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NOTIZIARIO
Neutroni e Luce di Sincrotrone

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**Cover photo:**
Nicolas Poussin, "Armida abducts the sleeping Rinaldo", 1st neutron autoradiography assembled from 12 image plate records: In order to investigate the whole picture, two separated irradiations were carried out and finally recomposed.

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# SUMMARY

# RESEARCH INFRASTRUCTURES FOR CULTURAL HERITAGE: A ROADMAP IN THE MAKING

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RICH (Research Infrastructure for Cultural Heritage), http://neutron.neutron-eu.net/n_nmi3/n_networking_activities/rich is the name of a new initiative to bring the worlds of multi-disciplinary research and Cultural Heritage closer together. The initiative is promoted at the European level by Research Infrastructures, scientific institutions, research councils and universities, and has been launched by an International Workshop, that has taken place on December 12 and 13 in Trieste (Italy), at the Abdus Salam International Centre for Theoretical Physics (ICTP). The meeting was co-organised by the three European Integrated Infrastructure Initiatives (I3) that promote the development of large-scale facilities (LSFs) in the fields of neutrons (nmI3), synchrotron X-rays (IA-SFS) and lasers (Laserlab Europe) and by EU-ARTEC, an I3 consortium operating in the field of artwork conservation. The RICH workshop was sponsored and supported by a large number of universities, central facilities and institutions across Europe, and generously hosted by ICTP. The stated aim of RICH was to survey the established research and the most promising lines of technical developments, with the goal of creating a portfolio of LSFs-based techniques that could effectively complement the well-established portable and laboratory-based tools for assignment, conservation and restoration of historical and artistic objects. In preparation of the RICH workshop of December 2005, a preliminary study meeting was held on October 5, 2005 in Rome, generously hosted at Istituto Sturzo, Palazzo Baldassini, Roma and organised by Andrea Granelli (Fondazione COTEC), where working groups of invited experts in the fields of "Cultural Heritage" and "Research Infrastructures" contributed to shape the structure and the contents of the December meeting.

During the first day of the workshop, a cross-section of the programmes currently active at LSFs in the field of CH, using, for example, synchrotron-based spectroscopy and diffraction, neutron activation and neutron diffraction, as well as specialised laser techniques, was effectively compared and contrasted with the experience matured over several years if not decades with the use of ion beam techniques and light spectroscopy in the assessment of historical artefacts. This was also an opportunity for the delegates to present some of their latest results, in a vibrant, multi-disciplinary atmosphere, where both oral and poster presentation received plenty of constructive feedback.

Some of the characterisation methods employed at LSFs have achieved a high degree of sophistication while others are still being developed. Not surprisingly, a re-occurring topic throughout the day was the non-destructiveness of the various techniques and probes. It is widely accepted that any examination method inescapably changes the sample in one way or another, even though the sample alterations may be undetectable with present-day scientific methods. Whether one addresses problems in archaeology and conservation with traditional destructive examination methods, micro-destructive techniques or "non-destructive" methods remains to be decided on a case by case basis. However, many objects of art and archaeology would never be examined if it was not for the non-invasive examination techniques.

The talks covered a wide range of established and emerging applications of synchrotron, neutron and laser radiation in Cultural Heritage and archaeological sciences. In his presentation on imaging methods, Eberhard Lehmann (Paul Scherrer Institute, Villingen, Switzerland) focused on neutron radiography and neutron tomography applications, although always emphasizing the strengths of the complementary of neutron and X-ray imaging techniques. In many cases, both neutron and X-ray radiographies are required to obtain a full 'picture' of the object. The tomographies, mostly on objects from the Swiss National Museum and Swiss private collections, were obtained on the neutron tomography set-up at the Paul Scherrer Institute and covered aspects of authentication (helmet reconstruction from Gubiasco), making techniques ('Merkur from Uster'), and conservation (in-situ imaging of infiltration of resin into wooden objects). Magnificent neutron tomographies, recently collected from bronze statues from the Rijksmuseum Amsterdam, highlighted the amazing imaging capabilities with state-of-the-art hardware and software. Costing and safety issues related to the transport, insurance and

transportation of objects were also discussed.
Roberto Triolo (University of Palermo, Italy) introduced rather novel examination methods, namely small (SANS) and ultra-small (USANS) angle neutron scattering, on white and polychrome marble used in ancient monuments and works of art for the purpose of tracing their provenance. These methods provide information on the 'mesoscopic' structure of marbles, in terms of particle or pore sizes and fractal geometries, which are often related to the metamorphic changes during formation, and hence, to the site of formation. Different grades of metamorphism, and thus, 'low and high' quality marble can be distinguished by looking at the building blocks, as demonstrated mostly on marble samples from Villa Adriana (Tivoli, Rome), also in relation with neutron tomographic images, obtained on the same samples at the Berlin neutron centre BENSC.
The next talk of the session by Birgit Schroeder-Schmeibidl (Hahn-Meitner Institute Berlin, Germany) was on neutron autoradiography, a fine technique to reveal different pigment and paint layers piled-up during the creation of a painting. In many cases the individual brushstrokes applied by the artist are revealed, as well as changes made during the painting process (the so-called *pentimenti*). Neutron autoradiographs may be used in support of restoration interventions, as it was demonstrated for 'The baptism of a Child' (Jan Steen, 17$^{th}$ century). Many *pentimenti* were revealed, indicating that Steen has painted over a picture with completely different content. In another case of authentication, 'The Hermit', a work of art of an unknown artist but suspected to be made by the hand of Rembrandt, no modern pigments and no contradiction to the works of Rembrandt were found. However, the structural features are in remarkable agreement with the 'handwriting' of the 17$^{th}$ century Dutch painter Govaert Flinck.
Gianluca Valentini (Politecnico di Milano, Italy) presented a totally different method for pigment identification, this time on marble sculptures, exploiting the fluorescence emission of UV laser excitation. A portable system allows one to produce spatial maps of pigments and contaminants such as wax, oxalates and cast residues even for multi-component mixtures. Complementary images can be produced by time-gated amplitude and life-time fluorimetry. The technique was used to survey marble sculptures such as the Michelangelo's 'David' (Florence) and the Pietà Rondanini (Milan) before and after cleaning procedures.
Gerard Sliwinski (Polish Academy of Sciences, Poland) reported on the Pomeranian Laser Laboratory in Gdansk, which focuses on Cultural Heritage research since 1998. Lasers are used for both artwork restoration and for conservation treatments, as well as for non-destructive identification and composition analysis of surface layers such as contaminants, substrate and pigments. The case studies presented at RICH included Godlandic Sandstone from the Baltic sea, historical paper documents, silver coins from Pomeranian museums, and pigment identification on a 15$^{th}$ century wooden crucifix.
Berta Guzman de-la-Mata (University of Warwick, UK) presented results on corrosion studies of rough, heterogeneous metal surfaces, as encountered in 'real' archaeological artefacts. The results were obtained with a new electro-chemical cell that was specifically developed (with support from COST-G8) for use on synchrotron beamlines. In-situ studies of electrochemical processes as they occur are important in developing and understanding potential conservation and stabilization treatments, and may be extended to study corrosion processes themselves. The first results of the combined electrochemical and SR-XRD study of copper objects exposed to sea water at the SRS at Daresbury were presented, demonstrating conversion of the 'non-passivating' nanatokite to the more protective corrosion phase cuprite during storage in sodium sesquicarbonate.
Birgit Kanngiesser (TU Berlin, Germany) presented a series of applications of micro-X-ray fluorescence (micro-XRF), which is able to reveal oxidation and migration processes of inorganic compounds in ink-corroded manuscripts. These non-destructive investigations are of great importance for understanding complex paper degradation processes. The latest development on portable micro-XRF, spatial mapping of $Fe^{2+}/Fe^{3+}$ ratios by micro-XANES and of a new 3D micro-XRF mapping instrument were presented. Examples included analyses of a manuscript of the 'magic flute', fragments of Goethe's 'Faust', and Dürer's 'sketchbook'. Trace element analyses of the gold stars on the Nebra skydisk were also presented.
Pier Andrea Mandò (University of Florence, Italy) introduced the LABEC Florence accelerator laboratory for ion beam analysis (IBA) and accelerator mass spectrometry (AMS) for radiocarbon dating. The new laboratory, which was opened in 2004, is capitalising on previous successes

in the solution of important problems, like the chronological reconstruction of undated Galileo's handwritten notes using the ink composition as a dating criterion.
In the afternoon session, Salvatore Siano (CNR Florence, Italy) gave a comprehensive overview of current laser technologies and neutron diffraction techniques in Cultural Heritage. Conservation interventions by laser techniques on ancient artefacts such as the Minerva from Arezzo and the Treasure of Rimigliano, as well as the Gate of Paradise were presented. These interventions are complemented by both traditional and novel metallurgical studies to provide the basic knowledge on the development of art and fabrication techniques. The first pioneering and systematic neutron-metallurgical investigations of a number of Etruscan, Picenan and Roman objects were presented. Time of flight neutron diffraction at the ISIS facility in the UK was used to non-destructively characterise the objects in terms of the structure properties, i.e. phase distributions, crystallographic textures and macrostrains. A lively discussion after this talk centered on the non-invasiveness of the neutron methods. It was commented that irradiation with neutrons compromises the thermoluminescense dating. A proposal for an experiment to study the effects of neutron irradiation on dating results was made, by considering both high-flux exposures typically done for neutron activation analyses, and low-flux irradiation on present-day neutron beamlines for tomography, gamma spectroscopy and diffraction.
L. Cartechini (University of Perugia, Italy) followed with a talk on time-of-flight neutron diffraction applications at the ISIS spallation neutron source. After an overview on the capabilities and limitations of neutron diffraction, results on three 17$^{th}$ to 12$^{th}$ BC century bronze axes from the Terremare settlements near Modena (Italy) were presented. Neutron diffraction elegantly and non-invasively provided a differentiation of the three objects in terms of phase compositions, microstrains and texture, properties which are related to the material treatment during fabrication or use.
Roxana Bugoi (National Institute of Nuclear Physics, Bucarest, Romania) presented a micro-XRF study of metal inclusions (e.g. platinum) in archaeological gold with a detailed description of the optimisation measures for the trace element analysis set-up at the ANKA synchrotron source at Karlsruhe, Germany. Results from several ancient gold objects from the Visigothic Pietroasa treasure were presented, along with data from natural gold samples from Transylvania.
Massimo Rogante (NDT, Civitanova, Italy) concluded the session by presenting results on Iron Age bronze, iron and pottery objects from a Picenan necropolis of Centre Italy studied with prompt gamma activation analysis (PGAA), an important tool for non-destructive bulk elemental analysis. Both major and trace elements were determined by PGAA and used for a classification of the objects.
An afternoon poster session with about 30 contributions concluded this 'science and techniques' day of the workshop. The poster session gave many participants the possibility to report on latest accomplishments and highlights of ongoing projects. All contributors to the Oral and Poster sessions of the meeting are invited to submit their contribution a part of the Workshop Proceedings, which will be subject to peer review and published in a special issue of the Nuovo Cimento C.
In spite of the obvious differences in scale (which ranged from the suitcase to the synchrotron) and, consequently, the mobility of the equipment described by the delegates, a number of common themes clearly emerged, and in particular, the need to establish an effective partnership between art historians, materials scientists and instrument scientist, with the museum-based research conservators playing a pivotal role. These themes were expanded during the second day with two sessions on "governance" and "the broader perspective", followed by a round-table discussion. Costas Fotakis (IESL – FORTH, Heraklion, Greece) stated quite convincingly that the European way is the one to follow. there is a clear added value from a pan-European initiative, in that there is often a geographical separation between the richest collections of historical artefacts and work of arts, the university departments and research councils that have already overcome the "language barrier" with the humanists and possess the expertise with the applied materials science and the more "conventional" techniques, and the large-scale, multi-disciplinary facilities. Costas concluded by illustrating the recent achievements of a pan-European collaboration, COIST-G7, centred on laser techniques (LIDAR mapping, spectroscopy and fluorescence analysis and laser restoration).
Jana Kolar (National and University Library of Slovenia, Lubjana) illustrated the key ingredients that must be put in place if a wider initiative is to be successful. The economic arguments were particularly compelling: in Europe, CH generates and annual income of 335,000M€, and 14,000 M€/years are effectively lost due to the degradation of the artistic patrimony, in addition to the irreparable loss of often unique artefacts. But what are the key elements of a future "European infrastructure"? Providing access to the LSFs was clearly identified as a central issue. Moreover, the management of this access will have to recognise the uniqueness of the CH field, not only in identifying appropriate ancillary facilities, for example, for the handling and storage of the artefacts, but also in providing dedicated peer review mechanism to assess the proposed work in the appropriate context.
Jean-Louis Boutaine (C2RMF, EU-ARTECH, Paris,

