales from minutes to hours. The beamline will combine the capabilities of Bragg edge imaging (BEI) and neutron grating interferometry (nGI). CUPI^{2}D will be installed on a cylindrical moderator, which offers a high brightness of cold neutrons with a short pulse width with a ~0.4% wavelength resolution needed for BEI at ~30 m from the moderator. This also accommodates a wide wavelength bandwidth of ~8 Å, ideal for nGI. The 3 × 3 cm^2 compact moderator and the proximity of other beamlines' components require that a neutron transport system be employed to form a virtual source ~18 m away from the moderator. A preliminary optical design based on elliptical guides is optimized to provide uniform and high flux beams at three different collimation ratio (i.e., L/D, where L is the distance from the pinhole aperture of diameter D, and the detector) settings, by using Monte Carlo neutron ray-tracing simulations. The high flux, wide wavelength bandwidth, and simultaneous (when needed) BEI and nGI capabilities will enable a unique characterization capability for scientific applications such as energy storage and conversion, materials science and engineering, nuclear materials, cementitious materials, biology/medical/dental applications, and life sciences.

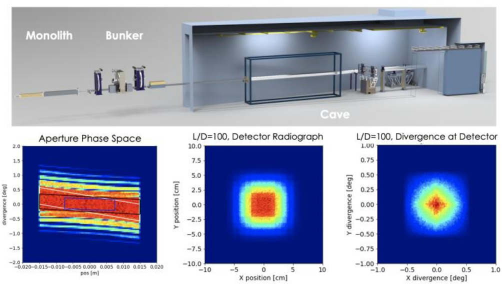

Figure caption. At CUPI2D, a ballistic guide design was optimized for neutron delivery to the aperture with a uniform distribution in the desired phase space region.

A portion of this research used resources of the Spallation Neutron Source Second Target Station Project at Oak Ridge National Laboratory (ORNL)

Engineering Challenges in the Design, Installation and Integration of the Imaging Instrument ODIN at ESS.

Elbio Calzada[1], Alexandre Goncalves Gerk[3], Jan Hovind[2], Virginia Martinez Monge[1], Manuel Morgano[2-3], Aureliano Tartaglione[1]

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[3] European Spallation Source, Lund, Sweden

Fifteen instruments for science are included in the ESS construction project.
Developed and built by teams across Europe, and people from five continents, they are each designed to be world-leading from day one.
The pulsed nature of the source will give access to wavelength-resolved information, giving a qualitative and quantitative informational advance over current state-of-the-art instruments.
Unique to ODIN is the flexible energy resolution, that allows a researcher to tune the energy resolution and, correspondingly, the flux to the specific experiment and technique used, in order to optimize the beamtime and maximize the scientific output of an investigation.
Criteria for the design of the main components, customized solutions, development strategies, special tools for remote handling in high radiation areas, as well as unexpected challenges, unconventional solutions and lessons learned will be explained in detail.

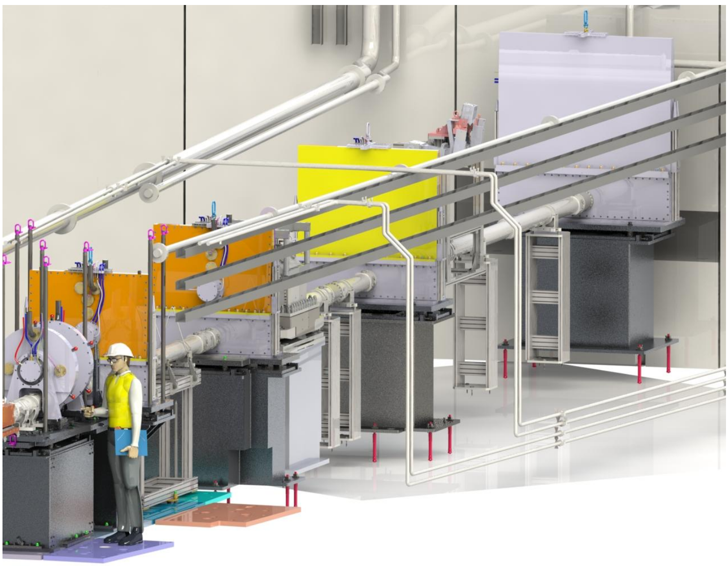

Illustration of the ODIN components located inside the bunker

The energy-resolved neutron imaging instrument (ERNI) at the China Spallation Neutron Source (CSNS)

Jie Chen[1,2,3], Zhijian Tan[1,2], Shengxiang Wang[1,2], Zhirong Zeng[1,2], Chaoju Yu[1,2], Haibiao Zheng[1,2], Liyi Wang[1,2]

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A new instrument named Energy-Resolved Neutron Imaging instrument (ERNI) is currently being constructed at the China Spallation Neutron Source (CSNS). ERNI has been designed as a dual use instrument with the combination of imaging and diffraction measurements. It will offer the attenuation-based transmission measurements such as neutron radiography, tomography, energy-resolved neutron imaging and spatially resolved neutron diffraction for strain scanning and texture analysis. Of an importance application for ERNI will be Bragg-edge transmission imaging analysis for strain and texture mapping. The instrument will have promising applications for investigations of various materials with emphasis on engineering. The basic design of ERNI have been completed. There will be two sample positions located at 30 m and 35 m from the surface of moderator. ERNI will cover a broad wavelength range from 0.03 to 18 Å with the transmission spectrum wavelength resolution ($\Delta\lambda/\lambda$) 0.15-0.5% at 35 m sample position. The spatial resolution for tomography and energy-resolved radiography will be about 50 μm with CCD based detector and the microchannel plate detector (MCP). It is expected that ERNI will start operation in 2023. The detail of the design and instrument parameters will be introduced in the presentation.

Keywords: Neutron imaging; Neutron diffraction; Bragg-edge transmission imaging; Instrument design

New Perspectives for Neutron Imaging and Diffraction through Advanced Event-Mode Data Acquisition

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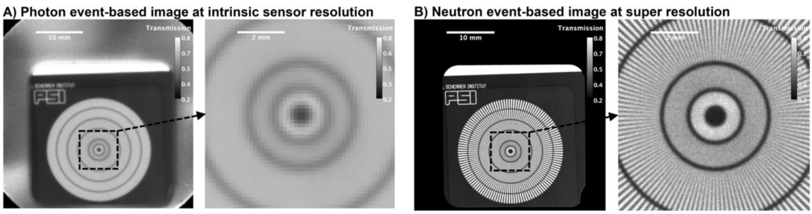
Recently developed event-driven detectors are capable of registering spots of light induced by neutron interactions in scintillator materials. Reconstructing the Center-of-Mass of the individual interactions, it is possible to significantly enhance spatial and temporal resolution of recorded radiographs. Utilizing this principle, we present a detector capable of Time-of-Flight imaging with an adjustable field-of-view, ad-hoc binning and re-binning of data based on the requirements of the experiment including the possibility of particle discrimination via the analysis of the event shape in space and time.

It is considered that this novel concept will replace regular cameras in neutron imaging detectors as it provides superior detection capabilities compared to conventional camera systems. Furthermore, the technology provides a viable option for replacing existing ^{3}He based diffraction detector systems.



Neutron radiographs of resolution pattern. Photon event-based image recorded with TPX3CAM at intrinsic sensor resolution in (A). Neutron CoM event-based image recorded with TPX3CAM at sub-pixel sensor resolution of 0.1 × pixel-pitch in (B).

Advanced Neutron Imaging and Instrumentation of the Applied Materials Group at PSI

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The Applied Materials Group (AMG) at the Paul Scherrer Institut, PSI, operates the neutron imaging instruments of the Laboratory for Neutron Scattering and Imaging (LNS) and has a long tradition advancing neutron imaging science. The instrument suite conveys the thermal neutron imaging beamline NEUTRA, which is currently in the process of being modernized and upgraded, the cold neutron imaging beamline ICON as well as the time-of-flight diffractometer POLDI and the polarized cold neutron instrument BOA. All these instruments are not only utilized for a successful user and a cutting edge imaging research program, but also to continuously advance neutron imaging and its capabilities. This contribution shall complement the presentations of other group members and users of AMG in introducing recent methodical and instrumental advances in particular in the field of dark-field contrast and polarization contrast neutron imaging as well as combinations of both. Alongside progress driving applications and corresponding results in fields such as in soft matter, engineering and magnetic materials research, the techniques, their implementation, sample environments and potential against the background of existing approaches will be introduced.

The Construction of the VENUS Imaging Beamline at the Spallation Neutron Source

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Located at the Spallation Neutron Source (SNS), VENUS is an instrument optimized for wavelength dependent neutron imaging techniques, namely Bragg edge and resonance imaging, across a broad range of neutron energies (from meV to hundreds of eV). The VENUS construction project started in 2019, establishing a detailed design of the major components and timeline for purchasing, testing, and installation. Completion of the VENUS instrument is anticipated in 2024. This instrument comprises components such as a set of $^{10}B_4C$ apertures designed for both thermal/cold and epithermal neutrons, a suite of choppers (T_0 and single disks), beam collimators, a cadmium filter. The principal detector at VENUS will be the TimePix3 micro-channel-plate (MCP) detector currently under development at SNS and will be positioned 25 m away from the source.

Installation of the front-end components at a distance up to 10 m from the source is challenging since the facility needs to be shut down for an outage of a minimum of 6 weeks (to allow enough time to unstack/stack temporary shielding blocks and perform VENUS installation activities). Poured-in-place shielding corresponding to the chopper shelf has been installed, along with other components such as the bulk shield insert, the cave rebar and trench (see figure). This presentation provides an overview of the beamline concept and optimization, installed components, timeline, and examples of scientific research, demonstrated at the SNS SNAP beamline.

Figure caption. Video camera capture of the VENUS beamline as of March 2022.

A portion of this research used resources at the Spallation Neutron Source, a DOE Office of Science User Facility operated by the Oak Ridge National Laboratory.

Multiple Joint Sparsity Regularized Multimodal Reconstruction

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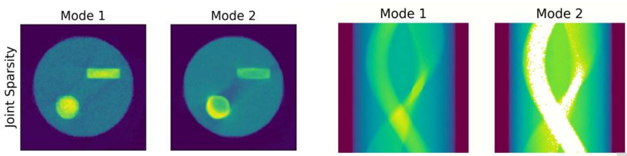
The tomographic interrogation of composite objects can present different challenges to different modalities, and the fusion of data from multiple modalities may be useful when interrogating objects using tomography.

Presented is a method based that regularizes the Simultaneous Algebraic Reconstruction of multiple data modalities with Joint Total Variation and K-Means Cluster Centre Descent. The two regularization methods encourage complementary sparsity in the image, gradient sparsity from Joint Total Variation and value sparsity from cluster descent. The algorithm treats the multi-modal problem as a shared Total Variation Denoising problem with the reconstruction locally regularized by cluster descent, the k-means cluster value map is regenerated at the end of each iteration using the scikit-learn routine.

The method has shown beneficial behavior for multi modal reconstruction against synthetic test phantoms designed to illustrate different regimes of non-mutually missing and degraded structural data, as shown in the figure. It is expected that this method should be extendable to an arbitrary number of modalities.



(Left) Reconstruction results after 100 iterations of a synthetic bi-modal test phantom with missing structural data in one modality and (Right) the sinogram showing the missing data in white

Robustification of pulsed neutron transmission spectrum analysis

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Pulsed neutron imaging is a method suitable for detailed analysis of the microstructure of materials in industrial products that can map nanoscale material information onto the cm-scale object image. In this method, the neutron spectrum transmitted through the sample is analysed in detail with nonlinear fitting for pixel by pixel over two dimensions. For the analysis of the 2D detector with many pixels, this means the conventional fitting analysis for imaging requires a great deal of time, effort, and experience. However, to be widely applied of this imaging method, it is necessary to develop a robust analysis approach so that a stable result can be obtained in a reasonable time, independent of who is analysing the data. For this robust analysis, we are investigating several ways such as analytical method, machine learning method, and method combined with computer simulation, so that arbitrariness of the analyst does not enter into the spectrum analysis. Among them, this presentation will focus on the analytical method, which is the directly analysing neutron transmission spectra. In this method, crystal micro-structural information are directly estimated without nonlinear fitting by using analytical formulas and calibration curves from shape features obtained just from numerical data of Bragg-edge spectrum. As shown in figure 1, although there were differences in the numerical values between the analytical and nonlinear fitting methods, their results were in agreement with the trend generally. Of course, the values obtained by the analytical method can be used as initial values for the nonlinear fitting to improve accuracy. It is important to emphasize that the analysis time has been reduced from 1/1000 to 1/10000 by the analytical method, if the initial value search for nonlinear fitting is also taken into account.

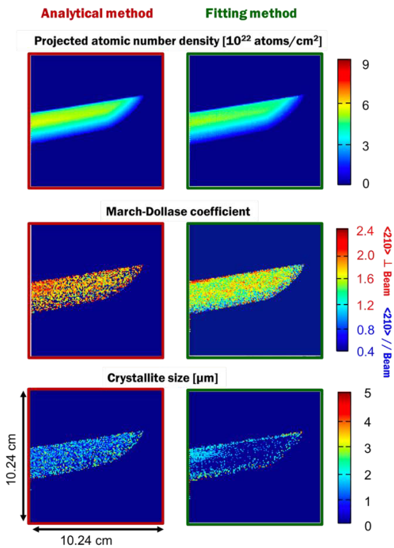

Fig. 1. Comparison of analysed results obtained by analytical method (left) and nonlinear fitting method (right). From the upper side, images correspond to projected atomic number density, degree of crystallographic texture evolution (March-Dollase coefficient), and crystallite size, respectively.

Strain Tomography Using Neutrons

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Bragg-edge strain imaging presents a natural rich-tomography problem focused on the reconstruction of strain distributions within polycrystalline solids. This problem has been the focus of some attention over the past decade or more following several successful demonstrations in axisymmetric systems. The extension of this work to general two and three-dimensional systems was hampered by the fact that the relevant inverse-problem was inherently ill-posed. This presentation provides an overview of a new approach to this problem based on Gaussian Process regression that involves the application of known constraints such as equilibrium and boundary conditions to the tomographic reconstruction of strain fields.

Experimental demonstrations of the technique in two and three dimensions are provided. The latter involved the reconstruction of a 3D strain field within a small steel-aluminum ‘cube-and-plug’ from a set of 70 Bragg-edge strain images measured using the RADEN instrument at J-PARC in Japan in conjunction with an MCP/timepix detector. Comparisons are made to traditional point-wise strain scans from the KOWARI instrument at the Australian Centre for Neutron Scattering and a finite element model. Opportunities and challenges for the wider application of the technique will also be discussed.

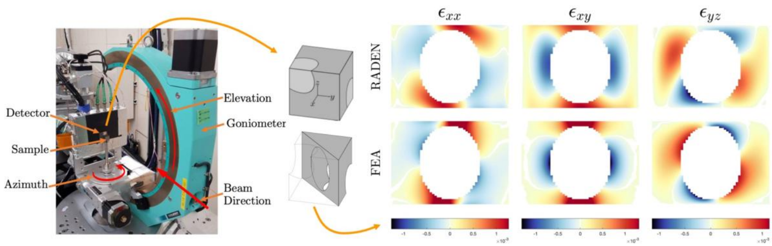

Figure 1: Three components of the triaxial strain tensor over a cross section of a steel/aluminium cube-and-plug sample (strain is measured only in the steel). The top set of images are from a full three-dimensional reconstruction of strain within the cube from a set of 70 strain Bragg-edge strain images. The lower set of images are for comparison to a finite element model of the same system. Comparison to point-wise strain measurements from the KOWARI instrument will be provided in the presentation.

Obtaining elastic properties of textured materials from energy resolved neutron transmission experiments

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In a previous work it was shown that integral values of the texture of polycrystalline materials can be obtained by the analysis of the energy resolved coherent elastic cross section measured in transmission experiments. The proposed method is based on the decomposition of the orientation distribution function of the material (ODF) in a Fourier series expansion. The total coherent elastic cross section becomes a linear combination of functions where the multiplicative coefficients can be written as a linear combination of the Fourier coefficients of the ODF. By the combined analysis of transmission experiments performed for different beam directions, the Fourier coefficients of the ODF for the lowest *l* values can be determined, and hence every material property that depends on these coefficients can be estimated as well. In the original paper, the case of determining the Kearns factors in hexagonal crystals (Zr alloy) was tested with great success.

In this work, we present an extension of this method where the symmetry of the crystals and sample is explicitly included. The method is applied to the case of estimating the elastic properties of a Cu alloy sample (fcc crystal phase) with a known texture and for which experimental energy resolved transmission spectra for different directions of the beam are available.

Decrepitation process of a hydride forming material observed by Neutron Radiography

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Hydride-forming materials are widely investigated for hydrogen storage, separation and purification, due to its reversible reaction with hydrogen at moderated pressures. These materials are mainly used in powder form and they show a considerable change in cell volume during the reaction with hydrogen (up to 27% for $LaNi_5$). This change can exert significant mechanical stresses upon the container vessel walls.

We have been studying this phenomenon by measuring the mechanical strains generated on the wall of a cylindrical vessel (Figure 1) during hydrogen absorption/desorption cycling. The complexity of studying the mechanical effects is due to the granulometry, porosity and flowability of the powder material are affected by the processes of decrepitation along the cycles. In this sense, neutron imaging has proven to be a useful technique to visualize the evolution of the powder rearrangement inside the reservoir. We have identified some key aspects for understanding the relationship between the degree of compactation of the powder, the geometrical parameters of the reservoir (slenderness, wall thickness, filling level), the equivalent pressure exerted by the material against the reactor walls, as well as the number of cycles.

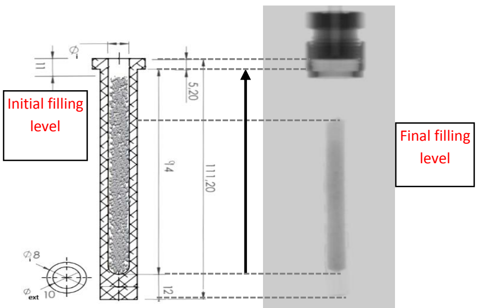

Figure 1: Powder fill level before (left) and after (right) 100 hydriding/deyhidriding cycles. The compactation process and changes in the granulometry are clearly revealed by neutron radiography, leading to the possibility of correlating this with the mechanical stress estimated.

Microplastic interaction with soil water distribution dynamics - visualization and quantification with dual neutron and x-ray tomography

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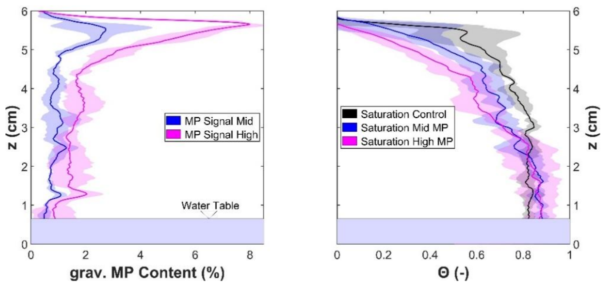
Soil is considered the largest sink of microplastic in terrestrial ecosystems. Though, little is known on implications of microplastic for soil. Since microplastic is hydrophobic, crucial for its fate is the feedback between microplastic and water. If microplastic is transported by water flow and, vice versa, microplastic impacts water flow, to what extent? This is important for degrading microplastic, as water is needed for colonization by microorganisms. To answer this, simultaneous imaging of microplastic and water in soils is needed.

Dual Neutron and x-ray imaging at ICON (PSI) was applied to trace microplastic and water in aluminum cylinders filled with sand and microplastic during wetting-drying cycles. Simultaneous Neutron and x-ray tomography was utilized to capture the initial microplastic distribution. Subsequently, neutron radiographies of deuterated water flow through the sample were recorded. After drying, repeated tomography gave insight into microplastic translocation.

Imaging showed that regions of major microplastic content are water repellent. Water flow bypasses and microplastic is retained. Resultant air entrapments lead to reduced water contents. In regions of minor microplastic content water can infiltrate. Here, air-water interfaces collect isolated microplastic and shift their distribution. Extrapolation of these results to natural soil systems suggests that less water at regions of high microplastic content might limit their degradation due to reductions in hydrolysis, coating, and colonization by microorganisms.



Left: Sample profile of local gravimetric microplastic content. Right: Sample profile of water saturation (Θ). Control in black, mid and high microplastic content in blue and magenta.

