International NR Newsletter

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International Society for Neutron Radiology

(www.isnr.de)

Participants of the NEUWAVE-4 workshop along the Great Smoky Mountain National Park Alum Cave Bluff Trail.

Content

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Introduction from the President

The current Newsletter at the end of 2011 wants to inform the ISNR members and all interested parties in Neutron Imaging about latest news and developments in our promising field.

I got the impression that (despite the shutdown of a few neutron sources and the consequences of the accident in Fukushima) there are many activities and practical results visible which give reason for optimism that Neutron Imaging becomes more and more a well-accepted method (next to neutron scattering and X-ray techniques) at many places. Furthermore, methodical improvements and the implementation of digital methods as a standard tool enabled the user service on high level and the approach to new research fields in collaboration with the involved partners.

Looking around world-wide we can find about 10 well established facilities and teams working on top and producing a lot of results and outcome. However, there is potential for further implementations of Neutron Imaging techniques at existing strong neutron sources. For this purpose, there are two problems to be solved:

1. The managers at suitable sources have to be convinced that neutron imaging will have a bright future beside the established applications in neutron scattering and in irradiation techniques, worth to be supported.
2. In developing countries, we can find underequipped and underutilized reactor sources which need funding to install Neutron Imaging capabilities and to start own programs.

In respect to the first aspect, several discussions are running with various labs (ILL Grenoble, LLB Saclay, IFE Kjeller, IBR-2 Dubna) and applications have been made for the required funding.

The second aspect is supported by the IAEA in Vienna and countries like Morocco, Portugal, China, and Indonesia are considered as partners with the aim of financial and technical support.

Finally, I like to mention the activities at the existing and upcoming pulsed sources operating on the principle of spallation. We were able to held the fourth meeting for energy-selected neutron imaging (NEUWAVE-4) in October in Gatlinburg (Tennessee, USA) and got the impression that neutron imaging facilities will be built in due time at all 4 places (UK, Japan, USA, Sweden).

As an outlook I like to attract your attention to the ITMNR-7 meeting to be held in Kingston (Canada) in June 2012 - a perfect platform to enable discussions about latest results, research initiatives and methodical investigations. We hope to see a majority of the ISNR members for this occasion.

Wishing you a peaceful and lucky Christmas season and hoping for further communication and collaboration with many of you I remain with best regards

Eberhard H. Lehmann
ISNR-President 2010-2014

Neutron Imaging at Spallation Sources

A new trend - imaging at pulsed spallation neutron sources

Neutron imaging has quite a long history - for more than 60 years this technique is available in different formats. However, it is also a young and modern imaging method considering all the new developments and their application in several important fields of research and technology.

Almost all applications have been done at stationary neutron sources until now, the majority reactor based. Although about 250 reactors are operational world-wide, their number is decreasing by tend also driven by latest nuclear discussions after the Fukushima accident.

Since a while, spallation sources have been built as an alternative. They are considered to be more safe and reliable than reactors. Most of them are pulsed in order to be able to perform energy selective neutron studies in a time-of-flight regime.

For the moment, none of them (in UK, USA, Japan - and later in Sweden) have yet installed a facility for neutron imaging purposes. However, initiatives were started about 3 years ago to consider the real option for neutron imaging at these spallation sources. A series of international meetings was initialized dedicated for energy resolved neutron imaging and other advanced techniques which can take profit form pulsed sources (NEUWAVE 1 to 4).

Next you can find status reports on all four sites reporting the different approaches and the degree of success. This is a very promising situation and it is to hope that first experiences can be gained at other places (e.g. at IBR-2 in Dubna or the chopped beam line at BER-2 at HZB) before the real and powerful installations are completed at these strong sources.

Eberhard Lehmann

IMAT: A New Neutron Imaging and Diffraction Instrument for ISIS TS2

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A new facility for neutron imaging and neutron diffraction called IMAT (Imaging and Materials Science) is currently being built at the pulsed neutron spallation source ISIS. IMAT will be the first neutron imaging instrument in the United Kingdom, and will be available for a wide range of materials science applications with a main emphasis on engineering studies. The special features of the instrument will be energy-selective neutron imaging and the combination of neutron imaging and neutron diffraction. It is expected that IMAT will start operating in 2015 and that the user program will start in 2016.

Background

IMAT is one of four new neutron instruments currently being built on the ISIS second target station (TS2), a low-power pulsed source of about 50 kW and operated at 10 Hz. IMAT will build on the existing engineering material analysis program at ISIS, adding neutron radiography and neutron tomography to the ISIS user program portfolio. IMAT will offer conventional neutron radiography and tomography analyses but it will also fully exploit energy-selective time-of-flight (TOF) imaging techniques. The instrument may well play an important role in developing and exploring new energy-selective techniques which will benefit future imaging beamlines at the high-power neutron spallation sources.

IMAT will offer a combination of imaging and spatially resolved diffraction modes such as neutron radiography, neutron tomography, energy-selective imaging, neutron strain scanning, crystallographic structure and phase analysis, and texture analysis. Many projects will require only one or the other analysis technique, but the diffraction or imaging options on the same beamline will enable new types of experiments to be performed, especially considering the ease with which energy-selective measurements can be carried out on a pulsed source. The residual strains/stresses and structures inside engineering-sized samples can be more effectively analyzed if the diffraction scans are guided by radiographic data. Vice versa, diffraction analysis may be indispensable for a quantitative analysis and physical interpretation of the attenuation features observed in energy-dependent radiography data. An important feature of IMAT will be "tomography-driven diffraction" and instrument control which will enable user-friendly operation of the instrument to study structurally and geometrically complex samples.

IMAT outline design

The instrument will take full advantage of the 10Hz pulsed source running. IMAT will be placed on a high-intensity moderator, and a long flight path will ensure good time-of-flight, i.e. energy resolution, while retaining a large neutron energy bandwidth. Figure 1 shows an outline design of the instrument with the main components indicated. Table 1 lists the main specifications for neutron imaging on IMAT.

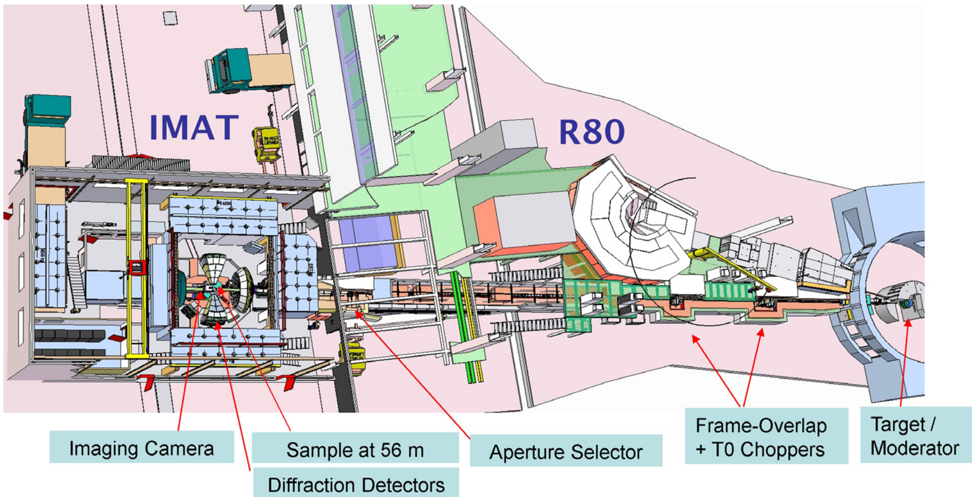


Figure 1
IMAT schematic. The sample position will be in an extension building to the main TS2 building.