France) and Hannelore Römich (COST office, European Science Foundation, Brussels, Belgium) invited us to avoid the tropisms of "aristocratic physics" and "aristocratic art history", and to consider the impact on the long-term viability of the collections, rather than simply the public relation aspect. In practical terms, this translates in providing, first of all, accurate information on the capabilities (and limitations) of each techniques, a competent, dedicated team of experts and reliable "routine" access rather than a series of "one-off" experiments. We must also "look in the neighbourhood", and take advantage of the vast capital of experiences developed by existing initiatives such as COST-G7, COST-G8 and EU-ARTECH. After all, CH research at LSFs is a growing field, but it is still a small fraction of the work involving science and technology for the comprehension and conservation of the European Cultural Heritage, as recently "photographed" in a report produced by the Labs Tech initiative.

An example of European involvement in this area, and a useful model for future expansion, is represented by the ANCIENT CHARM initiative, presented by Giuseppe Gorini (University of Milano-Bicocca, Italy). ANCIENT CHARM is the result of a collaboration between 10 universities, central laboratories and museum institutions across Europe, and is now a EU funded ADVENTURE project under the New and Emerging Science and Technology (NEST) programme of FP6. The central goal of ANCIENT CHARM is to develop an imaging technique based on Neutron Resonant Capture, but complementary diffraction/transmission-based imaging techniques will also be developed in parallel.

EU-ARTECH, as presented by Antonio Sgamellotti (University of Perugia, Italy) is another particularly relevant piece of this complex "patchwork" of existing and emerging activities, in that it represents a successful EU initiative to support access, networking and research related to existing infrastructures in the field of ion beam analysis and mobile laboratory technology. Antonio underlined the difficulty in persuading Brussels that this collection of techniques is indeed an "infrastructure", but stressed, at the same time, the value of a technology that "goes to the users".

Conversely, the unique issues associated with bringing artwork and expertise to the LSFs sites must be addressed if the powerful techniques available at LSFs are to become a routine tool in CH research. Loïc Bertrand (Synchrotron SOLEIL, France) illustrated in detail the proposed scheme for a dedicated CH "interface" that will be activated at the SOLEIL Synchrotron facility, to become operational in 2007. Preparatory work for this "interface" has already commenced, with a small amount of staff being involved in surveying the user base and defining the science portfolio and the access mechanisms, as well as in providing training activities for the users. The "interface" issue was to become the centrepiece of the final part of the meeting. The model proposed by Loïc involves a relatively small amount of dedicated staff at the LSFs, with the "institutional" CH laboratories providing the main link with the museums. Further down the line, the gradual development of standardise protocols would enable the museums to access LSFs directly. Robert van Langh (Rijksmuseum - Amsterdam, The Netherlands) presented a different model, pointing out that a number of museums already have research-based conservation departments, and that research conservators have shown to be quite capable of interfacing directly with the facilities. This was illustrated by drawing from Robert's recent neutron work on a bronze statuette collection from the Rijksmuseum, which also featured very prominently in Eberhard Lehmann's talk on day 1 and in a poster presented by Dirk Visser. For a more effective use of the LSFs, research conservators would need to interact with larger, dedicated teams of scientists based at LSFs, rather than with liaison officers or individual instrument scientists.

All these points were again touched upon during the Round Table discussion, with particular emphasis on networking, communication, training and access. Claudio Tuniz (The Abdus Salam ICTP, Trieste, Italy) and Wegrzynek Dariusz (The IAEA Seiberdorf, Austria) stressed the need to look beyond Europe and towards the rich cultural and technical reservoir in the developing countries, emphasizing the role that institutions such as the ICTP, UNESCO and IAEA could play in this context. The workshop was concluded by agreeing on a list of actions. First of all, the organising committee pledged to complete the original RICH objectives, which were focused on advising the LSFs and their supporting I3 on the best provisions to support current and future CH work. In this, the foresight study questionnaire, to be completed by all participants, should prove an invaluable tool. Specific recommendations will also be issued on the courses of actions to be taken vis-à-vis the provision of non-virtual LSFs-based interface/support units, the possible launch of a "horizontal" I3 initiative in FP7 to provide specific access, networking and research and on the blueprint for a possible new "research infrastructure" beyond FP7. In the meantime, one of the main objectives of RICH has already been brilliantly achieved: four different communities working with neutrons, lasers, synchrotron and "conventional" techniques, traditionally used to walk their separate ways, have started talking to each other and with the museum-based research conservators. Let us interpret this as a good omen for a "RICH" and productive continuing cooperation for the understanding and preservation of our common European heritage.

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# INES - ITALIAN NEUTRON EXPERIMENTAL STATION FINAL INSTALLATION AND PRELIMINARY TESTS

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**Abstract**
The installation of the diffraction instrument in the INES blockhouse has proceeded, almost continuously, from January to May 2005. The mechanical and detection parts have been assembled and put in place, the data acquisition electronics, as well as the standard security interlocks, have been set-up and made operative. All the controls have been connected to the main computer in the experimental cabin. Preliminary data acquisitions have been carried out on standard calibrating samples and have been processed in order to perform an instrument calibration and obtain a preliminary estimate of the resolving power. Further refinements on the acquisition electronics and more commissioning measurements are scheduled in second half of the year 2005.

## Set-up of the infrastructures

*The INES blockhouse*

The limited available space, behind the TOSCA instrument, forced us to find some compromise between the need of room, necessary for an instrument mainly thought for testing and training, and the constraints imposed by the other installations, already present in the experimental hall of ISIS. At any rate, a great care was exerted in order to maximize the available options without sacrificing simplicity of operations. In this context, one of the main requests for the instrument was the availability of an access door that would allow entering the blockhouse and putting "hands on" the sample space. At the same time, we planned to build an instrument that would respect, as much as possible, the local standards so that young scientists under training and experienced researchers would not feel in a peculiar environment with respect to other ISIS instrumentation. Therefore, a top-loading aperture was also planned, mainly for utilization of the standard sample environment of ISIS (cryostats and furnaces). Fig. 1 shows the planned layout of the blockhouse.
The actual realization is shown, partially, in Fig. 2. Here, we can see the crane, the service panel, and the aperture in the floor that would accept the sample cage (now in its place, but not installed when the picture was taken). An enlarged view of the service panel is shown in Fig. 3. Here, the system lock keys are visible, as well as the interface box for the CAMAC and the helium lines for the CCR and the ORANGE cryostats.

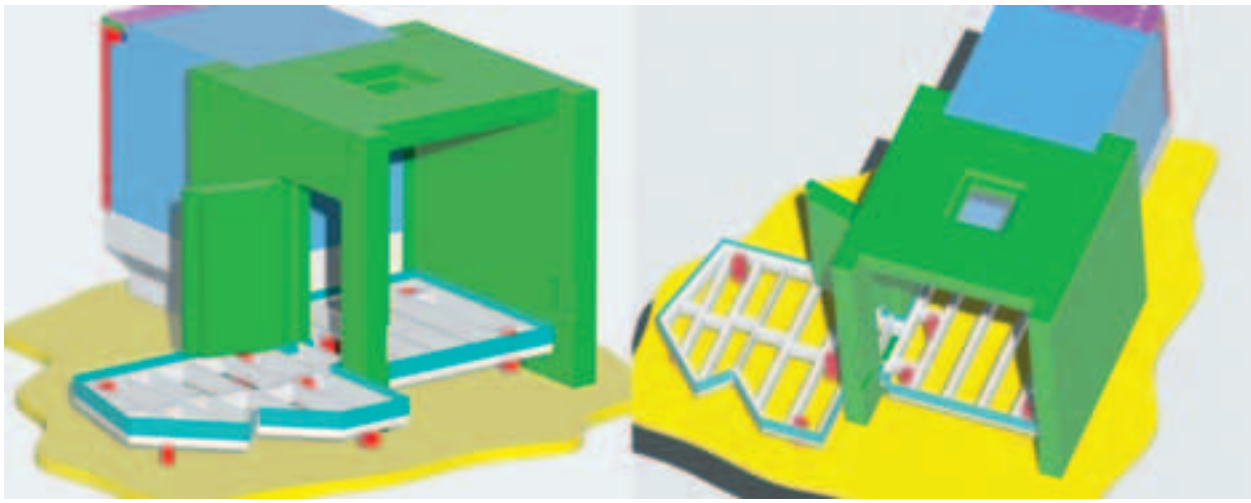

**Figure 1.** Layout of the INES blockhouse. Standard sample environment can be introduced using the top opening in the roof. Access is also available using the side door.

*Signal cables, power supply, and vacuum line*

The INES blockhouse has been equipped with electric energy wiring, for standard experimental needs, as well as for emergency and safety purposes. The doors (both, lateral and top aperture) were equipped with standard interlock systems for the full safety of the users. Safety monitors were placed, in order to detect possible radiation leaks.

The blockhouse was equipped with 256 coaxial cables for signal transmission from the neutron detector banks. They are bundled in 16 groups, of 16 cables each, carrying also a high voltage power supply cable. As the initial configuration of INES includes a cluster of 9 detector banks (16 detectors each), this leaves enough room for 7 extra banks that might be placed for future development. Two neutron beam monitors have been placed upstream and downstream the main sample container.

A vacuum line was also installed for evacuating the sample container using a rotary pump placed outside the blockhouse. Vacuum monitors and safety interlocks have been provided.

*Control Cabin*

The control cabin, where the main computer and the digital electronics are placed, has been realized on the ground floor, close to the side door of the INES blockhouse. The cabin is made of two distinct rooms. The first one, visible in the Figure 4, is intended to host the research team and is equipped with a main computer (alpha workstation) and several network connections. The second room, whose access door is visible in the left panel of Fig. 4, contains all the control electronics (DAE, CAMAC, SE control crates, etc.). Both rooms are conditioned (separately) for the electronics as well as for personal comfort.

## Instrument Installation

*Sample tank*

The components of the INES sample container have been set-up in the blockhouse. The centre position of the sample was defined by reference points traced on the floor and on the walls of the blockhouse. The sample container and its holder were assembled and oriented such as to be correctly adapted to the direction and height of the beam-line. The extension vacuum tubes, input and output for the neutron beam, were mounted and used to determine the correct orientation of the sample chamber with respect to the beam trace, drawn on the floor and on the walls. To this aim, a pair of lead lines was used to properly align the chamber and its frame.

