International NR Newsletter

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International Society for Neutron Radiography

(www.isnr.de)

Group picture in the last day (21/10/2022) of the ITMNR-9 meeting

Content

Editorial

Dear colleagues,

many virtual meetings in the last years underlined their advantages for information exchange, keeping human relations and even for extensive (scientific) discussions in times when personal meetings were nearly impossible. Economy of time and money as well as climatic aspects are further arguments for this type of interaction not to be dismissed out of hand. Despite these arguments, they cannot replace physical meetings from time to time in general as ITMNR-9 has shown. All the interactions between persons with their nuances can only happen in a physical context and never virtually (even by using emojis ☺) - just think about the short comments you are sometimes whispering to your neighbor during a presentation. From this point of view, as well as by the presented contents, ITMNR-9 in Buenos Aires was an absolute highlight of our community over the last years. How inspiring the meeting was you can see by the present issue of the NR newsletter. Never before we had so many contributions and so many pages. At this point a big thank for all those investing their time and efforts for contributing with one or more articles and a call for all others to keep up with own contributions for one of the next issues.

One important aspect is represented by two articles and deals with "education". This field may become one of the focuses of ISNR in the next year. This is already supported by the new Task Groups "Small or low-cost Neutron Systems" and "Computational Imaging" covering this topic in the broadest sense, too. What do you think about this? Do you have some ideas how to deal with this topic or do you already realize some projects? Don't hesitate to share your experiences and information with you colleagues.

One extremely important topic for our community is the availability of neutron sources, the basis for most of our work. While several upgrades and new installations of facilities are on their way, others are out-of-operation for reconstruction - or even worse - decommissioned. Several contributions in this issue are dealing with these aspects. The new Task Group "Neutron Instrument Access" is engaged giving actual overviews on facilities in operation, under construction and on user access. Here you are requested to actively contribute to keep this overview, that will be published on our webpage, too, up-to-date by sending information to the Task Group leader or the secretary of ISNR.

And not to forget the topics "Development and Testing" and "Applications", the latter being the ultimate goal of all our research, developments and investments. Only by promoting and demonstrating the uniqueness and usefulness of Neutron Imaging for public interests in general and economic and ecological aspects in particular we will have a real justification for our work. May you get some according ideas by reading this newsletter, realize them in the near future individually or by cooperation with some other members of the ISNR, and finally don't forget their presentation in an article in one of the next issues.

With this, enjoy reading and keep healthy

Thomas Bücherl
ISNR secretary

Words from the ISNR President

Dear Colleagues,

This has been a breakout year with conferences and meetings finally resuming for the first time since the start of the lockdowns in 2020. As you may be aware, our ITMNR and WCNR conference series were postponed by two years due to the pandemic. While some are yet unable to travel, it was an absolute pleasure to see so many of you at ITMNR-9 in Argentina.

Some application-specific meetings not organized by ISNR also resumed in 2022. The 12th International Conference on Methods and Applications of Radioanalytical Chemistry (MARC XII) in Kailua-Kona, Hawaii, USA that included a special session specifically on neutron imaging applications for the first time in that conference series. The Electrochemical Society met twice in 2022, Canada in May and USA in October, which drew multiple neutron imaging presentations for relevant applications. Additionally, the American Conference on Neutron Scattering was held in June 2022 and the International Conference on Neutron Scattering was held in August 2022. The world has opened back up.

The 9th International Topical Meeting on Neutron Radiography (ITMNR-9) was held in October 2022 with over 100 attendees represented 16 countries. There were 105 presentations and posters that represented new and interesting work in our field. The conference was a huge success! Many thanks to the sponsors, to Javier Santisteban, and the organizing committee.

The ISNR Board met during ITMNR-9 about multiple items of business, many of which are reported in this Newsletter. One item of business was to review candidates for hosting the next ITMNR. The selected host was first announced during the closing session of ITMNR-9. The Board is proud to say that the host of ITMNR-10 is Alessandro Tengattini representing the Institut Laue-Langevin (ILL) in Grenoble, France. Additionally, the NEUWAVE series is resuming with the next meeting being hosted by our colleague Takenao Shinohara in October 2023 near Tokyo, Japan.

The ISNR Board reviewed the status of its task groups, removing some task groups and establishing new ones. The Board is reviewing its constitution, bylaws and guidelines for clarity and consistency, which effort is ongoing within the ISNR Board. These documents are available at the ISNR webpage (isnr.de). The Board also discussed the prospect of combining the ITMNR and WCNR series, which idea has been proposed multiple times in the past. Details about these topics are available in the meeting minutes on the ISNR webpage. These efforts are all focused on the chief mission of the ISNR to facilitate communications and interactions among our growing worldwide community.

Finally, I would like to report that planning for WCNR-12 is actively moving ahead. We are planning to host WCNR-12 in late May or early June of 2024 in Jackson, Wyoming, USA.

This 18th edition of the ISNR Newsletter includes encouraging and interesting news from around the world. I hope that you enjoy reading the most recent news from our field, and are as excited as I am about our upcoming meetings.

Wishing you all the best in the new year!

Aaron E. Craft

Aaron E. Craft

ISNR President

Neutron Imaging Facilities

Neutron Source Availability for Neutron Imaging

Neutron imaging has been developed towards a well-established technique for many fundamental, but also very applied questions. It has similarities to X-ray imaging and can be seen as complement to this very common non-destructive investigation tool.

While X-ray sources are easily available in hospitals, research labs and even at manufacturing lines, neutron sources are rare. The main option for a strong neutron source is a fission reactor. In order to perform neutron imaging with an adequate quality, beams of thermal neutrons have to be extracted from the reactor core and the surrounding moderator, or even cold neutrons from a cold source next to the core. The power of research reactors has a range from a few Watt up to about 100 MW. Neutron flux scales with the power level accordingly.

Due to the introduction of digital neutron imaging techniques in the last decades, the sensitivity of these detectors has been dramatically increased. Typical acquisition time for one frame is in the order of seconds at a common beam line of a reactor with 10 MW power. This enables now also more sophisticated neutron imaging techniques like neutron tomography, real-time imaging, phase-contrast imaging and grating interferometry in reasonable times.

On the other hand, neutron computed tomography with new sensitive detectors has recently been demonstrated at the VR-1 reactor of CTU Prague with only 500W reactor power, using individual exposure times of a few minutes.

Because neutron imaging is now handled equally to other neutron techniques like neutron scattering, neutron activation analysis (NAA, PGNAA) or several irradiation techniques, many reactor sources have implemented or plan to implement neutron imaging facilities, however on different technical level. The state of the art has been described in several publications [1, 2, 3]. Again, only the larger reactor facilities have or will have cold neutron sources for extending the range of neutron wavelengths for the utilization of more advance neutron imaging techniques like Bragg edge imaging, Grating Interferometry, and many magnetic measurements. These techniques require a high-flux beam and are not feasible on smaller, low-power reactors for any reasonable utilization.

However, the situation of research reactors has been changing for several years and the trend is ongoing: While industrialized countries shut down their research reactors more and more, developing countries are installing new ones. The reasons for the stop of operation are often political, but also technical ones: Age of installations, higher safety requirements, underutilization, missing fuel suppliers or lack of qualified manpower. Prominent sources were shut down recently in Europe: BER-2 in Berlin (D), Orphee in Saclay (F) and JEEP-2 in Kjeller and the Halden Reactor (N). On the other hand, some of the knowhow went to ILL Grenoble, where a new facility named NeXT was built and is now already undergoing a major upgrade.

Also, reactor sources with high performance and utilization are not without operational risks. Recently, the FRM-2 (D) went out of operation due to technical problems and component failures. The reactor at NIST (USA) stopped the operation because of fuel element leaks caused by handling mistakes. The whole user program, well established at these sources, came out of balance and several projects have to be postponed.

The situation in the developing countries is different. Although the new reactors are operating well, their utilization is not yet established as in industrialized countries. Projects for imaging beam lines are on the way (Argentina, Jordan, Morocco, Chile etc.), but a real user program is not implemented, and not all of the new sources will have a cold neutron source for imaging methods. Many of these new reactors focus on technical applications like isotope production and nondestructive testing, and still have to establish a scientific community for more advanced scientific questions. Often, the budget is insufficient to establish the infrastructure and to hire qualified manpower. As a kick-off installation, a simplified, but high-quality digital imaging system for neutron computed tomography [4] is proposed, as it is comparatively simple to install, and immediately delivers results that are easily understood by the public.

Alternative neutron sources are based on accelerators, where a spallation process is induced by high-energy particles (mainly protons) during the bombardment of a heavy element target. Spallation sources are also equipped with neutron imaging facilities, mostly on high performance level (IMAT at ISIS, UK; RADEN at JPARC, Japan). Because most of the spallation sources are operated in a pulsed mode regime (5 to 50 Hz), time-of-flight based energy-selective imaging methods can be applied successfully by using respective detection systems.

Under construction are the VENUS facility at SNS, USA, and ODIN at ESS, Sweden.

Such high-power spallation sources are very expensive in the construction, but also in the operation. Therefore, some initiatives go for simpler accelerator driven sources with particle beams with lower particle energies, but higher beam intensity – e.g., 100 kW. The High-Brightness Source of the Jülich Research Centre (D) is probably the most promising and pioneering project to be operational not before 2025 [5].

Meanwhile, some less powerful sources have been equipped with neutron imaging capabilities and it is surprising to see imaging data with reasonable quality produced with source on the few Watt level (AKR-2 in Dresden (D), VR-1 in Prague (CZ)).

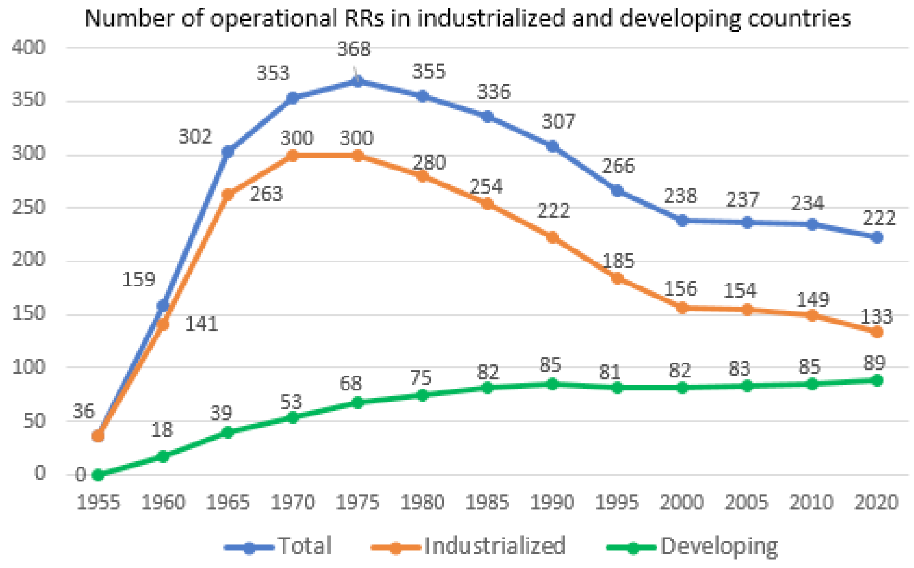

Fig. 1: Situation of the research reactors in a global context, information by IAEA, Vienna

With new instrument equipment, neutron techniques are currently receiving a revival and boost. The industrialized countries must make a major effort not to lose knowledge and knowhow, and make an effort to help to establish these techniques at new facilities worldwide.

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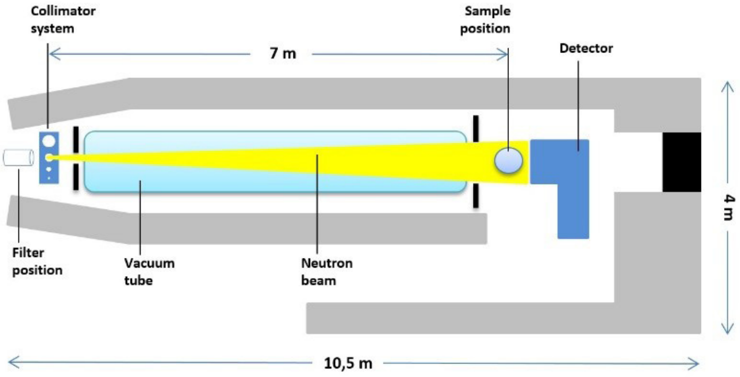
New Neutron imaging Station TITAN at the WWR-K Reactor in the Republic of Kazakhstan

Since 2017, work has been underway to design and construction of new neutron radiography and tomography facility at the WWR-K reactor by specialists from the Institute of Nuclear Physics (Almaty, Kazakhstan) and the Joint Institute for Nuclear Research (Dubna, Russia) [1]. In 2019, this experimental facility TITAN (**T**ransmission **I**maging with **T**herm**Al** **N**eutrons) was put into operation [2]. TITAN is the only neutron imaging instrument in the Republic of Kazakhstan, and is available for a wide range of applications in materials science and engineering research. In this brief report we want to introduce the facility and its main parameters.



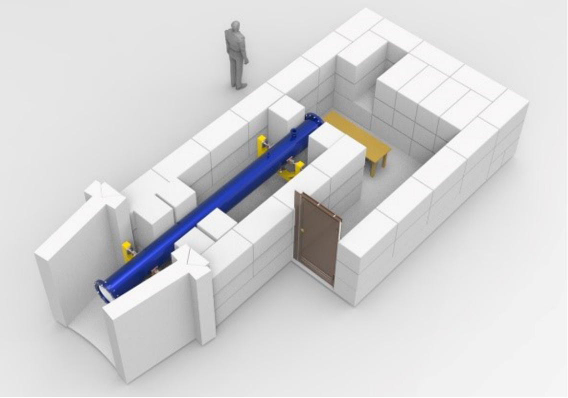


Figure 1. Upper: the horizontal view of the TITAN neutron imaging facility with indication of the main components of the facility. Right: The 3D scheme of TITAN facility.

The simple schema of a horizontal section of the TITAN facility, as well as its three-dimensional draw, are shown in Figure 1. Due to the design features of the reactor experimental hall and the first horizontal beamline, the distance from the source moderator wall to the sample position is 14 m only. The block of neutron filters serves as a reducer for unwanted background radiation [3]. An aperture system consists of several boron-polyethylene and cadmium layers and has different pinhole diameters of 40, 20, 10 and 5 mm for variation of L/D parameter from 100 to 1400.

A vacuumed tube with a length of 5.5 m is mounted to reduce the neutron scattering losses in air. The rotation table based on system of goniometers was installed for a performing neutron tomography experiment. The thermal neutron flux at the sample position is $1.4{\cdot}10^8$ n/(cm$^2{\cdot}$s) with L/D parameter of 100, while $1.2{\cdot}10^7$ n/(cm$^2{\cdot}$s) with L/D=350 [4]. The maximum size of the neutron beam in the sample position is 20 x 20 cm^2. The detector system is represented by a two-mirror scheme with changeable scintillation screens and high-sensitive CCD camera. The camera lens can change field-of-view parameter from 5 x 5 to 20 x 20 cm^2. A fast mode of neutron radiography experiments can be realized using high-speed CMOS camera. First test measurements for high-rate measurements provided minimum achieved exposure time of 100 ms, the full tomography collection was achieved during 72 seconds. Several experiments on the study of fast processes like water absorption were performed.

Now, several agreements have been signed with scientific organizations and universities about cooperation and wide sharing of neutron beam time for collaborative research. The various science programs, including archeology, paleontology, geology, meteorites, lithium-ion batteries, building materials, visualization of fast processes, and others, are realized using opportunities of TITAN facility [5]. As a resent example, the results of neutron tomography studies of the medieval dagger of the Kazakh khans are presented in Figure 2. Neutrons show a complex structure of the dagger handle. There is a strong neutron radiographic contrast between the inner components in the handle. The spatial resolution of TITAN facility is quite sufficient to distinguish small details of the inner structure of objects.

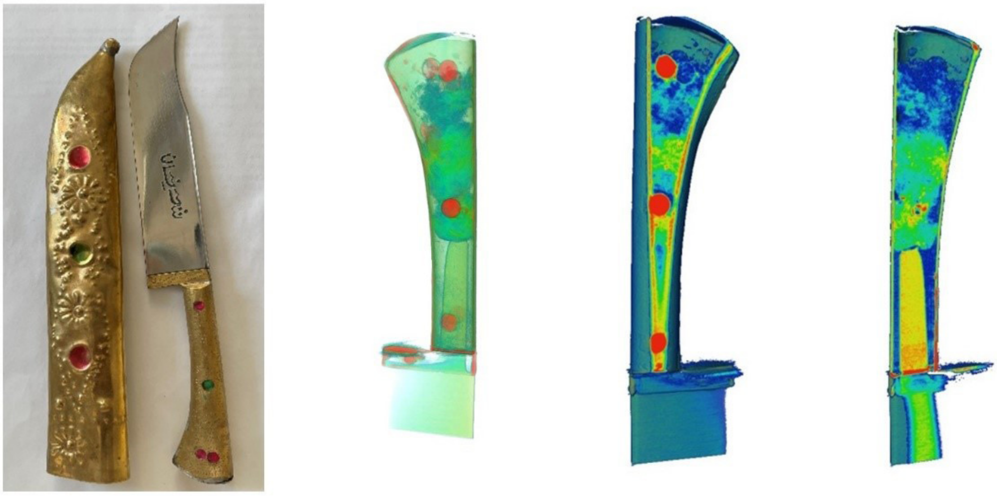


Figure 2. Photo and neutron tomographic 3D model of the medieval dagger of the Kazakh khans. Several slices of reconstructed model are presented.

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Update on the VENUS Construction Project

VENUS is a time-of-flight neutron imaging beamline currently under construction at the Spallation Neutron Source (SNS), located at the Department of Energy's Oak Ridge National Laboratory (ORNL).

In the past year, the VENUS construction project has reached significant milestones such as the completion of the concrete pours (see attached photograph) for the instrument cave and beam stop, as well as the completion of the front-end shielding (not visible in the photograph), installation of the variable aperture system (VAS), and the first flight tube positioned downstream of the VAS.

The construction project is expected to be completed in April 2024. The instrument will then enter a neutron beam commissioning phase with limited access to the user community that will last approximately 12 months. Once commissioning is completed, VENUS will be available to researchers as part of the ORNL Neutron Sciences general user program.

For more information, please contact Hassina Bilheux (bilheuxhn@ornl.gov)

VENUS Homepage: https://neutrons.ornl.gov/venus

Hassina Bilheux

Fig. 1 VENUS instrument cave and beam stop. The roof beams are visible on the floor (left of the beam stop). Credit: ORNL, U.S. Dept. of Energy.