IMAT will be placed on a cold, coupled LH_2-CH_4 moderator. Two double-disk choppers and one T_0 chopper will prevent frame overlap and remove fast neutrons and gamma radiation, respectively. A neutron supermirror guide will transports the neutrons to an aperture selector at 46 m, offering a choice of five apertures to define different L/D ratios. The aperture selector has one "open position" for the beam to pass through for diffraction experiments. The distance from pinhole selector to the sample position is 10 m. The resolution $\Delta\lambda/\lambda$ for energy-selective imaging will be better than 0.8%. In addition to imaging cameras, IMAT will have diffraction detectors to perform structure, strain and texture analysis. A single-frame mode with a wavelength bandwidth of 6 Å, and a double-frame mode with a bandwidth of 12 Å, will benefit both imaging and diffraction experiments.

IMAT will be built in several stages. In the first installation version IMAT will have two imaging cameras available, a gated CCD camera and a TOF capable high-resolution pixel detector. The CCD camera system is developed in collaboration with the Italian Research Council (CNR) by F. Aliotta, Messina. A TOF-capable imaging system is required to take full advantage of the pulsed source. A detector based on microchannel plates (MCP) developed by the Space Science Department, Berkeley, USA (A. Tremsin) is currently envisaged for IMAT. In addition, two large pixelated diffraction detectors at 90 degree scattering angles will be installed for diffraction analysis. Figure 2 gives an artist's impression of the initial IMAT experimental area. Further diffraction detectors at forward and backscattering angles will be installed in subsequent upgrade stages enabling in-situ texture studies in combination with phase, strain, and imaging analyses at non-ambient sample conditions.

Flight path	56 m, transport with 44 m neutron guide	
Single/double frame bandwidths [Å]	0.68 - 6.8 / 2- 14	
L/D	125, 250, 500, 1000, 2000	
Detector types	Gated CCD camera	Pixel detector
Field of View [mm^2]	200x200	
Best spatial resolution [µm]	50	50
Timing resolution [µs]	100	1
Energy resolution	ΔE/E < 0.8 %	
Neutron flux (L/D=500) n/cm^2/sec	10^7	

Table 1
Main parameters of the IMAT imaging mode

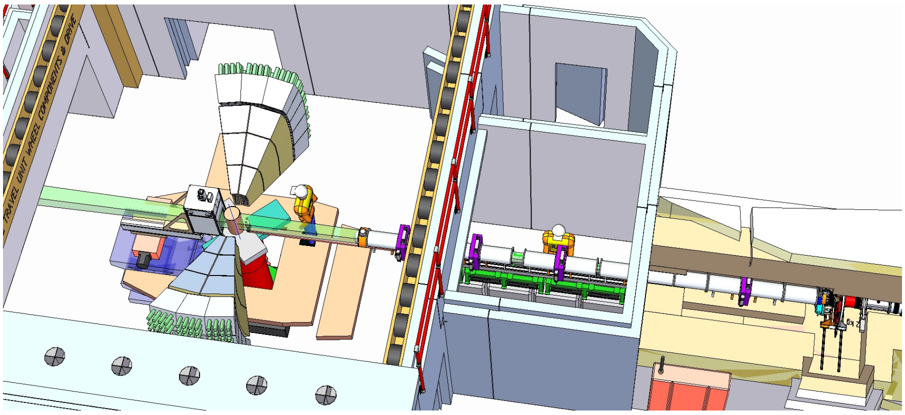


Figure 2
Artist's impression of the IMAT Day-1 sample area, including CCD camera, sample positioning system, and diffraction detectors with collimators at 90 degrees.

Application range

IMAT will enable a broad range of both established and innovative imaging and diffraction applications, covering a range of scientific and technological areas such as:

- **Aerospace & transportation:** e.g. structural integrity; lifetime and failure analysis; novel welding technology, fatigue properties; novel joining methods; composite reinforcements;

- **Civil engineering:** e.g. integrity of load-bearing structures, reinforced concrete; water repellent agents/ rising of liquids in concrete; concrete void & density distribution;

- **Power generation:** e.g. novel alloys; structural integrity of steam pipework / pressure vessels / hydrogen embrittlement in Zr welds, residual stresses of casts/weldings and weld repairs;

- **Fuel and fluid cell technology:** e.g. functioning and in-situ testing of gas pressure flow cells / fluid cells; water/lithium distributions in fuel cells/batteries; blockages, sediments;

- **Earth sciences:** e.g. deformation mechanisms in polymineralic rocks; water flow in porous media, mantle rheology, rock mechanics, spatial distribution of minerals;

- **Archaeology & Heritage science:** e.g. inorganic materials characterization; non-destructive characterization and multi-component analysis of archaeological objects and objects of art;

- **Biomaterials and soft matter, e.g. agriculture:** water uptake in plants and soil; water and hydrogen distributions in polymers and porous media;

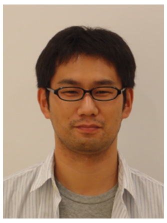
IMAT will especially excel in energy-selective imaging application, taking advantage of the pulsed source running and of the additional diffraction analysis capabilities.

IMAT Team

Lead Engineer:	Jim Nightingale (ISIS)
Science team:	Winfried Kockelmann, Shu Yan Zhang, Joe Kelleher (ISIS)
	Genoveva Burca, Jon James (Open University)

Winfried Kockelmann
Based on the Neuwave-4 presentation, 2-5 Oct 2011 in Gatlinburg, USA

J-PARC/MLF - Materials and Life science experimental Facility



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J-PARC/MLF (Materials and Life science experimental Facility) started its beam operation in 2008. The proton beam power was gradually increased and successfully got to 220 kW in December 2010. Pulsed neutron imaging experiments at J-PARC were also started in JFY 2008 by Hokkaido University and JAEA members. Because we have no dedicated beam line for the pulsed neutron imaging experiments yet, a beam port "NOBORU" located at BL10 [1], which was constructed for characterization of the neutron source, has been used for the imaging experiments. This beam line possesses some benefits to the energy-resolved neutron imaging. A good energy resolution ($\Delta t/t$=0.3%) due to the short pulse nature of J-PARC Spallation Neutron Source (JSNS) combined with the decoupled moderator for good energy resolution experiments is suitable to analyze wavelength dependent phenomena. A neutron beam with wide bandwidth up to 0.9 nm due to the short L1 (14 m) and long pulse interval (40 ms/25 Hz) is available. Then not only thermal and cold neutrons but also epi-thermal and fast neutrons, and even gamma-rays can be used for imaging experiments. In addition, a field of view of 100×100 mm^2 is the largest among the instruments at MLF, and a versatile experimental space of 2.5 (W) × 3.5 (L) × 3.0 (H) m^3 allows us to introduce various experimental setups. Now several R&Ds about energy-resolved neutron imaging techniques using pulsed neutrons are performed at J-PARC. For example, Bragg-edge imaging by elastic coherent neutron scattering, element selective imaging based on the neutron resonance absorption, magnetic field imaging using polarized neutrons, and developments and characterization on the pulsed neutron imaging devices including 2D detectors.