Once the correct placement was established, the three feet (point, line and flat) of a standard kinematic mount were fixed on the floor with screws and raw plugs. The use of this device will allow to reproduce the same position of the sample container to within a fraction of 1 mm. This result should be considered fully satisfactory, taken into account the size of the beam (≈ 4x4 $cm^2$).

It is worthwhile to spend a few extra words to describe the sample tank. Its size is 800 mm external diameter by 900 mm height. On the upper side, a standard ISIS flange allows using the available sample environment equipment. In addition, the upper cover can be removed completely, if necessary, so that quite large samples can be adapted inside (See Figs. 8, 10, and 11). However, for routine measurements (at room temperature), a smaller flange of reduced size (opening 150 mm) can be used with fast vacuum locking elements (see Fig. 6)

On the side of the chamber, a vacuum-tight inspection window is available so that it could be used to adjust the position of large samples (see Fig. 5). Four glass windows are also available for visual inspection, direct or by means of a web camera. Finally, the input beam tube is equipped with a periscope, holding a diode laser, that can be used for centring purposes of extended irregular samples like, for example, archaeological artefacts. Standard vacuum ports are used to connect the chamber to the vacuum pumping system and to vacuum gauges.

*Detector banks*

Each detector bank is composed of 16 squashed $^3He$ tubes (active volume: 100 mm height, 12.5 mm wide, 2.5 mm thick) charged to 20 bar so as to increase the detection efficiency. The tubes are placed in an aluminium box that also contains the preamplifiers (see Fig. 7). In the same box, we have also mounted the secondary collimation, made by $B_4C$ ceramic platelets. The various stages

**Figure 2.** Top floor of the INES instrument showing the crane, the service panel and the opening in the floor that will accept the sample cage.

**Figure 3.** View of the service panel with the interlock system keys (A), the CAMAC serial plugs (B) and the helium lines for cryogenic applications (C).

of the assembling are shown in the figure, where also some shielding of the lower part is visible (Fig. 7, right). This is made by *elastobore* absorbing material, fixed to the detector box with aluminium screws.
A rotating arm, mounted on the top of the sample container flange, was used to determine the correct position of the detector bank holders (Fig. 8).
These were then fixed to the floor and the detector banks were mounted on the aluminium planes which, in turn can be adjusted vertically, such that the detector centres are placed at the same height of the neutron beam (Fig. 9).
The aluminium boxes are insulated by the metal frame, by means of nylon spacers, in order to avoid mass loops and reduce electronic noise. The final configuration of the instrument is shown in Fig. 10, as it is seen from the top-loading aperture.

*The electronic chain*

Data acquisition electronics has been designed in order to reach the maximum compactness. To this aim, we used, as a base, the ISIS standard gas detector discrimination cards but these were redrawn in order to put two channels on a single card, thus halving the size of the whole electronic system. As we have mentioned before, the preamplifiers are placed inside the detector box (cf. Fig. 8), so that the long coaxial cable, on which the signal runs, is characterized by a low impedance and therefore by a low intrinsic noise. The discriminator cards are placed outside the blockhouse, in a rack holding the High Voltage power supply too. This is shown in Fig. 11. From bottom to top we see the HV power supply, some service electronics and the five euro-crates, containing the 80 double discriminator cards and 10 marshalling cards which convey the digital signal to the DAE.
The instrument is equipped with two ISIS standard monitors for transmission measurements. These are placed in air, on both sides of the sample chamber, close to the walls. The vacuum tubes, input and output of the neutron beam, were extended from the main sample chamber to very close to the position of the monitors. In order to minimize the amount of air in the neutron path, the final portions of the tubes were designed and realized after the installation of the main sample chamber (cf. Fig. 12).

**Figure 5.** Sample container and frame (left). Positioning and proper orientation of the sample chamber using a plumb line and the reference points marked on the walls (centre and right).

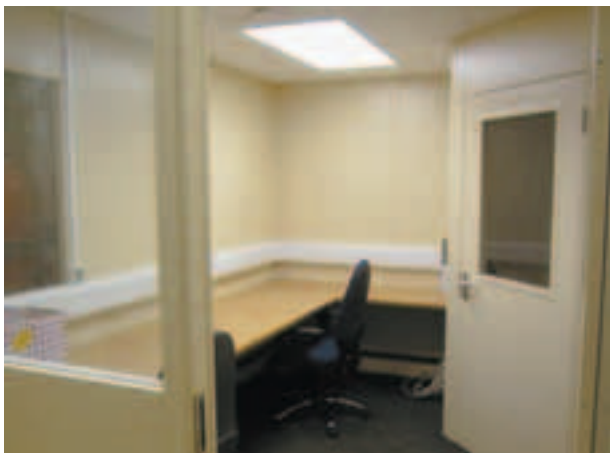

**Figure 4.** View of the control cabin (left panel) and DAE (data acquisition electronics, right panel). A main computer (actually placed on the desk and connected to the internal ISIS network) is used for controlling the experiment and for data collection.

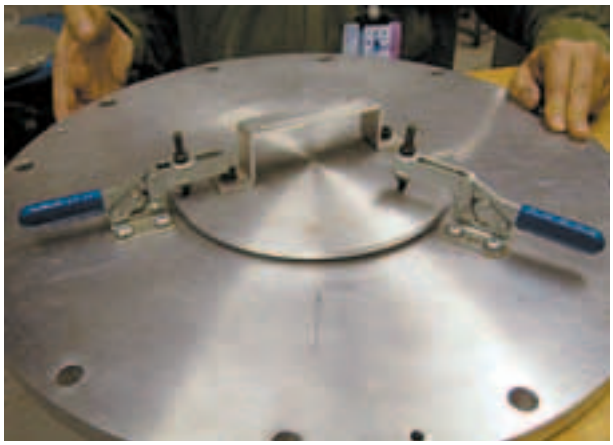

**Figure 6.** A reduced vacuum flange is available for routine room temperature experiments.

*The beam monitors*

As we mentioned before, two neutron beam monitors have been placed upstream and downstream the main sample container.

These are made of an array of 42 (7 lines x 6 columns) Li-doped glass cubes (0.25 mm side). The beads are equally spaced and set at the corners of squares whose side is 7 mm. Thus, they cover an effective area of 35x42 $mm^2$, that should be almost totally shined by the primary neutron beam. The beads are made of GS20 glass, doped with 18% (weight) of $Li_2O$ which, in turn, was enriched to 95% in $^6Li$.

From these data (the density of the glass is 2.50 g/cc), we could evaluate the overall efficiency of the monitor, that turned out to be $3.87 \times 10^{-4}$ (@ $\lambda$=1.0 Å).

**Figure 7.** A detector bank is composed of 16 squashed $^3He$ tubes (100.0 x 12.5 x 2.5 $mm^3$). The preamplifiers are enclosed in the same box, just above the detectors. The secondary beam collimation is made of $B_4C$ ceramic platelets.

**Preliminary test measurements**

*Beam size measurement*

Even though the instrument set-up is not concluded, and some final adjustments are still needed, we decided to do some preliminary test measurements to check the instrument performances. As a first task, we measured the size of the beam using a photographic plate. The image is shown in Fig. 13. The full size of the beam is close to 40x40 $mm^2$ with a penumbra region of about 3-4 mm. This result is not too different from that calculated on the basis of the beam-line design.

*Silicon calibration*

A preliminary calibration of the instrument was carried using a silicon powder sample. This was held in a vanadium container of 8 mm diameter by 53 mm height. Silicon powder is characterized by very sharp Bragg peaks and is usually employed for calibration purpose. The diffraction patterns from this sample are shown in Fig. 14, for two different scattering angles.

The measuring time for this sample was equivalent to 1905 μAh integrated proton current, about 10 hrs. The data are shown in *d-units*, for the sake of comparison, but no can subtraction, no normalization to the monitor and no Jacobian transformation was applied to the data. The simultaneous fit of the total neutron path and the scattering angle was carried out for each detector using the Bragg peaks of silicon. As the secondary flight path was known with great accuracy ($L_1$=1.000 m, to within 1 mm), we could determine the primary flight path, which turns out to be $L_0$=22.804 m, and the various scattering angles.

*Resolving power*

In order to evaluate the resolving power of the instrument we show, in Fig. 15, a narrow region of the diffraction pattern so that the full width of the single line can be evaluated. Again, we have shown the diffraction patterns taken by the same detectors as in Fig. 14. The data have been smoothed in order to allow a better evalua-

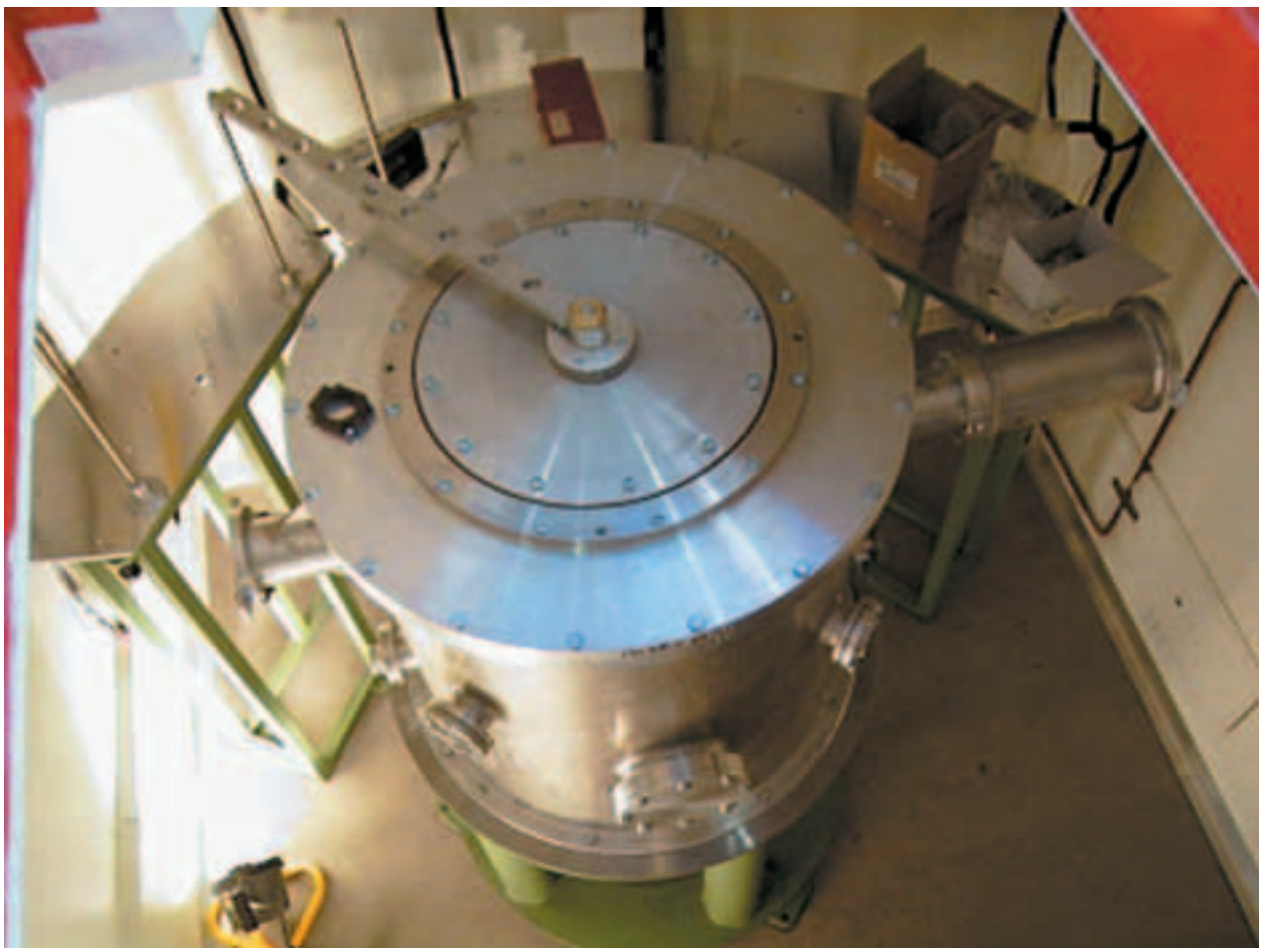

**Figure 8.** The rotating arm, fixed to the top central flange of the sample container, is used to adjust the frames holding the detector banks.