Update of NeXT

NeXT-Grenoble is the Neutron and X-ray at the Institut Laue-Langevin (ILL). This instrument is undergoing a major upgrade, to further expand the portfolio of contrast options. This is the result of a collaboration between the Universite Grenoble Alpes, the Helmholtz-Zentrum Berlin, and ILL, also via the newly founded Joint Research Unit NI-Matters. This

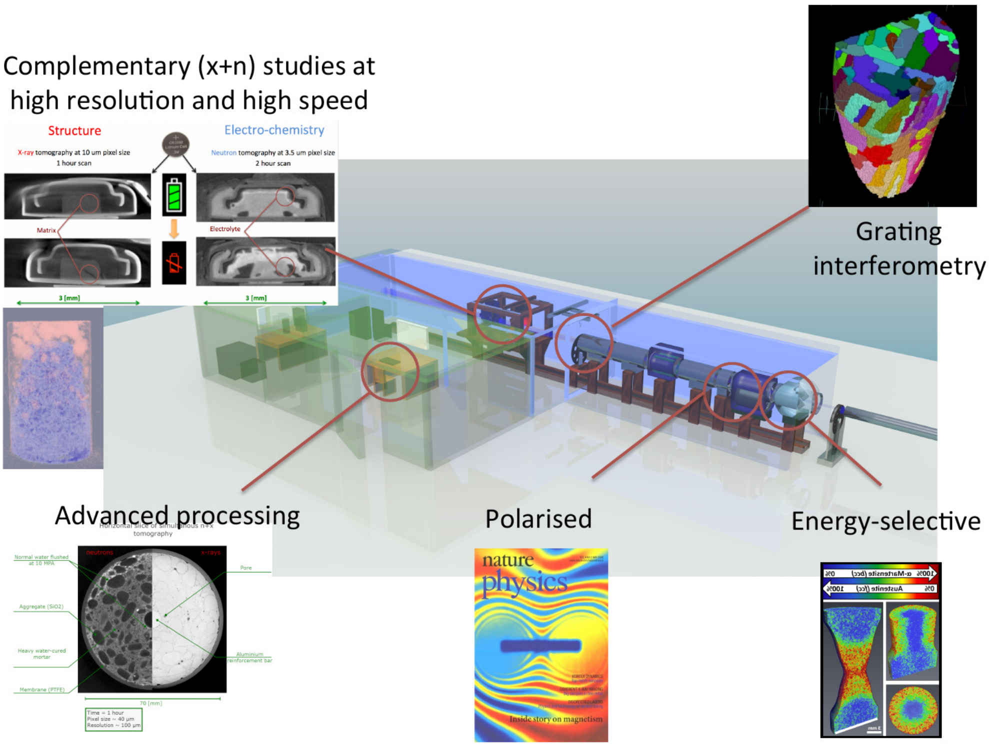


Figure 1. A schematic representation of the upgraded instrument.

upgrade is nearing its completion and the instrument will restart its operation in February 2023.

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 allow a native integration of neutron polarization equipment in order to perform vectorial tomographies of magnetic fields.

Alessandro Tengattini

Applications

Neutron imaging of Double-Row Ball Bearings Made of 100Cr6 High Carbon ChromiumSteel for Automotive Application

100Cr6 high-carbon chromium steel submitted to martensitic hardening and tempering is a typical construction material of bearings, rings, balls, and rollers, and the automotive sector is a main industrial user.

Neutron Tomography (NT) has been carried out for the investigation of two double-row ball bearings - one new (unused), and another damaged during use - made of 100Cr6 steel and applied for the belt tension lever of a car engine. This type of bearing, in particular, is located inside of the belt tensioner lever on the engine. In the case of malfunction, often due to wear, the belt tensioner would function inappropriately and may damage the whole internal combustion engine.

The achieved results can help to better evaluate the causes of the considered failure, yielding trends adoptable in the monitoring of the bearing's features.

Introduction

Double-row ball bearings are designed to deliver extreme precision, elevated rigidity, solid load features, and the necessary flexibility to rotate for a very long time at high speeds with marginal vibration and noise. These bearings are applied in various industrial fields (e.g., automotive, high-speed machine tools and electric machines, food processing machinery, and cryogenic engineering). They are particularly suitable for operating under humid, abrasive, and corrosive conditions.

The angular contact double-row ball bearings are widely used in the automotive sector as belt tensioners: this bearing is located inside of the belt tensioner lever on the engine. If this bearing fails, it can cause the belt tensioner to function improperly, possibly causing damage to the internal combustion engine. Any micro-particles present or flaking off the base material, e.g., can cause wear of the balls.

The ever-increasing performance and service-lifetime requirements for these components call for an enhanced manufacturing procedure. These parts, thus, are purposely produced (e.g., from seamless tube manufactured by hot rolling and high hardened to 58-67 HRC) and then typically heat treated (e.g., hardening, annealing, and tempering) to obtain specific properties such as high strength, wear and corrosion resistance, dimensional stability, and suitable magnetic properties. Special applications of these bearings include operation at high temperatures and fatigue conditions.

The construction material of these bearings is usually DIN 100Cr6 (AISI 52100, GB GCr15) high carbon chromium steel, which is the standard material adopted for bearing rings and rolling elements. The main applications of this material are related to the automotive and mechanical engineering sectors, i.e. to parts that require high hardness and excellent resistance to wear and deformation, such as balls, bearings, cams, rings, cold-ring rolled products, rollers, and helical springs [1]. This material is very suitable, e.g., for the thixoforming process. Balls of this type of bearing have a highly polished mirror surface, a high hardness through hardening (also in the range of 58-67 HRC), and a fine grain. The quality of this steel is strictly correlated with its micro- and nano-structure. Appropriate heat treatments allow lifetime enhancement, nevertheless, the eventual presence of residual austenite can reduce hardness and hence the component lifetime.

The applications of these bearings require high operating efficiency, less sensitivity to external loads, and better reliability under adverse conditions. The results of the heat treatment (HT) performed can be influenced by various factors, which cannot be controlled by the HT process itself. Inhomogeneities in the ingot material, e.g., may create undesirable treatment properties concerning microstructure and/or distortion and this can direct to low process-capability factors, despite a high-quality HT. The full manufacturing process, moreover, can be responsible for dimensional and shape variations as well as for nano(micro)-structure, phase transformations, geometry, and chemical composition. The lubrication of this sealed bearing is forced and special types of lubricant are supplied.

Investigated parts and results

Two angular contact double-row ball bearings - one not used, the other damaged after ≈3000 hours of operation (see Figure 1) - have been investigated by NT.

The chemical composition (mass %) is reported in Table 1.

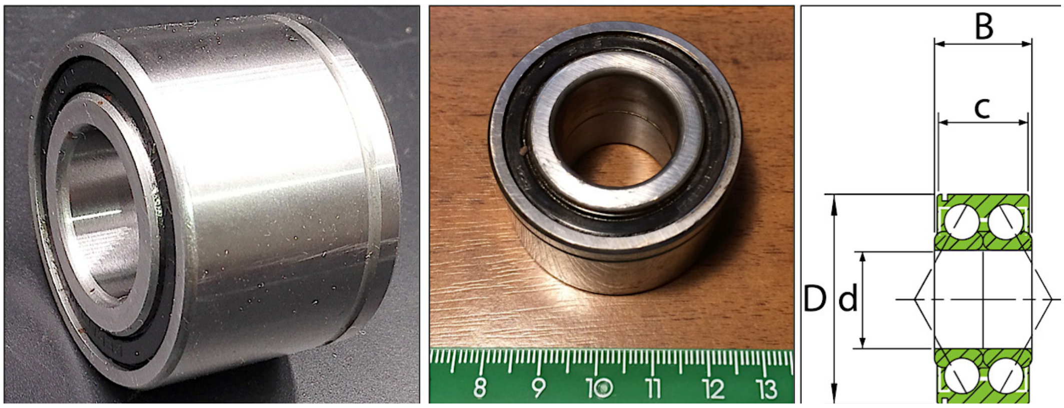


Fig. 1. The two investigated double-row DIN 100Cr6 bearings: new (left) and damaged due to the operation (centre); section (right). The indicated dimensions are: D = 42; d = 20; c = 29; C = 30 mm. The mass of each bearing is 178 g.

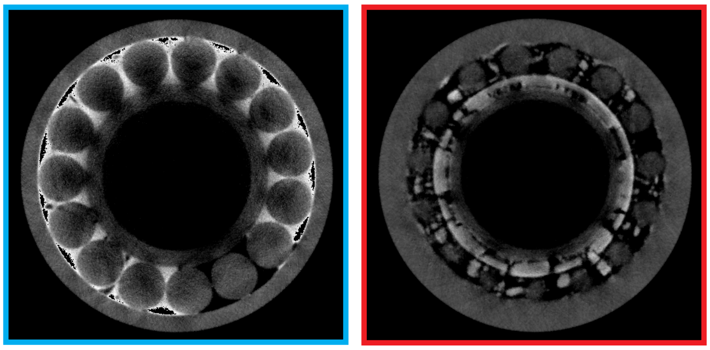
Table. 1. Nominal chemical composition of the investigated UNI 100Cr6 bearings, in weight %

Element	C	Si	Mn	P	S	Cr	Mo	Cu	Al	O	Fe
min.	0.93	0.15	0.25	-	-	1.35	-	-	-	-	balance
max	1.05	0.35	0.45	0.025	0.015	1.60	0.10	0.30	0.050	0.0015	

As neutrons are known to have higher penetration depth than X-rays and neutron imaging suffers from imaging artifacts due to beam hardening only to a much smaller extent, it was the method of choice to investigate this complex object. Neutrons are also sensitive to hydrogen, so the lubricant grease could also be visualized which would not show up in conventional X-ray images.

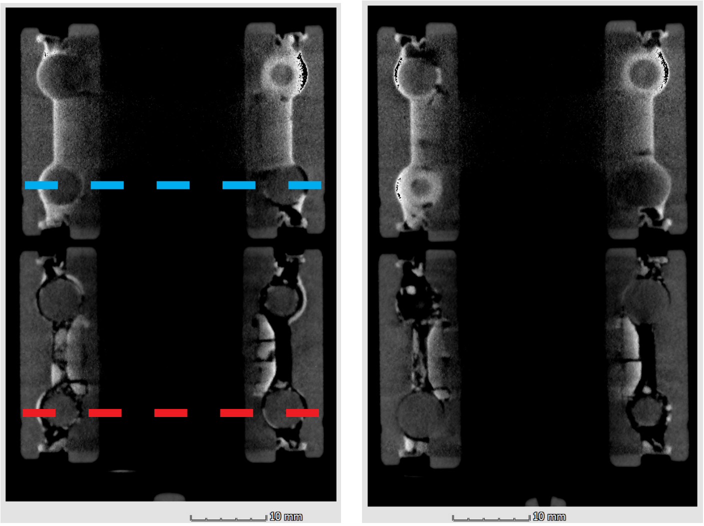
The comparative NT investigation has been carried out at the RAD neutron imaging facility of the Budapest Neutron Centre (BNC) [2-4], where we have set a 41.6 µm effective pixel size, 1500×1700 pixel field of view, and 12-bit pixel depth. A 360-degree rotation was made with 0.36-degree increments. The used and the damaged items were stacked on each other and were separated by a Teflon spacer to reduce the cross-talk due to neutron scattering, as shown in the left panel of Figure 2. This geometry ensured identical imaging conditions and facilitated the direct comparison of the resulting datasets. The 3D data were reconstructed with Octopus version 8.9.1.

The cuts of the tomograms presented in Figure 2 show several cracks in the inner ring of the damaged bearing and the missing lubricant near the damaged areas. A video available at the web link https://youtu.be/9of57wUy8X4 shows initially horizontal, and later vertical NT cuts at the damaged part of the item, followed by a 3D rendering evidencing the internal cracks of the damaged bearing.



Horizontal cuts (left: new, right: damaged)

Fig. 2. Neutron imaging of the two bearings of Fig. 1: the bearings stacked for imaging (lower left); horizontal cuts (top row); vertical cuts at two perpendicular planes (bottom).



Vertical cuts (top: new, bottom: damaged)

This 3D imaging of the intact items also documents the geometry and the general conditions of the item before disassembling it for further material analysis studies. These bearings are being measured by small-angle neutron scattering (SANS), using the Yellow Submarine instrument of the BNC. It would involve a Q-range from 0.003 to 0.7 Å^{-1}, to probe the critical parts at length scales from 5 Å to 1500 Å. The nano(micro)-structural characterization by SANS would allow monitoring of key parameters, e.g. size and concentration of inhomogeneities as nano(micro)-defects such as voids and precipitates-carbides, their volume fraction, and interface area. These defects can superimpose with the residual stress status and they can increase the risk of shredding the micro-particles, e.g. from the base material of the balls.

Conclusions

The neutron imaging presented in this case study successfully visualized the internal damages of the investigated bearings, in particular the crack in the inner ring of the damaged bearing, as well as the incomplete lubrication.

These experiments already contribute to the root cause analysis of the damage, and to avoid premature wear and failure of these bearings. Failure related to micro-particles - produced by cleavage or shredding from the base material of the balls, or of external origin due to the bad sealing of the bearing seals, can also be addressed. However, the imaging can document the status of the item before it is sent for further material analysis. The follow-up experiment with SANS can be useful to optimise the design, performance, and reliability of the considered bearings, helping the manufacturers to improve the quality of HT and other involved procedures, thus enhancing the bearing's service lifetime.

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Library and Gallery of Ancient Buddha Bronzes of the Tibet Region, Studied with Neutron Imaging

The non-destructive investigation of cultural heritage samples with neutron imaging methods has already a longer tradition [1, 2]. In this process, the ability of thermal neutrons to penetrate thick layers of metals and to be sensitive for light elements like hydrogen, carbon, lithium or boron can be used properly, while X-rays are failing mostly.

Bronze sculptures from the Buddhist religion field have been used and sacred since many hundreds of years in monasteries, but also in private houses. They are cast from Cu/Sn/Zn alloys according to old traditions in high quality and are filled in special ceremonies with different holy materials like wood, plants, bones, pearls, gemstones, papers, parchment or grains.

We have already demonstrated in 2010 [3] that an investigation of the filling of Buddhist bronzes is well possible with neutrons, but nearly impossible with X-rays (see Fig. 1). If the X-ray energy is low, the penetration through several millimeters of bronze metal fails. On the opposite side, when the X-ray energy is taken high, there is no remaining contrast for the light materials.

Based on this knowledge, we investigated until now 85 different objects provided by six collections. In all cases, we started with some simple overview neutron radiography attempts by camera detectors or imaging plates. This gives the hint if further tomography studies are reasonable. No tomography run has been performed when the objects are empty or so heavily filled that it will be impossible to differentiate the hidden content.

Fig. 1: Example of the study of an Buddhist bronze object: Buddha Amitayus, central Tibet, 17th century; middle: X-ray image, right: neutron image

The age (14th century or even older), the spiritual importance, the provenance, and the cultural background (area of origin) give the cultural-scientific importance of this study. Because the samples are covered and sealed completely after the holy filling act, the hidden content is saved since its first arrangement. Comparisons with currently filling procedures of today's objects have a high historical impact.

On the other hand, there is an opulent art market, where relevant samples are sold and bought for often very high prices. In some case, investigation of the object in advance to the selling process have been done. Although neutron imaging is nearly the only option for this purpose, faked X-ray images were taken into account [4].

How to publish these results of neutron imaging studies properly?

We have already sent out some papers to dedicated journals and presented talks in conferences on cultural heritage studies. However, we have the feeling to reach only a limited audience in this way.

Our new approach is the creation of an internet portal, where all image data can be presented in adequate manner, including detailed descriptions, comments on findings and technical details. This project will be started soon with first examples of the 85 objects and growing until the final one is included. In this way, more interest might be found by experts in the cultural and historical scene. Collectors are invited to provide objects of relevance to be studied at our facilities under certain conditions.

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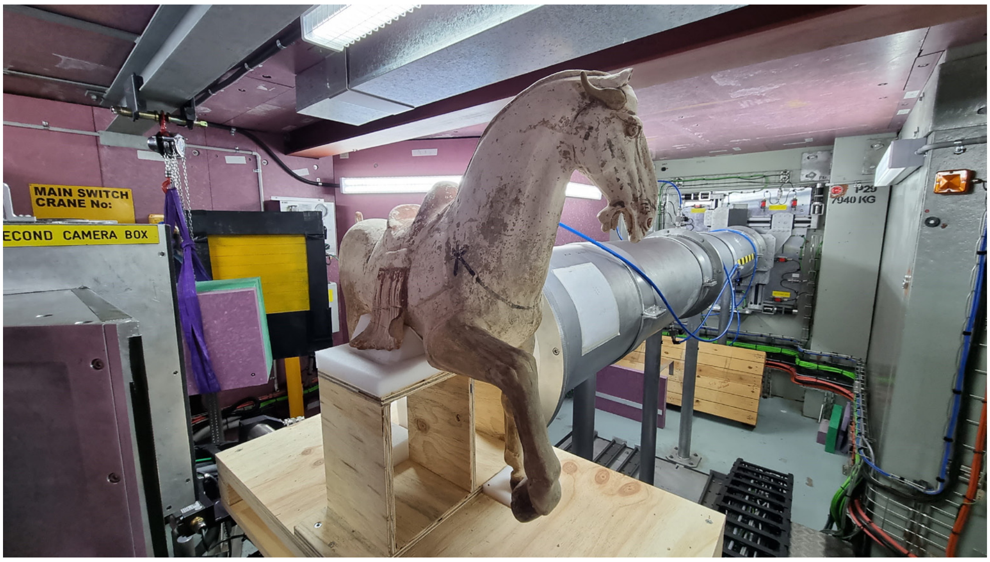
Eberhard Lehmann

26 objects | 3000+ years | 9 scientific processes - The Invisible Revealed, a Major Cultural Museum Exhibiting Showcasing Neutron Imaging

The Invisible Revealed exhibition (15 November 2021 - 25 September 2022) was an outcome of a partnership between the Museum of Applied Arts and Sciences (MAAS), the largest museum of industry and culture in Australia, and the Australian Nuclear Science and Technology Organisation (ANSTO). The exhibition examined 26 of the museum's objects from a materials research perspective using 9 nuclear and accelerator-based methods available at ANSTO. Through this partnership, MAAS and ANSTO gained material and cultural insights from the museum's ancient and modern collection, while presenting the outcomes and benefits of applying nuclear methods to cultural heritage.

Using state-of-the-art neutron beam and synchrotron X-ray facilities combined with digital visualisation techniques, this exhibition showed the discoveries made alongside

Neutron tomographs feature above three of the objects on display at the MAAS Powerhouse Museum.