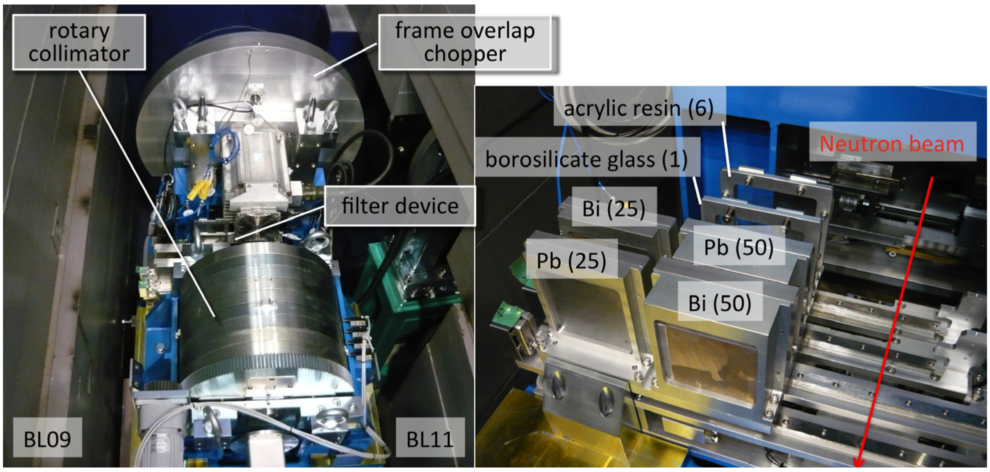

Figure 3
A photograph of the rotary collimator and filters installed in the beam line (left). Right side is a close view of the filter device.

In 2010 upgrading of the rotary collimator and installation of filters has been done (Figure 3). The rotary collimator with 4 slots was installed at about the middle of the beam line (L= 8 m) in 2009, which provided L/D ratios of 140, 190, 337, and 600. To obtain higher beam collimation, the middle size collimator (L/D = 337) was replaced with the tiny one (L/D = 1875). Figure 4 demonstrates comparison of neutron transmission images of a wrist watch obtained by neutron imaging plates with two collimator conditions, small (L/D = 600) and tiny (L/D = 1875). Obviously very fine structures of the watch such as a thread and cogs are depicted much clearer in the tiny case than in the small case. To avoid too much irradiation of the detectors, a remote-controlled filter device was introduced in the beam line. This device consists of 4 kinds of materials. A acrylic resin plate with 6 mm thickness and a borosilicate glass with 1 mm thickness are used to attenuate epi-thermal neutrons and cold neutrons, respectively. The lead metal and bismuth single crystal plates attenuate the gamma-flash [2].

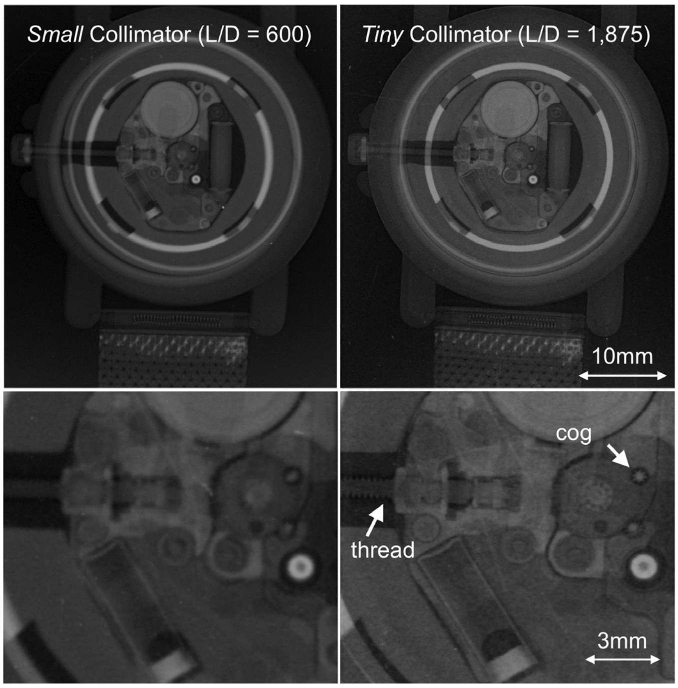

Figure 4
Neutron radiography images of a watch obtained with the collimator conditions small & tiny (top: whole view, bottom: enlarged view).

The design work of new instrument dedicated for the pulsed neutron imaging, named ERNIS (Energy-Resolved Neutron Imaging Station), is going on. This instrument is planned to build at the beam line of BL22, which views decoupled moderator of JSNS same as NOBORU beam line. In June 2009, a letter of intent (LOI) about this imaging instrument was submitted to the Neutron Instrument Program Review Committee of J-PARC Center by Prof. Y. Kiyanagi (Hokkaido University), and successfully passed the examination. Now we are asking the construction budget for the Japanese government.

On 11th March 2011, the giant earthquake attacked northeast region of Japan, and Tokai area, where J-PARC was located, has seriously damaged. Fortunately all the staffs and users of J-PARC were safe, but there were some damages in the facility. Hence, the user programs have been interrupted for the restorations. Most of repairs of facilities and instruments will be completed in December 2011, and now we are ready to resume the operation. It is scheduled to restart the user program in late January 2012.

[1] K. Oikawa, F. Maekawa, M. Harada, T. Kai, et al., Nucl. Instr. Meth., A 589 (2008) 310.
[2] F. Maekawa, M. Harada, K. Oikawa, M. Ooi and T. Kai, MLF Annual Report 2010 (in press).

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Neutron imaging at ESS

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Neutron imaging has been identified by the ESS and its scientific advisory committee (SAC) as a key instrument with a high potential to benefit from the planned long pulse source and thereby providing outstanding future scientific and industrial impact. Consequently an instrument scientist has been assigned and work packages (WP) have been allocated, which are covered to a big extend by German and Swiss in-kind contributions, in order to develop the concept of a future instrument and corresponding time-of-flight methods in the required detail for the ESS design update (DU) phase preceding the construction of the source and instruments. The DU produces the technical design report (TDR) by the end of 2012, a central document describing the planned facility and its science case in detail. The instrument development and work packages, however, continue into the prepare-to-build (P2B) phase during which the decision on the first seven instruments which are referred to as day-one instruments will be taken. In contrast to 15 more instruments on which decisions are made continuously thereafter, these first seven are intended to start operation together with the source in 2019. After review instrument proposals will be forwarded to the SAC and ESS steering committee (STC) in order to approve a build decision.

Accordingly the ESS and its partners in neutron imaging, i.e. the participants in the German imaging instrument WP led by N. Kardjilov (HZB), the HZB, TUM and HZG as well as the Swiss WP supervised by E. Lehmann, work towards the TDR and the first selection round by developing an instrument concept taking maximum advantage of the ESS long pulse source. In the framework of corresponding WP meetings taking place since Feb. 2011 the methods that should be covered by the instrument have been reviewed and identified and the conceptual works as well as simulations have started since then. Furthermore intense work to study advanced methods to be exploited in time-of-flight (TOF) imaging mode has begun and conveys Bragg-edge (BE) imaging methods for strain, texture and microstructure investigations as well as wavelength resolved polarized neutron (PN) imaging and the potential of dark-field (DF) contrast imaging in TOF. Additionally, the potential of fast and stroboscopic imaging as well as the inline phase contrast technique are still considered and investigated in terms of performance at the long pulse source by some of the partners. The requirements of the most favorable methods have been defined and can be found in the corresponding table below.