**Figure 11.** The main door of the INES blockhouse with its radiation control electronics and interlocks. On the left, the electronic rack is visible, that contains the high voltage power supply and the 5 euro-crates with the 80 discriminator cards.

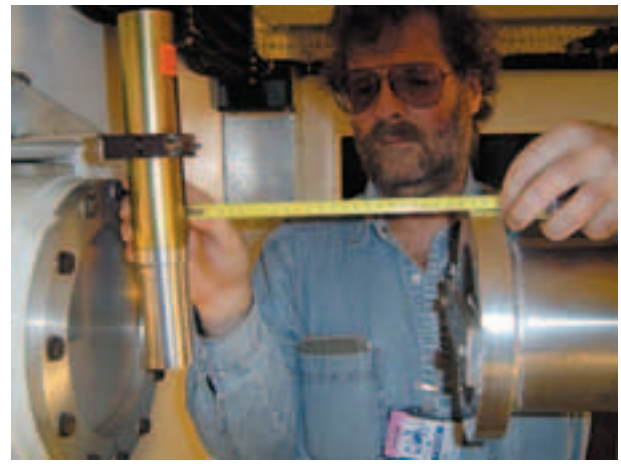

**Figure 12.** The vacuum tubes enclosing the main neutron beam have been extended very close to the monitor in order to reduce the amount of air in the primary beam path.

**Figure 9.** The nine detector banks span a wide interval of scattering angles from 10° to 170°.

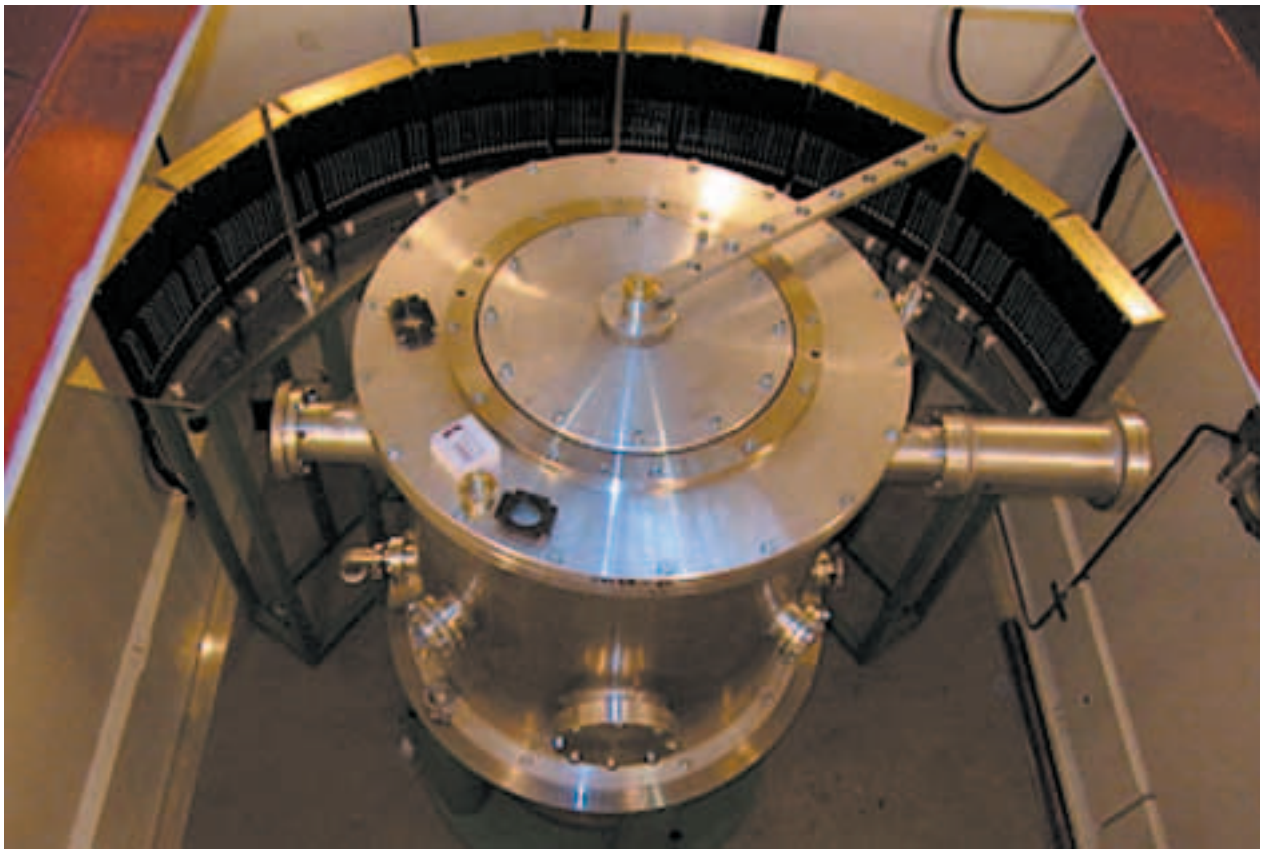

**Figure 10.** Final configuration of the instrument, as seen from the top.

tion of the relative widths. However, this procedure does not affect the line-width as the dashed red line, which represents the original data, clearly shows. From Fig. 16, we could evaluate the resolving power of the instrument at two different angles. From the left picture we get a $\Delta d/d$ = 0.19% while the right picture gives $\Delta d/d$ = 0.58% (both full width), which appears an extremely good result for a neutron diffractometer.

Similar results are also obtained using a different sample. In Fig. 17, we report a narrow interval (still 0.02 Å wide) from the diffraction pattern of $Y_2O_3$, which is also characterized by sharp Bragg peaks. In this case, the

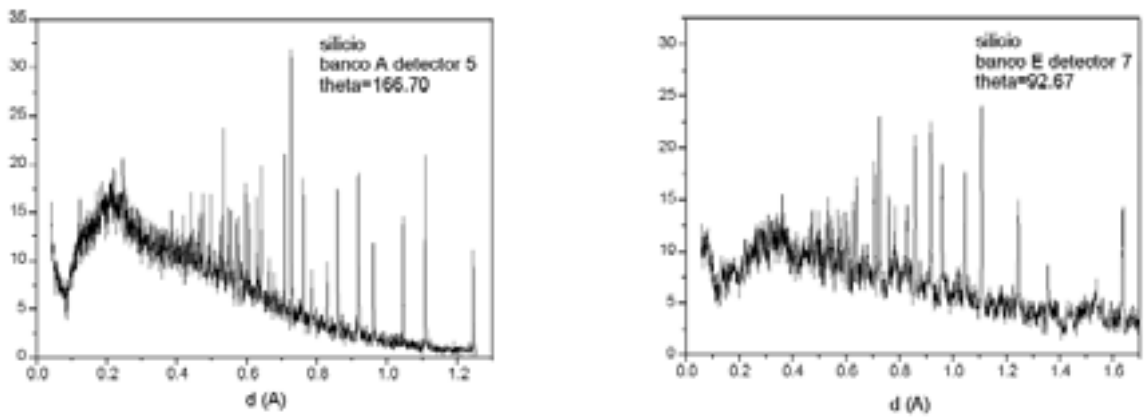


**Figure 14.** Diffraction spectrum of silicon powder taken by detector A5 (2θ = 166.70°, left picture) and E7 (2θ = 92.67°, right picture). Data are presented in TOF but the x-scale reports the d-spacing.

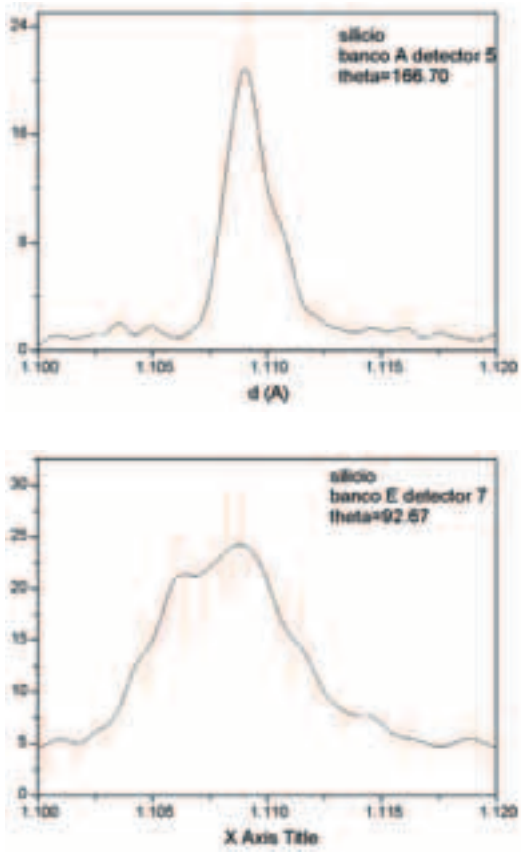


**Figure 15.** Focus on a diffraction line from silicon powder taken by detector A5 (2θ = 166.70°, left panel) and E7 (2θ = 92.67°, right panel).

measured $\Delta d/d$ is 0.23%, for the left peak, and 0.18%, for the peak on the right. Again, the detector is A5 (2θ = 166.56°).

*Vanadium sample*

Vanadium is a good sample for intensity calibration, due to its totally incoherent neutron cross section. To this aim, we used a rod of 10 mm diameter by 60 mm height. The sample was kept in the beam up to an integrated proton current of 3500 μAh. The resulting TOF spectrum, measured by detector A5 (2θ = 166.56°) is depicted in Fig. 17.

It is important to have an idea about the overall efficiency of our detector banks. In other words, we would like to compare the measured spectra, of which Fig. 17 is an example, with a calculation based on the theoretical scattering power of vanadium and the intensity distribution measured by the input monitor. To this aim, we have taken into account the monitor composition (see above) and, from its theoretical efficiency, we could reconstruct the real incident neutron flux. A Monte Carlo simulation was performed in order to evaluate the (single) scattering power of a vanadium rod, like the one used in the present test. From those ingredients, the computed solid angle spanned by the $^3$He neutron detector, and its efficiency, we could evaluate the theoretical vanadium scattering. This is shown by the red line in Fig. 18, where spectrum 16 is considered (2θ = 155.56°).

The overall agreement is fully satisfactory, taking into account that we are comparing absolute intensities and that some approximations were used in the calculation.