A T'ang Dynasty figure of a horse in position for neutron radiography.

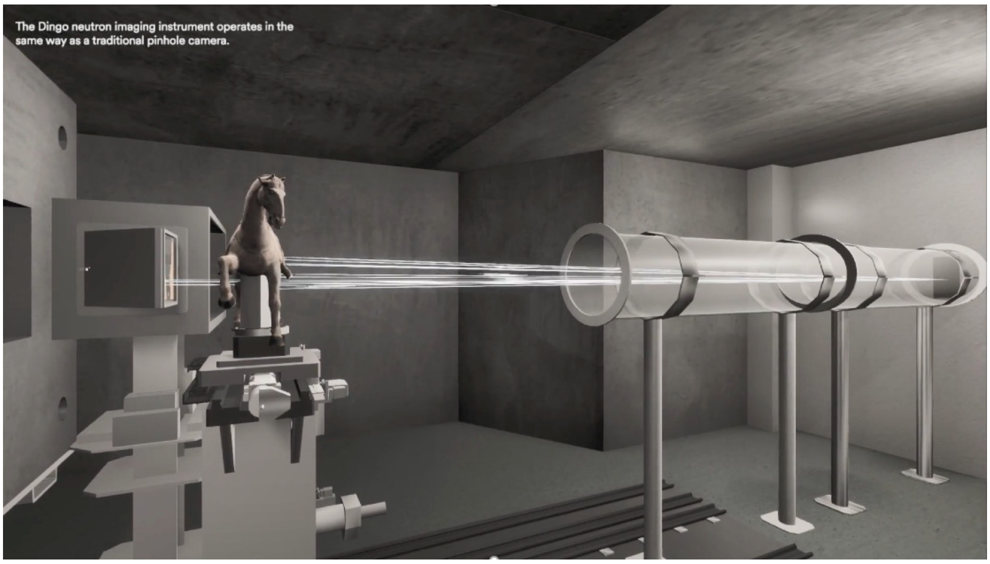
Neutron radiograph of the T'ang Dynasty horse, reproduced at full resolution at the entrance to the exhibition, revealing historical repairs made to the horse.

each object while comparing these two imaging modalities.

Neutron imaging was used to image the internal mechanisms of complex mechanisms and decipher a German Enigma machine, investigate the repairs and conservation status of a 618-906 T'ang dynasty horse figure, identify samurai sword production methods spanning the period 1346-1800. Coupled with the skills of sound artists, neutrons were used to reproduce the waltz played by a 200 year old musical pocket watch, and with subsequent neutron activation analysis, authenticate a 505-500 BC Lydian Stater, one of the oldest coins in the world. Also exhibited was an interactive Digital Twin of ANSTO's DINGO neutron imaging facility, created in collaboration with EPICentre, the Expanded Perception & Interaction Centre at the University of New South Wales.

In June 2022, ANSTO's The Invisible Revealed exhibition was awarded the prestigious Museums and Galleries National Award for Research; the judges commending the "*fantastic innovative concept incorporating the rigorous scientific method and the historical and artistic development of cultural objects. The focus on cultural engagement and consent with First Nations Australians and other key cultural stakeholders displays a commitment to contemporary museological, scientific and research ethics*".

A view of one wing of the exhibition space at the MAAS Powerhouse Museum



The Dingo neutron imaging instrument operates in the same way as a traditional pinhole camera.

Screen capture from the interactive Digital Twin of ANSTO's DINGO neutron imaging instrument. This module was used to illustrate the processes of acquiring radiographs and reconstructing tomograms from raw data.

The full collection set, large print exhibition guide, interactive 3D model AR experience and Glossary of Scientific Techniques are all available via the exhibition homepage: The Invisible Revealed – Museum of Applied Arts and Sciences (maas.museum).

Joseph Bevitt

(Left) Dr Joseph Bevitt of ANSTO and Nina Earl, Science Curator at the Powerhouse Museum receiving the Museum and Galleries National Award for Research.

Neutron Tomography Discovery Published in Science

Researchers in Australia have discovered a 380-million-year-old heart, the oldest ever found, alongside a separate fossilised stomach, intestine and liver in an ancient jawed fish, shedding new light on the evolution of our own bodies.

(left to right) Dr Alice Clement, Prof Kate Trinajstic, Prof John Long and Dr Joseph Bevitt with one of the Gogo fish specimens at the DINGO neutron imaging instrument, ANSTO.

The research, published in Science, found that the position of the organs in the body of arthrodires – an extinct class of armoured fishes that flourished through the Devonian period from 419.2 million years ago to 358.9 million years ago – is similar to modern shark anatomy, offering vital new evolutionary clues.

These fossils were found in the Gogo Formation, originally a large coral reef in what is now the Kimberley region of Western Australia, represents one of the best-preserved fossil sites of the Late Devonian (approximately 375 million years ago) in the world, having 3D preservation of original bones and mineralised muscle and organs.

When the lead researcher John Curtin Distinguished Professor Kate Trinajstic, from Curtin University's School of Molecular and Life Sciences and the Western Australian Museum, split open a fist-sized rock nodule, she discovered that it contained an exceptionally well-fossilised fossil fish. Knowing that the preferred method of removing fossil from the surrounding rock, acetic acid digestion, destroys the soft tissue and organs, Prof Trinajstic instead enlisted the help of neutron imaging at ANSTO in Sydney, and synchrotron X-rays at the European Synchrotron Radiation Facility in France, to scan the two specimens still embedded in the limestone concretions. With these techniques, Prof Trinajstic and colleagues were able to reconstruct three-dimensional images of the soft tissues inside them, based on the different composition of minerals deposited by bacteria within the surrounding rock matrix.

The neutron imaging data revealed that the heart of this ancient fish was complex and S-shaped, made of two chambers with the smaller chamber sitting on top. The heart was located under the fishes' gills, like sharks today. The discovery was remarkable given that soft tissues of ancient species were rarely preserved, and it was even rarer to find 3D preservation.

Publication

Exceptional preservation of organs in Devonian placoderms from the Gogo lagerstätte, Science, 377, 1311-1314 (2022). *https://doi.org/10.1126/science.abf3289*

Joseph Bevitt

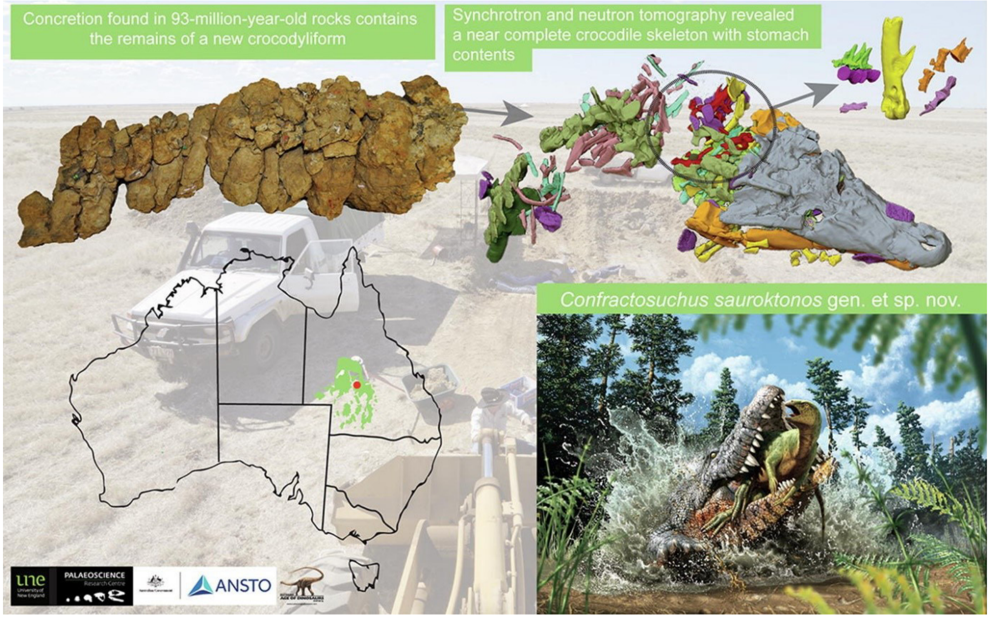
Cretaceous Crocodiles Ate Dinosaurs (or Discovering Dinosaurs with Neutrons)

Using neutrons, Australian palaeontologists have demonstrated the first evidence that ancient crocodiles ate dinosaurs, and the first direct evidence of dinosaur predation by any other animal.

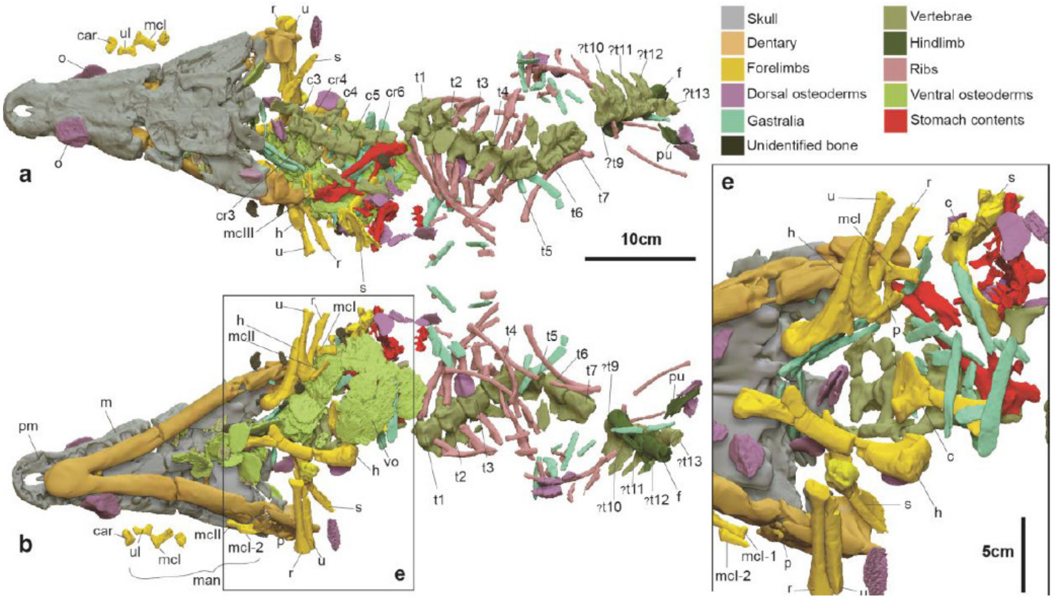
In 2011, during the search for giant herbivorous titanosaur remains in north-eastern Australia, staff and volunteers at the Australian Age of Dinosaurs Museum were using a front-end loader to shift a large boulder lying in the dig zone. The boulder shattered, revealing a mass of bones. As the fragile bones were embedded in a hard and brittle ironstone matrix, physical preparation, and X-ray CT were impossible. Museum staff spent two years piecing together the 3D fossil jigsaw puzzle before meeting Joseph Bevitt and learning about the new DINGO neutron imaging instrument at the Australian Nuclear Science and Technology Organisation (ANSTO). Within a week, the museum delivered a fragment of rock, seeking to use neutron imaging to determine where it fit in the puzzle. Expecting a report on which crocodile bone was embedded in the rock, the museum was shocked by Dr Bevitt's serendipitous discovery that the fist-sized lump held a total of 42 bones, including a partial ornithopod dinosaur femur with a bite mark in it!

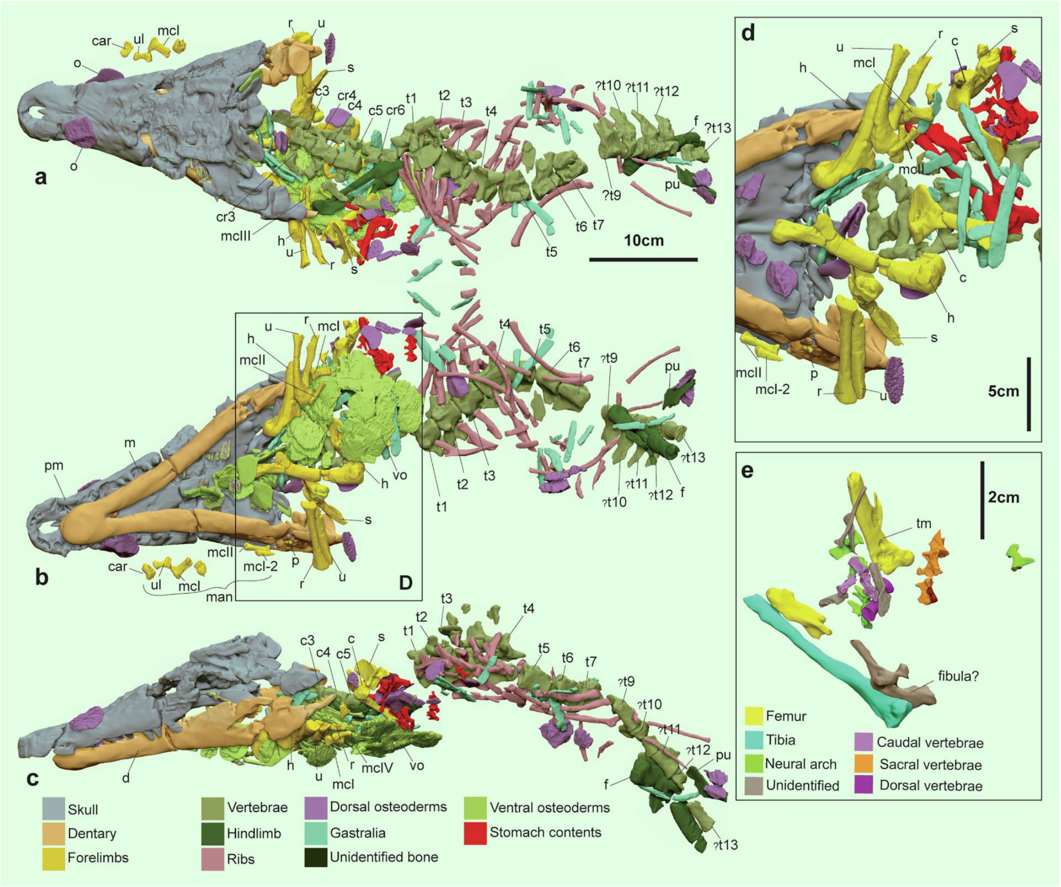
Over a six yar period, Dr Matt White from the University of New England, and Dr Bevitt used a combination of neutrons, and synchrotron X-ray imaging at the Australian Synchrotron to locate bones in every rock fragment. This data was used to guide the partial physical preparation of the specimen, which eventually enabled high-resolution scanning of the entire boulder. The result of this painstaking process was confirmation that this newly described Cretaceous crocodilian Confractosuchus sauroktonos (which translates to 'shattered crocodile dinosaur killer') had eaten and contained the remnants of a juvenile dinosaur, the size of a chicken in its stomach.

The outcomes of this research were published in Gondwana Res., 106, 281-302 (2022) https://doi.org/10.1016/j.gr.2022.01.016. The specimens and their tomographic reconstruction are on display at the Australian Age of Dinosaurs Museum in Winton, Queensland, Australia.



Dr Matt White with the reconstructed skull of Confractosuchus sauroktonos and a modern crocodile.





Digital dissection of Confractosuchus sauroktonos in (a) dorsal aspect; (c) ventral aspect; (c) left lateral aspect; (d) close-up of pectoral region with ventral osteoderms removed (in ventral aspect); (e) abdominal contents showing ornithopod remains. Image credit: White et al., DOI: https://doi.org/10.1016/j.gr.2022.01.016

Joseph Bevitt

Development and Testing

Update on Bragg Edge Analysis Round Robin Project

In the International NR Newsletter No. 15 published in 2019, we proposed a round robin on Bragg edge analysis. The motivation of the project was the recent advancements in Bragg edge imaging which leads to significant pick up of interest from the research community on Bragg edge imaging methods, coupled with the absence of thorough characterization and standardization of Bragg edge steps and techniques across large scale facilities. Among the objectives of the proposed round robin is to assess the level of accuracy, precision, and detection limits of Bragg edge transmission and neutron diffraction for residual strain and phase composition analysis in 1D, 2D and 3D, and to come up with recommendations and best practices for data collection and data analysis. Here, we would like to provide some updates regarding the Bragg edge round robin project.

Firstly, in the 2020-2021 period, we have carried out measurements with the purpose of characterising a number of candidate samples for the Bragg edge round robin, Figure 1(a). It is important for the success of the round robin that sample candidates are characterised early in the project so that the final set of samples can be selected and that a collection protocol can be created before the samples go around the beamlines. The studied samples are from previous research projects with different engineering science motivations. The campaign focused on characterising the residual strains within the samples using neutron imaging on BOA@PSI, and using neutron diffraction on SALSA@ILL and on POLDI@PSI through regular beamtime access routes of the facilities. These data are being compared to Bragg edge imaging data previously measured on IMAT@ISIS. The data analysis is in progress, some preliminary results are shown in Figure 2.

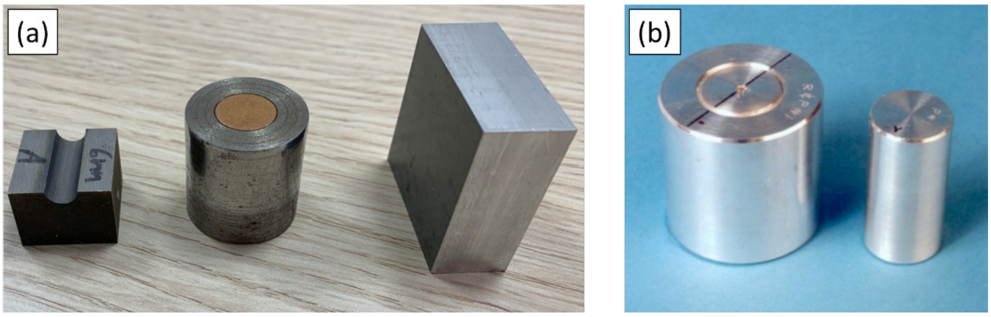


Fig. 1 Potential sample candidates for the round robin. (a) laser shocked peened (LSP) steel of complex geometry; shrink-fitted FeCu; two-phase Al/SiC metal matrix composite. (b) VAMAS aluminium ring&plug (50 mm diameter) with D0 cylinder (25 mm diameter).

There are a number of aspects to learn from such preliminary measurements with regard to assessing the suitability of each sample candidate for the round robin project. Among the factors are whether: i) a sample diffracts neutrons well and has strains of sufficient magnitude; ii) strain levels and gradients can be quantified by the two measurement techniques; iii) the variation of strain through the thickness of the sample in the transmission direction is significant, which is important for the interpretation of the results. Further questions also arose during the measurements, including the stability of the residual stresses, the complexity of modelling of the residual stresses using a finite element method, and how to incorporate ‘d0’ measurements for a sample.