Recent progress of Bragg-edge and Bragg-dip spectral analysis methods for wavelength-resolved neutron imaging developed in Hokkaido University

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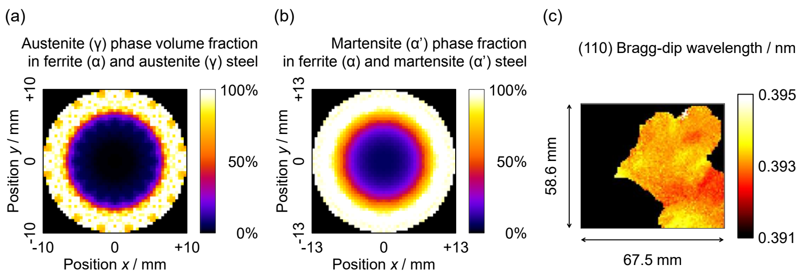
Bragg-edge imaging for polycrystalline materials and Bragg-dip imaging for coarse-grained materials, which are wavelength-resolved neutron transmission imaging techniques using pulsed neutrons, are unique material characterization tools. This is because these can quantitatively visualize various crystalline microstructural information with high spatial resolution over a large field-of-view in a bulk material non-destructively. We are further developing new spectral analysis methods for Bragg-edges and Bragg-dips in wavelength-dependent neutron transmission data. For example, an accurate analysis method for γ-austenite phase volume fraction in steel composed of α-ferrite and γ-austenite phases was developed. This was achieved by high wavelength resolution and low scattered-neutron background experiment, and data analysis using RITS with double March-Dollase texture correction functions (a). In addition, the quantification of α'-martensite phase fraction in steel composed of α-ferrite and α'-martensite phases was achieved by a profile analysis of a Bragg-edge integrated by both α{110} Bragg-edge and α'{110}-α'{101} Bragg-edge (b). These new crystalline phase fraction imaging techniques were conducted with the accuracy of several percent. Furthermore, the individual Bragg-dip profile analysis method could detect and visualize small crystal orientation changes (< 0.4°), defects and mosaicity in a crystalline grain (c). In the presentation, we will report progress of Bragg-edge and Bragg-dip analysis methods recently developed in Hokkaido University.



(a) Reconstructed CT image of γ-phase volume fraction in steel rod composed of α-ferrite and γ-austenite phases, measured at Hokkaido University Neutron Source "HUNS". (b) Reconstructed CT image of α'-phase fraction in steel rod composed of α-ferrite and α'-martensite phases, measured at J-PARC MLF BL22 "RADEN". (c) Bragg-dip wavelength image visualizing crystal orientation change (< 0.4°) in a certain crystalline grain in 3.4%Si-steel plate, measured at J-PARC MLF BL10 "NOBORU".

Targeted use of residual stress in electrical steel to increase energy efficiency

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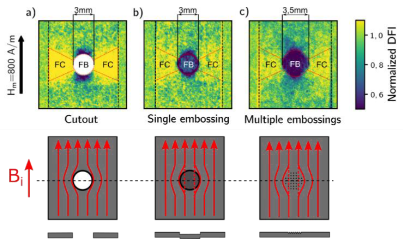
The magnetic flux guidance in an electric engine is usually achieved by introducing cutouts in the electrical steel (ES) sheets that make up its core. However, these cutouts create thin structures, reducing the mechanical strength of the ES sheets and limiting the achievable maximum rotational speed and therefore the energy efficiency of the engine.

Residual stress in ES sheets reduces the mobility of magnetic-domain walls due to the magneto-elastic effect. This can be utilized to create a novel type of magnetic flux barriers relying on the local decrease in magnetic permeability introduced by embossing of the ES sheet. Such barriers do not compromise the structural integrity of the sheets.

The influence of various embossing parameters on the residual stress state was calculated by Finite-Element simulations and probed using neutron grating interferometry (nGI). In nGI the dark field image (DFI) maps ultra-small-angle neutron scattering as resulting from the interaction of the magnetic moment of the neutron with the magnetic domain structure in the bulk of the sheet sample. In an applied magnetic field, a change in the domain size therefore results in a change of the DFI signal. Hence, enabling the visualization of the local distribution of magnetization.

Prototypes of magnetic flux barriers based on the magneto-elastic effect show similar flux guidance as traditional barriers while the mechanical strength is comparable to unworked ES.

In this presentation we will give a comprehensive overview of the effect of residual stress on the magnetic properties of electrical steel as well as show the applicability of nGI to probe such materials.



Conventional flux barrier by cutting a) compared to b) single macroscopic embossing and c) sequential microscopic embossing. Both b) and c) show similar effects of flux concentration (FC) in the non-embossed areas next to the flux barrier (FB), as seen in the conventional flux barrier.

The construction of ODIN at ESS: status update of the instrument and future perspectives

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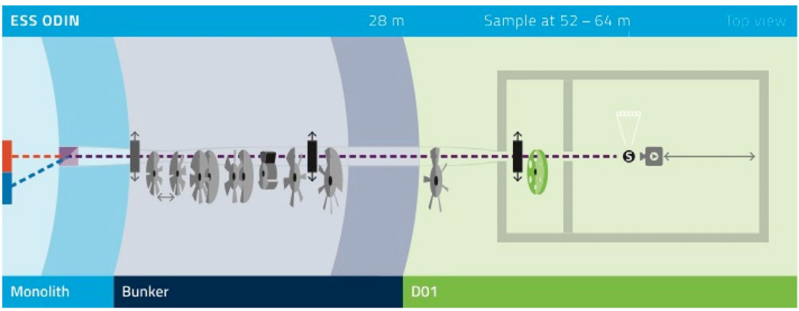
ODIN (Optical and Diffraction Imaging with Neutrons) is the ESS state-of-the-art multipurpose Neutron Imaging instrument. Using wavelength-resolved imaging with tunable medium to high wavelength resolution (10% and 1% down to <0.5%), ODIN will provide significantly increased chemical and structural sensitivity compared to other traditional neutron imaging instruments, with fixed (or absent) wavelength resolutions. ODIN is located at beamport S2 within the experimental hall D01, and it will view both the cold and the thermal moderators to increase the available wavelength range and hence enhance flexibility. Ten optimized choppers, together with the neutron extraction and guide system, are the main instrument components behind ODIN´s flexible performance. Nine choppers are located inside the bunker, together with the heavy shutter, while the remaining frame overlap chopper is in the experimental hall D01 (See figure). The cave is divided into two rooms: the beam shaping area with a variable pinhole and filter systems, and the experimental area with sample stages, flight tubes and detector systems; it will also provide ample space for sample environments, other equipment needed for specific imaging modalities (such as an upcoming x-ray source), as well as for future upgrades like a diffraction detector to perform simultaneous imaging and diffraction experiments. ODIN is now in its installation phase, after two and a half years of detailed design, procurement and manufacturing of all the components. Here we will present some of the design highlights, how the challenging installation is accomplished place in the framework of the ESS facility at Lund, Sweden, and what are the future perspectives towards the cold and hot commissioning phases.



References: Nuclear Inst. and Methods in Physics Research, A 957 (2020) 163402

A neutron radiography study of the imbibition and interdiffusion of superconcentrated lithium aqueous electrolytes in mesoporous carbon

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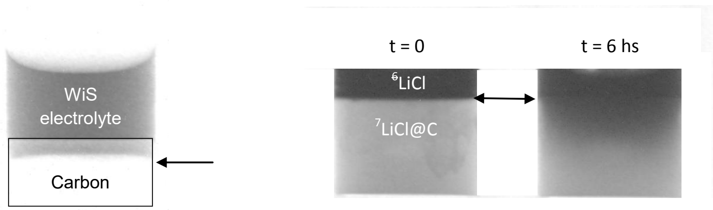
Superconcentrated ionic aqueous solutions (or Water-in-Salt, WiS) electrolytes, have been intensively studied in the last years as an alternative to organic electrolytes for Li-ion, Na-ion, K-ion, Li-air, and Li-S batteries, as well as for supercapacitors. WiS are especially attractive because they could mitigate the safety issues associated with organic electrolytes, while maintaining a wide electrochemical stability window of 3 V.

Here we studied, using the ANTARES neutron radiography facility at Heinz Maier-Leibnitz Zentrum (MLZ), the imbibition and the interdiffusion of concentrated aqueous lithium electrolytes in a novel mesoporous carbon that could be used as electrode in Li-air batteries or supercapacitors, with pore sizes in the range 4-25 nm.

Our results indicate that a WiS electrolyte based on lithium bis(trifluoromethanesulfonyl) imide (LiTFSI) in water (20 mol.kg^{-1}) soaks the carbon at a reasonable rate (left image), compatible with the needs of the cathode for a Li-air battery. The diffusion of an 8 m ^{6}LiCl aqueous solution in contact with a mesoporous carbon soaked with a 8 m ^{7}LiCl solution was also studied by neutron radiography. The interdiffusion coefficients measured by fitting the concentration vs. time profiles at different times are similar to that observed in LiCl bulk solution when corrected by the carbon porosity, indicating that the tortuosity effect, related to interactions of the Li^{+} ions with the carbon pore walls, are negligible.



Neutron images of the imbibition of a WiS LiTFSI 20 m electrolyte (left) and the interdiffusion of ^{6}LiCl (right) into a bimodal mesoporous carbon. The arrows indicate the carbon-solution interphase.

The Debye-Waller Factor for Temperature Distribution Determination in NBEI Experiments: A Case Study for GTAW

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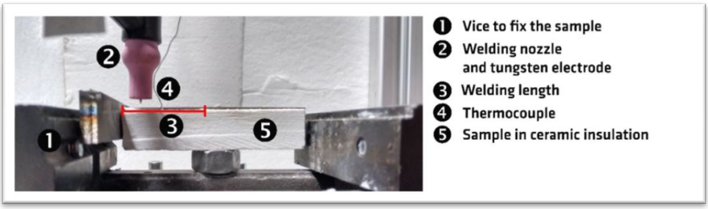
In Neutron-Bragg-Edge Imaging (NBEI) *in situ* experiments, we studied the phase transitions in martensitic steel sheets during butt-welding [1]. Gas tungsten arc welding (GTAW) was used with a motorized torch allowing automated weldments. The austenitization in the heat affected zone (HAZ) underneath the welding head could be clearly visualized. Also, the retransformation into the martensitic phase upon cooling. However, we observed an unexpected additional change in transmission at λ = 0.44 nm that is at a wavelength larger than the wavelength of the Bragg edges of both the martensitic and austenitic phases. We attribute this change to the Deybe-Waller-Factor that describes the temperature dependence of coherent scattering at a crystal lattice [2]. With help of temperature field simulations using software macros in ANSYS [3] that were calibrated by the reading of an attached thermo couple during welding, we could show that the Debye-Waller factor can produce an additional image contrast in the heat affected zone in NBEI experiments.



[1] Griesche, A.; Pfretzschner, B.; Taparli, U. A.; Kardjilov, N.: Time-Resolved Neutron Bragg-Edge Imaging: A Case Study by Observing Martensitic Phase Formation in Low Temperature Transformation (LTT) Steel during GTAW. Appl. Sci. 2021, 11, 10886.

[2] Ramadhan, R.S.; Kockelmann, W.; Minniti, T.; Chen, B.; Parfitt, D.; Fitzpatrick, M.E.; Tremsin, A.S.: Characterization and application of Bragg-edge transmission imaging for strain measurement and crystallographic analysis on the IMAT beamline. J. Appl. Crystallogr. 2019, 52, 351–368.

[3] https://www.ansys.com/

Optimization of Residual Strain Mapping in Additively Manufactured Materials by Energy-Resolved Imaging at Pulsed Neutron Sources

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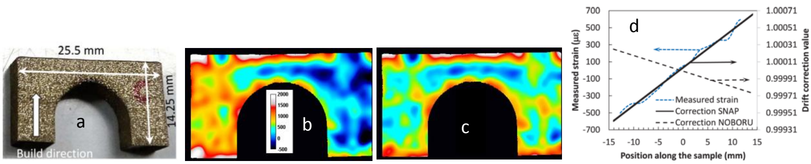
Non-destructive investigation of bulk residual strain within materials printed by additive manufacturing (AM) techniques is among frequently used applications of energy-resolved neutron imaging. Many experiments were conducted ex-situ on as-printed and heat-treated materials as well as in-situ during annealing. The resolution of these experiments has reached the levels of ~100 microstrain, which require a very accurate calibration of the experimental setup. The accuracy of this measurement depends on both the data analysis technique and the quality of the measured spectra. While the optimization of reconstruction methods was addressed in multiple previous studies, here we describe the effects introduced by the beamline configuration and by specific data analysis methods, which need to be taken into account in high resolution Bragg edge imaging experiments. As these imaging setups are often reconfigured for a particular set of samples an accurate calibration is required for each particular dataset. In this paper we show the importance of specific instrumental calibration for pulsed neutron beamlines. In addition, we also consider the precision of Bragg edge reconstruction as a function of integration time and the minimal sample area. Several examples of strain map reconstruction in Inconel AM printed materials will be discussed. These instrumental calibrations become even more important with the development of advanced neutron energy-resolved imaging beamlines and detectors with a large field of view.



(a) Photograph of Inconel 625 sample used in the experiment. **(b)** Residual strain map reconstructed without a proper correction for the instrumental drift across the field of view. **(c)** Same as (b), but with the proper correction. **(d)** Measured correction functions for two energy-resolved neutron imaging beamlines.

Quantitative analysis of magnetic domain sizes in electrical steel

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In electric machines, electrical steel sheets are used to guide the magnetic field. The energy loss due to reversal of magnetization is strongly dependent on the mobility of the magnetic domains. The magnetic domain mobility is in turn influenced by the treatment of the electrical steel sheet during fabrication. Residual stress induced during the manufacturing process (e.g. by blanking the sheets) causes a degradation of domain wall mobility due to the magneto-elastic effect. Consequently, the overall energy loss increases. This is evident from larger hysteresis losses in classical magnetization measurements. However, there is a shortage of spatially resolved techniques allowing to probe the magnetic domain constellation in bulk samples of technically relevant dimensions.

Neutron grating interferometry (nGI) gathers, among other things, information about the amount of ultra-small-angle-neutron scattering caused by a sample. Based on the high penetration of neutrons in electric steels and their high sensitivity to magnetic fields, nGI is the technique of choice for analysing the local effect of induced stress on the magnetic properties of a material. By varying the probed length scale and scattering direction, the correlation function of the considered sample as well as its anisotropy can be recovered and quantitative information about the domain size and shape can be extracted.

We will show how residual stress affects the properties of the magnetic domains when applying an external magnetic field and discuss which theoretical models may be applied to describe the system.

Development of Neutron Imaging Facility at the Very Low Power Reactor VR-1

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The paper deals with the design and the construction of a new neutron imaging facility at the very low power research reactor VR-1. The training reactor VR-1 is operated by Czech Technical University in Prague, Czech Republic, and it is mainly used for nuclear education and training. Since 2020, neutron imaging has been under development as a new possible field of utilisation. The paper describes many necessary challenges to build a neutron imaging facility connected with the extremely low reactor power at the level of 100 W. The NIFFLER – "Neutron Imaging Facility for Learning and Research" was designed in collaboration with the Technical University of Munich. Unfortunately, the development was carried out during the coronavirus pandemic, which brought another obstacle because of closed borders and institutions. Still, due to the mutual effort of both partners and using remote connections, all obstacles were solved, and the NIFFLER was successfully developed and tested. The paper includes the calculation of main parameters, such as neutron flux at the sample position for different L/D ratios and different moderator configurations, the basic concept and design of the instrumentation, the main issues that occurred during the construction and the results of both neutron radiography and neutron computed tomography. The results achieved at the training reactor VR-1 showed the potential of using neutron imaging at other low and very low power research reactors worldwide.

Measurements of gas-liquid two-phase flow dynamics using high-speed neutron imaging

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Gas-liquid two-phase flow appears in many heat exchanging devices. To understand the phenomena in such devices, the two-phase flow dynamics should be clarified. Although many measurement techniques have been applied to two-phase flow measurement so far, it is difficult to measure the gas-liquid interfacial structure, which changes temporally and spatially. In this study, high-speed neutron imaging is applied to the measurements of two-phase flow dynamics, and the accuracy of the void fraction measurement is investigated.

In high-speed neutron imaging, image blurring and distortion occur due to the intensification of light and the object motion. As a result, the quantitative accuracy might decrease. So, the rotating stainless-steel calibration plates, which simulate the bubble behavior in water, are observed by high-speed neutron imaging. Several noise reduction filters are tested to remove the blur and noise in the acquired images. Figure 1 shows the result of noise reduction using total variation denoising. The quality of the image can be enhanced, and the edges of the signals are preserved.

Finally, the air-water two-phase flow is visualized by high-speed neutron imaging, and noise filtering is applied. Bubble behavior in narrow rectangular channels and liquid film behavior in circular pipes are investigated.

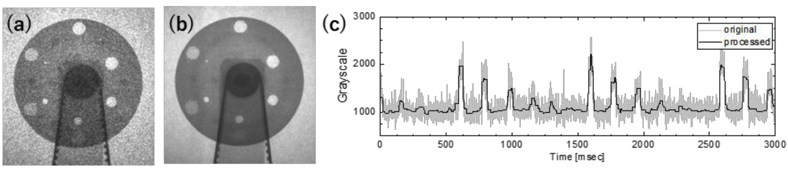

Figure 1 Neutron transmission image of stainless-steel calibration plates (a), processed image (b), and time-series signals of the rotating plate at a local point (right).

Teaching neutron imaging

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Neutron imaging is a topic rarely taught at universities. Instead, there are compact short courses in Ph.D. schools, preconference schools, and dedicated training activities such as the biennial IAEA AUNIRA (Advanced Use of Neutron Imaging for Research and Applications) Workshops. E-learning provides an attractive alternative to these classroom-based schools. Over the past years, online learning has become more frequent and accessed by a wider community. It has also turned out to be a convenient way to learn new material without being at a specific location for the lecture. However, online teaching is challenging to prepare as the material must be sufficiently self-explaining for the student to be autonomous while learning. Different forms of online education were used during the pandemic. The two extremes are (a) to replace the lecture room with a web conferencing system; this maintains the ability for the students to interact in the lecture directly. The other extreme (b) is to provide well-organized reading material, possibly complemented by quizzes. Combining these approaches offers interactive reading material that allows the student to directly explore the possibilities of the learned material by modifying parts like changing parameters to the order of different operations. This interactive approach should ideally be supplemented with short topic video recordings. For neutron imaging, we are together with the IAEA working on developing new e-learning material based on the use of Jupyter notebooks. These notebooks can be used for interactive teaching and self-studies when the notebook is combined with recorded instruction videos to explain specific aspects of the demonstrated topic. We will also show some technical details to consider when preparing tutorial videos. The materials developed will constitute the basis for the IAEA e-learning course on advanced neutron imaging, which expands and complements the already existing IAEA e-learning introductory course on neutron imaging, released in 2020 and recently updated [https://elearning.iaea.org/m2/course/view.php?id=633].

New detector system for neutron imaging using astronomy cameras

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The neutron radiography / tomography / imaging instrument DINGO is operational since October 2014 to support research at ANSTO. DINGO had a high subscription rate from a broad national and international scientific user community and for routine quality control for defense, industrial, cultural heritage and archaeology applications. The nuclear reactor runs a around 300 days a year, which leads to many hours of radiation damaging existing cameras and require regular replacement.
Under these conditions we used cameras from Andor and Photonic Science in a price range from 20kAUD to 95kAUD lasting many years in terms of ANDOR IKON CCD to one year for some CMOS cameras. Replacing these cameras is a significant cost factor and astronomy cameras offer a cheaper alternative. We will present our first experience running an ASI 2600 MM PRO camera with 24MP on DINGO for several month. These cameras can be easily integrated with existing SDKs. Even a python module is already available. Another advantage of the ASI camera is an unlimited exposure time setting. All scientific CMOS cameras we had were limited to 30 seconds exposure maximum, which is mainly due to amp glow. The latest generation of astronomy cameras show zero amp glow even after 300 seconds exposure.

Recent developments and application studies at RADEN in J-PARC

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The energy-resolved neutron imaging system, RADEN[1], in J-RARC was constructed to provide the most suitable environment to perform energy-resolved neutron imaging experiments, which utilize energy-dependent neutron transmission analysis to extract physical quantities and visualize their spatial distributions by using the short-pulsed neutrons' features. After the completion of its construction in 2015, RADEN accepted more than 200 user programs from various research field, not only academic but also industrial applications. In particular, an increase of industrial use is remarkable recently and in-operando experiments using practical devices which are loaded into real products are conducted frequently.