NI METHOD	wavelength – band	-resolution	field-of-view
Conventional	cold/thermal	-	25x25 cm^2
BE			
strain	0.5/1.5 – 5 Å	0.5%	10x10 cm^2
microstr	2-6 Å	10%	10x10 cm^2
texture	0.5/1.5-5 Å	1%	10x10 cm^2
PN	1.5-10/20 Å	1%	10x10 cm^2
DF	1.5-10/20 Å	10%	10x10 cm^2
Others			
Inline phase	1.5-10/20 Å	1%	15x15 cm^2
fast & strob.	cold/thermal	-	25x25 cm^2

Table 2
Neutron imaging methods and basic requirements

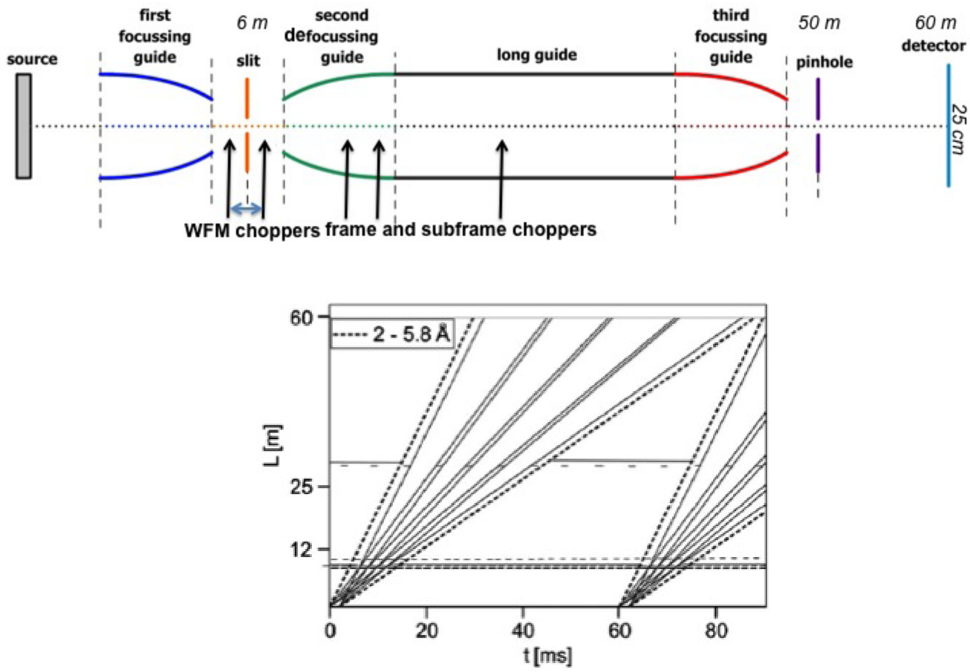

Figure 5
Upper: schematic conceptual layout of potential imaging beamline at ESS; Lower: principle of wavelength frame multiplication for imaging in a schematic TOF diagram based on the former ESS baseline parameters (taken from: M. Strobl NIMA 2009)

According to these and the precondition to not significantly compromise the performance of conventional attenuation contrast imaging exploiting the high time average flux at ESS, a conceptual design has been developed that potentially covers all needs. The current agreed layout is based on a 60m instrument that provides a minimum 10% wavelength resolution at 2Å and a bandwidth of about 4.5Å that can be shifted over the spectrum by the wavelength bandwidth chopper which additionally allows for pulse suppression in order to cover a broader wavelength range in one go. These conditions allow for the visualization of microstructural features in BE and DF imaging, while conventional attenuation contrast imaging can be conducted with either a selected wavelength band or using all neutrons passing the guide without any chopper in operation. Another mode is necessary in order to achieve an increased wavelength resolution of about 1% for quantitative and polarimetric PN imaging as well as for potential texture investigations or even down to <0.5% resolution for transmission strain mapping through BE imaging. Such resolutions are achieved by a wavelength frame multiplication (WFM) chopper system starting at 6m from the moderator with an optical blind pulse shaping chopper assembly enabling to tune the resolution through variation of the chopper distance. This system is meant to potentially work also in a single pulse suppression mode in order to increase the bandwidth and down to wavelengths of at least 1Å. Such spectral requirements imply the use of a bi-spectral beam extraction and has, like the chopper system a significant impact on the optimization of the guide system, where the boundary conditions defined are a homogeneously irradiated field of view of about 25 x 25 cm^2 at a distance of 10m from the pinhole at approximately 50m downstream from the source.

Markus Strobl
ESS

VENUS – Imaging at the Spallation Neutron Source for Energy Efficiency in Industry and Manufacturing

Unique Opportunity

The Oak Ridge National Laboratory (ORNL) has an opportunity to build a world-class neutron imaging instrument (VENUS) for the study of energy efficiency in industrial components and manufacturing systems. VENUS will uniquely utilize the Spallation Neutron Source (SNS), shown in Fig. 6, to measure and characterize large-scale engineered systems. VENUS will be the brightest and highest resolution neutron imaging instrument in the world and will provide industry with the opportunity to advance their development efforts in energy efficiency, transportation, material systems, and a wide variety of non-destructive engineering design and testing applications. Through three years of preparation and preliminary testing, the Instrument Development Team (IDT) at ORNL has received provisional approval to build VENUS at one of the few remaining beamline positions at SNS. The IDT team has been particularly active in identifying science and engineering roles in energy efficiency for VENUS, working with the U.S. Department of Energy (DOE) through the Energy Efficiency and Renewable Energy (EERE) program, concentrating on applications in vehicle technology, industrial technology, building technology, enhanced geothermal systems, and biomass technology.

Figure 6
The Spallation Neutron Source at the Oak Ridge National Laboratory.

Significance to Industry and Manufacturing

Neutron imaging is a non-invasive, non-destructive method that is complementary to other methods such as X-ray or gamma imaging. Neutron imaging has been under-represented in the United States, with available facilities severely oversubscribed and of limited capability. VENUS will provide a measurement instrument capable of studying complex engineered systems for energy storage, fuel cells, hydrogen storage, nuclear energy, geothermal systems, efficient engine and fuel injector designs, combustion imaging, heat exchanger design, magnetic material processing, materials under stress, and a host of other applications. The combination of SNS and high-sensitivity imaging technology will bring the United States into a leadership role in energy-selective neutron imaging and will provide industry and government with the opportunity to improve the energy efficiency and productivity of manufacturing and engineered systems.

ORNL has invested or attracted nearly $6M in funding since 2009 through ORNL internal R&D funding, U.S. DOE Early Career Award, the EERE Vehicle Technology and Geothermal programs and other federal funding to attract and work with industry on applications of neutron imaging. Much of our work has been accomplished at a demonstration beam line established at the High Flux Isotope Reactor (HFIR) at ORNL. Although only a fraction the capability of the planned VENUS instrument, the HFIR neutron imaging prototype beamline has attracted Industry partners to date that include Ford, GM, Chrysler, United Technologies Research Center, Cummins Engines, Detroit Diesel, Mack, Delphi, Navistar, PACCAR, John Deere, Caterpillar, Volvo, GE, Whirlpool, DuPont, Mars, Thermacore, Raytheon, and Bush. Companies have been interested in a range of investigations that include better understanding of lithium ion mobility in batteries, improved design of exhaust gas recirculators in combustion engine systems, understanding diesel particulate filter fouling and regeneration, and improved design of expansion valves and refrigerants in heat pump systems, among others.