Secondly, learning from the first sets of measurements, we have designed a dedicated Bragg edge round robin sample, a tension-compression (TC) sample, which fulfils the criteria of the Bragg edge strain imaging round robin activity: i) geometry and strain distribution largely homogenous along the beam direction; ii)) elastic strain generated through a deformation which is measurable using reliable methods (e.g., CMM), hence can be easily modelled using general FEA methods; iii) made of materials with well-separated Bragg edges, suitable grain size, and minimum crystallographic anisotropy. This sample will be first characterised on instruments at ISIS. Furthermore, we propose to include the well-characterised VAMAS ring-and-plug, which was used for a diffraction round robin in the past, in the pool of sample candidates.

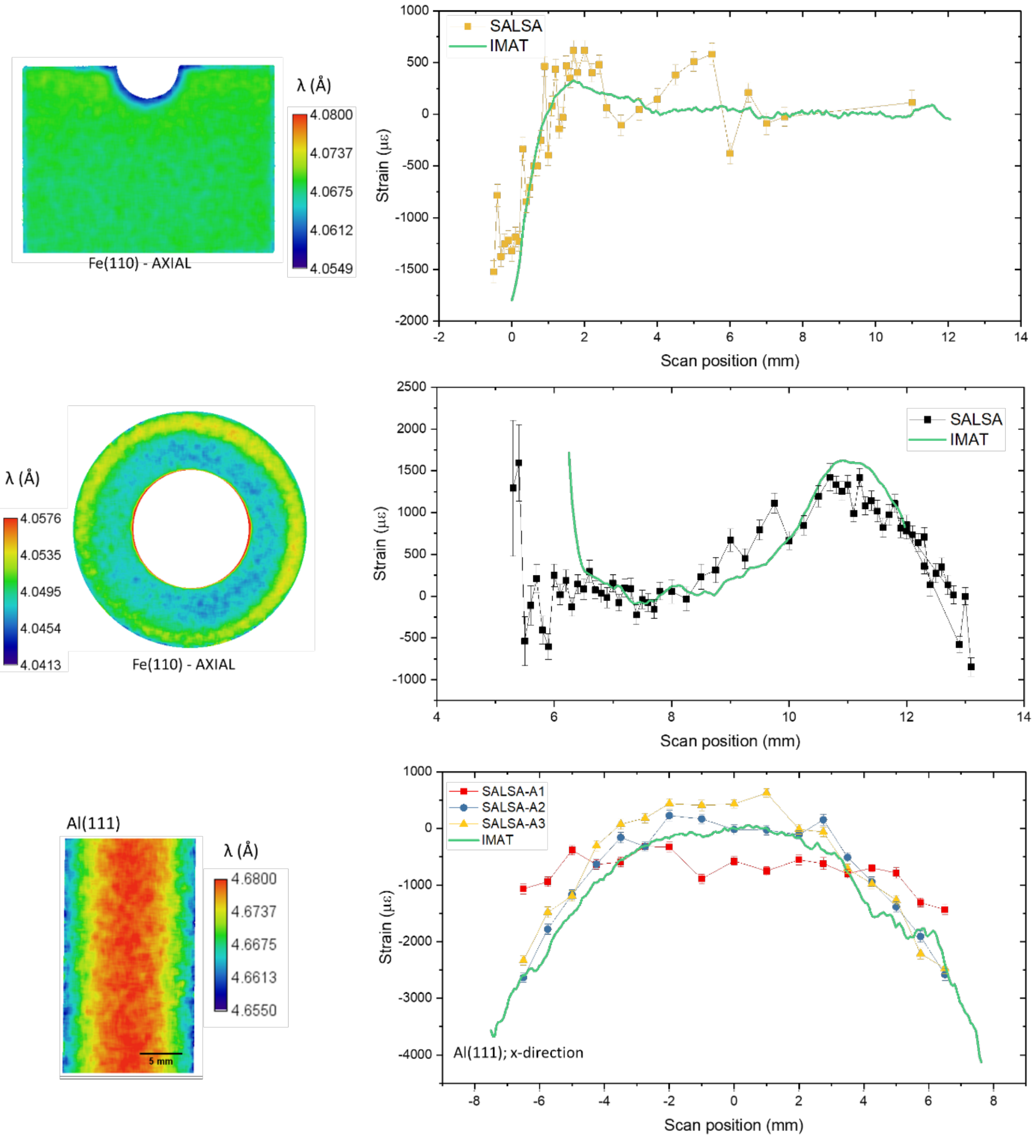


Fig. 2 Strain maps (IMAT) and comparison of strain profiles (IMAT, SALSA) of LSP sample, FeCu shrink-fitted cylinder and aluminium phase of metal-matrix composite. Good agreement between strain profiles is observed overall but also some discrepancies for the strains on the edge of the steel ring of the FeCu sample (middle panel).

It is envisaged to kick off the round robin project at a forthcoming NEUWAVE meeting and start the measurement campaign across different large scale facilities towards the end of 2023/ beginning of 2024. We have secured funding from EPSRC Postdoctoral Fellowship project (EP/X031284/1) (converted from a successful Horizon Europe Marie Sklodowska-Curie fellowship), with the Bragg edge round robin being the major component. Using this platform, it is proposed that the principal investigator (RR) will be responsible for the organisation of the round robin which will include:

- Invitation of scientists from neutron imaging and diffraction facilities to form a round robin consortium which agrees on a set of samples (which may include the above mentioned candidates): metallic/polycrystalline composites with specific geometries and materials properties (single/dual phase, gradients of residual stresses, degree of anisotropy, grain sizes, etc). The samples will represent different manufacturing routes and/or methods, e.g., quenching, peening, additive manufacturing, and/or welding. Most samples will be for 2D imaging to facilitate the round robin within the project's financial and time limits, whereas 1 or 2 samples may be designed for 3D Bragg edge tomography (optional for participants to run).
- Organisation of preparation of choses samples; if not yet done: manage characterisation of samples using established methods.
- Organise measurement schedule with interested beamline scientists
- Design of a collection protocol. Leading/supporting data collection and analysis at the facilities.
- Collating and reporting results

It is intended to translate the findings eventually into a 'Good Practice Guide' for neutron Bragg edge imaging and a 'requirements document' for further developments and standardisation, in order to raise awareness and confidence of the capabilities of Bragg edge imaging.

Ranggi Ramadhan
Winfried Kockelmann

Position Sensitive Detectors of Thermal Neutrons for Radiography Examinations of the Closed Objects, Developed in PhTI AS RT

Neutron radiography methods, in particular transmission and emissive tomography can find applications at customs inspection of loads and baggage. Emissive tomography can applied to searching of fission isotopes. Transmission tomography can applied to searching of substances containing isotopes with the high cross-section of interacting with neutrons, and light substances - hydrogen or other. In a combination with X-ray scanners, presume to searches the fission isotopes, explosives, and drugs also.

The important part of tomographs is a computerized position sensitive detectors of thermal neutrons. The paper presents works carried out about designing of multiwire proportional chambers with a ^{3}He converter and a multistep avalanche chamber with a solid-state gadolinium converter. Both detectors intended for a position-sensitive registration of thermal neutrons at neutron radiographic investigation.

Multiwire proportional chamber with a ^{3}He-based gas converter

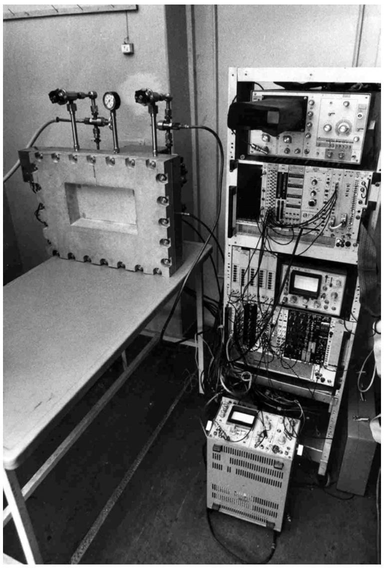
A two-coordinate multiwire proportional chamber (MWPC) consisting of three electrodes arranged one over another within a single gas volume is selected as the detector (Abdushukurov, 1983, 1986, 2008). The electrodes represent two orthogonally wired cathode and anode planes. The anode plane wound with a 20 µm thick gold plated wire with a 2 mm step. Cathode planes orthogonally wound with a 50 µm- thick beryllium bronze wire with a 1 mm step. The anode-to-cathode distances of MWPS are 5 mm. The sensitive volume of MWPS is 260x130x12 mm^3. The MWPS placed within a seal-tight box made from aluminum with a 6 mm-thick entrance window. The box's dimensions are 580 x 440 x 130 mm^3. The net gas volume of tile box is 4,5 liters.

The mixture of ^{3}He and (10-20%) of propane is used as a gaseous mixture of the detector. The operation pressure of the detector is 4 atm. Apart from the gaseous additive of MWPS the propane is used to reduce the path of protons forming as a result of the reaction n + ^{3}He - p + ^{3}He + 764 keV.

For long-term operation of the detector the Ni/SiO$_2$ getter-based gas recovery system is developed. To purify the gas from electronegative impurities the former pumped through the getter at room temperature by force (Abdushukurov, 2010).

The basic parameters of detectors are:

Sensitive volume: 260x130x12 mm,
Gaseous mixture: ^{3}He + (10-20%) of propane,
Entrance window: 6 mm Al,
Operation pressure: 4 atm,
Detection efficiency (at λ=1.8A): 70%,
Spatial resolution: <3mm (FWHM),
Time resolution (by anode signal): 20ns,
Counting rate: 10^5 1/s.



Multistep avalanche chamber with a solid-state Gadolinium converter

A multistep avalanche chambers (MSAC) consists of a conventional MWPC placed within a single gaseous volume with additional grid electrodes forming preamplification and drift spacing. Gadolinium converter settles down directly ahead of a preamplification grid. MSAC registers electrons escaping off in a back hemisphere. In the preamplification gap, there forms an electron-photon avalanche, which transferred to MWPC for consequent amplification and registration. Due to the exponential amplification in the preamplification gap there is implemented a tie of coordinates to the entrance point of particles to the detector volume. The spatial resolution of MSAC can be improved by the amplitude analysis and the consequent mathematical processing of events up to 0,2-0,3 mm. The gas amplification coefficient of MSAC is of the order 10^{6-7}, which provides registration of single electrons with practically zero energy. The registration efficiency of the MSAC-based detector mainly defined by converter's characteristics (Abdushukurov, 1985, 2007a, 2007b, 2011).

We have lead works on modeling calculations of efficiency of registration of thermal neutrons by foil converters from natural gadolinium and its 157 isotopes. In the reaction neutron capture by ^{157}Gd total 7937,33 keV energy is emitted. Totally 390 gamma lines with the energy in the range from 79,5 up to 7857.67 keV with intensity of lines from 2*10-3 up to 139 gamma-quantum on 100 captured neutrons are emitted. During capture of thermal neutrons by gadolinium nuclei, besides radiating -quantum also both electrons of internal conversion and Auger electrons are emitted. In our calculations, we considered only 444 most intensive discrete energies of electrons with the probability of output more than 10-5 on 100 falling neutrons. The basic results of calculations brought in publications (Abdushukurov 1994, 2007, 2010), 2011, 2013, 2018). The basic parameters of detectors are: Sensitive volume - 200x200 mm, Gaseous mixture - Ar + (2%) of acetone, Operation pressure - 1 atm, Detection efficiency (at λ=1.8A)-35%, Spatial resolution-<1mm (FWHM), Time resolution (by anode signal) - 20ns, Counting rate-10^6 1/s. (Abdushukurov, 2010b, 2013).

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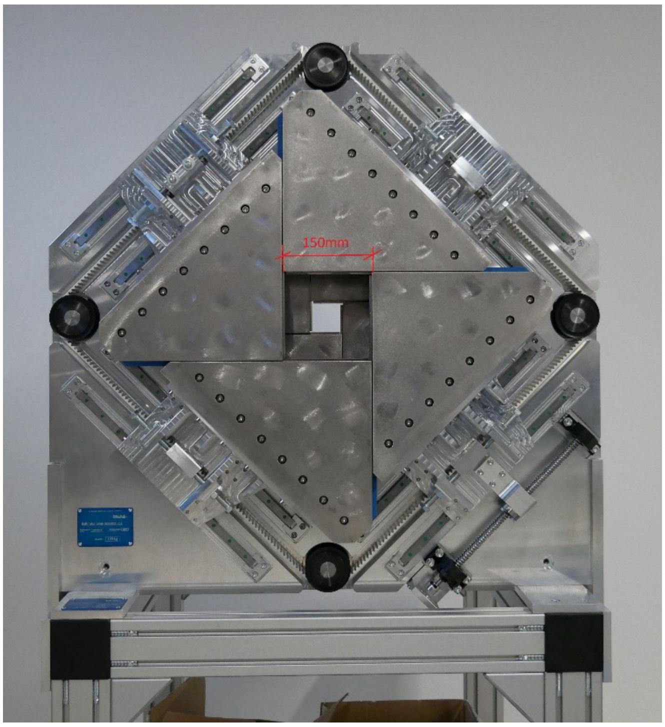
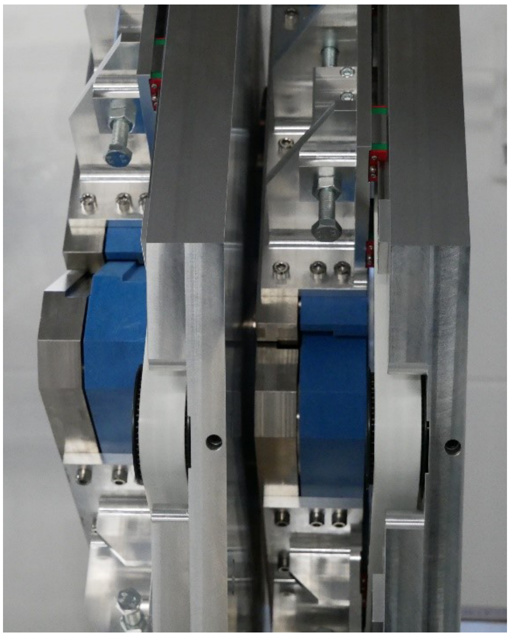
Djamshed Abdushukurov

Scraper Collimator NECTAR

This Scraper Collimator NECTAR is a collimator for fast neutrons (1.8 MeV). It was developed for the instrument NECTAR at the FRM II.

The aim of this development is to reduce the background of gamma radiation and scattered fast neutrons at the sample position and to increase the relative share of neutrons flying straight along the beam axis.





The main idea is to use a stack of several irises in a row. The materials for the collimation are borated Polyethylene (PE) and borated steel. Every iris has one layer borated PE (50mm thickness) and one layer borated steel (31mm thickness), so the materials alternate.

The maximum size of one window is 300x300mm^2 and the minimum is 6x6mm^2.

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Status of the Scintillator Development for Neutron Imaging

Neutron sensitive scintillator screens are the key components in digital neutron imaging detectors. There are two options for implementations within digital imaging systems:

1. camera based ones with optical coupling via lens systems
2. semi-conducting sensors (amorphous silicon or CMOS arrays) in direct contact with the scintillation screen

The basic concept of neutron sensitive scintillators has been known since decades: a material with a high absorption cross-section is mixed with a scintillation material, which is excited by the reaction products from the neutron capture (alpha, gamma, conversion electrons).

Because most of the neutron imaging facilities use thermal or cold neutrons, the materials with highest capture efficiency in this energy range are Cd, Gd, B-10, Li-6 and some less relevant neutron absorbers as Au, Hf, Dy, In or Eu.

From the scintillation materials, ZnS has been found to be the most brilliant one, given by highest light output per excitation reaction.

However, the excitation process in the reaction chain of capture and light emission is the unknown and challenging question in the mixture between absorber, emitter and binder. Although some basic considerations were done with suitable simulation tools, the practical results are not yet covered and understood. The granular structure of both absorber material and light emitting substance, the self-shielding by the neutron absorber for the neutrons and the light absorption by the whole compound are aspects that are difficult to handle.

In the case of Gd, one of the strongest neutron absorbing materials, gadoliniumoxysulfide (Gadox) with some doping is itself a scintillating material, however with much less light output than ZnS. Therefore, a mixture with another light emitting material is not needed and the low range of the exciting conversion electrons helps to keep the spatial resolution high.

The neutron imaging team at PSI invited in 2021 world-wide for a comparison study of neutron imaging scintillators, to be performed at the NEUTRA station as reference facility. It provides a well collimated beam of thermalized neutrons from the D2O moderator at SINQ with a very low background of gamma radiation. Because the market for such neutron sensitive scintillators is very small, only four companies/institution sent examples of their developments. In order to avoid commercial conflicts, the study was done completely anonymous with respect to composition and layer thickness. A special acquisition and evaluation strategy was established for this study [1]. The main output parameters are: Light emission, spatial resolution, neutron capture rate, signal-to-noise ratio (SNR) and detective quantum efficiency (DQI). Some of the results are under publication [2].

The main lesson learned from the study is that not only one favorite exists as dominating in all aspects, but some compositions are best in one or a few of the aspects. Then it depends on the particular application for which aspect in a study the particular composition and sample thickness has to be optimized. In particular, for best quantification and differentiation of small contrasts materials with highest SNR have to be preferred. Shown in Fig. 1, three samples are described w.r.t. the main parameters derived. An impression about the high variation in the light emission of the investigated samples in the comparison study is given by Fig.2.

From the absorber materials mentioned above, B-10 and Eu are still under investigation and consideration [3]. Regarding highest possible spatial resolution, Gadox with the isotope Gd-157 has been found to be the most relevant, in particular with very thin layers in the µm range [4]. Brightest light emission is still obtained with ZnS screens, excited by Li-6, where the free parameters are the mixture ratio, the binding material, the supplier of compounds and the most efficient layer thickness. Because the direct manufacturing process is also important for the final product, professional companies have advantages compared to small labs.

The PSI team and the NEUTRA facility are prepared to study further test samples from other companies/institutions according the test/evaluation procedure as mentioned above.