We are also continuing development of imaging techniques and related devices together with the user program. An efficient use of optical image intensifier with high-speed gate function has been confirmed to conduct energy-selective imaging with coarse energy resolution by opening the timing gate during a given time-of-flight of a pulsed neutron beam. Especially its quick switching of energy selection is quite useful for the time-lapse observation.

In this presentation, we will describe the current status of RADEN and our technical development. In addition, we will present results of application studies conducted at RADEN.

[1] T. Shinohara et al., Rev. Sci. Instrum. 91, 043302 (2020).

Microstructure analysis of lead-bismuth eutectic by wavelength-resolved neutron imaging

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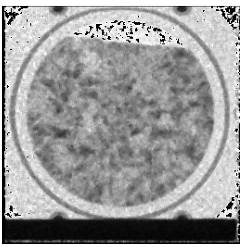
Lead-bismuth eutectic (LBE) is a promising candidate coolant for the Gen-IV reactors. LBE in those reactors will be heated up to melt, however, some specifical accident may cause its solidification. LBE has a unique characteristic which is the gradual expansion. The gradual expansion is caused by phase transition of ε (non-stoichiometric phase of Pb and Bi) to α-Bi phase and it may cause pipe deformation or rupture. The purpose of this study is to clarify microstructure of LBE and its two-dimensional distribution. To obtain local microstructure of LBE two-dimensionally, we performed wavelength-resolved neutron transmission experiment by using BL22 RADEN in J-PARC. RADEN is capable to obtain time of flight data of neutron two-dimensionally and we can obtain images of each time. Obtained neutron transmission spectrum was analyzed by using RITS code. Differences of the microstructure of LBE samples with different cooling rates and different ages was discussed. Fig.1 indicates the transmission image of slowly cooled LBE at d= 2.685 Å which we can see the preferred orientation and the spatially integrated transmission spectrum of different aged LBE which is less difference had been observed. The neutron transmission spectrum agreed well with existing data (see Fig.1). Two-dimensional analysis indicated that coarse crystal grain for slowly cooled LBE and relatively fine crystal grain for quenched LBE were observed. We also discussed crystal orientation of each coarse crystal grains. We clarified microstructure differences caused by the effect of aging and cooling rate.



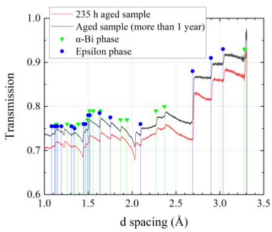


Fig.1 An example of wavelength-resolved transmission image of slowly cooled LBE at d= 2.685 Å (left) and neutron transmission spectrum of LBE with different aged samples and corresponding d-spacing of each phase in LBE (right).

Microstructural characterization of metal Additive Manufacturing complex artefacts made of different alloys through neutron imaging techniques

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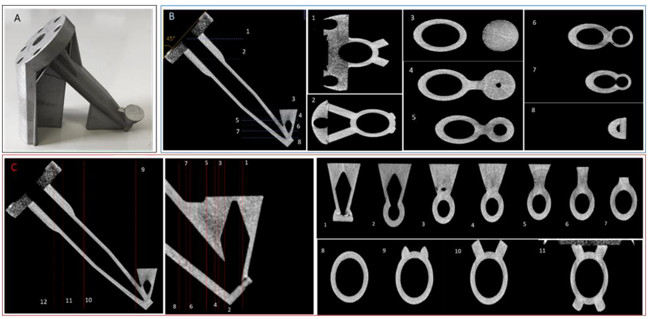
In recent decades, Metal Additive Manufacturing (AM) technology has arisen growing interest in various industrial sectors such as aerospace, biomedical and automotive. The advent of metal AM requires a constant and updated development of analytical methodologies to fully understand a process that is opposite to the usual manufacturing methods: casting and subtractive techniques. To achieve a non-invasive microstructural characterization of three complex integrated particle accelerator components made by Metal AM (pure copper, AISI 316L, maraging steel) both white beam neutron tomography (NT) and Bragg Edge Neutron Transmission (BENT) analysis were used. The investigated samples are exit nozzles designed for the "Machina" transportable proton accelerator. By employing these imaging techniques, we were able to describe density differences as well as morphological and microstructural inhomogeneities, such as micro-fractures, flaws, porosity and the presence of preferential grain orientations on the whole volume, thus allowing for a complete characterization of such complex artefacts.



We show in figure NT slices of AISI 316L metal AM exit nozzle where we can observe microstructural features as solidification lines, laser spot related porosity and density inhomogeneities.

Neutron Tomography Investigation of Homogeneity of Tungsten Beams for Gravitational Interactions of Vibrating Systems

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In the Mechanics and Experimental Dynamics group at ETH Zurich, tungsten beams are being used in cutting-edge fully characterized dynamic experiments in which the classical theory of gravitation is revisited at ~42Hz, i.e. more than 3 orders of magnitude higher than previous experiments and in the same frequency range as the gravitational waves detected by the laser interferometer gravitational-wave observatory (LIGO) system in 2015. The gravitational force field induced by two rotating tungsten beams produces harmonic motion of a resonating detector beam reaching measurable displacements in the order of picometres. In the underlying theoretical model perfect homogeneity of the material is assumed. Neutron tomographies of two different spatial resolutions were utilized for the quality control of the homogeneity and occurrence of defects in the tungsten rods. Based on these tomographic investigations the limits on the size of the defects that cannot be present in the rods were established. The general homogeneity of the material density has been directly derived from the distribution of the linear attenuation coefficient. As the investigated tungsten rods are of very high shape fidelity and are produced from a very high purity tungsten, the resulting neutron tomographic datasets can be well utilized for testing of various reconstruction and artifact removal algorithms for neutron tomography.

Tomographic reconstruction with Mantid Imaging

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'Mantid Imaging' has been developed to provide a graphical reconstruction process that users are accustomed to but is no longer available via commercial software such as Octopus. Mantid Imaging builds on algorithms provided by libraries including Astra Toolbox and Tomopy to offer noise reduction, artifact removal, alignment, filtered backprojection and iterative reconstruction methods. Extra functionality was added by using algorithms from ALGOTOM for ring removal and from the Core Imaging Library (CIL) for regularized 3D reconstruction (Figure 1).

Mantid Imaging 2.3.0 has just been released. It is an open source Python GUI, runs under Linux and can easily be installed on end user systems. Mantid Imaging is aimed at users with no programming background and with little image processing experience. At ISIS Mantid Imaging runs on the ISIS-Data-Analysis-as-a-Service (IDAaaS) platform, which is remotely accessible with any modern web browser and gives users access to sufficient hardware resources to handle large datasets. Extensions of Mantid Imaging for energy-resolved neutron imaging are planned for the future.

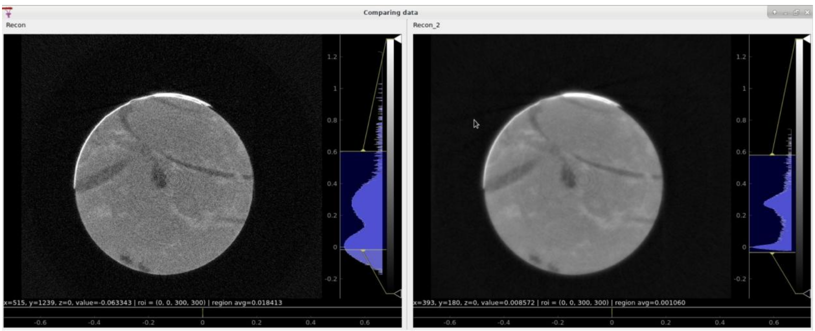

Figure 1: Reconstructed slice of a rock sample in Mantid Imaging. Left: filtered backprojection (Astra Toolbox). Right: regularized iterative reconstruction (CIL)

Diagnosing the failure of the FRM II cold neutron source by neutron imaging and PGAA

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The cold neutron source (CNS) of FRM II is designed as an isolated vessel containing approx. 12l of liquid D_2 at a temperature of about 22K located in close proximity to the fuel element of the reactor. The liquid D_2 serves as an additional moderator further reducing the energy of the thermal neutrons produced by FRM II to supply instruments in the neutron guide hall as well as the experimental hall of the reactor with cold neutrons. In regular operation, heat is mainly introduced into the CNS via radiation and a cooling power of ~6kW at 22K is required to maintain the temperature at full reactor power of 20MW.
During the scheduled startup of FRM II in spring 2021 it was discovered that already at 25% of the nominal reactor power, the cooling power of the CNS was insufficient to maintain the required temperature. After excluding a technical defect in the refrigerator supplying the CNS with He, the root cause of the problem was identified to lie within the vessel of the CNS itself. We have used the neutron imaging beam line ANTARES which directly views the CNS through a pinhole collimator to diagnose the defect in the CNS. Using a 2mm pinhole diameter we were able to acquire sharp images of the level of the liquid D_2 as a function of reactor power, as well as of the interior of the CNS. We were able to identify a neutron absorbing material inside the CNS vessel from these images. Subsequently, we have performed prompt gamma activation analysis (PGAA) of the material through a lead collimator and the pinhole of ANTARES to identify the absorber to be a tube of Cadmium from the shielding of the CNS that has sled down into the vessel. The high neutron absorption cross section combined with the high energy gamma radiation produced by Cd explains the additional heat load on the CNS refrigerator preventing proper operation.
In this presentation, we will show the systematic approach that led to the final diagnose of the defect of the FRM II cold neutron source by combining neutron imaging and PGAA.

The Neutron Autoradiography with Nuclear Tracks Detectors and the Boron Neutron Capture Therapy

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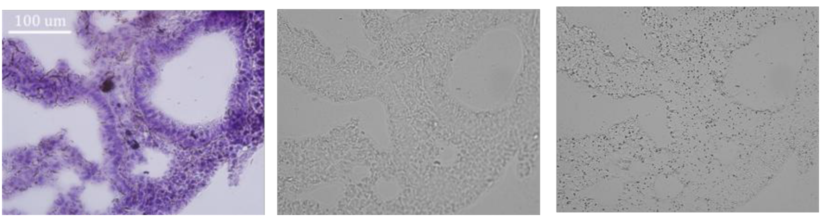
Boron Neutron Capture Therapy (BNCT) is a radiation treatment modality for cancer, based on the $^{10}B(n,\alpha)^{7}Li$ (BNC) nuclear capture reaction. When considering a BNCT protocol, knowledge of the spatial location of boron atoms is essential, since the BNC reaction products create lethal damage in a range comparable to a cell diameter. There are few techniques able to provide this information, being neutron autoradiography particularly suitable due to its high resolution and relative low cost.

A neutron autoradiography can be generated by placing a boron-loaded biological matrix (e.g. cell culture, tissue section) on a polymeric nuclear track detector (NTD). By irradiating this assembly with thermal neutrons, the BNC reaction takes place and the emitted lithium and alpha particles impact the NTD. This latent damage can be amplified to optical microscopy level though a chemical process. The spatial distribution of boron can be assessed by mapping the nuclear tracks in the NTD.

In our laboratory, we have established different approaches to address neutron autoradiography: (1) qualitative autoradiography (QLA), to observe boron microdistribution through differences in shades of gray; (2) quantitative autoradiography (QTA), which allows track density measurements (number of tracks per unit area) to be converted into absolute boron concentration values; and (3) UV-C sensitization of polymers (UVC-a), which produces an imprint of the biological material in the NTD revealed in the same process as the nuclear tracks, improving the spatial resolution (Fig.1). The aim of this presentation is to describe the work at our laboratory and to discuss future perspectives.

Figure 1. Example of UVC-a. Lung tissue section on CR-39 and stained with haematoxylin (a) and its corresponding images of imprints (b) and nuclear tracks (c).



Contrast options in ASTOR, the cold neutron imaging instrument at LAHN

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ASTOR (Advanced System for TOmography and Radiography) is a state-of-the-art neutron imaging instrument being developed by the Atomic Energy Commission of Argentina (CNEA) as part of the initial instrument suite of the Argentine Neutron Beam Laboratory (LAHN). ASTOR will be installed on one of the cold neutron beams of the 30MW open pool reactor RA-10, currently under construction at the outskirts of Buenos Aires. ASTOR will have direct view to a D_2 cold source and will include a primary collimator within the RA-10 biological shielding. Its design includes a beam conformation room with a set of exchangeable secondary collimators to further collimate the beam, and several devices (solid state refrigerated filters, a velocity selector and a double crystal monochromator) to tailor the energy spectrum for specific applications. Downstream the beam, it will have an experimental room with large space for objects and samples with a maximum field of view of 25x25 cm^2, and L/D ratios in the range 120-1500 with calculated fluxes of $3.7x10^8$ n/cm^{2}s and $2.4x10^6$ n/cm^{2}s respectively, and two rectangular pinholes designed to study unidimensional profiles.
ASTOR will include several contrast options designed to reveal the large differences in transmission for neutrons of different wavelengths exhibited by most materials, due to nuclear absorption or interference effects in the scattered neutron beam. Here, we describe the different configurations of ASTOR designed for Bragg edge imaging of texture, Bragg edge imaging of elastic strain and for neutron grating interferometry to reveal scattering effects occurring at very low angles. In particular, we describe the plans for the implementation of the Neutron Grating Interferometry system, composed by two absorbing diffraction gratings (to be fabricated in CNEA) mounted on rotating stages and a phase shift grating.

The current status of neutron imaging project at CARR

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The China advanced research reactor (CARR) of the China Institute of Atomic Energy is a 60MW multipurpose research reactor. The neutron imaging project include two dedicated neutron imaging facilities have been developed: the thermal neutron imaging instrument located in H8 port of reactor and the cold neutron imaging instrument located at the end of CNGC guide in the guide hall. The construction of thermal neutron imaging has been completed at the end of 2021 and the first neutron radiography measurements were made in January of 2022. The measured neutron flux at the sample position is 6.4×10^8 / cm^2 / s (L/D = 180). The cold neutron imaging is currently under construction with a projected completion date of Dec 2022.

In the last few years, we have successfully established a test station for neutron imaging, and developed several imaging methods, including indirect neutron CT, high resolution imaging, combined Neutron and X-ray Tomography, dynamic 3D imaging, Computed Laminography and Energy Selective imaging, which had been used to investigate various objects of interest, such as water management of fuel cell, concrete and rock imbibition, spent fuel element and steel welding, etc.

(a)   (b)

Fig1 Photograph of the (a) thermal and (b)cold neutron imaging facilities overview

PONTO: Exploring superconductivity with polarized neutron imaging

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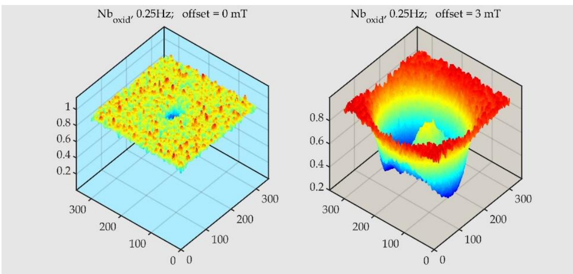
The PONTO instrument (POlarized Neutron TOmography) I and II, operated by the Berliner Hochschule für Technik (BHT, formerly Beuth Hochschule für Technik), was located at the BER II (Berlin Research Reactor II) and dedicated to polarized neutron imaging. Since 1996, neutron radiography and tomography has been developed in our department within the framework of five BMBF-funded projects of the university. Firstly, the focus was on studying "special" interactions that can be used for neutron imaging. Thus, it was possible to use refraction and ultra-small angle scattering for neutron imaging, which is now also known as neutron phase imaging. In the year 2010 PONTO II was installed optimized for polarized neutron imaging.

One of the most interesting applications of polarized neutron imaging is the study of thermodynamics in superconductors, i.e., the study of the interior of a sample in the superconducting state. Therefore, the scientific program focused on trapped flux under different boundary conditions. The studies were mainly performed with crystalline and polycrystalline lead (Pd) samples with different shapes (cylinder, cube, cuboid, sphere), comparing flux trapping due to field cooling (FC) and due to zero field cooling (ZFC). The influence of DC and AC currents on flux line mobility and magnetic flux trapping was tested with niobium samples (see figure). A short overview of the possibilities of polarized neutron imaging and the fields of application will be given, with some examples showing how exciting the topic of research can be and what can be achieved only with polarized neutron imaging.



Cylinder sample Niobium: FC, B_{ext} =5mT, AC field: 0.25Hz, left: T = 15K,no trapped field, right: T = 5K, trapped field, max ~3.8mT (note B_{ext} = 5mT)

Imaging the invisible: Electric fields and ghost imaging

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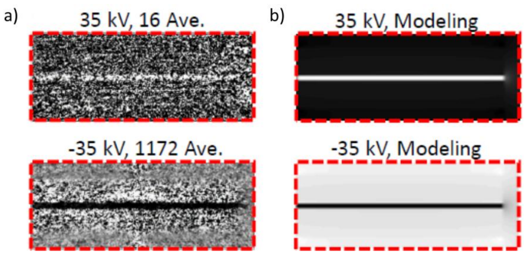
In these strange times, with limited access to neutrons, and global tensions high, we present a talk on imaging an unseen force using the power of neutron vision! Exploiting the Lorentz transformation, a neutron transiting a region of space at velocity **v** occupied by an electric field **E** will experience an effective magnetic field proportional to **v** x **E**. The spin of the neutron, if properly prepared will then undergo Larmor precession, with rotation proportional to E*L, where L is the path length of the electric field region. Because the precession is independent of velocity, one can use a polychromatic neutron beam. We present the first neutron images of an electric field from a simple parallel plate capacitor (doi: 10.1103/PhysRevLett.125.110801)Click or tap here to enter text..

Keeping with the spookiness of the times, we also report on initial investigations into ghost imaging. Inspired by Kingston et al (doi: 10.1103/PhysRevA.101.053844), but lacking an operating neutron source, we employ a synchrotron X-ray beam to induce fluorescent X-rays from a copper wire. Using a QR decomposition of the random mask patterns and subsequent image smoothing, we are able to resolve the image of the bent copper wire. We review our X-ray ghost imaging methods and propose how to adapt them for neutron prompt gamma activation analysis.



Neutron images of an electric field from a parallel plate capacitor with positive and negative voltage, compared with a model of the system.

A High Flux Transient Neutron Beam for Flash Neutron Radiography of Highly Dynamic Processes at the Transient Reactor Test Facility

Aaron E. Craft[1], Shawn R. Jensen[1], Joshua L. Gess[2], Wade Marcum[2], Lester J. Warby[2], Sophia A. Brodish[2], Jesus A. Mendoza[1], William C. Chuirazzi[1]

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The Transient Reactor Test (TREAT) Facility is a 19,000 MW reactor located at the Idaho National Laboratory which is used for transient testing of materials and experiments. The TREAT neutron radiography facility allows for low resolution radiography of experiments between reactor transients, with a neutron beam flux of 8×10^6 n/cm^2-s and the reactor at 80 kW steady power. However, recent efforts have pursued using the neutron radiography facility's neutron beam during a reactor transient for visualization of highly dynamic processes such as two-phase flow. During a 19,000 MW peak power transient, the neutron flux at the image plane is anticipated to exceed 10^{12} n/cm^2-s, nearly 1000 higher flux than the current brightest neutron imaging beams in the world. With typical neutron fluence per frame of 10^9 n/cm^2 for film-based radiography and 10^8 n/cm^2 for digital neutron radiography systems, the anticipated frame rates of a high-speed neutron radiography system could range from 10^3-10^4 fps.

The TREAT neutron radiography station and beamline collimation have been modified to produce a neutron beam suitable for use with a digital neutron imaging system. Supplemental shielding has been installed to attenuate the significantly higher neutron and gamma-ray dose rates anticipated with the neutron beam open during a transient. A high-speed digital camera-based neutron radiography system has been developed that users may remotely access during a transient from the TREAT control room safely located nearly 1 km away from the reactor. This presentation discusses the status of this project along with current measurements.

Neural network-based dose reduction strategies for neutron tomography

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High spatial resolution, ~ 20 µm, neutron tomography requires long exposure times due to the inherent lower fluxes of neutron sources. Adding in the high number, on the order of 1000, of projection images needed for filtered back projection renders tomography of samples with time-dependent features (e.g., batteries, fuel cells, water transport in concrete) infeasible. Dose reduction addresses this temporal bottleneck by composing a tomogram of either fewer angular projections or projections with shorter exposure time than optimal. When dose reduction is employed, reconstructions tend to be noisy with streaking artifacts that corrupt the image fidelity. This has led to a variety of techniques for reconstructing sparsely sampled projections including, most recently, neural networks (NN). This work focuses on strategies for employing NNs toward repairing sparsely sampled neutron tomography data with limited prior information (i.e., a seed dataset). NNs operating on both the angular projection data (sinograms) domain and reconstructed image domain are compared alongside traditional de-noising methods. Improvements to a variety of image quality metrics such as peak signal-to-noise ratio, structural similarity index and perceptual blur have been achieved with these methods which represent a factor of 5 decrease in acquisition time.