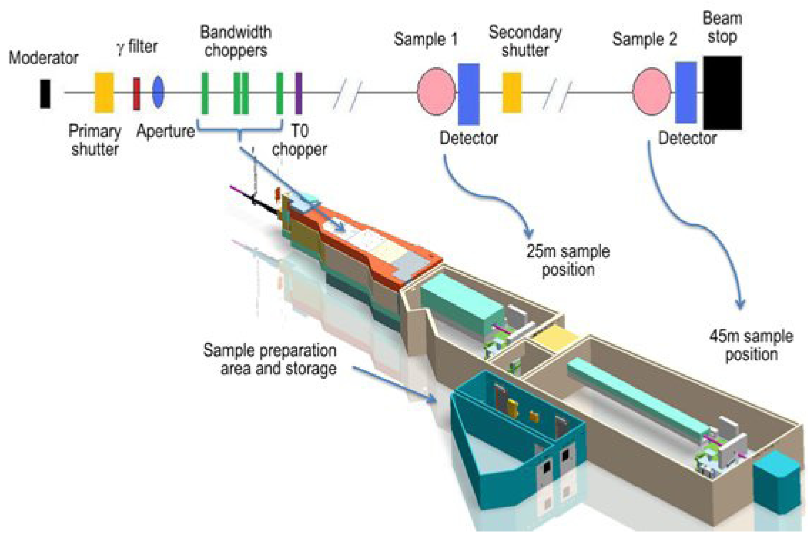

Figure 7
Schematic representation of the VENUS neutron imaging instrument showing the neutron chopper and beam filtering configuration for the two sample stations which will be at 25m and 45m from the neutron source and moderator.

Beamline Design

The VENUS design is being optimized to measure micro-scale spatial and temporal structure in meso- and macro-scale objects in transmission radiography (2D) and computed tomography (3D) modes. Fig. 7 is a schematic layout (top) and graphical representation (bottom) of the VENUS instrument. VENUS will be located in the SNS target building at Beam Line 10 (BL10), one of the few remaining positions at SNS that could support an imaging instrument (Fig. 8). The instrument configuration will contain two independent

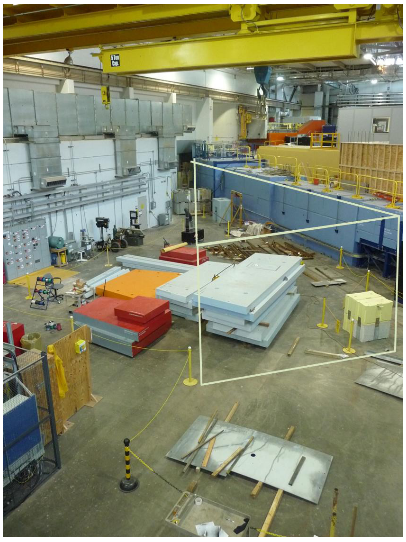

Figure 8
Approximate position of VENUS in the neutron instrument hall at SNS.

sample positions in their own housing units; one at 25m and the other at 45m respectively from the source and moderator. This configuration will require three wavelength bandwidth (BW) choppers to prevent frame overlap and destruction of time-of-flight (TOF) wavelength information. Neutrons from the moderator will pass through an aperture of variable size, through tapered flight tubes and through the sample at the first sample position (25m from the spallation source). Bandwidth choppers define wavelength of neutrons incident on the sample and eliminate contamination from preceding and succeeding neutron pulses. A T_0 chopper is placed downstream of the bandwidth choppers to mitigate the contribution of fast neutron flux. A removable cooled Bismuth filter, positioned between the moderator and the aperture will be used to reduce the gamma contribution to the beam.

The BW choppers will be composed of two single and one double bandwidth disks. The double BW disk can be rephrased by changing the phase of the two disks relative to one another to prevent wavelength contamination at the second sample position (45m from the spallation source). Since VENUS will have the two sample positions available for experiments, it will be equipped with two shutters; a primary shutter located upstream at approximately 2.5m from the source (close to the moderator), and a secondary shutter located downstream of the first sample position after the imaging detector at approximately 28m from the source. The secondary shutter will also be equipped with a rectangular guide. When samples are measured at the 25m position, we anticipate using no waveguides in the beam tube. However, at the 45m position, a guide system will be used to limit flux loss as appropriate to the experiment at hand. For these experiments, the guides will be located between the last choppers, approximately 35m upstream of the second sample position. In this configuration an aperture will be located at the end of the guide system. Although not illustrated in the figure, beam slits will be used as appropriate to limit the beam size when the sample is smaller than the native size of the beam to mitigate the neutron background.

To interrogate the wide variety of materials and engineered systems that are anticipated for analysis with VENUS, both sample positions will be equipped with a translation and rotation stage to facilitate 2D transmission and 3D volumetric reconstruction from projections. Although some of the experiments to be performed with VENUS will use conventional neutron imaging measurements (i.e., no wavelength discrimination required), the advantage of VENUS will be its ability to perform energy selective imaging capabilities. Therefore the imaging (i.e., 2D) detectors will be capable of measuring TOF information, which include arrival times of each neutron at sufficient spatial resolution.

The instrument is being designed to meet performance criteria specified by the wide variety of end-use applications described earlier. Performance capabilities are defined with respect to the required neutron wavelength range, temporal resolution, spatial resolution, field of view, and beam quality (e.g., divergence, length-to-diameter (L/D) ratio, gamma/neutron ratio, etc.). VENUS will take advantage of the large neutron wavelength spectrum provided by the SNS to perform energy selective imaging for applications such as Bragg edge measurements (proportional to stress/strain in materials), material contrast enhancement, or variable penetration to accommodate a wide variety of micro-environments and material interactions. A decoupled H_2 moderator will be used due to its narrow neutron emission-time uncertainty. The design flux (calculated) for the 25m sample position will be approximately $2.5x10^6$ n/cm²/s for a field of view (FOV) of 30x30cm² and an L/D of 500. For the 45m sample position, the calculated neutron flux will be $1.5x10^5$ n/cm²/s (no waveguide) and significantly higher with a waveguide, for a FOV of 90x90cm² and an L/D of 500.

For the decoupled H_2 moderator, the emission uncertainly increases approximately monotonically over the SNS beam's usable wavelength range of 1Å<λ<40Å. For the type and variety of experiments anticipated for VENUS, a timing resolution of better than $\delta t/t = \delta\lambda/\lambda = 0.01$ will not likely be required, although high neutron flux will be required. For experiments at VENUS that require high temporal (i.e., energy) resolution, e.g., $\delta t/t = \delta\lambda/\lambda = 0.001$, this resolution will be available at the 45m sample position, but at a reduced neutron flux.