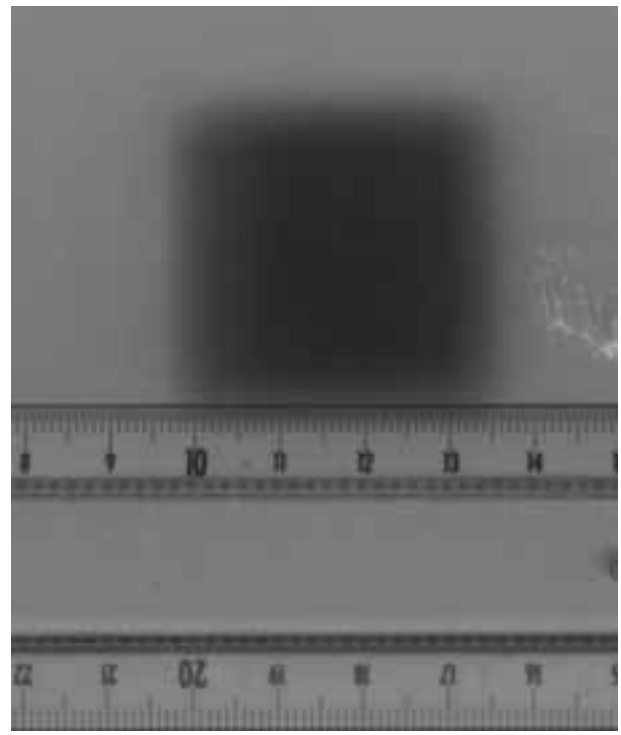

**Figure 13.** A picture of the beam has been taken using a photographic plate.

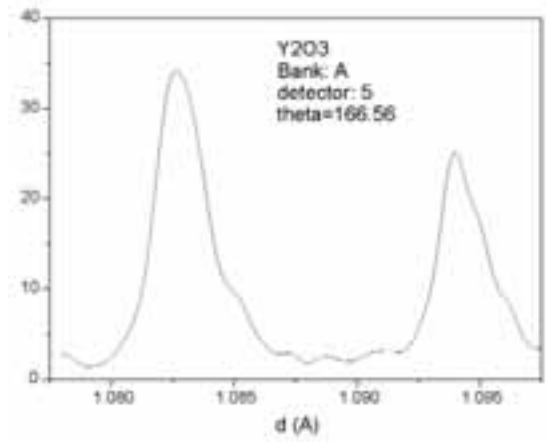


**Figure 16.** A narrow interval (still 0.02 Å, as in Fig. 15) of the diffraction pattern from $Y_2O_3$ powder.

At any rate, it is evident that the performances of the present experimental apparatus are in line with the initial expectations.

**Acknowledgements**

We wish to thank Z. Bowden, B. Holsman, N. Rhodes and J. Tomkinson for their invaluable help in the design and the installation phases of the instrument, U. Bafile and F. Sacchetti for helpful discussions, P. Landi for his support in the mechanical workshop, and A. Solenni for his help in the electronic workshop. A special thanks goes to K. Gascoyne and K. Allum for their help in the set-up of the electronic chain, to K. Knowles and the computer support staff of ISIS, for helping in the set-up of the data acquisition electronics, and to the whole staff of ISIS, in general, for their collaborative attitude.

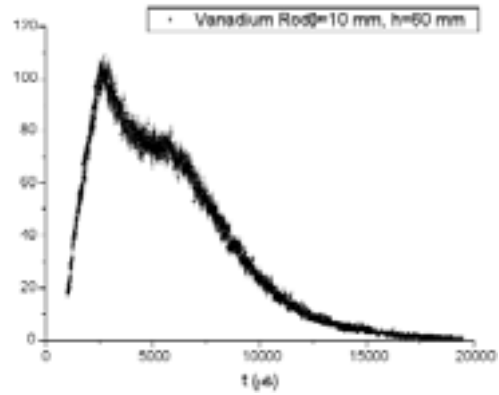


**Figure 17.** ToF measured (spectrum of detector A-5) diffraction pattern of a vanadium rod.

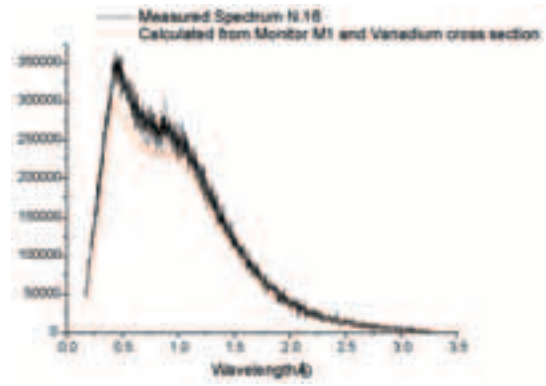


**Figure 18.** Comparison, on an absolute scale, of the measured (spectrum of detector A-16) diffraction pattern of the vanadium rod with a calculation performed using the monitor measured distribution.

# CNR FINANCIAL SUPPORT FOR ITALIAN USERS OF ISIS

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*Non-Italy based Italian ISIS users are **not** eligible for support.*

**M.A. Ricci**
*Chairman of the CNR neutron scattering committee*

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### PAPERS AND PUBLICATIONS

When writing papers for publication based on research carried out at the ISIS neutron source Italian investigators should include the following acknowledgement to Consiglio Nazionale delle Ricerche (CNR): **This work was supported within the CNR-CCLRC Agreement No. 01/9001 concerning collaboration in scientific research at the spallation neutron source ISIS. The financial support of the Consiglio Nazionale delle Ricerche in this research is hereby acknowledged.**

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# OVERVIEW OF IMAGING WITH X-RAYS AND NEUTRONS

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**Abstract**
The imaging with X-rays and neutrons are powerful non-destructive methods for investigation of a large variety of objects. The radiography provides a two-dimensional projection of the irradiated object while the tomography allows one to visualize the inner volume of a sample three-dimensionally without destroying or dismantling it. The different interaction mechanisms of neutrons and X-rays with matter make the two methods complementary to each other. In this contribution a description of the different beam sources, beam geometries, and comparison of these two methods show the advantages and limitations of different analysis configuration possibilities. Some results achieved with different methods are presented and examples of their contribution are given.

## Introduction

Within the last decade the X-ray and neutron imaging methods significantly gained importance. Especially their application in non-destructive testing for industrial components can be underlined. One of the reasons is the fast development in digital image recording and processing, which enables the computation of tomographic reconstructions from high-resolution images on a reasonable timescale [1,2]. The development of new detectors with better signal-to-noise characteristics and faster read-out electronics allowed to overcome some of the limits of conventional radiography and tomography concerning spatial and time resolution [3].

## Principles

The imaging methods are based on the detection of the transmitted radiation through a defined medium (sample) by position sensitive detectors. The radiation beam is attenuated differently by the composition elements of the sample giving contrast variations in the recorded radiography image, Fig. 1.
The attenuation properties of materials are dependent on the specific interaction processes with the used radiation. Absorption and scattering are the interactions that contribute to beam attenuation. In conventional radiography the attenuation of the incident beam by a sample can be described by an exponential function of two parameters - the transmitted thickness $d=\int_{path} dz$ and the distribution of the linear attenuation coefficient $\mu(x,y,z)$ in the sample (Eq. (1)).

$$I(x,y) = I_0(x,y)\exp\left[-\int_{path}\mu(x,y,z)dz\right] \quad (1)$$

$I_0(x,y)$ and $I(x,y)$ are the intensities of the incident and transmitted beam in a plane (x,y) transversal to the propagation direction $z$, Fig. 1.

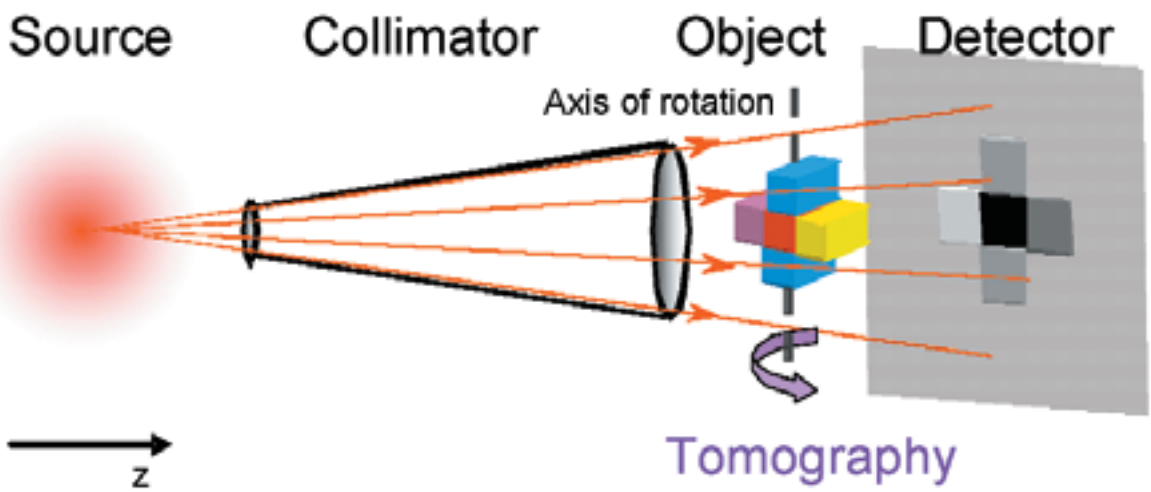


**Figure 1.** Schematic layout of a conventional radiography experiment.

For high resolution radiography purposes two kinds of radiation can be used: X-rays and neutrons. The charge-free neutron interacts with the core of the atom, while in contrast X-rays interact with the charge distribution of the electron shell. Therefore the X-ray attenuation coefficients increase with the atomic number of the elements, i.e. with the number of electrons. The interaction probability of neutrons with the atomic core depends on the coherent scattering length $a_{coh}$, which does not show a systematic dependence from the atomic number of the element. As a consequence, the attenuation properties of the elements for neutrons show a non systematic dependence from the atomic number as shown in Fig. 2.

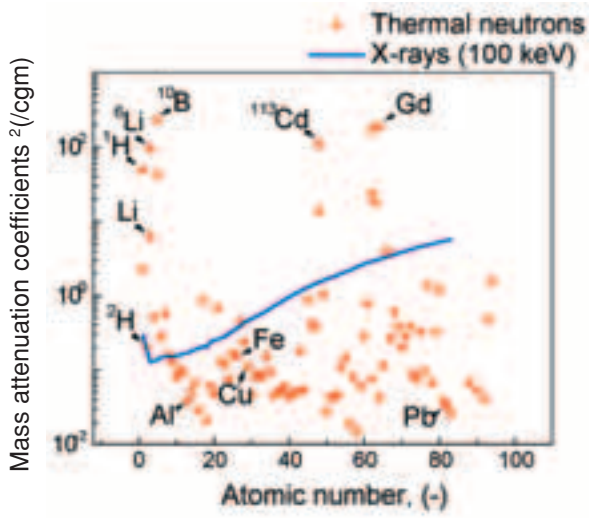


**Figure 2.** Comparison of the mass attenuation coefficients for thermal neutrons and X-rays (100 keV) in dependence on the atomic number[4].

The attenuation properties besides being dependent on the energy of the applied radiation, are different for different isotopes. For radiography purposes the energy of the neutrons is typically of the order of meV (thermal or cold neutrons). X-ray energies are normally in the order of ten to several hundred keV. Comparing the mass attenuation coefficients for different elements for the case of X-rays and thermal neutrons (see Fig. 2) the following main conclusions can be made:

- neutrons are very sensitive to some light elements like H, Li, B, where X-rays do not provide a good contrast (low and similar atomic numbers),
- the distribution of attenuation coefficients for neutrons is independent of the atomic number which helps to achieve contrast even for neighboring elements, for X-rays one finds an approximately exponential increase with the atomic number,
- neutrons easily penetrate thick layers of metals like Pb, Fe and Cu where standard X-ray imaging facilities with energies of several hundred keV fail,
- neutrons can distinguish between isotopes (for instance $^{1}H$ and $^{2}H$) which is not the case for X-rays.

In this context the two radiations appear to be complimentary in case of the radiography non-destructive investigations. To show the difference in the provided contrast from both radiations the following example is shown in Fig. 3. Depending on the different absorption, different structures can better be realized with X-rays or with neutrons. The neutrons transmit easily the steel cap of the battery of the device (bottom part) and reveal the structure of the LiI electrolyte in it. The X-rays fail to transmit the battery but they succeed to provide better contrast for the electronic components (top part) where the solder joints on the integral circuit contain some amount of lead.