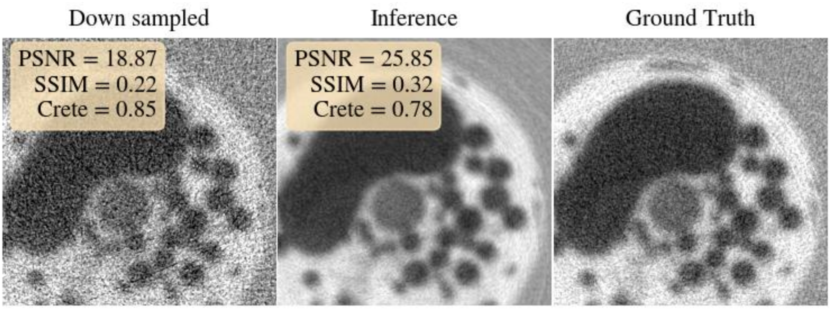

Figure 1: Example results (cropped from full image) from an alkaline AAA battery reconstruction. **Down sampled** is the 5× compressed reconstruction, **Inference** is a neural network prediction of the fully sampled reconstruction, and **Ground Truth** is the reconstruction of the fully sampled sinogram.

Neutron and X-ray Data Fusion Software Developments at NIST

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NIST operates the Neutron and X-ray Tomography (NIST-NeXT) system on the BT-2 thermal neutron beam line at the NIST Center for Neutron Research (NCNR). To support the NeXT system and truly leverage the complementarity of the method, NIST continues to develop user friendly tools for data fusion. After independent tomography reconstruction, the two modalities are aligned via rigid volume registration to account for the 90° offset of the two beams and any other small translational or rotational differences resulting from the instrument or reconstruction settings. The rigid volume registration program provides a user interface so that manual movement of the volumes can be completed to improve the initial guess for the automated Mattes Mutual Information algorithm. Optional denoising can be performed after registration before moving on to segmentation. The noise filtering program applies user selected filters and allows tuning of the filters before applying to the entire volume. Filters currently offered include 3D median, unsharp mask, and non-local means. Segmentation is accomplished through a bivariate histogram that leverages the complementary information of neutrons and X-rays. The program allows users to draw polygons around regions of interest on the histogram to tag, color, and label areas in the volume as shown in Figure 1. Binary volumes for each tagged region and a colorized volume are outputs to the program. This talk will discuss the methods we have employed for our data analysis pipeline, the directions we are looking to improve our capabilities, and some tips and tricks to avoid common pitfalls that have been found.

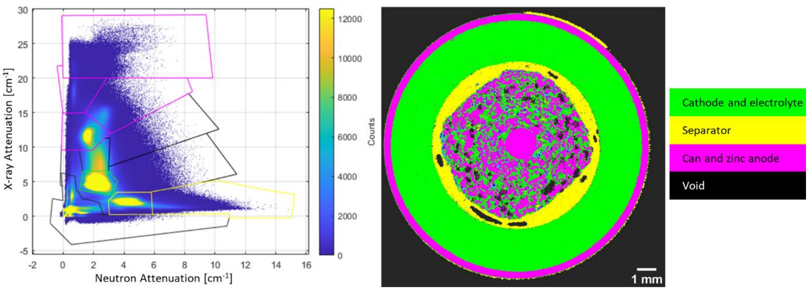

Figure 1: Bivariate histogram segmentation tool showing polygon selected regions (left) and corresponding colorized segmented slice of AAA battery (right).

Characterizing Materials for the Next Generation of Nuclear Reactor Designs with Neutron Imaging

Alexander M. Long[1*], Sven C Vogel[1], Marisa J Monreal[1], J. Matthew Jackson[1], S. Scott Parker[1], Holly Trellue[1], Erik Luther[1], Aditya Shivprasad[1], Thilo Balke[1], James Torres[1], and Anton Tremsin[2]

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Neutrons are an ideal probe for characterizing nuclear fuels and moderator materials for next generation nuclear reactors as their interactions with matter create complex attenuations that result in a unique combination of isotopic specific contrast mechanisms and penetrabilities, thus making neutrons well suited for investigating both high-z materials (actinides in nuclear fuels) and low-z materials (metal hydrides). Furthermore, the high material penetrability with neutron imaging allows for in-situ measurements at extreme conditions (high temperatures or activity) where bulky sample environments are required. Presented work will include the ongoing efforts at the Los Alamos Neutron Science Center (LANSCE) to develop advanced neutron imaging capabilities on Flight Path 5 (FP5) specifically for characterizing materials for advanced reactor designs. These efforts range from thermophysical property measurements of chloride-based molten salts, to hydrogen characterization in metal hydrides moderator materials, to post-irradiation examination with energy resolved neutron imaging of actinides in fresh and irradiated fuels.

Correlative Imaging with Neutron and X-ray Tomography

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When examining a sample, more information can be gained using multiple data streams. Neutron and X-ray tomography are complementary techniques as neutrons are attenuated by isotopes with high neutron cross sections whereas X-rays are attenuated by high Z materials. In practice this allows the separate techniques to emphasize different features of interest in a sample. This work presents efforts at Idaho National Laboratory (INL) to develop and implement correlative imaging where neutron and X-ray tomographies are combined to generate a more comprehensive understanding of samples. Using INL's Neutron Radiography (NRAD) Reactor in conjunction with the Zeiss Xradia Versa 520 X-ray microscope, samples are examined with both neutron and X-rays. The separate data streams are then processed and fused together to give a more complete understanding.

In this presentation, we discuss INL's imaging capabilities and workflow processes. Data preparation, curation, and image processing tools and procedures are also detailed. Several examples of correlative neutron and X-ray imaging that have been performed at INL are presented. Quantitative data extraction methods and techniques are applied to the correlated data to provide numerical information to researchers. Lastly, we conclude with a discussion of future applications, including the advantages of using correlative tomography for irradiated nuclear fuels and materials research.

The development of dark field contrast imaging simulation under INFER

Y. Kim[1,2], M. Wolf[3], S. M. Robinson[1], M.C. Daugherty[3,4], J.M. LaManna[1], E. Baltic[1], D.L. Jacobson[1], P. A. Kienzle[3], K. M. Weigandt[3], N. N. Klimov[1], M. G. Huber[1], P. N. Bajcsy[5], R. P. Murphy[3], D.S. Hussey[1]

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Small-angle neutron scattering techniques (e.g., SANS, USANS) are particularly useful for understanding the length-scale information of material structure from nano- to micro-scale regimes but are limited to average structure information for homogeneous bulk materials. Grating interferometry is an emerging imaging technique that provides the spatially resolved structure information and the subpixel fine structure information through dark field imaging, which can complement the measurement of heterogenous materials in SANS. Dark field imaging probes the pair correlation function at the autocorrelation length of the grating interferometer and quantitatively accesses the structure parameters of structure model (e.g., size, concentration, etc.). The National Institute of Standards and Technology (NIST) has developed a novel far-field grating interferometer and studied hierarchical materials in various fields such as polymer science, geology, additive manufacturing, etc. under INFER project.

In this work, we introduce the simulation of dark field imaging which is one of the goals of INFER. The simulation starts from the generation of a phantom, classified by attenuation, scattering length density and microstructural model. SASView generates a pair correlation function which used to simulate phase step images. The work is validated by the experimental measurement for the well-known reference of polystyrene particle solution. The result of this simulation can serve as a guideline to optimize the data acquisition scheme for instrument calibration purposes and design a training data set for the segmentation based on the machine learning.

Neutron Radiography at the SLOWPOKE-2 Reactor at RMC: Overview and Challenges

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The SLOWPOKE-2 nuclear research reactor at the Royal Military College of Canada (RMC) went critical in 1985. Installation of the reactor provided an educational tool for members of the Department of National Defence and an affordable neutron source for the application of neutron activation analysis (NAA) and radioisotope production. The SLOWPOKE-2 Facility supports teaching at the undergraduate and postgraduate levels, and runs laboratory courses in the programmes of Chemical engineering, Chemistry, Engineering Physics, and Physics.

Neutron beam tube was installed in the Facility several years after reactor commissioning and radiography system was opened in 1991. Over the years it proved to be an important tool for non-destructive evaluation of the CF-188 flight surfaces, and pilot seat ejection equipment detecting abnormalities in the internal structure such as moisture ingression, structural corrosion, and physical damage. In 2007 radiography system became digital with installation of the CCD camera and improved scintillation screen.

After 36 years of operation SLOWPOKE-2 reactor at RMC was successfully refueled in September 2021. As a result, the Facility is planning an upgrade to the imaging system that would allow to achieve better image resolution and contrast which is a non-trivial task considering low neutron flux and physical constrains in the Facility.

An overview of the SLOWPOKE-2 Facility capabilities and challenges related to the neutron imaging will be presented.

Visualization and Measurement of Molten-Metal/Water Interaction by using high-speed neutron imaging

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Interaction between molten metal and water is one of the important issues of nuclear safety, such as the cooling of molten-fuel in the severe accidents in the nuclear power plants. If the molten-metal temperature is higher than the spontaneous nucleation temperature, a vapor explosion may occur. Such a vapor explosion has been studied by using neutron imaging at the JRR-3 of Japan Atomic Energy Agency, Japan. However, the detail behavior of the interaction between the molten metal and water could not be well visualized due to the insufficient image quality of the imaging system. In this study, the modified imaging system was used to obtain the high spatial and temporal resolution so that the detail mechanisms of the interaction could be observed. Figure 1 shows the schematic of the imaging system for the high-speed neutron imaging at the thermal neutron radiography facility (TNRF) at the JRR-3. It consists of the lens, the image intensifier, and the high-speed camera. As the neutron converter, LiF/ZnS scintillator produced by TRITEC was used to get the good quality of the optical image. The frame rate of the high-speed camera was varied from 250 to 1000 fps in this experiment. Figure 2 shows the experimental setup, consisting of the aluminum rectangular tank, the cooling fan, the tube pump and the reservoir. The rectangular tank filled with Newton alloy, and water was injected from the injection nozzle at the bottom of the tank. The water evaporation through the heated molten-metal was clearly observed by using the TNRF at the JRR-3.

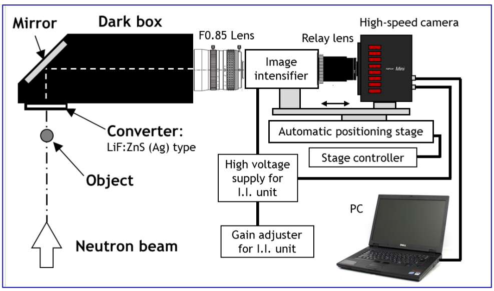

Fig.1 Schematic of Imaging system

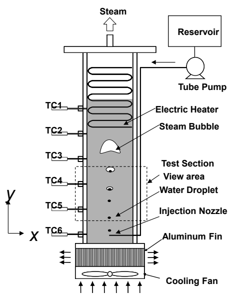

Fig.2 Test section

Neutron Imaging of PEM Electrolyzers at NIST

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The NIST Neutron Imaging Facility (NNIF) recently joined the U.S. Department of Energy's water electrolysis consortium H2NEW. Low temperature water electrolysis polymer electrolyte membrane (PEM) cells share common design aspects to PEM fuel cells, which have been the focus of many previous neutron imaging experiments. The use of neutrons to study PEM electrolyzers has also been shown in recent years to be useful in understanding transport phenomena related to performance in low temperature PEM electrolysis cells as well. As part of H2NEW NIST will work with consortium members and other NNIF collaborators to further develop methods imaging PEM electrolysis cells. This talk will focus on the current state-of-the-art facilities, methods and analysis tools at NIST and the scientific impacts of recent experimental efforts to image electrolysis cells at NIST.

Studying a Fe-rich vertebrate fossil skull through X-rays and neutron tomography

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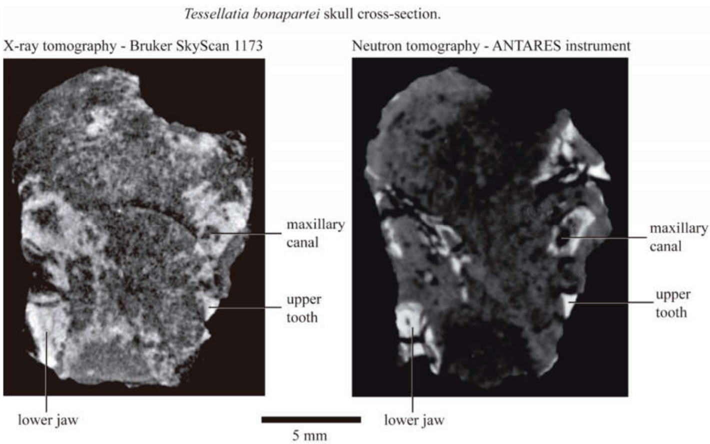
Abstract
Micro-tomography (µCT) data allowed for the identification and in-depth study of a new species of cynodont, *Tessellatia bonapartei*, that represents an early-diverging member of the mammalian-lineage. The fossil is inside a Fe-rich rock-matrix that could not be removed mechanically due to its small size and delicate bones. Tomographic images also made available inner features of the skull, inaccessible through traditional techniques. X-rays µCT was performed using a Bruker SkyScan 1173 instrument at YTEC (Ensenada, Buenos Aires, Argentina). The reconstructed images were difficult to interpret, as bone and matrix were in some regions indistinguishable from each other. This issue was thought to be caused by the presence of ferruginous material in the matrix. A preliminary neutron-tomography at the RA-6 facility (CNEA, Bariloche, Argentina) showed promissory results to overcome this problem. A high-resolution neutron µCT was conducted later by means of ANTARES instrument (FRM II, Garching, Germany). The new neutron µCT data allowed an improved distinction between bones and matrix. As a result, detailed 3D surface models of the preserved bones were generated, granting the detailed analysis and interpretation of the novel specimen´s internal and external anatomy.



Keywords: FOSSIL, Fe-RICH MATRIX, TOMOGRAPHY.

Posters

The INCHAMEL facility – a new device for In-situ Neutron Investigations under defined temperatures with applicable mechanical load

Sarah Weick, Mirco Große, Martin Steinbrück, Hans Jürgen Seifert

Regarding investigations on the material's behavior during long term dry storage, the diffusion of hydrogen and possible hydride precipitation processes in zirconium alloyed cladding tubes are studied. Parameters as the temperature and mechanical stress influence the hydrogen diffusivity in zirconium alloys. In order to quantify the outcome of these parameters, experiments will be performed at defined temperature and strain conditions that refer to long-term dry storage conditions of spent nuclear fuel elements in transport and storage casks. Therefore, in-situ neutron imaging at defined temperatures and under the influence of an applied tensile or compressional strain is required.

Final states of hydrogen diffusion in cladding tubes were already investigated non-destructively by neutron scattering experiments. In order to quantify the diffusion dynamics in-situ, a new device was constructed in cooperation with the company ZwickRoell - the transportable INCHAMEL (in-situ neutron radiography chamber with mechanical load) facility. The facility creates a homogeneous temperature field within the sample and is equipped with all features of a tensile testing machine. The machine's design was optimized in detail to fulfill the requirements for the usage in facilities with neutron radiation. In this manner, neutron radiography investigations can be performed with the neutron beam passing through the sample without any disturbances by installations like beam windows, furnace tubes, heater wires, etc.

This paper describes the characteristics and features of the new INCHAMEL facility and provides first testing results outside of neutron facilities, where mainly temperature and strain settings were tested.

Automated Fast Neutron Tomography at Ohio State University 500-kW Research Reactor

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The Ohio State University Nuclear Reactor Laboratory operates a 500-kW pool-type Research Reactor where a thermal and a fast neutron beam line are in operation to conduct neutron imaging research and applications. The fast neutron beam line provides a small circular beam about 33 mm in diameter with peak neutron flux ~ 1.0 x 10^7 n·cm^{-2}·s^{-1} at 1.6 MeV. The imaging apparatus is composed of a water-cooled EMCCD, a front-surface mirror and a MeV-neutron-sensitive PVT scintillator of 1 cm in thickness. The entire imaging apparatus is built into a customized mobile cart, featuring an on-line focusing capability. A total of 5 motion stages gives XYZ, rotational freedoms for sample positioning, and a fine tuning of the distance between camera and mirror. A Python code and user-friendly GUI were written to allow a fully automated imaging acquisition with a complete 360 views of neutron tomography dataset acquired in less than 2 hours, 20 seconds for each projection. The on-line focusing is accomplished with a commercial off-the-shelf dielectrically actuated liquid lens. Finally, tomographic reconstructions have been visualized using both Octopus and Livermore Tomography Tools (LTT) software packages. The spatial resolution for fast neutron radiography is ~ 195 - 435 μm, which depends on the thickness of the test target. The spatial resolution for thermal neutron radiography is ~ 156 μm. The effective pixel size is ~ 104 μm and ~ 131 μm for thermal and fast neutron radiography, respectively. The voxel resolution for fast nCT is 131^3 μm^3. Various of objects have been imaged for 3D tomography including parts made by additive manufacturing methods and lithium-ion batteries.

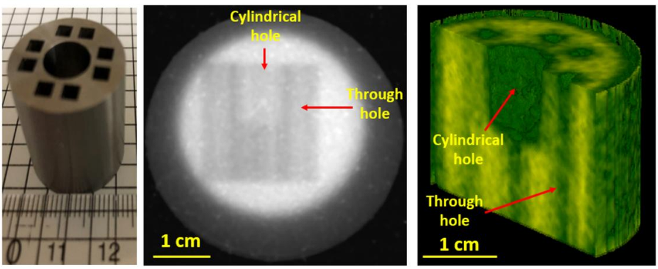

Fig. 1, A testing cylinder (left) with one radiography (middle) showing through holes, the Exposure time is 15 s / projection, 360 projections, total nCT data collection time is 90 min, and the Effective pixel size in this picture is ~0.131 mm, which was improved to 0.1 mm in a later setup. One slide of the final reconstructed nCT is on the right.

Epoxy-based ^{6}LiF/ZnS:Ag scintillator screens for neutron imaging

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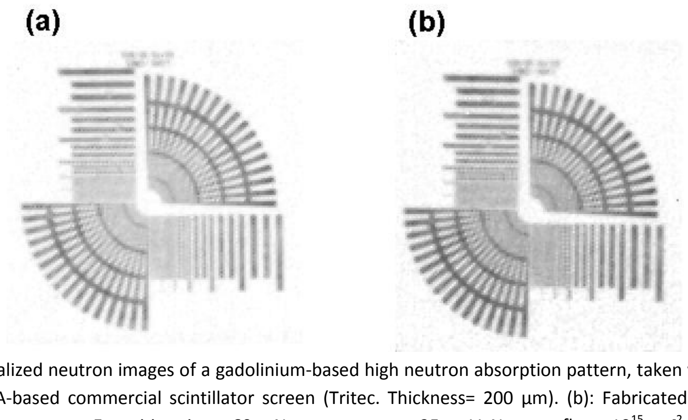
We developed an easy fabrication method for ^{6}LiF/ZnS:Ag scintillator screens based on the use of an aromatic epoxy resin as the powder binder, instead of the usually used aliphatic binders, such as poly(methyl methacrylate) (PMMA) or polyethylene (PE). In addition to the greater resistance to radiation reported for aromatic polymers, the epoxy resin allowed us to achieve precise film thicknesses with low material losses during the fabrication, which is very valuable due the high costs of the ^{6}Li.

Fabricated prototypes were tested in the neutron-imaging beamline of the RA-6, at the Centro Atómico Bariloche, Argentina, and properties such as homogeneity of the compounds in the film; intensity of light; spatial resolution and brightness were evaluated. All prototype tested presented high levels of light emitted, although quality in film conformation could still be improved. Comparison between PMMA-based commercial scintillator screens and fabricated prototypes showed no mayor difference in achievable resolution or brightness. These results encourage to develop a fully standardized fabrication method that would be beneficial in the operation of the future neutron-imaging instrument - ASTOR - in the LAHN, as well as rad-hard detectors for neutron flux measurement.