Conclusion

There is a clear need for neutron imaging at major U.S. facilities for a variety of applications. The instrument development team that is specifying and designing the capabilities of VENUS is represented by a large group of researchers from academia, industry, and national laboratories with a worldwide representation. VENUS will truly be a unique and unprecedented neutron imaging instrument for the U.S. and the worldwide neutron science and engineering community. It is anticipated that the world's brightest spallation neutron source coupled with energy-dependent neutron imaging and a significant field of view will produce insight into a wide variety of scientific and engineering applications that will impact our energy and manufacturing capabilities well into the future. Better vehicles, building envelope systems, enhanced geothermal systems, biofuels production, and a host of other complex engineered materials and systems will be realized as an outcome of the VENUS instrument.

Biographies

Kenneth W. Tobin, Ph.D., is a Corporate Research Fellow and the Director of the Measurement Science and Systems Engineering Division at the Oak Ridge National Laboratory, a research division of 170 staff members. He performs research in image processing, pattern recognition, and image-based metrology for automation and process characterization and was named an ORNL Corporate Research Fellow in 2003 for his contributions to the field of applied computer vision research. He is representing ORNL as principle investigator on the effort to develop and commission a world-class neutron imaging instrument designated the Versatile Neutron Imaging Instrument at the Spallation Neutron Source (VENUS). VENUS will uniquely utilize SNS to measure and characterize large-scale, multi-component, engineered materials and systems. He has authored and co-authored over 135 publications and he currently holds ten U.S. Patents and three pending patents in the areas of computer vision, photonics, radiography, and microscopy. He is a Fellow of SPIE and IEEE. Dr. Tobin has a Ph.D. in Nuclear Engineering from the University of Virginia, an M.S. in Nuclear Engineering from Virginia Tech, and a B.S. in Physics also from Virginia Tech.

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Hassina Bilheux, Ph.D., is the instrument scientist in charge of neutron imaging capabilities at SNS and HFIR. She obtained her Ph.D. (Physics) in 2003 from the University of Versailles-St-Quentin, France while performing her research project at the ORNL Physics Division, working on electron cyclotron resonance (ECR) ion sources. Dr. Bilheux is interested in exploring the novel use of energy selective neutron imaging in different research areas such as engineering, biological and forensic applications, and energy and environmental areas as well. She is PI on a NIJ research project and co-PI on several DOE Energy Efficiency and Renewable Energy (EERE) projects. She is one of the book editors of the Neutron Imaging and Applications book, published by Springer, and has authored and co-authored publications in the field of neutron imaging.

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The situation of Neutron Imaging in 2012

Neutron Imaging as research tool and as method for non-destructive investigations is clearly depending on the access to neutron sources. A well-defined and highly intense beam of preferentially thermal or cold neutrons is needed to be able to perform neutron imaging studies on a state-of-the-art level.

The majority of such sources is based on research reactors whereas new sources have been built as spallation neutron sources. The only strong stationary spallation source is SINQ, PSI, Switzerland, comparing in intensity to a 15 MW research reactor. The more challenging approach at spallation sources is to pulse them and to use the predetermined time structure for time-of-flight experiments. Although a lot of neutron scattering techniques will take profit from this source behavior, neutron imaging can also be performed easily and new imaging methods can be established. This is now the topic at ISIS, JPARC, SNS and also ESS in the future how to build the best suitable neutron imaging beam line there.

In respect to reactor based sources there is a clear signal for shutdown of aged sources, the recent example is FRG-1 at Helmholtz-Zentrum Geesthacht in Germany. New research reactors have been built in developing countries only. They suffer from the problem to be able to operate the reactor but have not enough budget and experience to install modern experimental techniques. Here, an urgent need for support e.g. by IAEA is obvious to use such powerful sources for neutron imaging in the best possible way.

The Research Reactor Data Base of the IAEA (http://nucleus.iaea.org/RRDB) delivered the following picture:

- 241 research reactors operational in 56 countries
- 188 with power > 1 kW; 110 with power > 1 MW – quite useful for neutron imaging
- 51 facilities claim to perform neutron scattering

However, 77 facilities claim to perform neutron radiography – what is surprising if we consider the participation in major conferences.

Looking deeper into details and comparing with own knowledge, the picture about neutron imaging faculties looks more as follows:

- 10 facilities can be considered as state-of-the-art even if there are specific differences in their performance
- About 18 faculties perform some neutron imaging, however not with latest technology
- 3 facilities were found to be shut-down already
- 15 places have to be considered questionable because no results or publication came up in the past
- 32 facilities were seen to have great potential to start a neutron imaging program because the performance of the reactor will guarantee a successful installation. As

mentioned above, there are some initiatives started already and further should follow to create new places for neutron imaging.

Recently, we found some signals that well established centers with main focus on neutron scattering methods are interested in to join the field of neutron imaging. Here, the message should be to make the job of building neutron imaging capacities professional and carefully without compromises. That means:

1. Select the most useful beam line, preferentially a cold one with reasonable high intensity and low divergence

2. Create a team with 2-3 ambitious experts willing to build the facility, to operate it for own and users interests and to communicate with partners from industry and scientific institutions (not only physicists).

3. Make the installation with sufficient funding (estimated about 1 Mio. Euro, when you start from scratch) with the same quality standard than neutron scattering systems are built. This investment should be based on the best present know–how within the neutron imaging community.

In summary, it can be stated that neutron imaging is a competitive research method which can be treated further if the access to prominent neutron beam ports will be enabled. Similar to the expanding X-ray imaging techniques at synchrotron light sources and with powerful laboratory sources neutron imaging can broaden its potential as research tool in the next years. More than on neutron beams it depends on people who are willing to go this promising way.

Eberhard Lehmann

NEUWAVE-4

Figure 9
Conference hotel

The series of NEUWAVE workshops was established in 2008 with its start-up at the Technische Universität München, Germany, followed by next meetings in Abington, UK, in 2009 and at the Hokkaido University, Japan, 2010. The intention of the workshops was and is still the support of neutron imaging facilities at spallation sources by the International Society for Neutron Radiology (www.isnr.de) and discussions about options for energy-selective imaging with neutrons generally by all other interested individuals during the meetings.

Traditionally, the workshops are started with a mountain hike (except for Abington, where due to missing mountains a walk along the Themse river took place) the day before its official start. This gives participants the chance to become familiar with each other, to exchange latest information in neutron imaging and related fields or simply enjoy the beautiful landscapes.

The 2011 NEUWAVE-4 workshop took place October 2nd – 5th, 2011, in Gatlinburg, Tennessee, USA and was perfectly organized by the team of Ken Tobin and Hassina Bilheux together with great assistance by Linda Stansberry from the Spallation Neutron Source at the Oak Ridge National Laboratory.