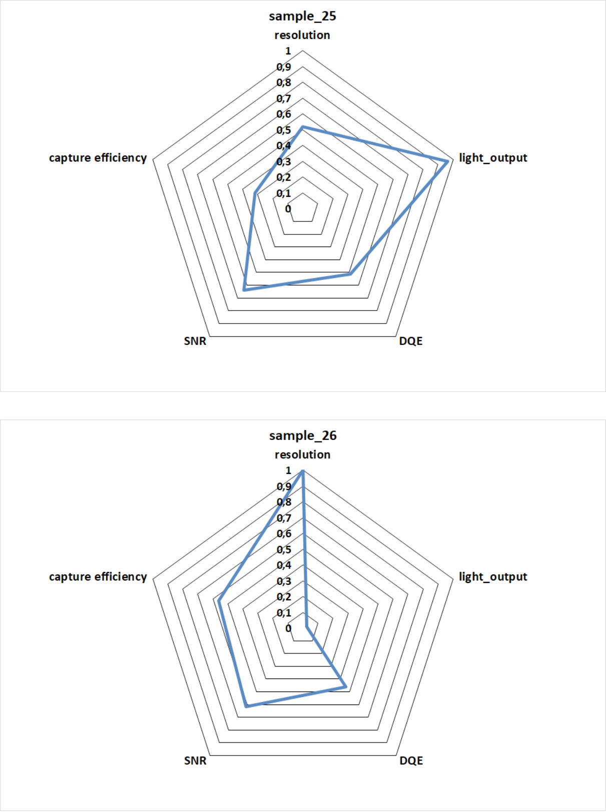


Fig. 1: Normalized parameters for examples with highest light output and highest spatial resolution, respectively

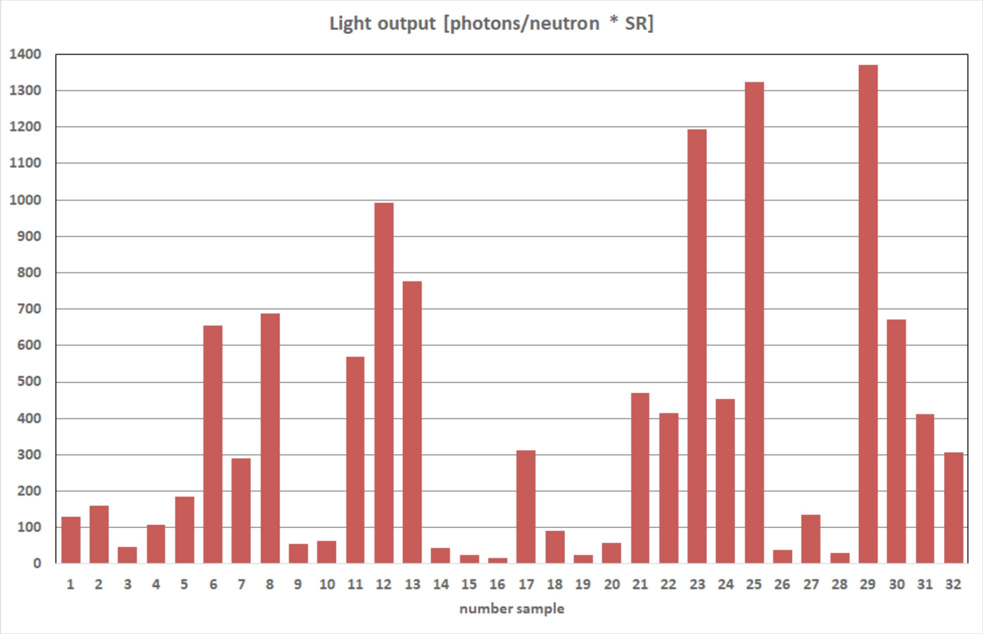


Fig. 2: Comparison of the light emission of all 32 investigated test samples, showing a high variation

References:

[1] P. Boillat, Who made the noise? A systematic approach for the assessment of neutron imaging scintillators, submitted to Optic Express

[2] E. Lehmann, P. Boillat, Advances in scintillator screen technology for neutron imaging submitted to NIM A

[3] W.C. Chuirazzi, A. Craft, Measuring Thickness-Dependent Relative Light Yield and Detection Efficiency of Scintillator Screens, J. Imaging 2020, 6(7), 56; https://doi.org/10.3390/jimaging6070056

[4] P. Trtik, E. H. Lehmann, Isotopically-enriched gadolinium-157 oxysulfide scintillator screens for the high-resolution neutron imaging, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 788, 2015, Pages 67-70, ISSN 0168-9002, https://doi.org/10.1016/j.nima.2015.03.076.

Eberhard Lehmann
Burkhard Schillinger

Education

E-Learning Platform for NI 2.0 by IAEA

In order to improve the utilization of research reactors, IAEA initiated some E-learning courses with open access to promote selected experimental methods. The first E-learning course was about “Neutron Activation Analysis (NAA)” [1] by P. Bode and S. Landsberger.

The authors Nikolay Kardjilov (Helmholtz-Center Berlin, Germany) and Eberhard Lehmann (Paul Scherrer Institut, Switzerland) were invited to cover the topic "Neutron Imaging". Their aim was to bring their long-time experience and know-how into a structure, which should be commonly understandable, but also scientifically and technically correct.

The purpose of the course is on the one hand to make neutron imaging methods more popular among the users of neutron sources. On the other hand, it presents the background for facility operators to use their devices most efficiently.

The project started in 2016 and a draft version of the course was introduced and tested by a user group of qualified neutron imaging experts during a workshop in Vienna in 2017.

After certain revision work, the final version of the E-Learning Course "Neutron Imaging 1.0" was implemented on the IAEA Nucleus Homepage in 2021, which can be accessed now [2].

The course consists of nine chapters in form of PowerPoint slides and is accompanied by a questionnaire for the check of the candidates' learning progress.

Until now, the remote course has been used several hundred times from interested users from all over the world.

Now an extended author's team including Anders Kaestner (PSI) in addition to the previous authors works on an upgrade of the course – E-Learning "Neutron Imaging 2.0" – using different methods to:

Interactive notebooks – A deeper study of selected topics is provided by implementing a collection of Phyton notebooks mixing the theory with short Python scripts practical demonstrations; for this aim, Anders Kaestner (PSI, CH) has been invited to contribute with his experiences as a lecturer.

Lecture recordings – Selected topics are put in focus in the format of lectures to provide more in-depth knowledge compared to EL NI 1.0., developed by Nikolay Kardjilov (HZB).

Presentation slides – This is the original format where further topics (12), which were not covered in EL NI 1.0, are now added, prepared by Eberhard Lehmann (PSI)

It is the intention to hand over the new material in early 2023 and to make it publicly available as soon as the IAEA as the contracting entity has confirmed the content and style.

References:

[1] *https://www.iaea.org/topics/neutron-activation-analysis*
[2] *https://www.iaea.org/newscenter/news/iaea-launches-new-neutron-imaging-e-learning-course-to-preserve-knowledge-improve-services-and-promote-the-use-of-research-reactors*

Eberhard Lehmann
Anders Kaestner
Nikolay Kardjilov

An Optical Model of a Neutron Imaging Instrument

Neutron imaging is a fascinating technique with a huge variety of applications that are appealing to the public. To demonstrate the principle of neutron imaging to a general audience outside the reactor environment and to teach students, we have developed an interactive, fully motorized model of the ANTARES imaging beamline using visible light.

This 1:20 scale model incorporates many of the basic features of the ANTARES beamline giving interested persons the option to adjust various instrument parameters from a touchscreen similar top performing a real experiment. Instead of neutrons the model uses an LED-lamp as a photon source, which can be shut off using a shutter system. These photons are the collimated using a set of different pinholes which can be adjusted from the touchscreen. The photons are detected using a quasi-scintillator, a mirror and a camera, built to resemble an actual neutron imaging detector. The effect of a neutron velocity selector or a double crystal monochromator can be shown by moving color filters into the beam path to adjust the wavelength spectrum. The sample can be rotated to simulate a tomography and the sample to detector distance can be adjusted to observe the effects of the collimation on the spatial resolution. The resulting transmission image is shown on separate screen.

Michael Schulz

News from the Board

ISNR Task Groups

The ISNR Board establishes Task Groups working on specific topics of interest to the neutron imaging community represented by our members. The first task groups were established in 2014. The Chair for each task group is appointed to convene and guide activities of the group.

The ISNR Board discussed each task group at their meetings during ITMNR-9 to decide the future direction for each group and make changes as necessary. In cases where the task group had completed its goals and was thus no longer needed, the task group was considered closed. Additionally, the Board discussed creation of new task groups.

The table below summarizes the task groups and actions taken for each, followed by some relevant explanation.

Topic	Chair	Action
Terminology	-	Closed
Characterization and Standardization	Aaron Craft	New chair appointed
Contact to other organisations	-	Closed
Promoting young scientists and technicians	-	Closed
ISNR Newsletter	-	Closed
ISNR web page	-	Closed
Publications	-	Closed
Small or low cost Systems	Burkhard Schillinger	New chair appointed
Computational Imaging	Jean Bilheux	New chair appointed
Fast Neutron Imaging	-	Closed
Neutron Instrument Access	Anton Tremsin	New

Generally speaking, the success of any task group depends on active involvement and activity by the Chair and the supporting members of the group. If the Chair is not active or uninterested, the group diminishes into nonexistence. Therefore, any ongoing task group is based on the active interest of a willing Chair to lead the group.

The Terminology task group led by Markus Strobl was successful in accomplishing its goals and is now considered closed. The Terminology group successfully oversaw the change of the name of the ISNR, replacing Radiology with Radiography. Additionally, working with the Standardization group, the Terminology group oversaw the addition of new terms to the ASTM Glossary, which now includes the terms "neutron imaging" and "neutron flux." Many thanks are owed to Markus Strobl for his work on the Terminology task group and bringing it to a successful completion.

Some of the task groups assigned to Thomas Bücherl, including the ISNR Newsletter and ISNR Webpage groups, are part of the duties of the ISNR Secretary and supported by the ISNR Board, and thus should not be considered as separate task groups.

The Publications task group was closed by the Board. Another colleague, John Rogers, maintains a fantastic website (radsci.uk) that compiled relevant publications in the field. This website is referenced by the ISNR web page for your convenience.

The Fast Neutron Imaging task group on led by Michael Schulz (FRM II) was successful and is currently considered closed. The group hosted a Fast Neutron Imaging workshop at FRM II that was well attended by the international community and fostered exchange of ideas within the community. This topical area is still of interest to the community, however, and can be reactivated.

Two new task groups were formed:

1. Computational Imaging: Chaired by Jean Bilheux (ORNL), this group will foster developments in computational aspects of neutron imaging.

2. Neutron Instrument Access: Chaired by Anton Tremsin (University of California Berkeley) and supported by Winfried Kockelmann and Markus Strobl. This task

group will survey available neutron sources at user facilities worldwide and make this information available to the ISNR membership in an effort to address the current shortage of neutron availability worldwide due to multiple facilities currently offline.

Task groups do not necessarily have to be led by an ISNR Board member. If you are interested in contributing to and working with any of the current task groups, please contact the group's Chair. Also, if you are interested in leading a new task group, please contact the ISNR President to discuss your idea.

Aaron Craft

Task Group "Small or Low-Cost Neutron Systems"

Neutron CT goes portable: 3D printed detectors and standalone professional control system

Compact camera detectors

More than 20 years ago, we began neutron imaging with the best possible instrumentation, since we did not know which parameters had the most influence on the image quality. Our first ANDOR CCD camera costs 65.000 Euros.

Today, we know that

- Good beam collimation with L/D >>100 is essential for image quality
- Scintillation screens should have no more than 100-200 µm thickness
- Cameras must be shielded against gammas from neutron capture in the sample and in detector and bunker walls.

Today, a lot of cooled high-quality but low-cost astronomy CMOS cameras match or surpass our high-end CCD cameras. Their cooling is sufficient for low-noise pictures of several minutes of exposure time – we do not need four hours as the ANDOR cameras can do at -100°C. They are faster in readout, have more pixels and similar full-well capacity, for prices between 1.600 and 3.000 Euros. Smaller C-mount lenses can be used for these cameras instead of large and bulky DSLR lenses, and because of closer proximity to the screen, the light collection efficiency, given by the solid angle covered by the lens in the required working distance is about the same. This allows for very compact setups with compact lead and PE shielding directly around the camera instead of large and bulky boxes that require a vast amount of lead inside. However, these cameras do not have a hardware trigger input and can be controlled only by software. We added an outer water cooling ring because compact shielding around the camera hinders the air flow of the cooling fan [1].

We have developed, 3D-printed and used several new camera boxes for neutron detection [2]. Housing is as compact around the cameras as possible, shielding must be stacked externally around the box. The relatively small C-mount lenses allow to place a lead brick in two halves with a cutout for the lens directly in front of the camera inside the box which shields the camera from direct sight to the sample where gamma rays are produced on neutron capture that may hit the camera directly, and produce white spots. This single lead brick is essential for protection of the camera.

The camera box and the box for mirror and scintillation screen are separate items that are connected with a flange. This allows for easy exchange of the mirror and scintillation screen box for different sizes and fields of view, or specialized setups like a 90 degree Heliflex lens.

Fig.1 shows the latest and most simplified version of the camera box and mirror box, as well as a setup at the Atominstitut Vienna. The beam intensity was not very high, so just two lead bricks outside and the frontal lead brick inside were sufficient.

So far, the setup has been tested at several low to medium flux reactors, and it seems that the 3D printed plastic housing has led to a significant reduction of gamma spots

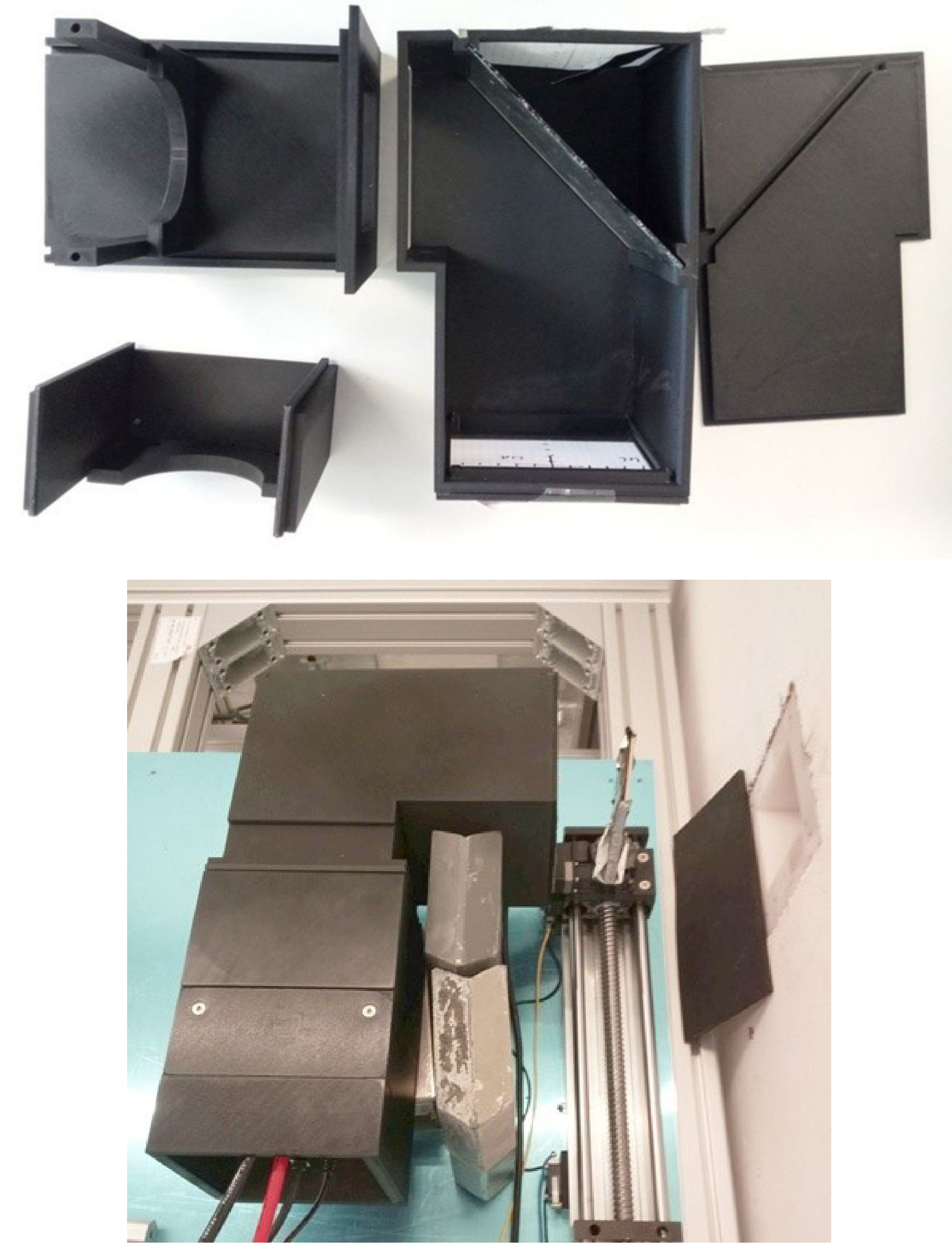


Fig.1: Latest and most simplified version of the camera box and mirror box, as well as a setup at the Atominstitut Vienna.

compared to an Aluminum housing. Defects by scattered neutrons have not yet been observed.

And while a first surface mirror is of course the best solution, we still have yet to observe quality loss with a simple bathroom mirror, which is sufficient for a single-mirror system. However, this kind of mirror failed in a double-mirror system with periscope like optics, where double reflections seemed to deteriorate the image.

In the mirror box, grooves are foreseen for the mirror where the mirror is pressed to the front edge by rubber cords pressed into the remaining gap at the back, which proved to have sufficient accuracy.

For the RA-6 reactor in Bariloche, Argentina, we built a special periscope setup (Fig. 2) which had to look through an only 6 cm opening in the shielding. Image quality was very good, but the light collection efficiency on this long distance is unsatisfactory, but this cannot be changed for the current beam line setup.