Normalized neutron images of a gadolinium-based high neutron absorption pattern, taken with(a): PMMA-based commercial scintillator screen (Tritec. Thickness= 200 µm). (b): Fabricated epoxy-based prototype. Exposition time= 60 s. Neutron energy ≈ 25 meV. Neutron flux ≈ 10^{15} cm^{-2}s^{-1}

A freely distributable professional computed tomography system using NICOS

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Several articles have described instrument control systems using NICOS which are and will be used at FRM II, PSI, ESS and other facilities, together with network based hardware drivers like TANGO. We previously described a CT system for Idaho National Lab which was downscaled from decentralized network components to a single computer controlling a camera, a rotation and two translation tables. A copy of this system was transferred to Ohio State University.

An updated and more advanced version of this system is currently being developed, and this system will be free to copy for other radiation facilities, with an absolute beginner version as well as a professional installation.

Via NICOS, the camera and an arbitrary number of stepper motor controllers can be controlled by command line, graphical widgets, or python scripts for arbitrary tomography scans. Controlling will be done using everyday units such as seconds or millimeters. NICOS provides a complete command history, and a live display of the current image.

The system will provide a local network with optional network translation to an institute network. It will use a Raspberry Pi with HAT motor controller for the simplest beginner's version, and Phytron motion controllers for the professional version that can be interfaced to any arbitrary stepper motor with or without encoders.

Hard disk images will be provided for free copying on request.

Flexible camera detector box design using 3D printers

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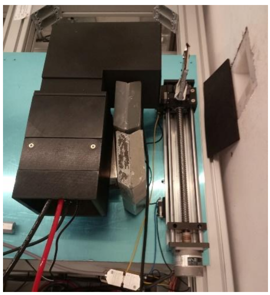
Big neutron centers have started their neutron imaging facilities with the best available and most expensive equipment, trying to do the very best in every single parameter. Experience has now taught us which parameters are truly important, and which were often exaggerated. High-end cameras enable for hour-long exposure times, which are never really required for typical minute-long measurements. New cameras for astronomy provide much higher pixel resolution than classic high-end cameras, and at a much lower price, without noticeable reduction in quality. First-surface mirrors provide the theoretical optimum, while 'bathroom mirrors' showed no noticeable deterioration of image quality. 'Classic' camera detector boxes often tried to accommodate a large range of fields of view in a single box so in the end, none was optimal, and interior shielding was mostly insufficient.

With 3D printers now easily available, we designed and built a whole line of different detector setups with 3D-printed components. A compact camera housing is used that contains front side lead shielding of the camera, but externally stacked shielding around the camera box. Various mirror boxes with different-sized scintillators can be connected to the camera box with a unified flange in order to easily adapt different cameras with different chip sizes to different fields of view.

The talk will show several detector systems and illustrate the design process depending on camera, chip size, lens and required field of view. Different detector designs are available for download for free.

Test of portable detector and tomography system at Atominstitut Vienna.

Towards Intelligent Hyper-Spectral Neutron Computed Tomography Systems

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Time-of-flight (ToF)/hyper-spectral (HS) neutron computed tomography (CT) systems enable novel scientific investigations through discrimination of materials and phases using resonance spectra, Bragg-edges, etc. A typical approach uses a fixed number of HS projection images obtained by rotating a sample about a single axis; these images are then processed using a 3D CT reconstruction algorithm. However, imaging with neutrons at facilities such as the Spallation Neutron Source (SNS) VENUS imaging beamline currently under construction and elsewhere presents several challenges in acquiring high quality reconstructions. First, HSCT measurements are flux-limited, typically requiring hours for a single HS radiograph at a signal-to-noise ratio (SNR) sufficient to discriminate spectral features. Second, standard 3D CT algorithms such as filtered back-projection require hundreds of such radiographs to produce 3D reconstructions of sufficient quality. Third, conventional systems collect all HS projections before beginning 3D reconstruction, which can be costly if there are measurement anomalies that result in an undesirable reconstruction.

Our research focuses on building robust, efficient, and intelligent HSCT systems powered by new hardware, machine learning and 3D reconstruction algorithms at the SNS and the National Synchrotron Light Source II. More specifically, we have developed a system that takes a set of HS projection images, streams them to a powerful computing resource, performs real-time, high-quality CT reconstructions using all images obtained so far, and informs the instrument of the next set of scans to acquire using a 3-axis orientation system. As a first demonstration, we implemented a scanning strategy inspired by the golden ratio scanning protocol. After every few measurements, we perform a real-time, model-based reconstruction to obtain high-fidelity images from extremely sparse and low-SNR data. We use these 3D HS reconstructions as inputs to a machine learning algorithm, which either chooses to stop the scan if a certain HS quality standard has been met or proposes a novel set of control inputs to the sample positioning system to continue measuring. Because the computation times are much smaller than the measurement time, our system can dramatically reduce the overall scanning time for HSCT systems while enabling users to obtain real-time feedback.

A portion of this research used resources at the Spallation Neutron Source, a DOE Office of Science User Facility operated by the Oak Ridge National Laboratory.

Update of Bragg edge analysis software "GUI-RITS"

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Spectral data of Bragg-edge imaging, which is one of the energy-resolved neutron imaging methods, can be analyzed by single-edge analysis and full-pattern analysis with the Bragg-edge analysis code RITS developed by Sato et al. This program has a function to generate neutron transmission data considering wavelength-dependent pulse-shape function, atomic number density, crystalline structure, etc., and to extract these parameters from the measured data by the nonlinear least-squares fitting.

By the RADEN team at the MLF, this code has been rewritten from Fortran to C/C++, and then called from Python and made into GUI software. The “GUI-RITS” software includes the “RITS” program for fitting a full pattern of a single spectrum, the “EDGE” program for fitting a single edge, the “RITS2” and “EDGE2” programs for multi-threaded fitting of up to 512 × 512 spectra, and “RITS Simulation” program for generating simulation patterns.

Last year, we worked on updating the operating environment of the platform Scientific Linux 6 and the language Python 2, which have been discontinued, to Windows 10 and Python 3, and added some functions to improve usability. GUI-RITS for the windows platform has been released to users.

In this presentation, we will show concrete examples of the results of the analysis of the same data by the old and new programs, and compare the efficiency of data analysis.

Performance evaluation study of fast-neutron images based on neutron generators and reactor

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The interaction cross sections and transport properties for neutrons and X-rays in matter are very different. While for X-rays the interaction cross section in matter depends on the atomic number, the cross section for neutrons depends on the specific nucleus and its nuclear structure and only very weakly on its atomic number. On the other hand, fast-neutron imaging technique is a non-destructive testing method similar to the well-known X-ray and gamma- rays imaging techniques. Further fast-neutron imaging technique is really attractive for large objects in industrial applications, because of its penetration capability. Fast neutrons have much larger penetrating ability than thermal neutrons as well as X-rays. Its penetration ability will be able to use for identification low-Z materials in the elemental composition materials. For utilization of fast-neutron imaging technique in industrial applications, a study on performance evaluation of fast-neutron imaging has performed with a variety of neutron sources as a tokamak with D-D plasma, a fission reactor, and a D-D neutron generator. The performance evaluation were done with fast-neutron transmission imaging and tomography techniques for a variety of neutron sources by means of a scintillator based CCD camera device. Each neutron source has their individual benefits such as massive and intense neutron source, well collimated neutron beams, high L/D ratio, easy-to use, and so on. In conclusion, fast neutron imaging techniques can be considered as a complementary technique to X-ray imaging if the composition of the sample requires visualization of light materials in the presence of high-Z materials for industrial applications. Details will be presented.

The Neutron Radiography using mixed radiation source

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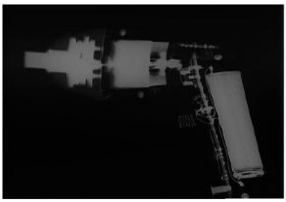
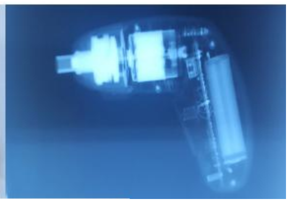
There are many Neutron radiation sources used for radiographic imaging. Common neutron sources include nuclear reactors, neutron generators, and radioactive isotopes. Most of these are neutron sources of a single energy band, and some radioisotopes have multiple neutron energy bands. In particular, Am-241/Be emits various neutron energy bands and gamma rays. In this paper, we have studied neutron radiography using Am241 / Be source. The Am241 / Be source has a neutron energy distribution of up to 11.5 MeV and an average energy of 5.4 MeV. In addition, gamma rays of 0.033 MeV are generated and have a mixed radiation field, which is good for radiographic imaging of composite materials. Half-life is 433 year, and long time is available, and when enough flux is provided, it can be used for shooting thick objects because of high energy. In this paper, we would like to discuss radiography when Am-241/Be radioisotope with a complex radiation field is used.



Drill Image of X-ray

Drill Picture of object



Drill Image of Am241/Be

Bragg edge imaging characterization of multi-material laser powder-bed fusion specimens

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In recent years, multi-material additive manufacturing has gained significant interest due to the high level of design freedom that it can offer, integrating complex geometry and functionality to create components with tailored local properties. The latest progress of multi-material laser powder-bed fusion (M2LPBF) makes it possible to print at least two different materials along the built direction and within a single layer of a component.

Here we applied Bragg edge imaging to characterize M2LPBF specimens of stainless steel and CuCrZr alloy, employing the instruments BOA and POLDI at PSI. A diffuse interface is observed in samples with both vertical and horizontal interfaces. The analysis of the (111) and (200) Bragg edge heights across the samples demonstrate a clear difference between the crystallographic texture of both alloys, with a strong alignment of the (002) planes along one of the transversal directions in the steel and a random texture within the copper alloy. On the other hand, following the position of the (311) Bragg edge, it is possible to study the residual strain across the specimens. The results are compared with neutron diffraction measurements, and they show that at the interface, the steel experiences in-plane tensile strain while the copper alloy shows compressive in-plane strain. However, potential alloying and phase mixtures at the interfaces hinder a clear strain characterization. We currently attempt to correlate the diffraction measurements with simulations and further advanced imaging techniques, such as dark-field contrast neutron imaging, observing micro-cracks, porosity and phase precipitation at the interfaces of the two materials.

NeXT 2.0; Upgrading the Neutron and X-Ray Tomograph at ILL

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NeXT-Grenoble is the Neutron and x-ray tomograph born in 2015 from a collaboration between University Grenoble Alpes (UGA) and the Institut Laue-Langevin (ILL). The instrument is undergoing a major upgrade to further expand the portfolio of contrast options. This is the result of a collaboration between the initial partners (UGA and ILL) plus the Helmholtz-Zentrum Berlin (HZB), also via the newly founded international mixed research unit NI-Matters.

The upgraded instrument will further push the maximum attainable spatio-temporal resolutions by increasing the maximum flux (expanding the accessible collimation ratios L/D) as well as by upgrading the range of detectors. The simultaneous x-ray imaging will also be improved to explore a broader range of geometrical configurations. The improved sample stack will help automation and expand the possibilities (in size/weight) of in-situ apparatus that can be easily installed on the instrument, as well as adding a laminography option.

A number of new contrast options will be added: a velocity selector as well as of a double crystal monochromator will allow versatile energy selection, depending on the application. A grating interferometer will allow the characterization of heterogeneities on the scale of 0.1 µm to 10 µm and above through dark-field imaging, while differential phase contrast can be employed to differentiate even modest variations in the refractive index. The new instrument will also make available a native integration of neutron polarization equipment in order to perform vectorial tomographies of magnetic fields.

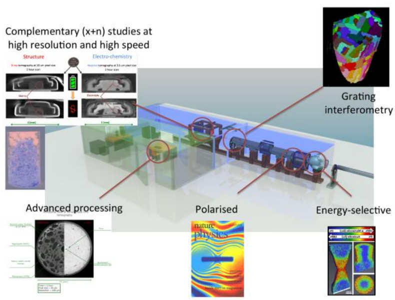

Figure 1. A schematic representation of the upgraded instrument.

Study on Phase Distribution of Refrigerant Boiling Flows in Mini-Channel Cross-Flow Type Evaporator

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Compactness and decrease in temperature difference between two fluids are still important issues in developing heat exchangers. Microchannel compact heat exchangers manufactured by diffusion bonding process are expected for compact evaporators due to quite high heat transfer area density. In the case where the refrigerant flows with evaporation, non-uniform flow distribution might be caused by the temperature change of the heating medium because pressure loss of refrigerant flows depends on not only mass flow rate but also vapor quality.

Boiling two-phase flows in cross-flow type mini-channel evaporator were visualized by neutron radiography at the research reactors, KUR of Kyoto University and JRR-3 of Japan Atomic Energy Agency. Vertically upward flows of HFC134a [CH_2FCF_3] in 21 parallel channels with the hydraulic diameter of 1.47 mm were heated by the heating medium of fluorocarbon FC3283. The refrigerant was supplied as a subcooled liquid. Distributions of void fraction, defined as the volumetric ratio of vapor to the total channel volume, of evaporating two-phase flows were measured from neutron radiographs.

Void fraction distributions are shown in the following figures with the schematics of rib configurations. The rib patterns are, from left to right, straight, perforated, and offset. The heating medium flows from right to left as its temperature decreases due to heat exchange. It could be seen that the non-uniformity in void fraction distribution could be improved by the perforated rib. Because bubble nucleation might be enhanced at the perforated section.

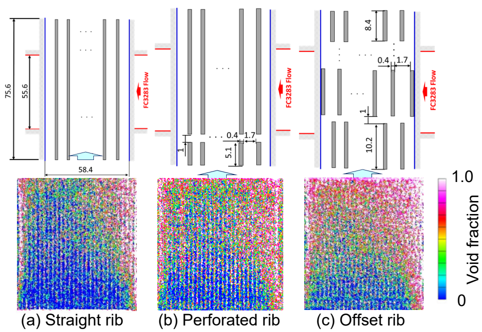

Fig. Void fraction distribution

Neutron Imaging Services at Phoenix's Accelerator Based Imaging Facility

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Phoenix, LLC's state-of-the-art radiographic imaging center is the first facility of its kind to offer commercial neutron imaging services without the use of a reactor. The imaging center's compact, high-yield, accelerator-based neutron imaging system produces collimated sources of both thermal and fast neutrons for imaging applications. Conventional film-based neutron radiography at the imaging center produces the highest measurable image quality by ASTM standards.

Located in Fitchburg, Wisconsin, USA, the 10,000 square-foot facility came online late in 2019. Since its inception, we have actively explored many new applications of fast and thermal radiography and continue to look for more opportunities in the R&D space.

Upgrading Neutron Imaging Facility at TRR-1/M1 Reactor

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The neutron imaging system at Thai Research Reactor 1/Modification 1 (TRR-1/M1) is located at Thailand Institute of Nuclear Technology, Bangkok. It has been developed for research and non-destructive investigation using radiography and tomography techniques. The main instruments of the system consist of a neutron camera, a sample rotation system operated by in-house developed software, and a neutron shutter remotely controlled via a WIFI switch. Since the first quarter of 2022, the TRR-1/M1 has been temporarily shut down for annual maintenance, and additional shielding is being installed in the imaging room to improve radiation safety. Due to the long-term use of the neutron camera, the scintillation screen and the CCD chip are consequently damaged by neutron and gamma irradiation. Image quality has deteriorated as a result of the low brightness and high image noise. The current neutron camera will be replaced with a new one to improve the image quality. The new camera performance, such as brightness and image quality, will be investigated by varying the exposure time and imaging of the standard specimen, Siemens star, respectively. The progress of the imaging system and its performance will be discussed.

Keywords: Thai research reactor, Neutron camera, Scintillation screen, Radiation shielding, Image quality

NEUTRA 2.0

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After more than 25 years of successful operation of thermal neutron imaging beamline NEUTRA, the NEUTRA 2.0 upgrade project has been approved. The upgrade to NEUTRA 2.0 implies a complete reconstruction of the instrument including the redesign of the shielding bunker. The inner usable area of the bunker will be more than doubled (see Figure 1) thus creating ample space required in modern neutron imaging instruments for complex measurement with bulk sample environments. Likewise, the full access to the front position, MP 1, of the beamline will allow utilizing about half an order and one order of magnitude higher flux than at the currently accessible measurement positions MP2 and MP3, respectively. This will enable higher temporal resolution neutron imaging investigations and the use of the Neutron Microscope detector at NEUTRA. Together with more available space the higher flexibility of the interior arrangement will enable accommodating components for advanced neutron imaging techniques such as in-situ simultaneous bimodal neutron/x-ray imaging, time-of-flight imaging and thermal neutron grating interferometry.
While the upgrade will enable advanced neutron imaging capabilities at NEUTRA2.0, the instrumentation/techniques that were pioneered on at NEUTRA in the past, namely the XTRA option for in-line bimodal neutron/X-ray imaging and the NEURAP insert for neutron imaging of highly radioactive samples will be retained in the suite of the available modalities at the beamline. Being an ongoing project at the time of the conference, the presentation will summarize the project status.

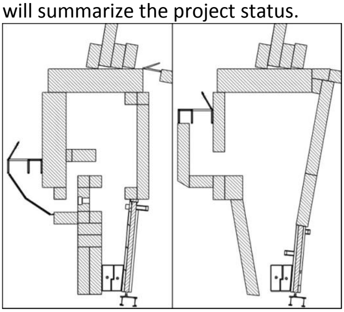

Figure 1 – bunker footprints of NEUTRA before and NEUTRA2.0 after the ongoing upgrade

Neutron Wavelength Dependent Imaging Capability at the Spallation Neutron Source (SNAP) High Pressure Diffractometer

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The VENUS (VErsatile Neutron Imaging instrument at Sns) beamline is currently being constructed at the Spallation Neutron Source (SNS). Parallel efforts to develop wavelength-dependent neutron imaging are underway at the SNS SNAP (Sns Neutrons And Pressure) diffractometer. Although this instrument is optimized for diffraction, it is well suited for imaging for two main reasons: (1) it shares the same moderator as VENUS and (2) it has no guide system. A dedicated sample positioning system and micro-channel-plate (MCP) detector (see Figure below) have recently been installed in order to prototype the data acquisition, reduction, processing, and analysis software in preparation for VENUS. The current capability enables multiple sample translation and sample rotation via a multitude of motion axes including rotation stages, goniometers, and a hexapod. A limited number of days are available in the general user program to grow the wavelength-dependent imaging program while VENUS is being built. This presentation focuses on the current imaging capabilities with a few selected experimental setups.

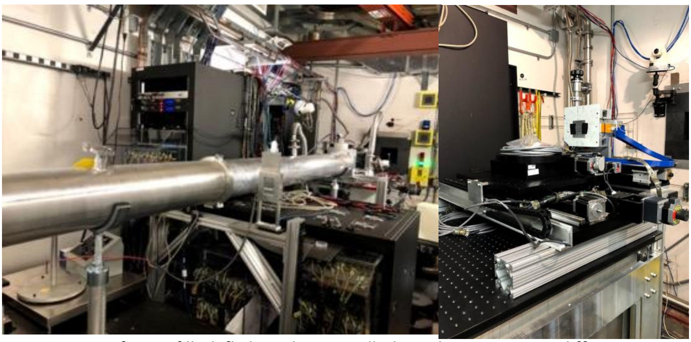

Figure caption - Left: He-filled flight tubes installed at the SNS SNAP diffractometer when performing imaging experiments. **Right:** Sample positioning assembly with MCP detector installed at SNAP, 19.885 meters from the moderator. The neutron beam comes from the left on each photograph.

Development of a crystalline microstructure analysis method with machine learning in wavelength-resolved neutron imaging

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The wavelength-resolved neutron imaging method is widely used to analyze many kinds of material. In this method, we can get information of crystalline microstructure in a bulk material by analyzing neutron transmission spectrum per position over a large field-of-view. However, it has been quite difficult to evaluate a dual-phase polycrystalline material with complex crystal structures, microstructures, and macrostructures so far. Also, a spectrum with large statistical errors makes it difficult to analyze small pixel. We have been attempting to solve these issues by applying machine learning.

In this study, we tried to analyze crystalline microstructure of lead-bismuth eutectic (LBE) with two-dimensionally solidification sample. LBE has complex crystal structures itself and these spectra could change depending on how to be solidified. To analyze these spectra, we applied principal component analysis (PCA) and clustering analysis. Firstly, PCA was applied to LBE spectra, and we could quantitatively identify the character of spectra at each pixel. Next, clustering analysis was applied to the PCA-applied spectra to categorize its feature. As a result, we succeeded in classifying spectral patterns of solidified LBE in four types as shown in Fig.1 and visualizing solidified LBE sample with each pattern as shown in Fig.2. By analyzing the spectrum patterns shown in Fig.1 with the Bragg-edge analysis code RITS, we could obtain quantitative distributions of textures and crystallite sizes of LBE and consider the relationship between them and solidification speed of LBE.