This year's hike went along the Great Smoky Mountain National Park Alum Cave Bluff Trail. Announced was a moderately difficult 4.6 miles round trip. A group of about 20 participants made a rather quick walk enjoying Mather Nature's majesty and power, but making up changing smaller groups having extensive discussions. As one of the original initiators

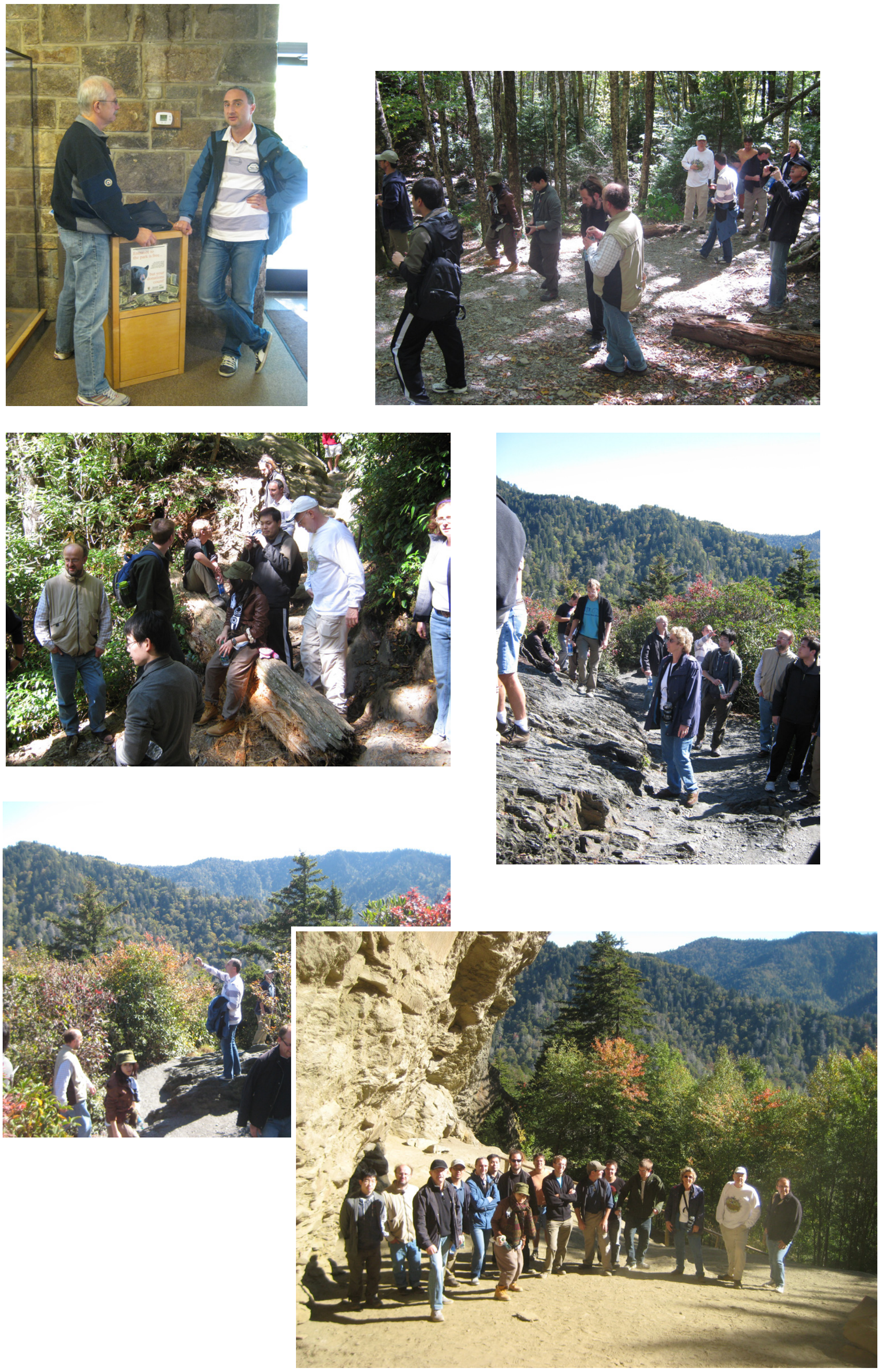

Figure 10
Some impressions of the mountain hike

of the workshop series was unable to participate in the hike, the traditional "Gipfelbier" (translation: having a beer on the top of a mountain) was omitted. Regardless the hike was an excellent introduction to the workshop starting the next day.

The Workshop was subdivided in five sections

- Beam line design and activity at existing facilities
- Advanced Techniques (Polarized, Phase and Fission Imaging)
- Bragg Edge and Energy Selective Imaging
- Detectors and Optics
- Applications

The first day was mainly focused on the status of the (planned) imaging facilities at the four spallation sources SNS, ISIS, J-PARC and ESS. More detailed information on these facilities is presented by individual reports within this newsletter. The participants were informed on the actual running upgrade program of the CONRAD facility at HMI and on some the highlights achieved during the last years (e.g. high resolution, energy selective and magnetic imaging etc.). Another presentation was devoted to measurements at the HFIR CG1D imaging prototype beamline. Information on beam characterization, the use of diffusers and data treatment were given.

Figure 11
Preparing the next presentation ...

A new monochromator for energy-selective imaging at PSI, called TESI, was presented. It enables two- and three-dimensional mapping of material properties with high spatial resolution and a flexible $\Delta\lambda/\lambda \approx 2\%$-$5\%$. First results were presented. The next talk focused on the investigations of superconductors with polarized neutron radiography. here it was demonstrated that Nb samples suppress the Meissner effect and that their surface treatment apparently influences the local field distribution. For Pb–single crystals the Meissner effect seems to prefer crystals showing no flux pinning, while for high purity Pb–polycrystalline materials a partial Meissner-effect with non-uniform flux pinning shows up. The next presentation on experimental and theoretical considerations on edge enhancement in neutron imaging was extensively discussed by the participants as this topic may bring together the fields of neutron physics and neutron imaging. Further investigations must be supported by improved modeling of the experiments to get best agreement to the experimental results. This is essential for the expanded understanding of this effect. The last presentation of this day reported on some new results on imaging of dynamic processes using fission neutrons.

At the succeeding general discussion on the topic spallation based concepts in neutron imaging participants reported on their experiences on detectors based on new sCMOS devices, which seem to be well suited for time-of-flight measurements giving a great improvement compared to former CMOS detectors, the latter especially for the signal-to-noise ratio. They also enable exposure times of up to 10 minutes showing a stable dark image. The only disadvantage seems to be the somewhat low detectum quantum efficiency (DQE) of about 60 %. Other interesting detection systems reported were the MEDIPIX / TIMEPIX based system as well as the systems build by Anton Tremsin and Volker Dangendorf.

Figure 12
... and listening attentively

The presentations on Bragg edge and energy selective imaging were continued on the second day. Results on investigations using a double crystal monochromator at a steady neutron source were presented demonstrating that this method can provide complimentary information but having the advantage of position sensitive resolved scattering signals. The wavelength resolution of the used double crystal monochromator device enabled to observe residual stresses and texture effects. A comparison with TOF techniques showed the advantage of pulsed neutron beams in case of high wavelength-resolution applications. A method for data evaluation of Bragg edge transmission imaging results by a Rietveld type analysis was presented in the next talk. The results of this development were verified by experiments resulting in the availability of crystalline phase imaging for user measurements. The following presentations were devoted to the application of Bragg edge imaging. First, in-situ strain mappings under multi-axial loading were demonstrated successfully in case studies for plane stress and for a sample with stress concentration, respectively. Next, the applicability of Bragg edge imaging was shown in neutron tomography and diffraction of intact, commercial Lithium-ion polymer batteries. While two-dimensional inspection worked successfully, some more research on three-dimensional analyses is necessary. Investigations and results on strain mapping using Bragg edge imaging were the topic of the next presentation, too. Additionally, the simultaneous imaging of the same material or object using both neutrons and X-rays at multiple energies and resolutions to exploit multi-modality was discussed in this presentation e. g. for carbon fiber vinyl ester composite structural materials. The talk on archaeometallurgical studies at ICON and a closer look at the velocity selector highlighted the suitability of energy resolved imaging for the example of historical Japanese swords. The last presentation of the session closed the circle of Bragg edge and energy selective imaging and of neutron imaging at pulsed sources by reporting on various applications of pulsed neutron TOF imaging.