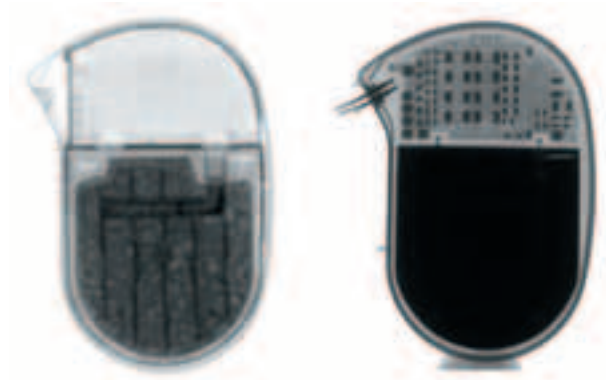

**Figure 3.** Comparison between radiography images of pacemaker performed with neutrons (left) and X-rays (right).

In case of tomography investigation the sample is rotated around a defined axis where 2-dimensional projections are recorded under different rotation angles. The mathematical reconstruction of the matrix of the attenuation coefficients in the sample volume can be done using the collected set of projections[5].

### Beam sources and imaging geometries

*Sources*

The sources for X-rays and neutrons determine the intensity of the radiation, the brilliance, if parallel or cone imaging geometry is used, if poly- or monochromatic radiation can be used, the possibility of real-time measurements, the detectors needed, etc., and of course also the beam disposability. The measurement time in a synchrotron or a neutrons reactor is limited, in comparison e.g. to a X-ray microfocus tube which can be used in a small lab.

*X-ray sources*

There are two main X-ray sources available for radioscopy and tomography, the X-ray tube with cone geometry and the X-ray synchrotron with parallel one. There are also other differences between them like the brilliance (see Fig. 4), the energy range, the irradiation section or the chromatism:

Synchrotron X-ray "light" is generated in electron accelerators and electron storage rings. The spectrum of the light emitted from these sources extends from the infrared to the vacuum ultra violet (VUV) and the X-ray region. BESSY [6], DESY [7], ESRF [8], SSRL [9], SRC [10], etc. are some of these facilities. The most important advantage of a synchrotron in comparison with a X-ray tube is their great brilliance (see Fig. 4) that is at least 10 orders of magnitude higher. But this is not the only difference, as we will see.

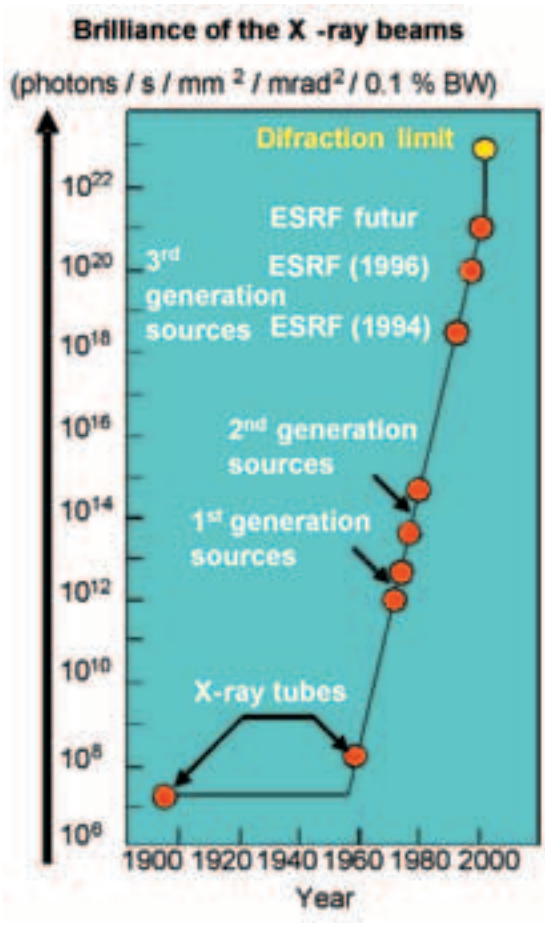


**Figure 4.** Comparison of the brilliance of the X-ray beams for tubes and for different Synchrotron sources (source: ESRF [8]).

X-ray tubes for radioscopy and tomography are normally microfocus ones, with a higher acceleration voltage in comparison to tubes used for diffraction. The microfocus is necessary to reach enough resolution and the high voltage to have enough penetration depth. Their energies vary from 20 keV to several hundred keV. With increasing energy the penetration depth also increases, but that automatically means the reduction of spatial resolution (increase of the beam spot), because the focusing e-beam in the tube cannot exceed a certain energy density, in order not to melt the target material used. For this reason microfocus X-ray sources usually have a Tungsten target and the source current is limited. Due to the cone geometry relatively big samples can be irradiated and magnification is possible. At present the evolution of the microfocus sources is going on, e.g. transmission tubes are considered, with diamond targets and water cooling [11] to increase the brilliance and the penetration depth, but keeping a micrometer spot.

*Neutron sources*

To extract an intense neutron beam for radiography purposes a large scale facility like a research reactor or a spallation source is needed. In research reactors neutrons are produced by fission of Uranium. The energy of the neutrons as produced is in the order of a few MeV. These high energies are not appropriate for conventional experimental purposes. Therefore, neutrons are moderated to energies of a few meV in a moderator, usually water or heavy water. The advantage of a steady source like a fission reactor for neutron imaging is the stable and continuous neutron flux which enables tomographic measurements with extended exposure times.

The spallation sources are accelerator-driven sources where the neutrons are produced by the excitation of the nuclei in a heavy-metal target (often Ta or W alloy). Again the fast neutrons are slowed down by collisions in a moderator set around the target. The accelerator has a defined repetition rate giving a corresponding time structure of the pulsed neutron beam. This time structure is very appropriate for time-of-flight experiments and energy-selective radiography investigations, respectively. More information about the neutron research reactors and splalation sources can be found elsewhere [12].

For high resolution neutron radiography and tomography both sources (reactors and spallation sources) provide sufficiently high neutron fluxes of app. $10^6$ to $10^7$ neutrons/cm$^2$s at the sample positions. Typical exposure times are in the range of a few seconds, with the exception of high flux facilities (~ $10^9$ neutrons/cm$^2$s) where radiographic images can be taken in fractions of a second [13].

An important characteristic of a neutron source is the mean energy of the neutron beam provided for experiments. As mentioned above the neutrons are moderated

to thermal energies, corresponding to a few meV. Additional moderation by a "cold source", i.e. a moderator at very low temperature (e.g. Hydrogen or Deuterium at 30° K) is used to obtain cold neutrons. Due to their low energy the attenuation coefficients of penetrated materials are higher for cold neutrons [14].
Other types of neutron sources for radiography purposes are the mobile sources based either on portable linear accelerators or a combination of neutron emitting isotopes [16]. This type of source is currently with a poor performance providing a low neutron flux with no optimum image resolution and complicated shielding and operation systems. So this is the reason why they are not spread among the standard radiography methods.

**Imaging geometries**

Two beam imaging geometry configurations have been considered: The parallel and the cone beam geometry (see Fig. 5). In both cases the acquired projections have to be reconstructed for the tomography, in the same way as it is known from the medical tomography. This is made by an algorithm that applies a special inversed Fourier transformation, the so-called Radon transformation which is described in detail elsewhere [5].
The parallel beam geometry, typical for the neutron tomography, has the advantages that there is no distortion in the images like in the cone geometry (see Fig. 5 (right) and Fig. 6) and that the reconstruction algorithms of the pictures are more simple. Depending on the sample dimensions and imaging arrangement the distortion can be neglected (see Fig. 6). On the other hand the cone geometry allows magnification. This is important e.g. because the parallel synchrotron beams analysis area is normally limited to a small windows of a few square centimeters. Bigger samples cannot be studied or have to be scanned. Due to magnification in the cone geometry the resolution can also be increased if the detector pitch is small enough.

*X-ray imaging arrangements*

A single X-ray image can simply be recorded with a photo plate as we know from the medical radiographies. Series of analogue pictures for real-time radioscopy can be recorded with a video recorder and a video camera focused on a scintillation screen. As analogue single pictures are not appropriate for the tomography, digital recording is favored at present. X-ray detectors are based on a X-ray sensitive screen, an optical image amplifier, and a CCD camera. An alternative is the last generation of flat panel detectors where all detector components are integrated on a flat screen. They have a digital output with a resolution down to 50 μm pitch size and save place.
In the special case of parallel synchrotron X-ray radiation the typical imaging arrangement consists of a source, a beam line, a shutter, a filter, a monochromator, a slit, the sample and a detector. As we get a wide frequency spectrum of the light, a monochromator, e.g. a Si <111> crystal or multilayer, is used to filter this white radiation to the desired wavelength. The loss of intensity can be compensated through the high brilliance of a synchrotron. The beam size normally varies between some square millimeters to several square centimeters. Larger samples have to be scanned.
For a microfocus source the cone geometry has to be considered with a magnification geometry (see Fig. 6). One implication is the possibility to adjust the required magnification M. It is given by M = b/a (a is the distance between source and sample and b between source and detector). Useful M's can be as high as 10 for our configuration. To find the best imaging parameters with, e.g., the best spatial and time resolution and the desired magnification, other factors have to be considered such as

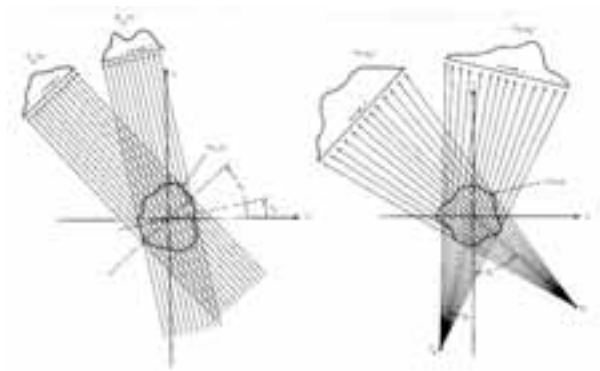

**Figure 5.** Parallel (left) and cone (right) beam geometry for X-ray and neutron radioscopy and tomography [5].

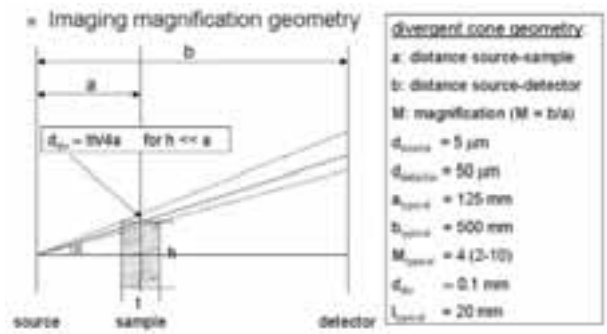


**Figure 6.** Typical cone imaging geometry for metallic foams radioscopy [15].

the sample geometry, the source pitch ($d_{source}$), the detector pitch ($d_{detector}$) or the divergence distortion $d_{div} \approx t \cdot h/4 \cdot a$ for $h << a$. At a given magnification a higher distance between source and detector will reduce $d_{div}$, but the intensity will also be reduced as $I \sim 1/b^2 \sim 1/M^2$. The resolution is determined not only by the detector pitch but also by the magnification and the source pitch.
As the absorption of X-rays increases with the atomic number, the dimensions of the samples are limited. Also the beam energy and the brilliance play a role. Typically they can vary from down to a millimeter to several centimeters. The sample dimensions that are allowed depend strongly on the absorption properties of the material.