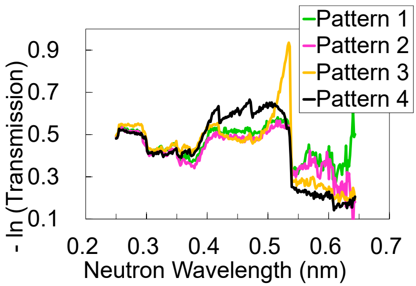

Fig.1 Spectral patterns of LBE distinguished by clustering analysis.

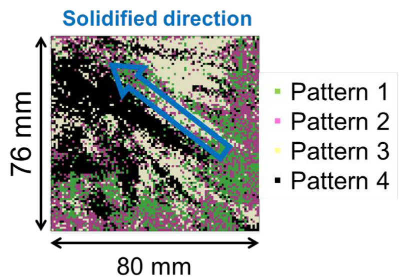

Fig.2 Spectral pattern-identified imaging of LBE after solidification.

Development of a ferrite/austenite phase fraction imaging method using neutron double Bragg-edges profile analysis

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A multiple crystalline phase steel such as TRIP steel is mixture of different types of steel microstructures with their own crystal structures. Because the mechanical properties differ depending on the crystalline phase fraction, the phase fraction evaluation of such steel is important. Also, a neutron Bragg-edge imaging method is effective way to evaluate these steel materials which are used in large scale. So far, ferrite (α)/austenite (γ) phase volume fraction imaging method using the Bragg-edge analysis code "RITS" has been successfully established. Though it can provide highly accurate α/γ phase fraction, it needs a complicated data analysis because it has so many fitting parameters. For the improvement of the data analysis practicality, we considered to apply a double Bragg-edges profile analysis method to analyze α/γ phase fraction easily. The double Bragg-edges profile analysis is similar to our recent analysis method for precise α/α'(martensite) phase fraction analysis.

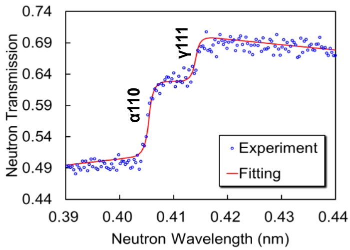

Fig. 1: Result of double Bragg-edges profile fitting analysis.

At first, we measured neuron transmission spectra of samples consisting of α-phase and γ-phase with known phase fraction information at HUNS and J-PARC. Figure 1 shows a result of double Bragg-edges profile fitting analysis for a sample that γ-phase fraction is 50%. In the data analysis, we performed an accurate data analysis with some corrections considering crystal structure factor, multiplicity, crystallographic texture, crystallite size, and element. As a result, accuracy of crystalline phase analysis was drastically improved as shown in Figure 2.

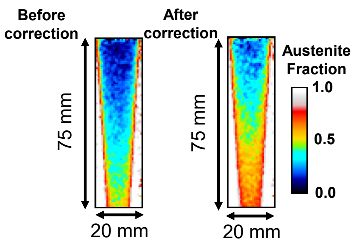

Fig. 2: α/γ phase fraction imaging using double Bragg-edges profile

In the presentation, we will report methodology, various experimental imaging results including

The IAEA e-learning course on Neutron Imaging

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Abstract

Neutron imaging is currently the second most common nuclear technique present at research reactors (RR), with 69 RRs out of 235 operational RRs reporting its availability in the IAEA Research reactor Data Base (https://nucleus.iaea.org/RRDB, March 2022). Of these, around 10 are user facilities (some operating more than one imaging instrument) open for international access by scientific and industrial partners and performing state of the art experiments. The remainder have in-house and test facilities mainly for their own projects, of which a number have upgrade activities or plans.

The IAEA developed an e-learning course on neutron imaging, which was made available to Member States through the IAEA's e-learning Open Learning Management System CLP4NET [https://elearning.iaea.org/m2/course/view.php?id=633] in October 2020 after being reviewed by the participants of a dedicated European workshop and those of the 4th IAEA AUNIRA (Advanced Use of Neutron Imaging for Research and Applications) Workshop. The course comprises lectures and quizzes for self-assessment. It provides an introduction to neutron imaging, including radiography and tomography, non-conventional methods, dynamic and stroboscopic neutron imaging, instrumentation, and data fusion with X-ray imaging. The course thus offers a broad view of the capabilities, requirements and applications of neutron imaging, through a mainly theoretical approach.

The course is directed to young specialists or beginners without extended experience of conducting neutron imaging independently. It can also be used by experienced practitioners who want to implement or use another variety of neutron imaging; professional technicians and analysts; users of neutron imaging and other stakeholders who wish to understand the techniques better; professors teaching nuclear sciences and applications & nuclear analytical techniques; undergraduate and graduate students interested in nuclear sciences and applications and nuclear analytical techniques; and facility managers or supervisors who have to make decisions for a neutron imaging system at their neutron source.

In the last two years, feedback from course users and learners was collected. In particular, the participants of the 5th AUNIRA Workshop, which took place virtually in September 2021, provided extensive feedback and suggestions for improving and expanding the course. On careful examination of the breadth and scope of the feedback, it was decided, on the one hand, to develop a new e-learning course covering advanced aspects of neutron imaging through a more practical approach, and, on the other hand, to update the existing course. Here, we report on the development, update and current status of the original e-learning course on neutron imaging.

Study of Er diffusion in Zr-20%Nb and pure Nb by neutron imaging experiments

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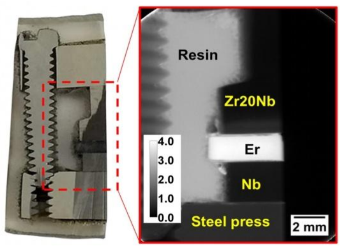
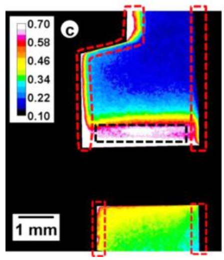
Due to its high neutron absorption, Erbium (Er) can be incorporated as a burnable poison in a proposed fuel cladding made of zirconium-niobium (Zr-Nb) alloys. However, as Er reduces the corrosion resistance of the material, this requires a three-layer cladding formed by inner and outer layers of Zr-Nb alloys, and a middle layer of a tailored Zr-Er alloy, currently under development. Then, the control of Er diffusion between the different layers is important to ensure mechanical and corrosion performance. In this work, diffusion coefficients (D) of Er in a Zr-20%Nb (wt.%) and pure Nb at 1000°C were determined using neutron imaging (NI) and laser-induced breakdown spectroscopy (LIBS). NI experiments were performed in the cold neutron imaging facility CONRAD 2 of the Helmholtz-Zentrum Berlin (HZB). In Zr-20%Nb, values of D were found using NI and LIBS, respectively, sampling very different volumes of material. D of Er in Nb measured by NI is more than two orders of magnitude smaller than in Zr-20%Nb. The spatial resolution of NI revealed that diffusion of Er occurred by the growth of a layer of 12% Er concentration from the Er/Zr20%Nb surface. These results show that NI is an adequate technique to study the diffusion of Er in nuclear fuel cladding.





Left: Optical image of the specimen together the neutron attenuation image. Right: coloured attenuation map in Zr-20%Nb and Nb. Regions contoured by red lines are affected by changes in the thickness while regions contoured by the dotter black line is a Zr-20%Nb enriched in Er.

Measurement of hydrogen diffusion in a biphasic Zr alloy

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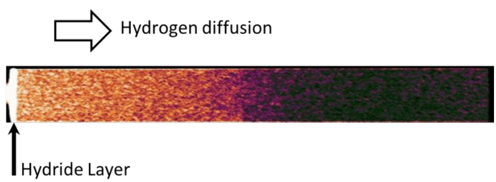
Hydrogen diffusion plays a key role in the delayed hydride cracking (DHC) mechanism in Zr-2.5Nb pressure tubes of CANDU nuclear reactors. Zr-2.5Nb is a biphasic alloy composed of alpha (hcp Zr) and beta (bcc Zr / Nb) phases. In particular, it has been postulated that the beta phase has an important effect on the hydrogen diffusion coefficient in the alloy, an issue which is still under discussion in the literature.

In recent years, neutrography has proven to be reliable in detecting low amounts of hydrogen or hydride contents with higher spatial resolution than traditional methods, thus emerging as an ideal technique for measuring the hydrogen diffusion coefficient in Zr alloys.

In this work, we used neutrography to study the hydrogen diffusion coefficient in an alloy of Zr-2.5Nb with two very different heat treatments that greatly modify the beta phase, leaving the alpha phase mostly unchanged.



Example of neutrography taken showing the hydride layer on the left side and the hydrogen diffusion profile from there. The dimensions of the samples are 20x4x6 mm. The beam passes through 6 mm of the material.

Time evolution of hydrogen diffusion in Zirconium alloys at 300°C-400°C by in-situ neutron imaging experiments

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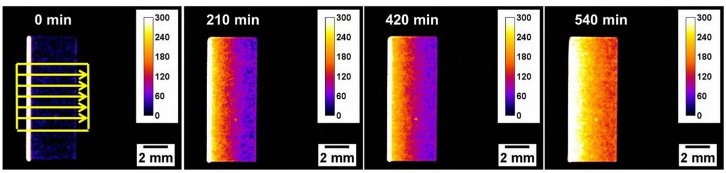
Zr-based alloys are widely used in nuclear power plants as fuel cladding due to an excellent combination of mechanical resistance, corrosion resistance and very low neutron absorption. However, these materials are susceptible to hydrogen (H) degradation and for long operational service Zr-based components can suffer a mechanism known as Delayed Hydride Cracking (DHC) which reduces their service life. In DHC the velocity of crack propagation is governed by H diffusion towards the crack tip. Then, a correct description of the H mobility, related to the diffusion coefficient, is an important issue for the safety operation of nuclear power plants. In the present work, the isothermal diffusion of H in two common Zr alloys (Zircaloy-2 and Zr2.5%Nb) at different temperatures was observed and quantified by in-situ neutron imaging experiments. Several specimens of dimensions 10x10x4 mm^3, specially prepared to contain a homogeneous hydride layer on one of their faces, were heated in the beam to temperatures of 300°C, 350°C, 375°C and 400°C and held for times ranging between 60min and 210min. Images were registered over periods of 30 sec. The time evolution of the H concentration across the specimen allowed the determination of diffusion coefficients, and an assessment of the limitations of existing models commonly used to describe H diffusion. In particular, the linear spatial resolution of the technique (~30 μm) revealed the dynamics of the moving boundary between precipitated hydrides and the region where H exists in solid solution.



H content maps for Zr-2.5%Nb rolled plate at different times. Colour bar is in weight ppm. Highlighted region was used to determine the H content profiles and calculated the H diffusion coefficient.

Real-time Evaluation of Hyperspectral Neutron Computed Tomography based on Machine Learning Algorithms at the Spallation Neutron Source

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Over the past 10+ years, hyperspectral (HS) neutron computed tomography (CT) systems have emerged at spallation neutron sources such as the Spallation Neutron Source (SNS) at the Oak Ridge National Laboratory (ORNL). These neutron wavelength-dependent imaging beamlines can measure Bragg edges and resonance spectra, which provide crystalline (phase, strain, preferred grain orientation, etc.) and isotopic information, respectively. Historically and at continuous neutron sources (i.e., reactors), the typical scanning and reconstruction pipeline consists of a single-axis rotation of the sample with predefined view angles and filtered-back projection reconstruction. However, this method is not adequate for pulsed sources since HSCT scans inherently suffer several problems: 1) each projection usually requires several hours of acquisition time to reach a reasonable signal-to-noise ratio (SNR); 2) the HS projections are made without real-time optimization of the scan; and 3) the quality of the HS reconstructed data is only assessed at the end of the experiment which might yield low SNR and artifact-ridden reconstructions.

This research implements the mechanisms to decide whether to continue or stop the CT scan. Using this approach, a trained ML algorithm estimates a CT quality score from model-based iterative reconstruction (every 3 HS projections) and determines if the scan has reached a convergence in quality. Since the evaluation time is much less than a single HS projection acquisition time, this dramatically reduces the total HSCT scan by preventing the acquisition of data sets that improve reconstruction infinitesimally. Additionally, users can both evaluate the scans and visualize the reconstructed data as the measurements progress.

A portion of this research used resources at the Spallation Neutron Source, a DOE Office of Science User Facility operated by the Oak Ridge National Laboratory.

An open data set to understand neutron tomography image quality

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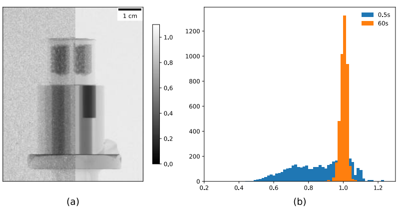
The everyday decision at the imaging beamline is how many projections at which exposure time a tomography scan should be acquired. This decision involves many factors; on a high level, it is essential to know which resolution is required to detect the relevant features and what signal-to-noise ratio is acceptable for a successful investigation. These requirements boil down to the acquisition dose, i.e., the number of detected neutrons per pixel. The dose is the product of the neutron flux and the exposure. In tomography, the SNR depends on the total acquisition dose, i.e., you can achieve the same acquisition dose either by a few well-exposed projections or by many projections with a short exposure time. This choice is not apparent in neutron imaging, where the flux often is limited. On the one hand, you want to fulfill the sampling theorem, but you may lose in contrast due to short exposure times. With this background, we made a series of neutron tomography scans at NEUTRA, Paul Scherrer Institut, using two test items from the IAEA imaging QA sample collection. Each scan has 1125 projections using exposure times between 0.5s and 60s, including references for open beam, dark current, and scattering correction. The presented data set is available as an open data set that can be used to understand the best acquisition strategy but also for algorithm evaluation and teaching.



Comparing the two projections shows the difference in SNR for 0.5s and 60s exposures (a). The histograms in (b) show the distribution of grey levels in the two projections.

Introduction to Neutron Radiography Facilities in JRR-3

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Japan Research Reactor-3 (JRR-3) owned by Japan Atomic Energy Agency (JAEA) is a research reactor with thermal power of 20 MW. JRR-3 had been used for a number of academic research and industrial applications since its criticality in 1990. However, the facility operation had been interrupted for 10 years after a periodic inspection in November 2010. The reason was to comply with the regulatory standards about research reactors which was revised following the Great East Japan Earthquake in March 2011. Consequently, although JRR-3 itself was not fatally damaged by the earthquake, it was necessary to perform various antiseismic reinforcements, such as preventing the exhaust tower from tipping over and reinforcing the reactor building of JRR-3. After the reinforcements were completed, JRR-3 operation resumed successfully on February 26, 2021, following a periodic inspection.

JRR-3 has two neutron radiography facilities, TNRF (Thermal Neutron Radiography Facility) and CNRF (Cold Neutron Radiography Facility). TNRF has a large irradiation field (W255 mm × H305 mm) and a high neutron flux (approximately 1.0×10^8 n/cm^2/s). By utilizing these performances, it is capable of not only normal radiography and CT with the large field of view, but also dynamic imaging using a high-speed camera. On the other hand, CNRF has a small irradiation field (W30 mm × H30 mm) and approximately 1.0×10^7 n/cm^2/s neutron flux. In this presentation, we will introduce the specifications, performances, updated devices, and imaging examples of the neutron radiography facilities in JRR-3.

Pydingo, a new GUI software package for simple CT reconstruction

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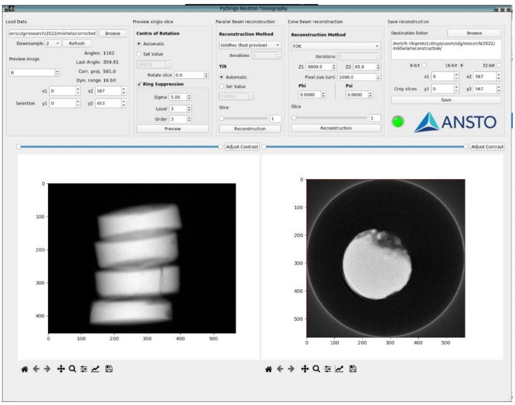
The neutron imaging instrument DINGO did use Octopus for CT reconstruction since operational until Ocotpus has withdrawn further support. We tried several new software packages and did end up using Tomopy and the graphical extension Neutompy for a while. Unfortunately these packages require some skills in python scripting and lacking user friendliness. Because of our diverse customer base we were looking into a user friendly GUI providing the functionality of Tomopy and the GPU acceleration of the Astra Toolbox.

The new developed Pydingo provides once installed easy access to Tomopy and the Astra Toolbox through its GUI which comes in three different sections. The first section handles the repreparation of the raw data including normalisation and selection of region of interest. In addition a phase retrieval can be selected. The corrected image output will be handled in a second section calculating the centre of rotation, tilt and final reconstructed slices. The reconstruction algorithm is available for parallel and cone beam geometry. In a last section the reconstructed slices can be corrected for beam hardening.

All GUIs are open source and can be extended with additional correction and reconstruction algorithms.



GUI for the reconstruction part of Pydingo

Performance study of the ANET Compact Neutron Collimator at the PSI BOA facility

Oriol Sans-Planell[1,2], Saverio Altieri[3], Roberto Bedogni[4], Francesco Cantini[5], Marco Costa[1,2], Francesco Grazzi[6], Ettore Mafucci[1,2], Valeria Monti[1,2], Manuel Morgano[7], Masako Yamada[8]

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This communication presents the design, construction and test of a novel compact multi-channel neutron collimator developed by the ANET collaboration.
The ANET neutron collimator has a scalable structure, both in collimation power and in field of view. It needs to be coupled to a moving stage in order to smooth out its chess-board geometry from the final image as it has been fully demonstrated and tested. The dynamic acquisition mode can be tuned in size, pattern and speed to adapt to different facilities.
A complete study of its performances, evaluated at the PSI BOA facility is here presented.
An evident improvement in spatial resolution is perceivable when the ANET collimator has been introduced in the beamline. The collimator has been tested under fluxes from 10^6 up to 10^9 $cm^{-2}s^{-1}$ and no degrades of its performances have been observed.
An extensive simulation work using high-end tools has been conducted in order to study the device properties. The agreement between the experimental and simulated data is remarkable.
The BOA beamline was characterized by the presence of a traditional pin-hole system. The inclusion of the ANET collimator in combination of the former set-up produced an unexpected improvement: the effect has been mathematically described and verified through simulations. The theoretically calculated values for the beam divergence are in agreement with those measured in the experimental campaign.
A first application on a tomography reconstruction will also be presented.

The double crystal monochromator at ICON – design and experiments

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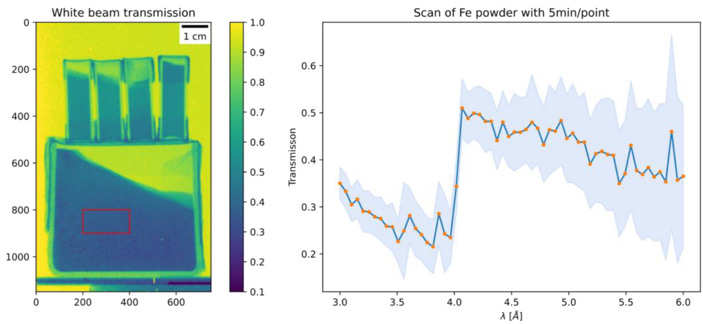
Many applications using neutron imaging for materials science use diffraction-based contrast to explore and understand the condition of the samples. Diffraction-based methods require that specific neutron wavelengths can be selected. The neutron imaging instrument ICON at Paul Scherrer Institute has, until recently, only provided this functionality using a velocity selector. We designed a new Double Crystal Monochromator (DCM) for the conditions at ICON as an option to meet the resolution demands of new experiment objectives. The DCM can also be used combined with the velocity selector. The device uses two pyrolytic graphite crystals as active components, allowing the selection of wavelengths in the interval 2-6 Å, covering the main applications intended for wavelength selective imaging at ICON. The device is designed for installation near the instrument shutter system. This position has the advantage that the valid field of view is larger at the experiment position due to the beam divergence of the ICON. On the other hand, this position means that the beam displacement relative to the main beam is relatively short. Thus, shielding is vital for the installation. Also, the concurrent use of the velocity selector can suppress the background. The figure below shows an example of a transmission spectrum wavelength scan (3-6Å) of Fe powder using the DCM with 300s exposure time per measured point. The figure demonstrates the performance of the device. The total scan time was ten hours for sample and reference images.



A wavelength scan of Fe powder using the new DCM at ICON.