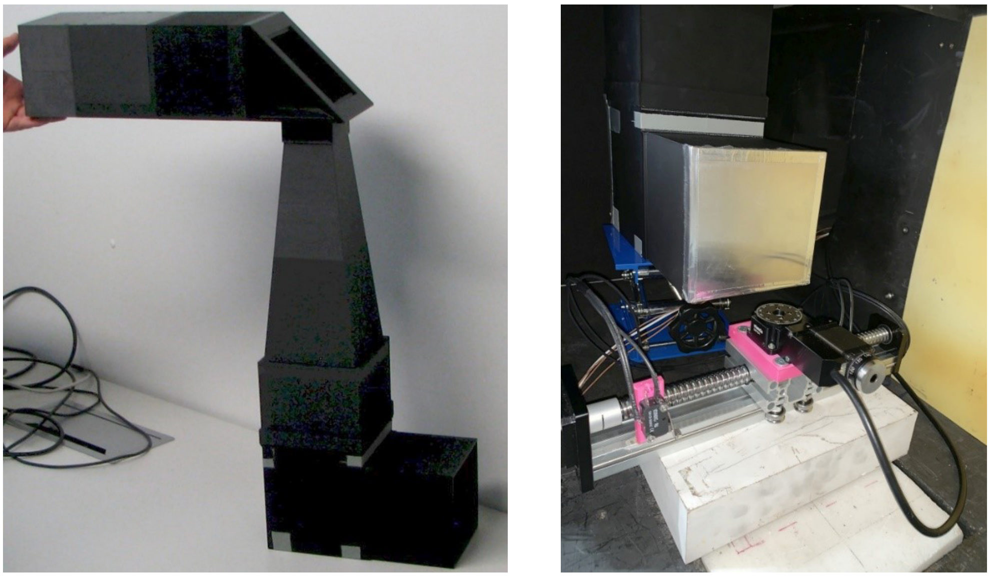


Fig.2: Periscope setup for the RA-6 reactor in Argentina.

Compact CT setup

In the beginning of neutron CT, with ‘486 computers, rotation of large images was virtually impossible, so the geometry of the detector and rotation table had to be adjusted best as possible to have rotation axis and CCD pixel columns aligned. As we can today shift and rotate images with sub-pixel accuracy, perfect alignment to the camera is no longer necessary – the axis of rotation should be adjusted within one degree, and the center of rotation needs to be stable, but not absolute, since it is later determined by software.

Tilt of the rotation axis perpendicular to the beam direction has the most influence on CT reconstruction, following the sine of the tilt angle, but it is easily corrected by software. Tilt in beam direction influences the projection with the cosine of the tilt angle, and its influence is much less severe. Although we should strive to adjust the beam axis as upright as possible, the influence of a slight tilt is bound to be much less than the influence of insufficient beam collimation, especially at smaller reactors, where the collimation is usually only in the range of L/D=100.

For open beam images, the rotation table with the sample must be moved out of the beam, then back for the actual CT scan. If open beam images are only recorded before the CT scan, which should be done anyway because of afterglow on the screen after the last images were recorded, absolute positioning of the rotation table is not necessary, because the axis of rotation is determined by software. Therefore, we do not need a high-accuracy translation stage, a simple linear stage for 3D printers with a high-slope spindle for about 100 Euros is sufficient.

As a rotation stage, a simple stepper motor with only 200 steps per rotation is insufficient as it cannot deliver sufficiently fine angular steps, which should be at least 1000 per rotation. Motors with attached gearbox have been used successfully, but we found a high-precision professional rotation stage for only 900 Euros at standa.lt, which is also visible in Fig.2.

CT controller system

We use a Raspberry Pi to control two stepper motors using a HAT motor controller (Fig.3), although any arbitrary professional controller could be interfaced.

The beginner's version runs a python script on the Raspberry Pi to control the motors, and clicks a relay connected to the left mouse button of a mouse connected to the camera computer to start an image. It can control another relay for a beam shutter.

The advantage of this setup is that one can interface any arbitrary camera program without much programming, it is very simple and transparent, and can be gotten to run very fast. But it is a crummy solution for professional use.

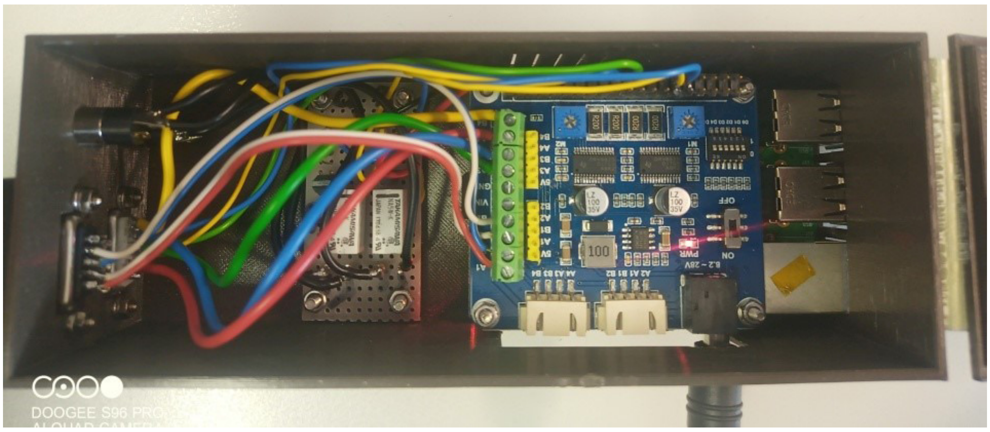


Fig. 3: The complete motor controller made from a Raspberri Pi, HAT motor controller board and relays for beam shutter and mouse click.

The professional version [3] uses the same hardware plus a control computer or a virtual machine with Debian linux that controls the camera - at the moment, all ASI cameras [4] - , and interfaces the Raspberry Pi via a local network, which is spanned by a NAT router or simply an old DSL modem. The Pi has TANGO servers installed to drive the motor controller, and NICOS on the control computer is a full control system for arbitrary network devices with graphical widgets, command line and Python script interface. It is the professional control system used at ESRF, PSI, FRM II and ESS. We have downscaled the ANTARES control system onto this single computer, but it has the full capability of the ‘big’ installation, and can control any arbitrary device on the network. This can run on a standalone network without any additional IT infrastructure, or be connected to an institute network via a NAT router.

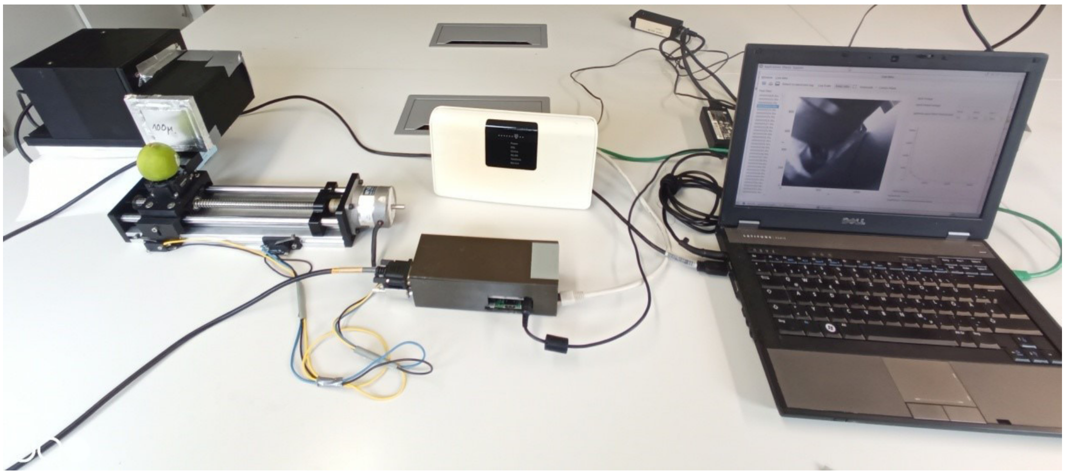


Fig. 4: Complete CT setup with Camera detector box with camera, rotation stage on translation stage, motor controller, modem as router, and the control computer with NICOS.

Fig. 4 shows the complete CT setup with Camera detector box with camera, rotation stage on translation stage, motor controller, modem as router, and the control computer with NICOS. Everything fits into a suitcase, and has been transported to and employed at the RECH-1 research reactor in Chile.

Building your own CT system

On request, we share the 3D print files for several detectors for free; the controller project is hosted on [5], where we will provide schematics, an image of the SD card for the Raspberry pi, and the virtual machine running Debian with Nicos – or a hard disk image for a native installation. Please contact Burkhard.Schillinger@frm2.tum.de for more details.

References

[1] B. Schillinger, An affordable image detector and a low-cost evaluation system for computed tomography using neutrons, X-rays or visible light, https://www.mdpi.com/2412-382X/3/4/21

[2] Burkhard Schillinger, Tobias Jünger, Tobias Neuwirth, Fynn Oppermann, Simon Sebold, Flexible camera detector box design using 3D printers, in preparation

[3] https://astronomy-imaging-camera.com

[4] Burkhard Schillinger, Jens Krüger, A freely distributable professional computed tomography system using NICOS, in preparation

[5] https://forge.frm2.tum.de/wiki/projects:mobile_tomography:index

Burkhard Schillinger
Tobisa Jünger
Jens Krüger
Tobias Neuwirth
Fynn Oppermann
Simon Sebold

Task Group "Computational Imaging"

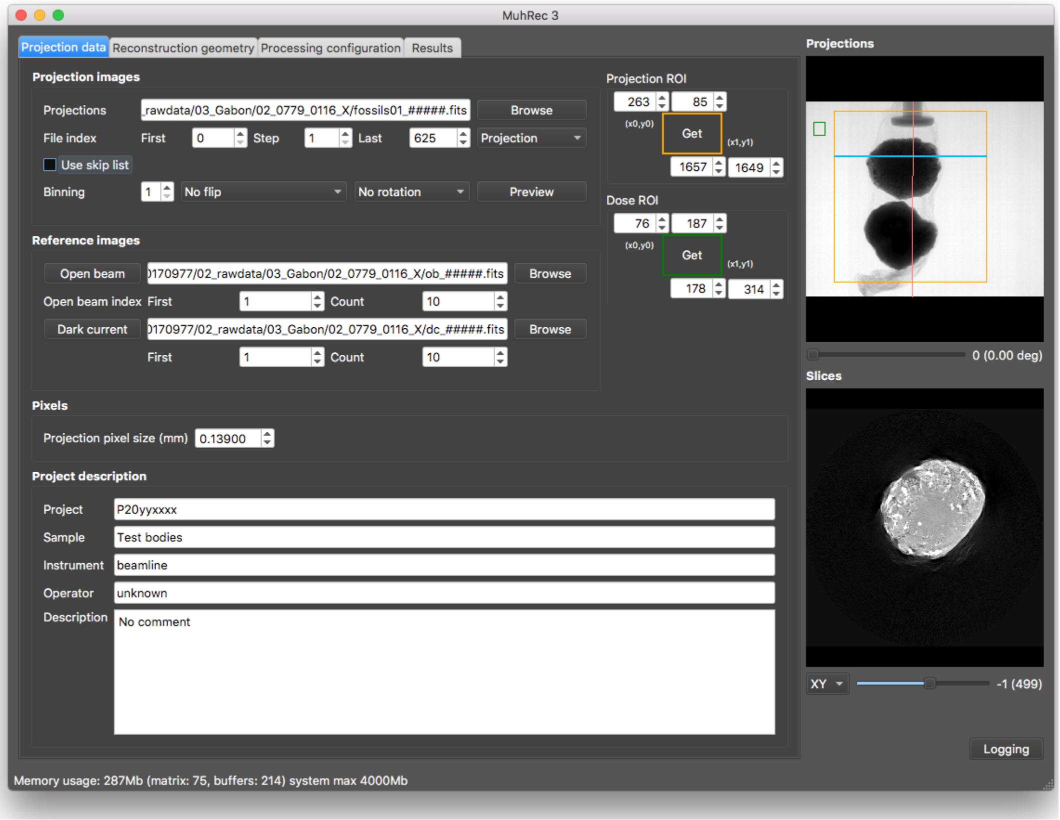
Neutron imaging is a very versatile capability that requires different software tools. Moreover, the advances of novel imaging techniques are quickly followed with the development of new software tools, or even the improvement of current ones. Below is a non-exhaustive list of current software development efforts, as well as the main tools used by the neutron imaging community.

Computed tomography: available reconstruction software

MuhRec (PSI)

- https://github.com/neutronimaging/muhrec
- Contact: Anders Kaestner
- Main languages: C++ and Python

MuhRec is a software that is optimized to perform computed tomography (CT) reconstruction. The software is well maintained with updates and improvements. A python binding is under development to run the C++ methods called by the user interface. Full documentation can be found in the github wiki page at https://github.com/neutronimaging/imagingsuite/wiki/Usermanual-MuhRec



Projection images

Projections: _rawdata/03_Gabon/02_0779_0116_X/fossils01_#####.fits

File index: First 0, Step 1, Last 625, Projection

☐ Use skip list

Binning: 1, No flip, No rotation

Projection ROI: 263, 85, 1657, 1649

Dose ROI: 76, 187, 178, 314

Reference images

Open beam:)170977/02_rawdata/03_Gabon/02_0779_0116_X/ob_#####.fits

Open beam index: First 1, Count 10

Dark current:)170977/02_rawdata/03_Gabon/02_0779_0116_X/dc_#####.fits

First 1, Count 10

Pixels

Projection pixel size (mm): 0.13900

Project description

Project: P20yyxxxx

Sample: Test bodies

Instrument: beamline

Operator: unknown

Description: No comment

0 (0.00 deg)

XY -1 (499)

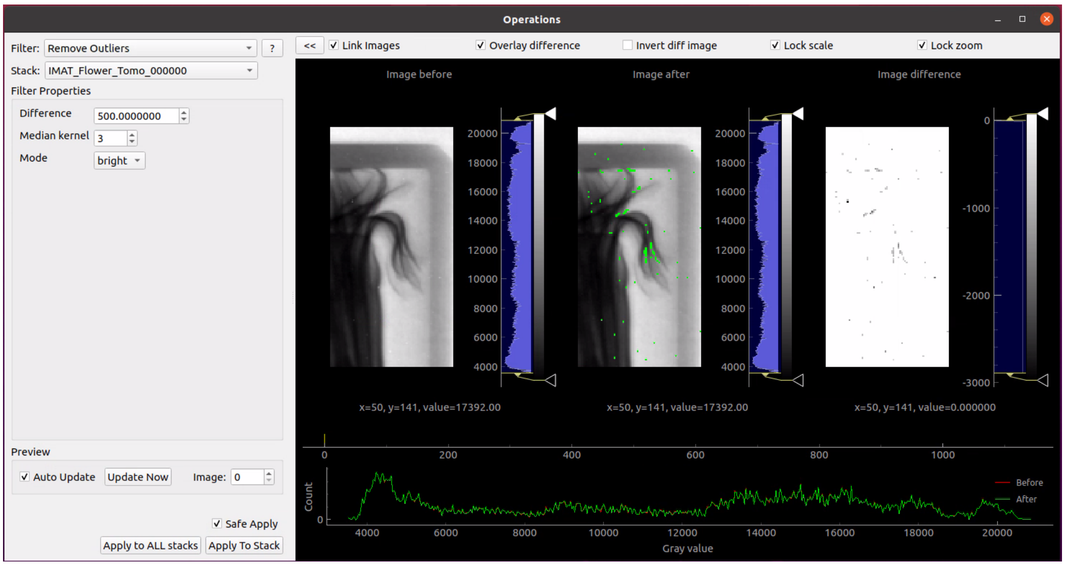
Memory usage: 287Mb (matrix: 75, buffers: 214) system max 4000Mb

*Figure 1. Display of the **MuhRec** user interface showing the input tab.*

Mantid (ISIS)

- https://mantidproject.github.io/mantidimaging/
- Contact: Sam Tygier
- Main languages: C++ and Python

Mantid Imaging is a user-friendly graphical tool for neutron radiography and CT. It is built on top of several open-source libraries tand provides tools for pre-processing and advanced iterative reconstruction. The next effort focuses on providing an API (Application Programming Interface, or in other words, the way the program is called from the command line) capability to the methods used in the user interface.



Filter: Remove Outliers

Stack: IMAT_Flower_Tomo_000000

Difference: 500.0000000

Median kernel: 3

Mode: bright

☑ Auto Update

Image: 0

☑ Safe Apply

☑ Link Images ☑ Overlay difference ☐ Invert diff image ☑ Lock scale ☑ Lock zoom

x=50, y=141, value=17392.00

x=50, y=141, value=17392.00

x=50, y=141, value=0.000000

Figure 2. Overview of ***Mantid*** *Imaging displaying result of reconstruction*

CT reconstruction

Description

This notebook allows you to run a full CT reconstruction.

Tutorial

Select your IPTS

Need help using the IPTS selector?

Select the input data set

Here is a tutorial to learn to use the file selection tool

raw data

Select the folder containing the data to reconstruct

ob

Select one or more folders containing the open beam

dc

Select one or more folders containing the dark cur

Load and display data

Just run the cell to import all the data. A progress bar will display the progress of the loading. Once done, 3 plots will show the minimum value for each pixel, for each data (projections, ob, and dc)

Beam fluctuation correction

Reconstruction

This is the final step where the data are reconstructed using tomopy engine.

Export

Select the final location where you want to export the images. A folder based on the input projection folder name + date will be created. By default, the starting folder will be the shared/processed_data of the selected IPTS.

Oak Ridge National Laboratory is managed by UT-Battelle for the US Department of Energy

Privacy | Accessibility/508 | Nondiscrimination/1557

Figure 3. Preview of the ***iMars3D*** *tutorial documentation available at https://neutronimaging.ornl.gov/ctreconstruction/*

iMars3d (ORNL)

- https://github.com/ornlneutronimaging/iMars3D
- Contact: Jean Bilheux
- Main languages: Python

iMars3d has been fully rewritten and modernized and is based on calls to Tomopy (https://tomopy.readthedocs.io/en/stable/). Furthermore, in-house algorithms have been developed such as the tilt correction calculation. The first version of the upgraded iMARS3D software aims at providing a command-line version of the library. A notebook has also been implemented to provide a user-friendly interface to the library. A full step-by-step tutorial of this notebook can be found at https://neutronimaging.ornl.gov/ct-reconstruction/.

pyMBIR (ORNL)

- https://github.com/svvenkatakrishnan/pyMBIR
- Contacts: Singanallur, (Venkat) Venkatakhrisnan, Shimin Tang
- Main languages: Python

Developed in collaboration with Purdue University, pyMBIR is an iterative reconstruction method based on the ASTRA toolbox (https://www.astra-toolbox.com/). Fundamentally, pyMBIR implements model-based computed tomography reconstruction algorithms based on a Markov random field (MRF) prior and requires computers with GPU. A user interface has been developed to improve the usability of the library (https://github.com/ornlneutronimaging/pyMBIR_UI).