*Neutrons imaging arrangements*
One neutron radiography facility consists of a collimation system which directs the neutrons to the sample, a sample environment which allows to scan the sample through the beam and to rotate it in case of a tomography investigation and a detector which converts the beam attenuation to a 2D image saved in an electronic format.
The collimation system installed between the source and the sample is of fundamental importance for the imaging quality that can be achieved with a specific experimental set-up. The collimation system consist of several apertures manufactured from high absorbing materials like $B_4C$, Li or Cd which are embedded in an evacuated beam tube. The apertures are increasing along the beam propagation direction and are hence defining the beam path. However, the collimation is defined by the size of the first aperture *D* and the length of the beam path L from the first aperture to the sample position. The ratio *L/D* [17] is used to characterize the collimation of a radiographic set-up as it is limiting the spatial radiographic image resolution which can be achieved in the experiment. The higher the *L/D* ratio the better is the beam collimation. Typical *L/D* values for standard neutron radiography facilities are between 200 and 500. At a defined *L/D* ratio each point of the sample will be projected on the detector plane as a spot with a diameter $d = l/(L/D)$, where *l* is the distance between the sample and the detector (see Fig. 7). For example in the case of an *L/D* ratio of 500 and a given sample-to-detector distance *l* of 5 cm the corresponding spatial resolution (blur *d*) will be in the order of 100 µm. While for radiography contact images are possible, for tomographic measurements it has to be taken into account that the minimum distance *l* between sample and detector is determined by the largest dimension of the sample perpendicular to the rotation axis.
Other necessary components of a radiography facility are the sample manipulation system to scan – and for tomographic purposes – to rotate the sample and the 2D image detection system. Of course the achievable image resolution is very much dependent on the detector system as well. Position-sensitive detectors for high resolution imaging are based on the detection of light photons emitted from thin scintillation screens. However, neutrons cannot be detected directly by a scintillation process. Therefore an additional converter material is needed which captures the neutrons and emits some ionizing (secondary) radiation like X-rays or α-particles. Two types of converter materials are mainly used in neutron radiography detectors: $^6$Li converting by an (n,α) and Gd by an (n,γ) reaction. This secondary radiation is then converted to light by a standard scintillating material such as ZnS. The mean free path of the secondary radiation in the scintillation material is limiting the spatial resolution of the detector to about 100 µm. A typical neutron radiography detection system is the combination of a scintillator screen and a CCD camera, which is recording the scintillation light from the screen via a mirror and a lens system. Imaging plates, flat panels and classical X-ray films (covered with a proper neutron to X-ray converter) are used as alternative 2D detectors.

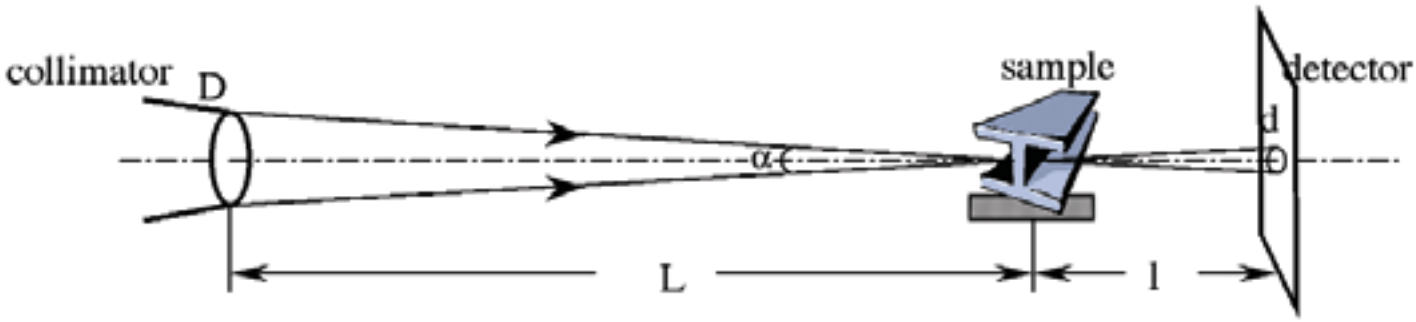


**Figure 7.** Geometrical limitations of the resolution using a conventional radiography geometry.

## X-rays

*Radioscopy*

Real-time imaging

Recording a series of single radiographs of an expanding metal foam (see Fig. 8) allows us to follow the dynamic process in real-time. The X-ray intensity of a microfocus

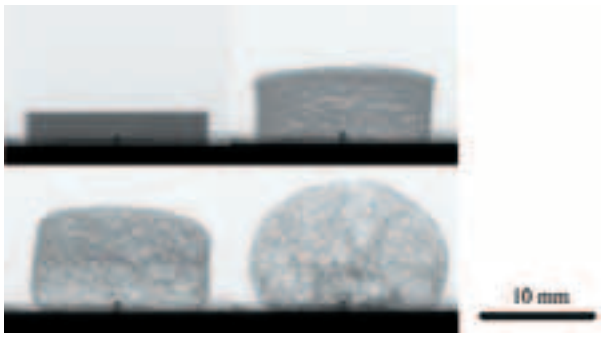


**Figure 8.** Real-time X-ray radioscopy of an expanding Al-foam.

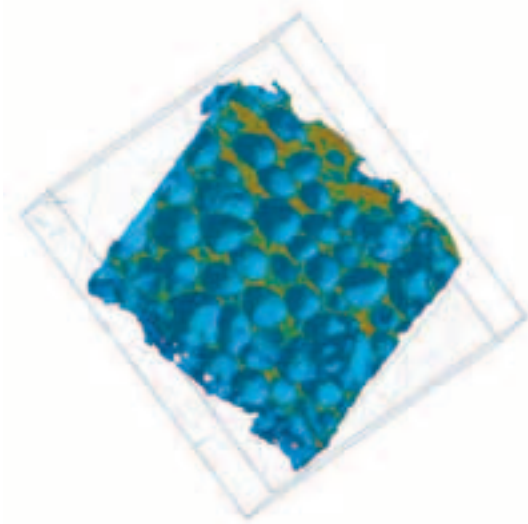

**Figure 9.** Tomography of a Zn-foam with $TiH_2$ particles < 28 mm [18].

source is much smaller than that of a synchrotron source resulting in limitations with short exposure times imposed by the signal-to-noise ratio. However, with a measurement configuration like in Fig. 6 the intensity is enough to get a satisfactory contrast for many applications, even for real-time picture acquisition at moderate image acquisition rates of around 1 Hz, even with the highest spatial resolution of 5 µm. However, time and spatial resolution are limiting each other. For very fast imaging the use of synchrotron rays is mandatory due to the higher brilliance.

*Tomography*

Tomography is a powerful non-destructive method for the investigation of a large variety of different objects. It allows to visualize the inner volume of a sample without destroying or dismantling it. The tomography principle is based on the mathematical reconstruction of the 3-dimensional volume from 2-dimensional projection images collected while the sample is rotated around a defined axis. With the reconstructed data 3-dim. material and pore analysis are possible. Using filter and different algorithms very informative pictures can be obtained. Mostly one or several phases are shown or hidden to analyze their location and distribution. Fig. 9 shows a Zn-foam with small $TiH_2$ particles. A bimodal pore size distribution can be found. Depending on the software representation method (see Fig. 10) pores, matrix or particles can be visualized separately.

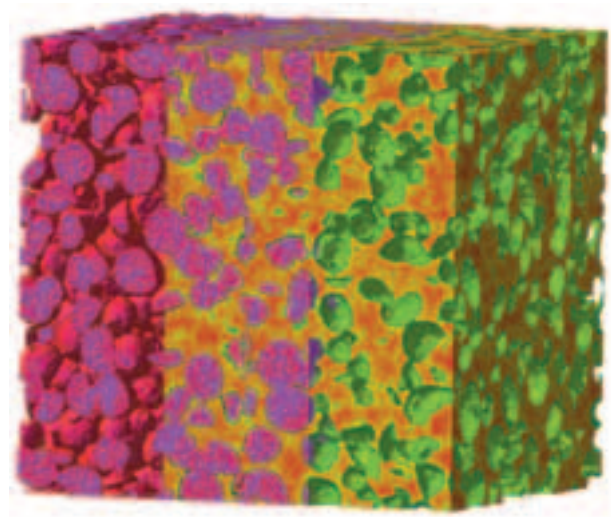

**Figure 10.** Al-foam tomography reconstruction with different software representations. Pores, matrix or particles can be analyzed separately [18].

## Neutrons

*Radioscopy*

Real-time imaging

The brilliance of neutron sources is much smaller than the synchrotron sources. The maximum possible thermal neutron flux of $3x10^9$ neutros/$cm^2$s with a beam size of ca. 20 cm of diameter is available for radiography purposes at the radiography station at ILL called Neutrograph [19]. High-flux radiography station using cold neutrons with a comparable flux is constructed recently at HMI, providing a rectangular beam size of $1x10^9$ $cm^2$. Under such experimental conditions the possible short-

est snapshot radiography times are in the order of some milliseconds. Some gain can be achieved if the so-called stroboscopic technique for repetitive processes is applied. An example for it is the presented below experiment performed at the cold neutron radiography station at HMI called CONRAD[20]. As an example, images of a

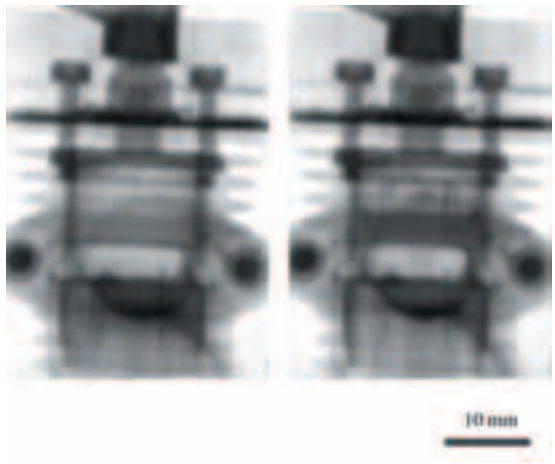


**Figure 11.** Two snapshot images of the model air-craft engine at 0 ms (left) and at 5 ms (right).

real-time radiography investigation of a small model air-craft engine using a stroboscopic method [3] are shown in Fig. 11. The exposure time was 1 ms at a rotation speed of the engine of 6000 rpm. The number of accumulated images per piston position was 500.

*Tomography*

The neutron tomography is analogue to the X-ray tomography. The limitation of the image resolution to 100 µm determines the number of projections used in the tomography experiments by the simple rule $M/N \sim \pi/2$, where M is the number of projections and N the number of used rays. Typical beam size in case of neutron radiography imaging is 10 x 10 $cm^2$ which determines 1000 x 1000 rays taking into account the resolution of 100 µm/ray mentioned above. In this case for a neutron tomography experiment the number of projections is determined by $M = 1000\ \pi/2 = 1570$. Using a CCD chip with 1024x1024 pixel with an integer format per pixel (2 Byte/pixel) and 600 projections (in order to save measuring time) per standard tomography experiment the data size for a tomography data volume could be estimated to be 1.25 GB which is not a problem for the existing computer systems nowadays. The measuring time at a standard neutron tomography facility is approximately 2-3 hours per experiment and the reconstruction procedure afterwards takes no less than 1-2 hours which means that for the maximum of 5 hours the tomography volume could be established. The next procedures which take much more time are the 3D-processing and segmentation of the data and the data archiving.

The neutron tomography is mainly used in cases where a high sensitivity to hydrogen or hydrogen containing materials is required. Some examples from the new neutron tomography facility at HMI are presented below.