Recent advances at the cold neutron imaging instrument at High Flux Isotope Reactor

Yuxuan Zhang[1], Hassina Bilheux[1], Erik Stringfellow[1], Jean-Christophe Bilheux[1], Jonathan Smith[1], Leslie G. Butler[2], Kyungmin Ham[2], Wieslaw Stryjewski[2], and Michael Vincent[2]

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Abstract

Over the past several decades, neutron imaging has gained its position as a powerful technique in spatially and non-destructively resolving internal features/structures in bulk materials. In recent years, higher spatial resolution and advanced contrast mechanisms have become the major goals in further advancing the technical capabilities of neutron imaging beamlines. At the cold neutron imaging instrument (CG-1D) of the High Flux Isotope Reactor (HFIR), recent efforts have been focused on improving the spatial resolution utilizing optical magnification. An improvement from ~100 µm to 20-30 µm has been achieved with a reduced field-of-view. Additionally, a Talbot-Lau neutron grating interferometer (nGI) has been implemented at CG-1D and enables simultaneous access to three imaging modalities: attenuation, differential phase contrast, and scattering. Respective details about the high resolution and nGI setups will be presented, along with a few scientific applications.

Acknowledgments

This research was sponsored by the Scientific User Facilities Division, Office of Basic Energy Sciences, U.S. DOE. This research used resources at the Spallation Neutron Source and the High Flux Isotope Reactor, U.S. Department of Energy (DOE) Office of Science User Facilities operated by the Oak Ridge National Laboratory.

Identification of the manufacturing process of Sardinian bronze statuary: a research project through neutron techniques

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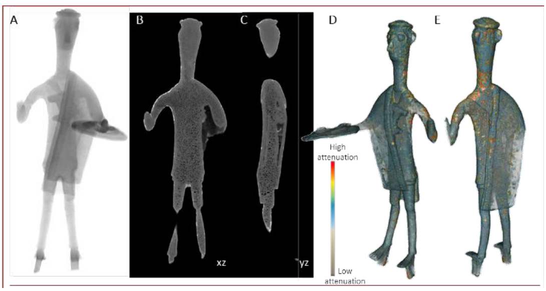
The production of "Nuragic" Bronze Figurines from Sardinia represents a rich historical archive that provides key information about the iconography, the metal production and casting techniques, and on the development of metallurgy in the Mediterranean basin. Since manufacturing methods employed in Sardinian bronze metallurgy are yet not fully understood, the investigation of such complex bronze artefacts is essential to determine which manufacturing techniques were employed. For example, complex bronze sculptures, made using lost wax technique, were rarely cast in a single solution: most of the parts of the wax model were moulded separately and then joined, as can be inferred also from a simple visual inspection. This work is devoted to the identification of metallurgical procedures applied to the production of bronze artefacts of the "Nuragic" Period in Sardinia. We analysed a set of six artefacts, three anthropomorphic statues (a warrior, a priestess and an offering figure), one miniature of a basket, one boat model and several bronze weapons; all of them appear outstanding concerning the accuracy of their manufacture, the originality of the subjects and the descriptive details. The samples were made available by Museo Nazionale Preistorico "L. Pigorini" and by the Sassari Archaeological Survey Office. The analyses were performed using neutron tomography (NT) and Bragg Edge Neutron Transmission (BENT) at the Paul Scherrer Institut (PSI) and ISIS. NT allowed to acquire a full 3D volume reconstruction of the statues, thus obtaining important details about casting procedure and connection among the different components. BENT provided Cu-Sn alloy composition analysis and details about the microstructure.



Neutron radiography (A), tomography slices (B-C) and rendering (D-E) of a votive Nuragic bronze figurine.

Development of in-situ Delayed Hydride Cracking tests using in-situ neutron imaging to study the H redistribution in Zr-2.5%Nb

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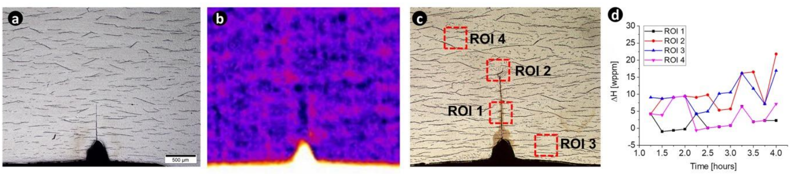
Zirconium based alloys nuclear components which operate under stress are particularly exposed to a failure mechanism called delayed hydride cracking. The main conditions for its occurrence are hydrogen concentrations above the terminal solid solubility at the temperature of interest, internal or external stresses and a flaw acting as a stress concentrator. When a certain stress threshold is exceeded, hydrogen diffused into the high stressed zone precipitates in the form of hydrides, a fragile phase which promotes cracking propagation in stages, i.e., by definition, delay hydride cracking (DHC). In order to study this phenomenon in situ, cantilever beam tests were performed material coming from Zr-2.5%Nb extruded and cold rolled pressure tubes microstructures which were tested in-situ on ANTARES cold neutron imaging facility in the air at 250°C. A properly test rig was developed to perform these tests on the neutron beam. H redistribution during mechanical testing was followed in-situ by changes in the neutron transmission and the microscopic analysis of the samples once time finished the test. DHC test is observed by optical microscopy in the figure below. The hydride precipitation was observed in the samples and by neutron imaging an increase in the H content between 5 and 10 wt. ppm was detected.



Images of Zr-2.5%Nb pressure tubes: (a) optical image before the DHC test, (b) neutron image before the test, (c) optical image after the DHC test (7 hours at 250°C), (d) evolution of H content determined by neutron imaging in different region of interest or ROI.

A work-horse neutron imaging station at the Laboratorio Energia Nucleare Applicata (LENA) in Pavia (Italy): Instrumental components and applications in the frame of the CHNet-NICHE INFN experiment.

Francesco Grazzi[1,2], Nicla Gelli[1], Francesco Cantini[1,2,3], Oriol Sans Planell[4], Luisa Vigorelli[4,5], Alessandro Re[4], Michele Prata[6], Daniele Alloni[6], Giulia Marcucci[7], Massimiliano Clemenza[7], Maria Pia Morigi[8], Naomi Orlandi[8] and the CHNet-NICHE collaboration

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The range of application of neutron radiography to the morphological diagnostic in cultural heritage materials is quite wide since it is a non-invasive technique which allows the identification of different materials and their relative spatial distribution with a reasonable level of contrast and resolution. In this frame, the Cultural Heritage Network (CHNet) of the Italian Nuclear Physics Institute (INFN) proposed and started a project called Neutron Imaging in Cultural HEritage (NICHE), devoted to the development and exercise of a neutron imaging station on the thermal port of the 250 kW TRIGA Mark-II reactor managed by the Laboratorio Energia Nucleare Applicata (LENA) in Pavia.

In this work, we will present the status and operation of the first two years of development of the project: technical characteristics of the beamline and the imaging station component, typical measuring configuration, possible applications, and examples.

Test Neutron Tomography slice and 3 D rendering and sectioning of a 30 mm height plastic figure, containing magnetite hemisphere in the basement made at the CHNet-NICHE station.

NTexture: simulation of wavelength-resolved neutron transmission experiments of textured polycrystalline materials

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The wavelength-resolved neutron transmission of textured polycrystalline materials has a complex dependence on the orientation distribution function (ODF) of the crystallites composing the sample due to the presence of crystallographic textures. After the original model by Fermi for a completely random crystalline powder, several models have been developed to evaluate the actual shape of the transmission curve between Bragg edges, by taking into account crystallographic texture effect on the elastic coherent neutron cross section.
Here we present NTexture, an open source software designed to evaluate wavelength resolved neutron transmission experiments on polycrystalline materials accounting for crystallographic and geometrical effects. The software is intended for general users and incorporates information about the specimen, such as geometry, crystalline lattice structure and crystallographic texture, together with experimental parameters such as neutron beam divergence, instrumental resolution and orientation of the sample in the beam, to simulate the wavelength-resolved transmission spectra of textured materials employing different models. NTexture includes a database containing neutron and crystallographic information from common structural materials, and user-friendly options to define sample geometry and the ODF of the specimen.

Design of a hydrogen-storage device for evaluating tensions induced by volumetric expansion during hydrogen absorption

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Hydride-Forming Materials (HFMs) allow to storage hydrogen in solid state. The reaction can be reversed by heat or pressure, releasing gaseous hydrogen. When hydrogen is incorporated into its structure, the HFM experiences a volumetric expansion. In the case of $LaNi_5$, a commonly used AB_5 type material, it can be as high as 27%. During cycling (successive cycles of hydrogen absorption/desorption), the HFM decrepitates and suffers compactation (Fig. 1, left). The decrepitation reduces heat transfer, while compactation, in the most extreme case, may deform or even break the container.

For constructing a safe and efficient hydrogen storage system it is of crucial importance to characterize the volumetric expansion and the tensions originated by the HFM. With these objectives, we have designed a device with an adequate geometry for being studied by neutron imaging (Fig. 1, right). With this technique, it is possible to observe the interior of a metallic vessel and at the same time distinguish, trough a convenient contrast difference, the hydrogen distribution in a HFM.

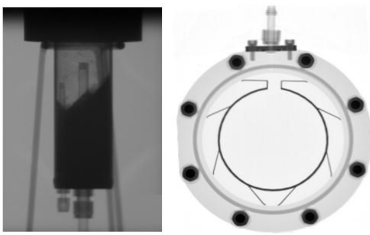

Fig. 1: Left: neutron image of a HFM container. The body is made of stainless steel which is easily penetrated by neutrons. In the interior it can be observed the compacted HFM after being cycled. Right: neutron image of a device made of aluminium. In its interior it has a 3D printed piece designed for evaluating tensions in situ. The gap at the extremes of the piece will vary during hydrogen absorption/desorption as a consequence of volume changes of the HFM.

Spatiotemporal dynamics of water in plant-soil interface measured by combination of time-series Neutron tomography and X-ray tomography

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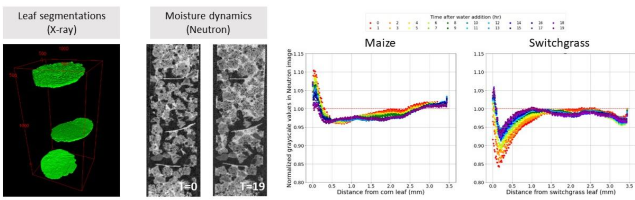
The water distribution at the interface between decomposing plant residues incorporated into the soil and the surrounding soil matrix can be distinctively different from that in the bulk soil, leading to accelerated residue decomposition and subsequent CO_2 emissions. However, investigating the water dynamics at residue-soil interface has been limited due to challenges of water visualization.

Using a combination of time-series neutron (nCT) and X-ray (xCT) computed tomography, we explored the distribution of water in the soil surrounding decomposing leaf residues. We assembled soil microcosms with leaves of two plant species with contrasting C and N concentrations: maize and switchgrass, where leaf disks were separated by layers of dry soil material. Dry samples were subjected to xCT and nCT, followed by water addition and time-series nCT monitoring of the subsequent water distribution (hourly, for a total of 19 hours). The xCT images were used to identify the locations of leaf disks and soil pores, and then overlayed with nCT images. The nCT grayscale values (GV) were used as indicators of the soil moisture content levels, enabling us to explore spatial patterns in standardized GVs as a function of time and distance from the leaves.

Two plants markedly differed in their water distribution patterns. Maize leaves quickly absorbed the added water and created a ~0.2 mm layer of higher moisture in the soil of their immediate vicinity. Switchgrass absorbed water very slowly and led to water-depleted regions in its vicinity. Concomitantly, more CO_2 was emitted from maize than switchgrass microcosms.



Examples of leaf disks segmented from X-ray CT (left), Neutron CT image (middle), and moisture distribution represented by grayscale values by distance from the leaf and by time (right). Three fragments of leaves were embedded in the soil column. Both X-ray and Neutron images were taken at the imaging beamline of ICON facillity at Paul Scherrer Institut, Switzerland.

Neutron Imaging of Irradiated Zr-based Claddings – Comparison of Results from POLDI, ICON and BOA Beamlines

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The understanding of hydrogen diffusion and precipitation in irradiated Zr-based claddings is of the utmost importance since inhomogeneous hydride precipitation affects the mechanical integrity of Zr-based claddings which is critical for the after-service operations of the spent nuclear fuels. Recent studies have shown that high-resolution neutron imaging (HR-NI) is an unrivalled method for the quantitative spatially-resolved assessment of the hydride accumulation in irradiated Zr-based claddings. The attenuation contrast and the extent of the refraction artifacts in attenuation-based neutron imaging are strongly dependent on the energy distribution of the incoming neutron beam. For HR-NI investigations, DX-D4 cladding samples were imaged at three beamlines with different energy spectra (POLDI – thermal, ICON – thermal to cold and BOA – cold neutron spectrum) by using Active Boxes to contain the irradiated samples at PSI Neutron Microscope. The irradiated DX-D4 cladding samples stemmed from the same nuclear fuel rod that was in operation for five reactor cycles with a burn-up of about 72 $GWdt^{-1}$ at Gösgen nuclear power plant (KKG, Switzerland). Generally, hydride accumulations at the liner-substrate interface and circumferential hydride accumulations were revealed in the images from all three beamlines. The layers of large attenuation contrast occurred on both the outer and the inner side of the cladding edges that were however strongly affected by the presence of the refraction artifacts. While the superior attenuation contrast has been advantageous for the visualization of hydride packets at BOA and ICON, the refraction artifacts that affect both the qualitative and quantitative analysis was the least at POLDI.

Keywords; High-resolution neutron imaging, Hydrogen, Irradiation, Neutron energy spectrum, Zirconium-based cladding

High-throughput neutron tomography using a drillcore rig for rapid and parallelised scanning

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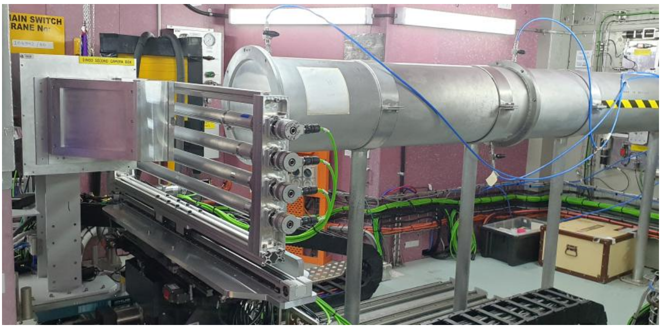
The Australian mining industry is increasingly reliant on the digital visualization of exploration drillcores, using X-rays, for the accurate determinate of ore mineral content, mine life potential, and acceleration of the exploration-to-profit mining lifecycle. Utilisation of neutron tomography (NCT) by the mining industry is, however, limited to highly specific research, primarily due to the high cost and long neutron-irradiation times, which limits the opportunity for broad-scope and high-throughput applications.

Recent upgrades to the DINGO thermal-neutron imaging instrument at ANSTO have enabled a significant reduction in NCT scan time and improvements in data quality. In collaboration with Macquarie University, a drillcore sample cartridge has been designed to hold up to 6 × 1 metre lengths of full core for rapid and parallelised NCT. This unique setup enables NCT of geological cores, at an equivalent resolution to industry X-ray units, at a commercially viable rate of 1 metre per hour. The high-throughput drillcore rig was successfully tested with the support of Aurelia Metals Ltd (AU) who provided cores for testing from the Federation Project, a significant gold-lead-zinc-copper-silver mineral deposit and proposed underground mine development in Australia. Given the importance of the mining industry in Australia, this new technique has the potential to enhance exploration activity, and better inform environment sustainability.



The high-throughput drillcore rig installed on the DINGO thermal-neutron imaging instrument.

Evaluation of fluxes, field of view and spatial resolution of ASTOR by MCNP & MCSTAS Monte Carlo simulations

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ASTOR (Advanced System for TOmography and Radiography) is a state-of-the-art neutron imaging instrument being developed by the Atomic Energy Commission of Argentina (CNEA) as part of the initial instrument suite of the Argentine Neutron Beam Laboratory (LAHN). ASTOR will be installed on one of the cold neutron beams of the 30MW open pool reactor RA-10, with direct view to a $10x10cm^2$ section of a D_2 cold source, located at 55 cm from RA-10 core. ASTOR will include a primary collimator within RA-10 biological shielding, and a set of 6 exchangeable secondary collimators at the shielding surface, at 2.55 m and 4.2 m from the cold source surface, respectively. Four beam-adjusted collimators will offer L/D ratios in the range 120-1500 with calculated fluxes between $3.7x10^8$ n/cm^{2}s and $2.4x10^6$ n/cm^{2}s and field–of-views between $11x11cm^2$ and $25x25cm^2$, respectively. The remaining two collimators will have rectangular pinholes to study linear profiles by either increasing the flux at moderate resolution (linear L/D=460 with a flux of $1.1x10^8$ n/cm^{2}s), or by improving the resolution (up to a linear L/D of 6300 with a flux of $2.4x10^6$ n/cm^{2}s).
Here we present the detailed design of ASTOR collimation system, together with the Monte Carlo simulations performed to estimate the flux, field-of-view homogeneity and spatial resolution for the different configurations of the instrument. The absolute values of neutron flux for several neutron energy groups for the coarsest resolution (L/D=120) were evaluated with the code MCNP5 from a full model of the reactor core. These results were used as reference values to define a source in the code McStas 2.7, in order to simulate the remaining configurations with detailed descriptions of the secondary collimators.

Understanding processes in the soil using neutron imaging

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Soil and the processes in it are essential for all life on earth. Water plays an important role in most of these processes, like imbibition, evaporation, transport of substances and nutrition, and mechanical stability. These applications have relevance for agriculture, civil engineering, environment protection, and natural hazard protection. Neutron imaging was early identified as a suitable method to study these processes, and over the years, many applications have been addressed. The common factor for these experiments is to benefit from the high sensitivity to water which provides high contrast images. In addition, the increasing demands on quantitative accuracy and image quality of these studies have been one of the driving factors for the methodological development of neutron imaging instrumentation. This development has given us methods like real-time tomography, scattering correction, and bimodal imaging with x-rays. We will provide a historical overview of the achievements in soil and plant science where neutron imaging played an important role. This overview will, in parallel, also describe the required development of the neutron imaging instrumentation and measurement strategies. Early experiments focused on soil hydraulics, while today's experiments have a wider spread of objectives such as the transport of particles like microplastics and bacteria, root water uptake, the carbon cycle.

Improve resolution for neutron imaging via CMOS camera based event mode detector

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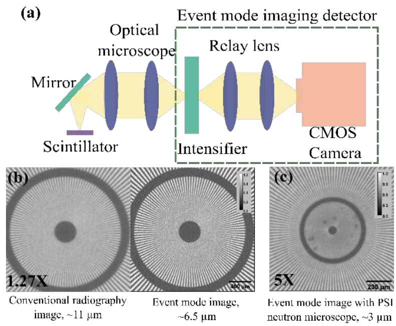
There always existed a big demand to achieve higher spatial resolution in neutron imaging. One possible way to improve the resolution is via event mode imaging, which captures visible light from each neutron event interacting with the scintillator in order to find accurate event positions by center of mass calculation. Utilizing this concept, we have developed a CMOS camera based event mode detector with zero acquisition dead time and real-time event data reconstruction. Our detector consists of an image intensifier and a high-speed CMOS camera. The resolution improvement has been demonstrated by combining our detector with a bespoke microscope optics with a magnification of 1.27X at ILL and with the PSI neutron microscope with a magnification of 5X at PSI (Fig. 1). We can also obtain detailed information about the image formation process from single neutron events. Thus, the event size, photon number per event, detected number of events (scintillator detection efficiency) and decay time can be directly measured for different scintillators. Moreover, neutron events arising from different compounds of the scintillator can be distinguished spatially or temporally, and can be reconstructed separately to determine the true resolution contribution and guide the scintillator mixture. Therefore, the technique offers large potential not only for the improvement of spatial resolution and signal-to-noise levels but also for the characterization and optimization of novel scintillator materials.

Fig. 1 (a) Sketch of an event mode neutron imaging system. (b) Resolution test results by a microscope with.1.27X: conventional neutron radiography (left, resolution ~11 µm), and with event mode imaging (right, resolution ~6.5 µm). (c) Resolution test result with PSI neutron microscope.