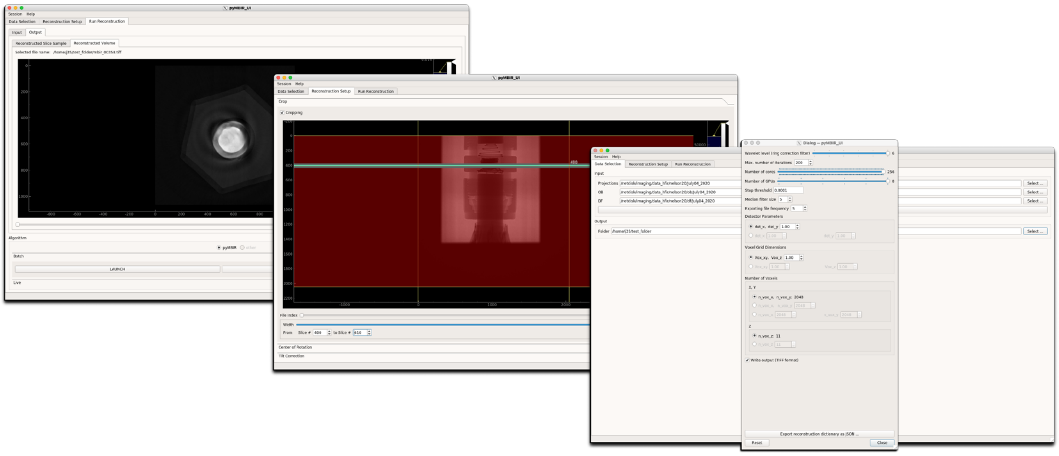


*Figure 4. Screenshots of **pyMBIR**-UI showing the result of the reconstruction (left), cropping interface (middle) and configuration interface (right).*

algotom (BNL)

- https://github.com/algotom/algotom
- Contact: Nghia T. Vo
- Main languages: Python

This data processing algorithm for tomography brings a lot of pre-processing tools needed when running a CT reconstruction. The repository is still very active.

Savu (BNL)

- https://github.com/DiamondLightSource/Savu
- Contact: Nicola Wadeson
- Main languages: Python

Savu is a Python package to assist with the processing and reconstruction of parallel-beam tomography data. The last commit to Savu was around August of 2022.

X-ACT (commercial)

- https://www.rx-solutions.com/en/news/x-act-software-release-29
- Visualization, reconstruction, and analysis tool.
- cost: $

Bragg Edge Radiography: Edge Fitting and Strain Mapping

ToFImaging (PSI / ORNL)

- https://github.com/neutronimaging/ToFImaging
- Contacts: Matteo Busi, Jean Bilheux
- Main Languages: Jupyter notebook, Python and PyQt

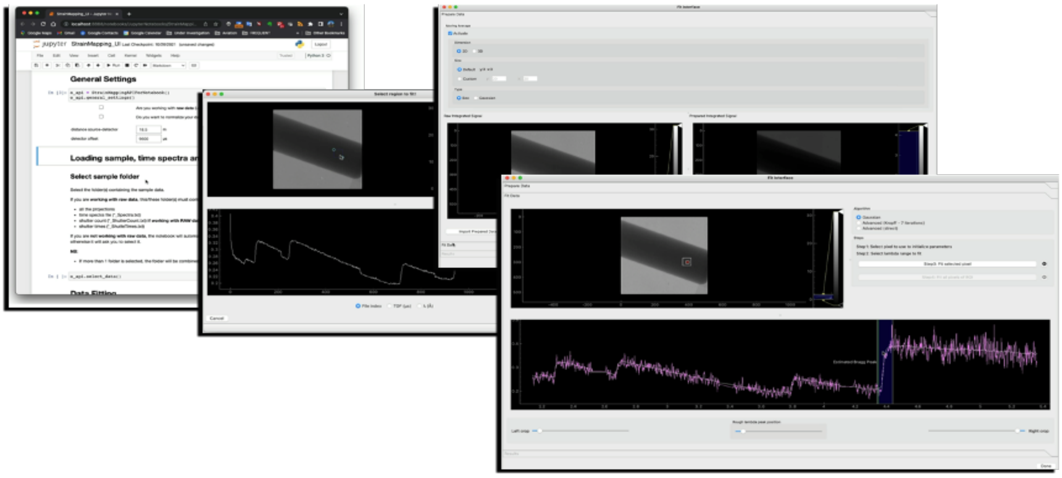


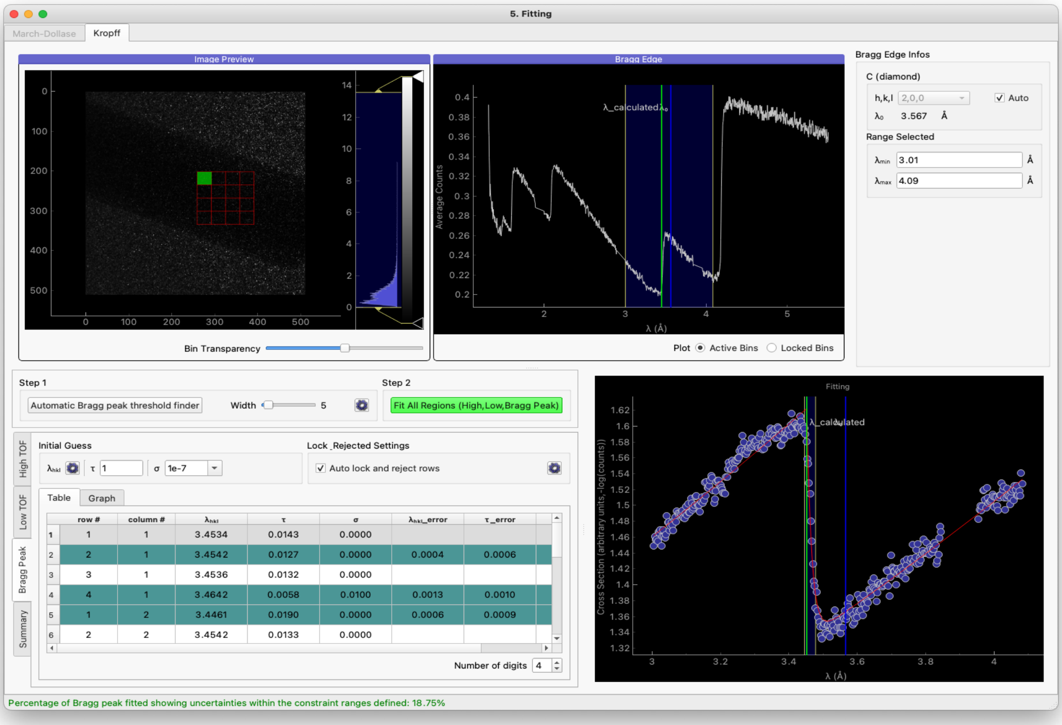
Figure 5. Screenshots of some of the views offered by the notebook showing the main notebook entry (top left view) then profile view (next on the right), normalization and configuration view (top right) and fitting window (bottom right).

Set of modules for data reduction and analysis of TOF data sets, such as Bragg edge fitting. A user interface via a notebook is under development.

iBeatles (ORNL)

- https://github.com/ornlneutronimaging/iBeatles
- Contact: Jean Bilheux
- Main languages: Python and PyQt

iBeatles (Imaging Bragg Edge Analysis Tools for Engineering Structure) is currently under beta testing. the software is a standalone application, that normalizes, fits Bragg edges using an analytical method called Kropff, calculates strain and visualizes a strain map superimposed with the sample geometry.



Bragg Edge Infos

C (diamond)

h,k,l 2,0,0 ☑ Auto

λ_0 3.567 Å

Range Selected

λ_{min} 3.01 Å

λ_{max} 4.09 Å

Step 1

Automatic Bragg peak threshold finder Width 5

Step 2

Fit All Regions (High,Low,Bragg Peak)

Initial Guess

λ_{hkl} τ 1 σ 1e-7

Lock _Rejected Settings

☑ Auto lock and reject rows

	row #	column #	λ_{hkl}	τ	σ	λ_{hkl}_error	τ_error
1	1	1	3.4534	0.0143	0.0000		
2	2	1	3.4542	0.0127	0.0000	0.0004	0.0006
3	3	1	3.4536	0.0132	0.0000		
4	4	1	3.4642	0.0058	0.0100	0.0013	0.0010
5	1	2	3.4461	0.0190	0.0000	0.0006	0.0009
6	2	2	3.4542	0.0133	0.0000		

Number of digits 4

Percentage of Bragg peak fitted showing uncertainties within the constraint ranges defined: 18.75%

*Figure 6. **iBeatles** has 6 steps (loading, normalization, view, binning, fitting and strain mapping). Here is a view of the fitting interface.*

Grating Interferometry

Angel (FRM-II / PSI / ORNL)

- Not available as open source
- Contacts: Tobias Neuwirth, Simon Sebold, Jean Bilheux
- Main languages: Python and PyQt

Angel 2.0 is the new interface to Angel (Antares nGi Evaluation), a UI developed mostly for the Antares (FRM-II) beam line. The new version will support any neutron beam line thanks to the development of new python libraries such as i/o, normalization and visualization.

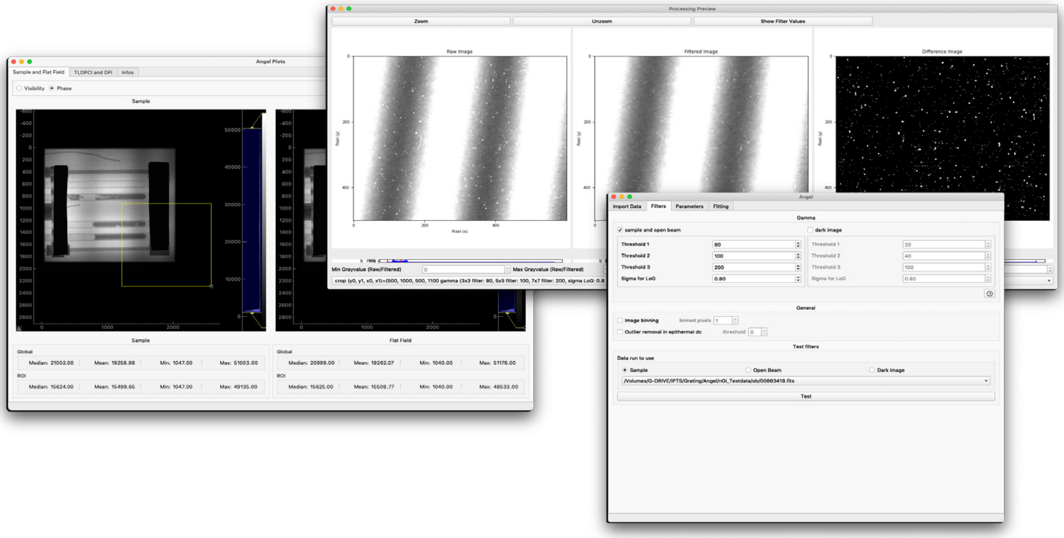
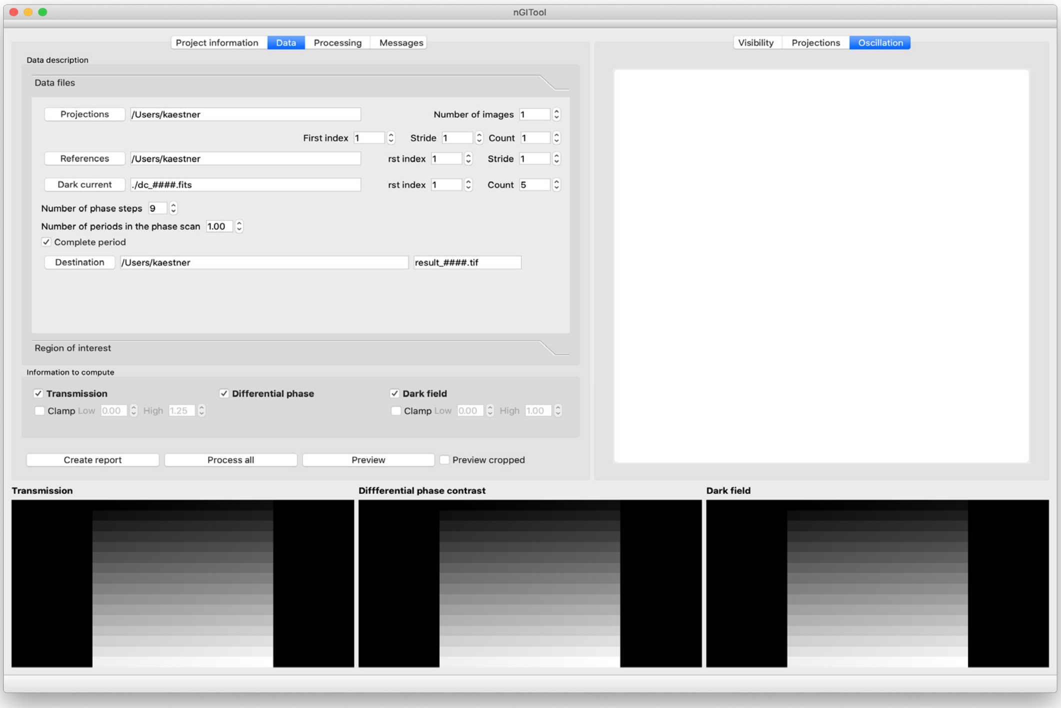


*Figure 7. Preview of **Angel 2.0** user interface. Left view displays some basic side by side comparisons of sample and flat field data. Top view, filter window and bottom right view displays the parameters to set up before running the normalization.*

nGITool (PSI)

- https://github.com/neutronimaging/nGITool
- Contact: Anders Kaestner
- Main language: C++

nGITool reduces the phase stepping scans to the three ngi quantities TI, DP, and DF. This can be done on single scans as well as multiple scans. The indexing of the images can be



Projections /Users/kaestner
Number of images 1
First index 1 Stride 1 Count 1
References /Users/kaestner
rst index 1 Stride 1
Dark current ./dc_####.fits
rst index 1 Count 5
Number of phase steps 9
Number of periods in the phase scan 1.00
☑ Complete period
Destination /Users/kaestner result_####.tif
☑ Transmission
☐ Clamp Low 0.00 High 1.25
☑ Differential phase
☑ Dark field
☐ Clamp Low 0.00 High 1.00
☐ Preview cropped

*Figure 8. Preview of the **nGITool** interface*

adjusted to handle two different scanning strategies, (1) phase scans grouped together or (2) for the case of tomography scans it is also possible to reduce sequences where a full tomography scan is acquired before moving to the next phase step. The tool also provides filtering options to remove outliers. The a collection of fitting algorithms are provided, all based on a least square principle. The tool is implemented in C++ and has a GUI to make the parameterization more convenient.

General Tools

Jupyter Notebooks (ORNL)

- https://github.com/neutronimaging/python_notebooks
- Contact: Jean Bilheux
- Main languages: Python, Jupyter notebooks and PyQt

40+ notebooks have been developed for various pre-processing steps, reduction, analysis, visualization, etc. Each notebook is fully documented on the ORNL neutron imaging web site at https://neutronimaging.ornl.gov/tutorials/imaging-notebooks/. Users accessed the notebooks via a simple browser connecting to the ORNL servers and can work on their data during or after their beam time.

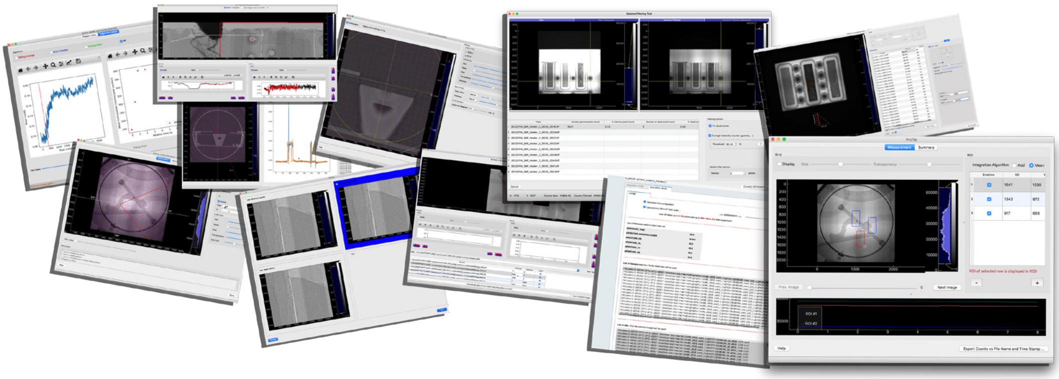


Figure 9. Screenshot of some of the numerous notebooks provided as part of the suite of tools.

Spam (ILL)

- https://ttk.gricad-pages.univ-grenoble-alpes.fr/spam/
- Contact: Edward Ando, Emmanuel Roubin, et al.
- Main languages: Python and C++

Spam is a software aimed at the analysis and manipulation of 2D and 3D data sets in material science.

Visualization

There are a few commercial software available (free or not) which also often go beyond the simple visualization, such as analysis, processing, etc. Here is a list of the most common ones.

AMIRA (commercial)

- https://www.thermofisher.com/us/en/home/electronmicroscopy/products/software-em-3d-vis/avizo-software.html
- cost: $$
- pros: python scripting, very powerful, very good tutorials

AMIRA/AVIZO is a software that aims at the visualization and analysis of scientific data in 2 and 3 D. Many tutorials can be found on their YouTube channel (https://www.youtube.com/@ThermoSciEMSpec).

VG Studio by Volume Graphics (commercial)

- https://www.volumegraphics.com/en/products/vgsm.html
- cost: $$$
- pros: powerful set of toolboxes, excellent fly-though tool.

VG Studio is a software that provides capabilities such as visualization, CT reconstruction, analysis, etc.

Volview (commercial)

- https://volview.kitware.com/
- cost: free
- pros: free, easy to jump in

Dragonfly (commercial)

- https://info.dragonfly-pro.com/home.html
- cost: free
- pros: free for non-commercial use, python scripting

ImageJ (commercial)

- https://imagej.nih.gov/ij/
- cost: free
- pros: popular tool to visualize and perform basic analysis of 2D data. 3D visualization is also available in ImageJ

Jean Bilheux

Task Group "Neutron Imaging Instrument Access"

Neutron imaging beamtime continued to be in short supply in 2022. Some neutron sources have been down for considerable periods such as FRM-2 and NIST, some sources such as ILL and ISIS TS1 have had planned long shutdowns. A silver lining for this year is that instruments will come back into operation, and that there is substantial progress visible at some of the new neutron imaging facilities at reactor and spallation sources. Concerns about reduction of running times of sources due to rising energy costs have somewhat abated. Furthermore, AMG (formerly NIAG) will continue to offer additional beamtime on BOA and POLDI (see ISNR #17 2022).

Here we provide an update on the availability of neutron imaging beamlines, to offer some additional instrument status information to what is available on the ISNR website (https://www.isnr.de/index.php/facilities/user-facilities), especially for the year 2023. Table 2 gives an overview of operational user facilities, their status and web links to instrument pages and beamtime application pages at the facilities. It may be well worth checking user office application links about various ways of accessing beamtime for industry and universities, as some facilities have dedicated fast access schemes in addition to the usual bi-annual proposal deadlines listed in Table 2. A number of neutron imaging facilities are currently being installed and will come up over the next few years, and we list those in Table 1.