The session detectors and optics was opened by a talk on high resolution energy resolved neutron imaging and transmission diffraction and resonance absorption imaging with multi-channel plate (MCP) detectors. Here the impressive features of these detectors were presented for different applications. Although the next presentation wanted to show results on their way towards 1 µm spatial resolution in neutron radiography, the emphasis of the talk was on a general overview of activities including high resolution imaging developments. The last presentation of the second day was on focusing mirrors for neutron imaging resulting in extensive discussions on the applicability of Wolter mirrors in practice.

Figure 12
The Workshop Dinner at Gatlinburg aquarium

Due to the extensive discussions which already took place during and after the individual presentations (and first signs of fatigue of the audience) the final wrap-up discussion was canceled.

On the evening the Workshop Dinner took place at the outstanding Gatlinburg aquarium. Most of the participants enjoyed the beautifulness and diversity of the marine wildlife even a long time after the end of the dinner.

The third day of the workshop was devoted to applications. It was reported on neutron radiography of water in soil and plant systems, on high resolution neutron and X-ray imaging of partially saturated materials and engineering applications, on improving the detection of water in a fuel cell using cold neutrons and finally on the first applications at the HFIR CGID from engineering to plants.

With a guided tour to the Spallation Neutron Source (SNS) and the High Flux Reactor (HFIR) at Oak Ridge the NEUWAVE-4 was completed. Participants, who returned to ORNL after the IAN2006 workshop were impressed by the new installations and the status of the user program. The beam port CG10 at HFIR was found quite useful for dedicated tests for neutron imaging. It should be used further for different purposes until the VENUS project is completed.

Summarizing the few days of the NEUWAVE-4 workshop, an extremely high level in quality of the presentations must be stated, demonstrating the increasing efforts the different neutron imaging groups worldwide put on their research, developments and facility upgrades. New data and evaluations not published yet have been presented and been extensively discussed, often resulting in new ideas for further improvements. Continuing this way, neutron imaging might become even more recognized within the scientific and technological societies.

During the workshop it was decided, that NEUWAVE-5 will take place at Lund, Sweden, in early 2013. It will be interesting to see where the mountain hike will take place.

Thomas Bücherl

Tips from the lab

Proper collimation of neutrons

Gadolinium is the most suited material for the collimation of slow neutrons but emits a large number of high energy gamma radiation resulting in problems for shielding and dose. To overcome this problem Burkhard Schillinger (TUM) proposed at NEUWAVE-4 to realize a pinhole by a layered structure of gadolinium, cadmium and borated polyethylene, respectively, with a small sheet of Gadolinium as basic pinhole, fixed on a Cadmium ring, that is fixed on a larger polyethylene plate (Fig. 13). Thus the amount of gadolinium is reduced while Cadmium is emitting secondary gamma-radiation of much lower energies, which can easily be shielded.

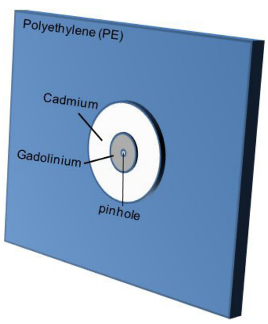

Figure 13
Design of a proper collimator

Upcoming Conferences

Neutron Imaging User Symposium
April 15.-18.4.2012 Neutron Imaging User Symposium, Bad Zurzach (Switzerland)

18th World Conference for Non-Destructive Testing
April 16 - 20, 2012, Durban, Republic of South Africa
www.saint.org.za/saint_007.htm

ITMNR-7
7th International Topical Meeting on Neutron Radiography
June 16 – 24, 2012, Confederation Place Hotel, Kingston, Ontario, Canada
www.itmnr-7.com

NEUWAVE-5
early 2013, Lund, Sweden

WCNR-10
10th World Conference on Neutron Radiography
2014, Switzerland

ITMNR-7 and Review Workshop (Announcement)

for more detailed information see www.itmnr-7.com

From June 16-24, 2012, the Seventh International Topical Meeting on Neutron Radiography will be held in Canada. The oral and poster Paper Presentations will be held at the Confederation Place Hotel in Kingston, Ontario, with a preceding Laboratory and Welcoming Tour on June 16 and a follow-on Review Workshop at Arowhon Pines, Algonquin Park, June 22-24.

This meeting is intended to bring together both technique developers and users of neutron radiography and tomography from around the world. Both specialists involved in technique development of neutron imaging, as well as facility design, establishment, operation and use of the neutron beam are encouraged to attend as well as those that have current or potential applications in their own fields. Participants may come from academic, industrial, military and government areas. The intent of the meeting is for the providers and users to share experiences and goals in order for their future needs and applications to be met. The language of this meeting will be English.

Schedule

16 June 2012: Laboratory & Welcoming Tour of the SLOWPOKE-2 Facility at the Royal Military College of Canada and a visit to nearby Prince Edward County, an historic and wine-growing region, to include lunch and tours. This day-long activity is appropriate for both attendees and accompanying persons, The Laboratory Tour is only available on this day as the building in which the Facility is housed is under renovation. Accompanying persons will be given a tour of RMC during the Laboratory Tour.

17 – 21 June 2012: Paper Presentations as oral lectures and posters at the Meeting venue, the Confederation Place Hotel, in downtown Kingston. Participants will be able to attend every presentation, as they will be held serially. Several discussion periods and a breakout time will allow for interaction among attendees.

The ITMNR-7 dinner will be on the evening of June 19 and will feature local food and beverages described by a guide. The breakout time will be on board the Island Queen for a special 4-hour tour of the Thousand Islands on June 20. Departure is conveniently a short walk from the hotel and the return to Kingston will be at sunset.

21 – 24 June 2012: Review Workshop at Arowhon Pines. After lunch on June 21, the Meeting locale moves to Arowhon Pines, Algonquin Park, a world renowned Ontario Provincial Park four hours North of Kingston by road. This 2½-day Review Workshop, also appropriate for accompanying persons, is intended for providers and users to discuss the presentations and mutual matters.

Arowhon Pines is an all-inclusive Canadian wilderness venue with gourmet meals and excellent outdoor facilities. Note that there is minimal cell phone and internet availability to distract our discussions in this remote location. Evening events such as campfires, nature talks and Wolf calls from the Park Rangers will be arranged. Wildlife sightings are common.

Details on these activities are given below. Additional Information can be found on their respective websites, e.g., Kingston, www.kingstoncanada.com; the Royal Military College, www.rmc.ca; Confederation Place Hotel, www.confederation place.com; Thousand Islands, www.1000islandstourism.com, www.visit1000islands.com; Prince Edward County, www.visitpec.ca; Arowhon Pines, www.arowhonpines.ca; Algonquin Park, www.algonquinpark.on.ca.

Figure 14
Some impressions on Arowhon Pines

Time Lines

Submission of Abstracts	January 16, 2012
Notification of Acceptance	February 20, 2012
Meeting Registration and Payment of Fees	April 6, 2012
Hotel Registration	May 1, 2012
Confirmation of Meeting Registration	May 11, 2012
Submission of Manuscripts	June 1, 2012
Topical Meeting	June 16-24, 2012

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