Failure characterization by pull-out test on structural inserts in sandwich panels used in the aerospace industry applying neutron imaging

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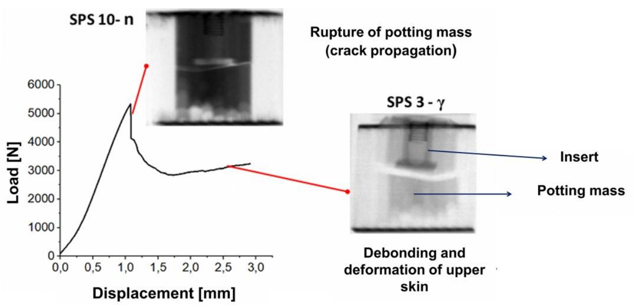
Sandwich panels are commonly used in the aerospace industry due to their high flexure resistance, strength properties and light weight. These components are fabricated by two laminates or skins made up usually of carbon fibres or aluminium plates and between these exists a honeycomb core made principally of aluminium alloys. These components have threaded inserts used for the union of panels or electronic components. They are bonded into the honeycomb core by filling the cells with a potting compound in the insert installation zone. To evaluate the resistance strength of the union, pull-out tests are performed by applying a normal load to the sandwich structure to determine the failure of the insert union. In the present work, failure characterization of inserts due to pull-out test was analyzed using neutron imaging. Experiments were performed on NECTAR, the thermal neutron imaging facility at FRM II. Two series of specimens with dimensions of $(10x10x2.5)cm^3$ and $(5x5x2.5)cm^3$ were tested by applying different normal loads to detect singular points in the load-displacement curves. Images were acquired using thermal neutrons and gamma rays by the use of a Cadmiun (Cd) layer filter on the neutron beam. Neutron imaging was useful to detect potting's failure while using the Cd-filter allowed to analyze the effect of the mechanical loading in the metallic components such as the insert and the aluminium plates.



Experimental load-displacement curve for sandwich panel of $(5x5x2.5)\ cm^3$. Different failures in the component are indicated using neutron imaging (n) and gamma radiation (γ).

Development of Tracer Particles for thermal hydraulic experiment by Neutron imaging

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Velocity field measurements of liquids is one of the most important teqniques for thermal hydraulic research. Various kinds of measurement methods have been developed for velcoty field measurements, however, most of them can be applied for transparent liquids in transparent test sections, such as the flowing water in a acrlylic tube. Even for water, such velocity measurment methods cannot be used if the test section is not transparent, such as the boiling water in a metalic duct. To measure the velocity field of liquids, appropriate tracer particles are needed for neutron imaging. The visibility and the tracerbility of the tracer particles should be estimated to obtain accurate velocity measurments. In this study, the visibility and the tracerbility of AuCd3 paricles and other paricles dispersed in a liquid metal was experimentally investigated by using steady neutron source at the JRR-3 of Japan Atomic Energy Agency. The experiments were made by varying the density and the diameter of the tracer particles.

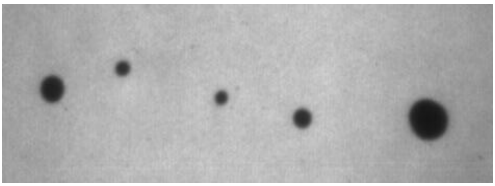

Fig.1 Examples of tracer particle (Cd) image by thermal neutron

Progress of cold neutron imaging facility at China Advanced Research Reactor

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A new cold neutron imaging facility is under construction at China Advanced Research Reactor (CARR) to support the area of neutron radiography and tomography research, which is located at the end of CNGC neutron guide with m=2 in neutron guide hall. The expected maximum neutron flux at the sample position is 1.87×10^{8} n/cm^{2}•s, and the maximum beam size is 30cm×30cm. The L/D ratio can be varied from 160 to 1600 with pinhole sizes ranging from 1 to 5 cm. At present, all the components have been developed, and the installation of its shielding system has been finished. Owing to the effect of COVID-19, the installation of neutron guide from Mirrotron company is delayed. It is expected that the instrument construction will be completed at the end of this year.

The cold neutron imaging facility was designed to be a flexible space to develop advanced neutron imaging methods. At present, energy-selective neutron imaging, high resolution neutron imaging, neutron/X-ray bimodal imaging have been developed at CARR. The possibility to perform polarized neutron experiments will be provided next year.

Energy selective neutron imaging study for metal cultural heritage

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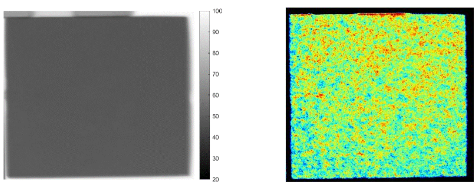
Compared to destructive analysis, non-destructive analysis can preserve the original cultural heritage. but technology using X-rays and gamma rays have limitations in the internal precise analysis due to low transmission to metallic materials. However, the metal cultural heritage analysis technology using neutrons has the advantage of being able to check the internal structure of the material and the information of crystal structures without destroying the cultural heritage.

In this study, standard samples produced using a technique known as Bragg-edge neutron transmission were analyzed and recorded using a two-dimensional array of detectors. we used the body-centered cubic (BCC) ferrite 110 refection for the single-edge analysis. The experiment was conducted in a small neutron resource at Hokkaido University in Japan (HUNS) and HANARO at the Korea Atomic Energy Research Institute, and the data were analyzed through MATLAB. As a result of the experiment, the degree of the phase distribution of ferrite (BCC) and austenite (FCC) could be confirmed. Also, internal defects were observed and compared with the X-ray transmission image.

This study confirmed that the crystalline structural characteristics of metal cultural heritage that cannot be analyzed for destructive analysis can be identified through non-destructive analysis using energy-selected neutrons. Detailed experimental results, including other parameters such as absorption and multiple diffractions, will be presented in the workshop.



A neutron image of a standard sample (magnetic sand). (Left) Neutron transmittance (%) imaging, (Right) BCC structure distribution imaging obtained through Bragg-edge.

Visualization of local two-phase flow structure in a packed bed of spheres

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A two-phase flow structure in porous media is essential to clarify the debris cooling characteristics during a severe accident in nuclear power plants. In the previous studies on debris cooling, a packed bed of spheres has been mostly used instead of the porous debris bed. Many models to predict the flow characteristics in the packed bed have been proposed. However, those models have not considered the local flow structure, and it should be studied to enhance the prediction accuracy. In this study, the local flow structure of the gas-liquid two-phase flow in the unit model of the packed bed of spheres was measured by neutron imaging. The bubble behavior was observed by high-speed neutron imaging and 3-D void fraction distribution was estimated by neutron computed tomography. From these results, the breakup and coalescence of the bubbles in the packed bed were evaluated.

Diffusion bonding evaluation of a microchannel cooling system using neutron imaging technique

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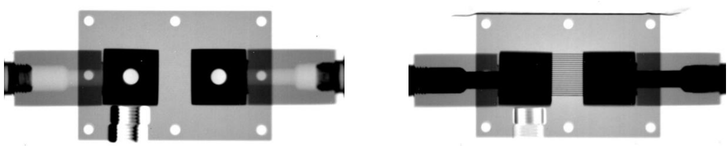
For several years, CNEA has been developing an electrostatic accelerator technology for neutron production through nuclear reactions induced by charged particle beams. In order to carry out these nuclear reactions, a high current deuteron beam impacts on a material called neutron production target, and as a consequence of this impact, a large amount of energy is deposited, generating heat. In order to drain the heat to keep the neutron production target working under safe temperature ranges, it is proposed to incorporate a high-performance refrigeration system.

One of the challenges during the manufacture of this device consists in the joining between the two pieces; a flat aluminum plate and a parallel microchannel system that has been machined with a 500 µm rectangular geometry. The welding technique chosen in this case is diffusion bonding.

In order to verify in a non-invasive way that the procedure by which this welding has been carried out did not produce water cross flow, leakages or obstructions in the microchannel system, it is proposed to use the neutron imaging technique using the CNEA radiography and tomography facility of the RA-6 Research Reactor in the city of Bariloche.



Neutron images of a high-performance refrigeration system prototype with (right) and without (left) water flowing through the microchannels system. Images were taken at the imaging beamline of the RA-6 Reactor in Bariloche, Argentina.

Diagnosis of the conservation status in archaeological objects from Museo de la Patagonia by using imaging complementary techniques

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In the framework of the Integral Plan for Conservation and Restoration of the Giai collection of the Museum of Patagonia (PNNH-APN), we developed a working methodology for the study of cultural assets. In this, the diagnosis of the conservation status of each object is the first mandatory methodological instance to propose and execute suitable conservation treatment.

The aforementioned collection consits of several objects of indigenous funeral assets, collected in the center of Neuquén, Argentina in 1943. It lacks any contextual information about the finding or the objects itself, which motivated the implementation of non-destructive investigation techniques in order to reconstruct some morphological, structural and compositional information for each object.

Here we present the analysis of a metallic jingle bell from this collection, by implementing complementary Neutron and X-Ray tomographies performed at the Helmholtz Zentrum Berlín. Jingle-bells are traditionally metal spheres with a small opening, inside of which there is another object of smaller size called “jinglet”. By measuring the absorption coefficients in areas of interest, we could infer that the jinglet material is similar to the outside part. Also we could measure thicknesses, and visualize representative morphological traces of the manufacturing process that were found under the corrosion layer.

The information obtained in this analysis is a great contribution to the construction of an accurate conservation status diagnosis, showing the capabilities of the complementary techniques in this field.

Development toward mapping multi-grain samples with single crystals using neutron transmission

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The mapping of grains and their orientation is used to investigate the correlation between polycrystalline materials properties and their microstructure. Techniques such as scanning electron microscopy electron backscatter diffraction (SEM-EBSD), and X-ray diffraction (XRD) imaging are often used for grain orientation mapping. Both techniques are limited by their penetration depth, sub-micrometers (SEM-EBSD), and micrometers (XRD imaging). Neutrons higher penetration depth provides outstanding structural features for studying bulk samples. The transmission spectra of single crystal or multi-grain samples are characterized by dips at wavelengths, where Bragg's law is being fulfilled for unique crystal orientations, which can be used to resolve the orientation of the crystals and assess the microstructure at the local grain level. In this presentation, I will discuss efforts to map multi-grains with single crystal using the Sinpol application. *Sinpol* is a collection of routines for calculation of the attenuation of neutron beam by crystalline specimens. The total cross section is calculated as a function of neutron energy, crystal structure, temperature, and crystal orientation. The contribution of Bragg (elastic coherent) scattering to the total cross section is evaluated within secondary extinction theory using both the crystal's mosaic spread value and its orientation with respect to the neutron beam direction as parameters. The *Sinpol* simulations can be used in an iterative way to determine a single crystal orientation and offer a potential tool to discriminate between multiple single crystals in a multi-grain sample.

Development of an intensified neutron camera system for high sensitivity white-beam imaging

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Neutron Imaging is a steadily expanding area of imaging technology with increasing interest from applications such as non-destructive inspection, cultural heritage, and metallurgy. Increased demand for access combined with a limited number of suitable beamlines requires efficient use of available beamtime. Here we present test results of a prototype thermal and cold neutron camera system, N-Cam, designed for increased sensitivity, thus able to capture detailed images with reduced exposure time as compared to most neutron cameras. The N-Cam prototype utilizes a 20 µm thick Gd_2O_2S:Tb (Gadox) scintillator applied directly onto the input window of an image intensifier. In experiments performed at the Rutherford Appleton Laboratory ISIS-IMAT facility, the N-Cam prototype demonstrated good contrast imaging with 10 lp/mm spatial resolution in 5 second exposures at multiple locations over its 75 mm field of view (FOV). The measured Modulation Transfer Function (MTF) is consistent with that expected based on the system's Nyquist limit and the measured resolution of the image intensifier. A contrast phantom was used to measure 350 grey scales over a spatial scale of several mm in 600 seconds at a neutron flux of 2×10^7 n/(s·cm^2). The Detective Quantum Efficiency (DQE) of the system is estimated to be 16% based on detailed analysis of flat field images. Tomography will be presented using a quantitative mixed media phantom.

Conceptual design of neutron imaging instruments for the HBS

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Keywords: neutron imaging, instruments, design, pulsed neutron sources, time-of-flight

The High Brilliance Neutron Source (HBS) project aims to develop a high-current accelerator-based pulsed neutron source (HiCANS) for neutron scattering, analytics, and imaging. Fast neutrons with an energy of about 0.5 MeV will be generated by the interaction of 70 MeV, 100 mA proton beam with a tantalum target. To deliver individually tailored beam characteristics for each instrument, three target stations will operate at different frequencies. For the low (24 Hz) and medium (96 Hz) frequencies stations, the neutrons will slow down to 100 meV by a thermal moderator and down to 10 meV by a cold source. In addition, a high-frequency mode can be adopted for a short pulse station (384 Hz), where a dedicated epithermal moderator will be used. Amongst the various instruments planned at HBS, there will be at least four different neutron imaging instruments, each one for a different neutron energy range: cold, thermal, resonance/epithermal, and fast.

The cold neutron imaging instrument will perform high spatial resolution, and high sensitivity measurements, utilizing in many cases the time structure of the source for quantitative wavelength dispersive imaging. It will have at least three sample positions: 5 m, 15 m, and 35 m. All these positions are selected to optimize the flux, the spatial resolution, and the wavelength resolution, and will be ideally suited for different studies: hydrogen in metals, energy conversion processes, water uptake in different materials or two-phase flows, the contrast in crystalline structures such as in phase mapping studies in engineering and applied metals, Bragg edge imaging applications with a specific focus on strain mapping, and so on.

The thermal neutron imaging instrument will feature high time-averaged flux, high spatial resolution, and large FoV. It will have at least two sample positions: 4 m and 10 m. These conditions will enable investigations of dense objects and devices such as statues, ancient weapons, engines, and other industrial devices, wood and metals, running engines, motor blocks, components from automotive and aerospace applications, etc.

The resonance/epithermal neutron imaging instrument will be optimized to maximize the flux, spatial resolution, and energy resolution with sample positions at 15 m and 35 m, one for conventional high-energy neutron imaging and one for resonance absorption investigations. Neutron resonance and fast neutron imaging will be performed on two separated beamlines. Those instruments will enable, for example, isotope and element mapping through resonance absorption in the epithermal range using time-of-flight imaging. Moreover, higher energy neutrons provide the potential for transmitting denser and thicker samples. This is important in many cases of technological interest, such as for large batteries.

The objective of this poster is to present to the neutron imaging community the principal parameters, the potential capabilities, and the conceptual design of these instruments.

Modelling of Neutron and X-ray radiography system

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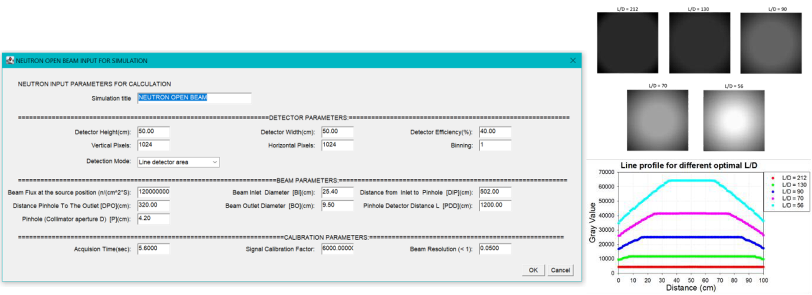
Radiography is an imaging technique that is extensively used for the non-destructive investigation of materials and objects. The technique is used in the scientific and industrial communities to retrieve both qualitative and quantitative information, of the internal structure of the sample under investigation. The integrity of the investigation lies in the quality of the radiograph and analytical techniques used in the information retrieval. An experimental process for arranging the parameters such that the most optimal quality radiograph is produced, for a given investigation, is a time consuming and labour intensive process which is prone to human error. Therefore, a radiography system model which allows the integration of an automated optimization function is being developed. The model provides a virtual environment in which Neutron/X-ray scanning parameters can be optimized within pre-set criteria for the specific design purposes. The model was designed using a ray-tracing technique combined with the exponential law of attenuation, to provide the primary function of such a virtual environment which is the modelling of the radiography system. This approach provides a direct "uncomplicated" virtual environment for basic radiography training, development and basic experimental planning. In this presentation the updated menus and added functionality of the simulator are demonstrated.



Input menu for the neutron radiography system modelling (Left) and the modelling of the L/D ratio (right)

Creating new capacities in human resources within the UMSS in the specialized applications of neutron radiography for the Bolivian Nuclear Research Reactor

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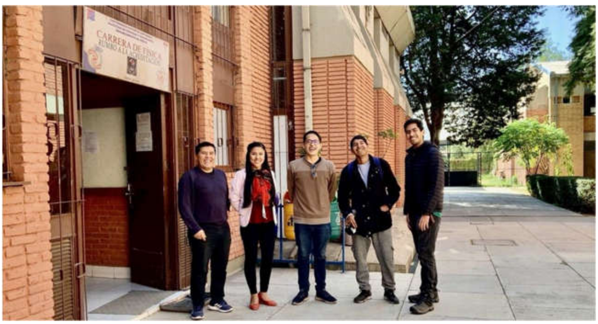
Abstract
The Bolivian Government is investing in equipment for research and development of nuclear technology applications within the framework of the Bolivian Nuclear Project (PNB). Central to this is project is the first Bolivian nuclear research reactor, which will include a neutron radiography beamline. Incorporation of these new technologies in the region requires specialized professionals in the different areas of nuclear technology. The Universidad Mayor de San Simón, through the Departmento de Física of the Facultad de Ciencia y Tecnología, is promoting the implementation and application of neutron radiography, aiming to the study and characterization of archaeological and paleontological specimens.
In the present work, we present the activities and new capacities were generated in human resources through the dissemination of neutron radiography applications in seminars aimed at the university community, where it was possible to introduce the basic concepts of nuclear technology and neutron radiography. As a result of those seminars, a "Neutron Physics" research group was created that through graduate and undergraduate thesis projects further disseminates and promotes neutron radiography applications to a wider community.
Keywords: Neutron radiography, collimation ratio, Nuclear research reactors



First members of the "Neutron Physics" research group

Design, manufacture and application of high contrast devices to measure neutron imaging resolution

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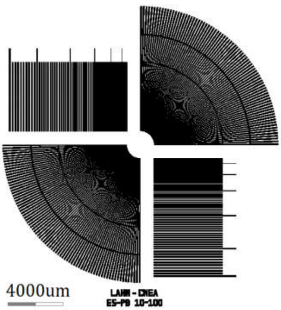
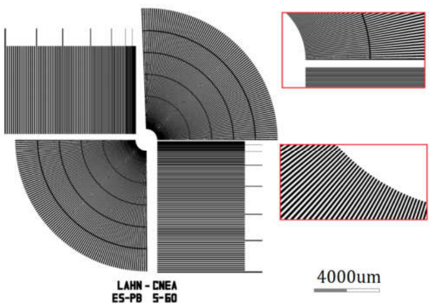
Abstract
The characterization of the spatial resolution of a neutron imaging instrument allows the precise determination of its experimental capabilities and the confidence of the information produced from the analysis of the images produced with it. Here we present the design, manufacture, and application of a set of high neutron contrast devices capable of determining spatial resolutions within the 5 - 500µm range. The basic design combines two quarters of a Siemens star with horizontal and vertical linear patterns, and use gadolinium oxide powder as absorbing material on a monocrystalline silicon substrate. MEMS technology was chosen for fabrication as it can effectively deal with the resolution ranges included in the device.

The efficacy of the fabricated patterns for the determination of spatial resolution was defined by experiments performed in the thermal neutron imaging beamline of the RA-6 reactor (Argentina) and the cold neutron imaging beamline NG6 of the NIST Centre for Neutron Research (USA). The results allowed establishing the spatial resolution of both instruments under different configurations, the characterization of epoxy-based scintillator screens, and the characterization of the test device up to the intrinsic resolution of the NG6 beamline.

Keywords: SIEMENS STAR, GADOLINIUM OXIDE.





NTexture: simulation of wavelength-resolved neutron transmission experiments of textured polycrystalline materials

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The wavelength-resolved neutron transmission of textured polycrystalline materials has a complex dependence on the orientation distribution function (ODF) of the crystallites composing the sample due to the presence of crystallographic textures. After the original model by Fermi for a completely random crystalline powder, several models have been developed to evaluate the actual shape of the transmission curve between Bragg edges, by taking into account crystallographic texture effect on the elastic coherent neutron cross section.

Here we present NTexture, an open source software designed to evaluate wavelength resolved neutron transmission experiments on polycrystalline materials accounting for crystallographic and geometrical effects. The software is intended for general users and incorporates information about the specimen, such as geometry, crystalline lattice structure and crystallographic texture, together with experimental parameters such as neutron beam divergence, instrumental resolution and orientation of the sample in the beam, to simulate the wavelength-resolved transmission spectra of textured materials employing different models. NTexture includes a database containing neutron and crystallographic information from common structural materials, and user-friendly options to define sample geometry and the ODF of the specimen.

ITMNR-9

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