Table 3 surveys some of the operation modes of neutron imaging instruments at user facilities. Many instruments now offer (or plan to provide) wavelength-selecting or resolving (e.g. Bragg edge) imaging and/or grating interferometry (e.g. dark field) analysis options. Polarized neutron imaging is now/will be available at many facilities. Access to Time-of-Fight (ToF) epithermal neutrons at pulsed sources permits resonance (elemental) analysis. Some instruments offer simultaneous X-ray CT collection. Resolution values given in Table 3 are only indicative, and meant for white beam imaging. Facilities that offer high spatial resolution on their instrument (suite) have either high primary neutron fluxes and/or have embarked on dedicated projects to improve spatial resolution.

Table 1. Neutron imaging instruments in construction or commissioning: status information.

Instruments in Construction				
Institute	Beamline	User Operation	Proposal deadlines	Comments
CNEA	ASTOR	From 2025		
	https://www.lahn.cnea.gov.ar/index.php/instrumentacion/tomografo			
CSNS	ERNI	From 2024	Nov/May	First beam established; commissioning started
	http://english.ihep.cas.cn/csns/fa/in/202109/t20210915_283262.html https://user.csns.ihep.ac.cn/			
ESS	ODIN	From 2027		
	https://europeanspallationsource.se/instruments/odin			
ORNL	VENUS	From 2024		
	https://neutrons.ornl.gov/venus https://neutrons.ornl.gov/users/proposal-calls			

Table 2. Operational neutron imaging instruments at user facilities: status and access information.

Operational Instruments				
Institute	Beamline	User Operation 2023	Proposal deadlines 2023	Comments
ANSTO	DINGO	Yes	15 March/15 Sept	long shutdown 2nd half of 2024
	https://www.ansto.gov.au/facilities/australian-centre-for-neutron-scattering https://www.ansto.gov.au/facilities/australian-centre-for-neutron-scattering/call-for-proposals			
BNC	RAD NORMA	Yes	Mid-April/Mid-Oct	offers prompt gamma activation imaging
	https://www.bnc.hu/?q=rad https://www.bnc.hu/?q=norma https://www.bnc.hu/?q=current_beam_time_call			
FRM2 / MLZ	ANTARES NECTAR	Restart 2024		ongoing source repair
	https://mlz-garching.de/antares https://mlz-garching.de/medapp-nectar https://mlz-garching.de/user-office			
ILL	NEXT	Yes	15 Feb/Early Sept	major instrument upgrade completed
	https://www.ill.eu/users/instruments/instruments-list/next/description/instrument-layout https://www.ill.eu/users/			
ISIS	IMAT	Yes	Mid-April/Mid-Oct	
	https://www.isis.stfc.ac.uk/Pages/Imat.aspx https://www.isis.stfc.ac.uk/Pages/For-Users.aspx			
JAEA / JRR-3	TNRF CNRF	Yes	Mid-May/Mid-Nov	
	https://jrr3uo.jaea.go.jp/about/institution/tnrf.htm https://jrr3uo.jaea.go.jp/jrr3uoe/index.htm			
JPARC / MLF	RADEN	Yes	Early May/Early Nov	
	https://mlfinfo.jp/en/bl22/ https://mlfinfo.jp/en/user/proposals/			
LANSCE/ LUJAN	ERNI/FP5	Yes		
	https://lansce.lanl.gov/facilities/lujan/instruments/fp-5/index.php https://lansce.lanl.gov/facilities/lujan/instruments/index.php			
ORNL	CG1D SNAP	Yes	22 Feb/Mid-Sept	
	https://neutrons.ornl.gov/imaging https://neutrons.ornl.gov/snap https://neutrons.ornl.gov/users/proposal-calls			
NIST/ NCNR	BT2 CNII	Restart 2023		cold source replacement from fall 2023
	https://www.nist.gov/ncnr https://physics.nist.gov/MajResFac/NIF/ www.nist.gov/laboratories/tools-instruments/cold-neutron-imaging-instrument			
PSI	NEUTRA ICON BOA POLDI	Yes	15 May/15 Nov	
	https://www.psi.ch/en/niag https://www.psi.ch/en/sinq/beamtime-applications			

Table 3. Neutron imaging instruments at user facilities. Current and planned methods.

Source type:	*steady (S) or pulsed (P).*
Spectrum type:	*cold (C), thermal (T), epithermal (E)*
Resolution:	*approximate/estimated achievable best spatial resolution for white-beam imaging.*
Bragg edge:	*double monochromator (DCM) or time-of-flight (ToF) analysis.*
NGI:	*Neutron Grating Interferometry. Pol: polarized neutron imaging.*
X-ray:	*simultaneous X-ray imaging*

Institute	Instrument	Neutron Source	Neutron Spectrum	Resolution [µm]	Bragg Edge	NGI	Pol	X-ray
ANSTO	DINGO	S	T	50				
BNC	RAD	S	T	70				Yes
	NORMA	S	C					
CNEA	ASTOR	S	C	25	DCM	Yes		Yes
CSNS	ERNI	P	C	50	TOF	Yes		Yes
ESS	ODIN	P	C	10	TOF	Yes	Yes	Yes
FRM2/ MLZ	ANTARES	S	C	20	DCM	Yes	Yes	
	NECTAR	S	E, T	100				
ILL	NEXT	S	T	10	DCM	Yes	Yes	Yes
ISIS	IMAT	P	C	60	TOF			
JAEA/ JRR-3	TNRF	S	T	140				
	CNRF	S	C					
JPARC MLF	RADEN	P	E, T, C	15	TOF	Yes	Yes	
LANSCE/ LUJAN	ERNI/FP5	P	E, T		TOF	Yes		
NIST/ NCNR	BT-2	S	T	10	DCM	Yes	Yes	Yes
	CNII	S	C					
ORNL	CG1D	S	C		TOF			
	SNAP	P	T, C					
	VENUS	P	E, T, C					
PSI	NEUTRA	S	T	10	DCM / TOF	Yes	Yes	Yes
	ICON		C					
	BOA		C					
	POLDI		T					

Winfried Kockelmann
Anton Tremsin
Markus Strobl

Review of Conferences

MARC-XII Session on Neutron Imaging

It is my pleasure to report about some recent activities where neutron imaging is becoming more involved other fields and, specifically, in their meetings.

The International Conference on Methods and Applications of Radioanalytical Chemistry (MARC Conference, www.marcconference.org) is an international topical conference sponsored by the American Nuclear Society. MARC-XII was held on 3-8 April 2022 in Kona, Hawaii, USA.

The MARC-XII conference organizers invited us to organize a special session specifically on neutron imaging applications. I want to point out that this invitation was instigated by a colleague, Dr. Lei (Raymond) Cao from The Ohio State University, who has long been very involved with the MARC Conference series and with a variety of neutron beam instrumentation technologies. Some previous sessions at MARC included radiographic imaging generally, but this would be the first session at MARC specifically on neutron imaging applications.

The organizing committee consisted of: Aaron Craft (INL), Hassina Bilheux (ORNL), Pavel Trtik (PSI), Burkhard Schillinger (FRM II), and Takenao Shinohara (J-PARC). The session was titled, "Neutron Imaging Technologies and Applications," and solicited topics related to radiochemistry, chemistry generally, nuclear fuels and materials, related nuclear technologies, and interesting neutron imaging presentations generally.

The session was very successful, and garnered more submissions than most other session topics at the conference, which was surprising because it was a new session for this meeting. In fact, the neutron imaging session garnered enough submissions to fill a whole day instead of being a typical half-day session.

The 16 presentations, listed below, represented a variety of international research institutions and universities.

1. Unique capabilities and applications of neutron counting MCP/Timepix detectors in neutron imaging and diffraction experiments. *Presented by Anton Tremsin from University of California Berkeley.*
2. Optimization of a reactor based fast neutron imaging system. *Presented by Matt Bisbee from The Ohio State University.*
3. Image fusion for neutron imaging applications. *Presented by Aaron Craft for Bill Chuirazzi from Idaho National Laboratory.*
4. Automated fast neutron tomography for complex objects at a 500 kW research reactor. *Presented by Ibrahim Oksuz from The Ohio State University.*
5. Mass transport in renewable energy devices by neutron imaging. *Presented by Andreas Borgschulte from the Swiss Federal Laboratories for Materials Science and Technology.*
6. High-throughput hydrogen analysis of energy materials. *Presented by Andreas Borgschulte for Marin Nikolic from the Swiss Federal Laboratories for Materials Science and Technology.*
7. Thermal neutron measurements with an unpowered, miniature, solid-state device. *Presented by Will Flanagan from University of Texas Austin and Cerium Laboratories.*

8. Use of neutron radiography for measurements in concrete. *Presented by Rita Ghantous from Oregon State University.*
9. Neutron tomography of a highly radioactive SINQ spallation target rod. *Presented by Pavel Trtik from Paul Scherrer Institute.*
10. Neutron radiography at LANSCE: Interrogation and characterization of materials for next generation nuclear reactor designs. *Presented by Alexander Long from Los Alamos National Laboratory.*
11. Hyperspectral neutron computed tomography with material decomposition. *Presented by Thilo Balke from Los Alamos National Laboratory.*
12. Digital neutron imaging of transient irradiated nuclear fuels. *Presented by Aaron Craft from Idaho National Laboratory.*
13. PVT scintillator characterization and fast neutron computed tomography at Idaho National Laboratory's Neutron Radiography Reactor. *Presented by Ibrahim Oksuz from the Ohio State University.*
14. Pulsed neutron characterization of irradiated fuels at LANSCE. *Presented by Sven Vogel from Los Alamos National Laboratory.*
15. New neutron imaging detectors using astronomy cameras and 3D printed detector housings. *Presented by Burkhard Schillinger from Heinz Maier-Leibnitz Zentrum (FRM II).*
16. New measurements on borated neutron imaging screens. *Presented by Burkhard Schillinger from Heinz Maier-Leibnitz Zentrum (FRM II).*

The session drew an average of around 40 people in the audience for any given presentation, most of which were from outside the neutron imaging field.

MARC's first session on neutron imaging was a success! We anticipate hosting a similar session at MARC-XIII in March or April 2025. Please feel free contact Aaron Craft if you may be interested in participating in a future neutron imaging session at MARC XIII.

Aaron E. Craft

This picture shows many of the presenters from the neutron imaging session on a pier during an atypically cloudy yet still enjoyable day in Hawaii.

ITMNR-9 Buenos Aires, Argentina

The 9th conference in the ITMNR series "Applications of Neutron Imaging for Science, Industry and Heritage" has been held completely as an in-person meeting in Buenos Argentina, between October 17th and 21st 2022. The meeting took place at the Kirchner Cultural Center (17-19), and was closed at Palacio San Miguel (21).

The conference follows ITMNR-8 at Beijing in 2016 and it was originally scheduled for 2020, but it was postponed due to the COVID pandemia, so it was the first in-person meeting of the neutron imaging community after a long period. ITMNR-9 was co-organized by ISNR and Argentina's Atomic Energy Commission (CNEA), which is leading the construction of a novel 30 MW multi-purpose research reactor located near Buenos Aires city, called RA-10. The reactor will host the Argentine Neutron Beam Laboratory (LAHN), where a state-of-the-art neutron imaging instrument for cold neutrons - ASTOR- is being developed. On Thursday 20, ITMNR-9 attendants participated of a visit to the RA-10 site, where they could see buildings as well as the details of the neutron beam channels before the start of the reactor.

The conference had 11 oral sessions (58 contributions including 2 Keynote and 9 invited speakers) and one poster session (53 posters) covering topics on applications and technical developments including: Instruments, Nuclear materials, Hydrogen & processes, Materials Science & Engineering, Detectors, Methods & Analysis, Electrochemistry, Earth Science & miscellaneous applications, Software and Tomography. There were also two sessions with 47 posters presentations.

A total of **99 participants** from **sixteen countries** (Argentina, Australia, Bolivia, Canada, Czech Republic, France, Germany, Hungary, Italy, Japan, South Africa, South Korea, Switzerland, Thailand, The Netherlands, United Kingdom and United States), with 26 of them from Argentina, whom seven oral presentations demonstrated the interest in the technique that accompanies the deployment of the new neutron imaging instrument.

ITMNR-9 started with the keynote lecture from Dr. Nikolay Kardjilov from HZB about the many successes of the instrument CONRAD during its 15 years of operation, whilst Dr. Pierre Boillat presented a keynote lecture on the important applications of neutron imaging in the characterization and understanding of electrochemical devices for the energy transition, in the session dedicated to Electrochemistry.

Remarkable advances in the session dedicated to detector technology, new scintillators, unpowered solid state devices, high -resolution event-mode detectors and very economical CMOS sensors. The progress reported by projects for new high-flux neutron imaging instruments (ODIN, VENUS, ASTOR), upgrades in existing instruments (Next 2.0, NEUTRA 2.0, JRR-3), and for upgrades and new facilities at small reactors (VR-1, RA-6, TRR-1/M1) foresee a bright future for neutron imaging.

Impressions of poster sessions, coffee breaks and coffee break discussions

ITMNR-9 participants visit to the RA-10 reactor site

The conference had seven sponsors from around the world: Swiss Neutronics, Phoenix, Tibidabo, Mirrotron, Tritec, Amsterdam Scientific Instruments and Volume Graphics, who had the opportunity to present their novel products and interact with the participants during the breaks. ITMNR-9 was funded of IAEA, which allowed us to support the trip of two participants from Thailand and Bolivia.

The book of abstracts of ITMNR-9 can be downloaded from the conference website (https://itmnr-9.sciencesconf.org/resource/page/id/15)

Finally, we are now in the process of receiving the proceedings of ITMNR-9, which will be published free of charge as open access articles in the Journal of Physics-Conference Series, edited by IOP, UK. So far, 41 authors have expressed their intention to present their work as a paper.

The next ITMNR Conference will take place in France in 2026.

Javier Santisteban

During the sessions.

Conference dinner at El Tropezon restaurant

Upcoming Conferences and Workshops

NEUWAVE-11

J-PARC will host the 11th NEUWAVE (NEUtron WAVElength-dependent imaging) workshop in Japan in 2023. The meeting will take place October 23 – 25, 2023, at the Miraikan (The National Museum of Emerging Science and Innovation) located in Odaiba, Tokyo. Following the traditional NEUWAVE workshop format, we will accept a limited number of oral presentations to allow plenty of time for discussion. A poster session will be held during the break between oral sessions.

Details of the workshop are still under consideration and will be announced soon.

Tentative schedule:

Workshop web page open:	middle of February 2023
Abstract submission:	May 1 – June 30, 2023
Acceptance notification:	end of July 2023
Walking discussion:	October 22, 2023
NEUWAVE-11 Workshop:	October 23 – 25,2023
Facility tour:	October 26, 2023 - Tour of J-PARC and JRR-3 (applicants only)

Takenao Shinohara

WCNR-12 Update

The World Conference on Neutron Radiography (WCNR-12) and the International Topical Meeting on Neutron Radiography series are the two main meetings organized by the ISNR. The upcoming WCNR-12 meeting is being organized by the ISNR President, Aaron Craft from Idaho National Laboratory, in collaboration with the Deputy to the President, Hassina Bilheux from Oak Ridge National Laboratory, with the support of professional event organizers from Idaho National Laboratory.

WCNR-12 is planned to be held in Jackson, Wyoming (USA) which is nestled in a valley adjacent to the Teton Mountain Range just south of Yellowstone National Park. The anticipated venue is the Snow King Resort, which can provide a beautiful large meeting room with hotel rooms and luxury residences on site. Additionally, the living arrangements in the surrounding area span a wide range of economical to luxury accommodations as each of you may desire.

The dates for WCNR-12 will be late May to very early June in 2024. The cost of hotel rooms increases significantly for later dates in this season, so having the meeting in late May will likely be more suitable for the conference. We are currently negotiating group rates, which will inform the decision about dates for the meeting.

The planning process is steadily moving ahead. Further announcements will be delivered by email to ISNR Members.

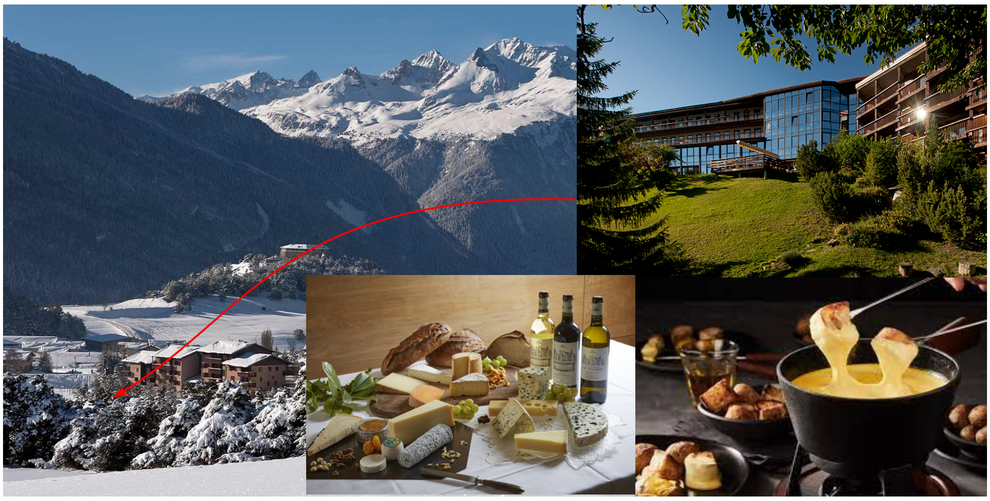
We look forward to seeing you at WCNR-12!

Aaron Craft

ITMNR-10

The 10th International Topical Meeting on Neutron Radiography (ITMNR-10), will be organised by the imaging group of the Institut Laue-Langevin, in Grenoble and will take place in the French Alps in winter 2026. A likely location will be the Centre Paul Langevin in Aussois, also in the French Alps .

Alessandro Tengattini



Dates

22-26. October 2023:	NEUWAVE-11, Odaiba, Tokyo, Japan
late May to early June 2024:	WCNR-12, Jackson (Wyoming), United States
winter 2024:	ITMNR-10, French Alpes

... and finally

... the List of Members

Please review your data on the website (www.isnr.de/index.php/about-us/list-of-members) and inform me on errors and / or changes.

If you want to **access the database** you have to unravel the following mystery: what's the probe, we are using for our investigations? Take the first two letters in lower case. Add the number that sounds like "for" followed by the first two letters for a synonym for "picturing" in lower case letters.

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