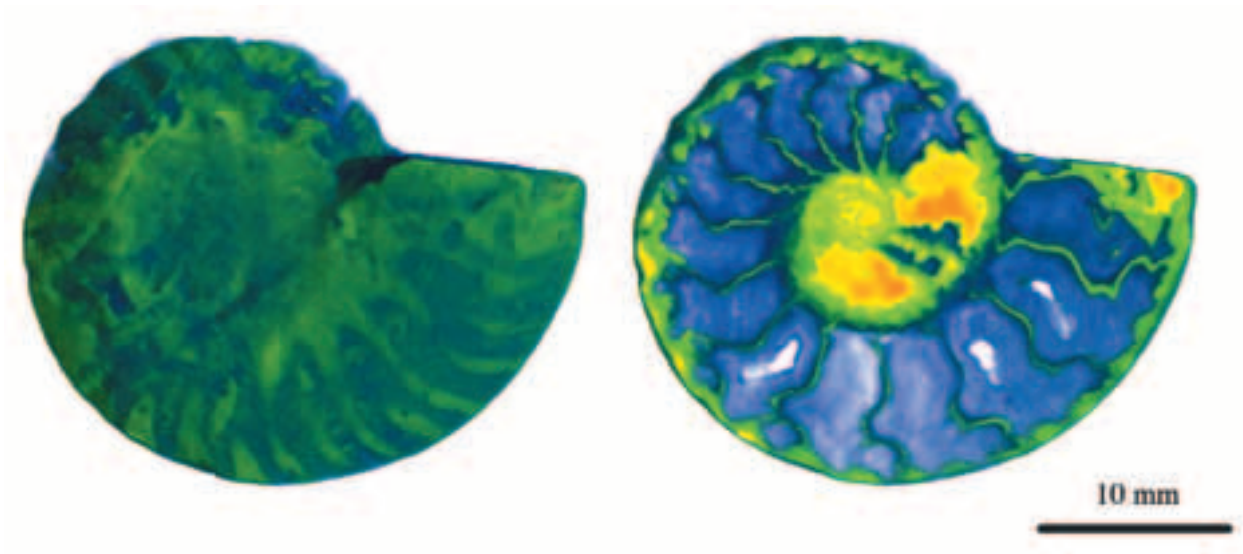


**Figure 12.** High resolution neutron tomography of a fossil sample (ammonite). General view (left) and tomography slice (right). The color scale represents the attenuation values from low (blue) to high (red).

*Fossils*

An example of high-resolution neutron tomography is the fossil sample (ammonite) presented in Fig. 12. For this experiments 300 projections were take from the sample on an angular range of 180 degree. The exposure time for a projection was 25 s resulting in a total measuring time for the whole tomography experiment of 2.5 hours.

The shell structure is of interest to the palaeontologists because of the relation between the formation speed of the shell, determined by the shape and the size of the shell segments and the day cycle for million of years. The high attenuation values (marked in red) can be related to areas of high hydrogenous content where some organically fossil remains are assumed.

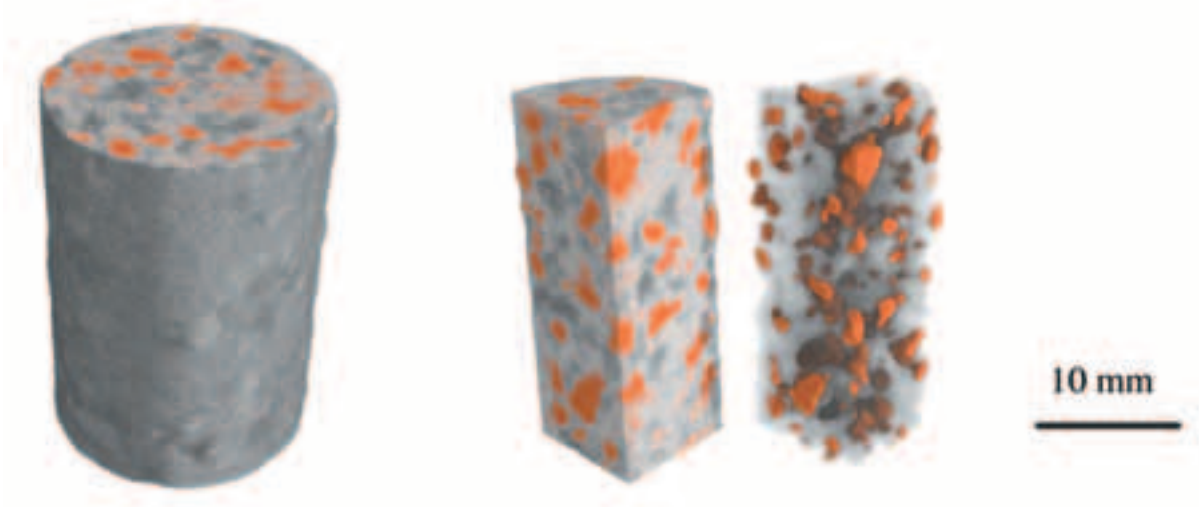


**Figure 13.** The tomographical reconstruction of the granite cylinder shows the spatial distribution of the mineral Kaolinit ($Al_2Si_2O_5(OH)_4$) marked with orange in the sample. The presence of four hydroxyl groups in the chemical composition leads to a strong contras for Kaolinit crystals in the tomography reconstruction due to high scattering properties of hydrogen.

*Geological samples*

In a further experiment, the density variation and the distribution of different minerals in a granite-sample were investigated (Fig. 13). This information helps to make conclusions about the formation of granite. In this case the presence of Kaolinit mineral (marked with orange) in the sample is an evidence that the granite material has underwent a hydrothermal alteration probably due to the flow of hot water through it. In this case the big Feldspar crystals frequently presented in granite have been transformed to Kaolinit by the following chemical reaction: $KAlSi_3O_8 + H_2O$ ? $Al_2Si_2O_5(OH)_4$. This kind of experiment may help to find a precise quantitative classification of different types of geological materials.

## Conclusions

Non-destructive radioscopic and tomographic analysis methods are a powerful tool for material science development. Several configurations are possible: neutrons or X-ray, large source or lab source, parallel or cone beam, attenuation or phase contrast, etc.

The neutron tomography appears as a complimentary technique to the X-ray imaging methods. It allows a higher sensitivity to hydrogenous materials and some light elements like Li and B which is very useful for investigations of glued joints of metallic parts, observation of diffusion processes of gasses and liquids in closed systems, water uptake and distribution in plants and building materials.

Some further developments in the X-ray and neutron detectors, sources and optics will help to improve the time resolution and the image resolution. Real-time radioscopy and tomography are very attractive techniques among the non-destructive material analytical methods.

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# BENSC NEUTRONS FOR "CULTURAL HERITAGE" RESEARCH: NEUTRON AUTORADIOGRAPHY OF PAINTINGS

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## Armida abducts the sleeping Rinaldo by Nicolas Poussin and The Baptism of a Child by Jan Steen

### Abstract

*Neutron autoradiography (NAR) is used for non-destructive analysis of materials and techniques of paintings. X-ray-radiography indicates the distribution of heavy elements. In contrast, NAR is capable of revealing different paint layers piled-up during the creation of the painting. In many cases the individual brushstrokes applied by the artist are made visible, as well as changes made during the painting process. When investigating paintings that have been reliably authenticated, it is possible to identify the particular style of an artist. By two examples the efficiency of neutron autoradiography is demonstrated as a non-destructive method for the examination of paintings.*

### Introduction

In close collaboration, the Berlin Picture Gallery (Gemäldegalerie Berlin, Stiftung Preußischer Kulturbesitz) and the Hahn-Meitner Institute Berlin investigate old masters paintings by means of neutron autoradiography. Neutron autoradiography is a very effective, non-destructive, but rather exceptional method applied in the examination and analysis of materials and techniques used in painting. It allows the visualization of structures and layers under the visible surface and, in addition, enables one to identify in detail the elements contained in the pigments. The instrument B8 at the Berlin Neutron Scattering Center BENSC is dedicated to these investigations. In this article the procedure of investigation is explained and two examples are given which demonstrate the success of this method.

### Neutron autoradiography - the method and the instrument

Usually, when examining paintings, museums apply methods based upon the use of photon radiation. However, the information provided by these methods is limited. Infrared reflectography reveals black carbon-based media, whilst X-ray transmission records only indicate dense matter or the distribution of heavy elements such as lead, e.g. in the pigment lead-white. Neutrons have a high penetration depth and interact also with light elements. Neutron autoradiography is capable of revealing different paint layers piled-up during the creation of the painting. In many cases, the individual brushstroke applied by the artist is made visible, as well as changes and corrections introduced during the painting process. By using paintings that have been reliably authenticated, one can identify the unique style or "hand" of a particular artist.

### The experimental principle

The experimental principle is simple: In the first step, the painting is exposed to a flux of cold neutrons ($\Phi_n$=1·10$^9$ cm$^{-2}$s$^{-1}$) at the instrument B8 at the research reactor BER II. Some of the atomic nuclei within the painting capture one of the neutrons, thus becoming radioactive and then, this neutron-induced radioactivity decays with time.

The probability of capture depends on the activation cross-section specific for every isotope. During the irradiation, the painting is adjusted under a small angle (< 5º) with respect to the axis of the neutron guide. By this grazing incidence the main free path of the neutrons within the paint layer becomes much longer than in the case of perpendicular transmission.

Due to the short irradiation time only 4 of $10^{12}$ atoms became radioactive on average, insofar the method is considered as a non-destructive investigation. Approximately a dozen different light and heavy isotopes – emitting β- (electrons) and γ-radiation – are created. The most important isotopes and their half-lives are presented in table 1.

The induced, β-decay blackens highly sensitive films or imaging plates (Fuji BAS 2000, 20x40 cm$^2$), thus unveiling the spatial distribution of the pigments.

The large advantage of this method lies in the fact that different pigments can be represented on separate films. This is due to a contrast variation created by the differences in the half-life times of the isotopes.

The imaging plate technique allows for direct digital

analysis and processing. In addition, a Ge-detector is used to analyse the radiation from specific locations on the painting. The γ-spectroscopy provides information about the element composition in the pigments.

**Representative Results for two Pictures**

a) Investigation of "Armida abducts the sleeping Rinaldo" (c. ~ 1637) by Nicolas Poussin, Picture Gallery Berlin, 120 x 150 cm$^2$, Cat No. 486

The French painter Nicolas Poussin (1594–1665) was one of the main representatives of pictorial classicism in the Baroque period, but he spent his entire career in Rome with the exception of two years as court painter to Louis XIII.

The illustrations in his paintings address scenes from the bible and from classical antiquity. Already in 1625, the legend of the sorceress Armida and the crusader Rinaldo had inspired Poussin to a painting named "Armida and Rinaldo", now owned by the Dulwich Picture Gallery in London, that is accepted as being an original. In contrast, the painting at the Berlin Picture Gallery "Armida abducts the sleeping Rinaldo" (Fig. 1) showing a different but similar scene, is until now listed in the Berlin Gallery's catalogue as a copy. To clarify the open question of the ascription, an investigation by means of neutron radiography was carried out at the Berlin Neutron Scattering Center BENSC.

The record of an X-ray radiography (Fig. 2) applied as a complementary method did not contribute to the solution of the problem, it primarily revealed the image of the wooden frame. In figure 3, one of the autoradiographs is depicted. The different sets of image plates

**Figure 1.** Nicolas Poussin, Replica, "Armida abducts the sleeping Rinaldo", (c. 1637), Picture Gallery Berlin, 120 x 150 cm$^2$, Cat No. 486

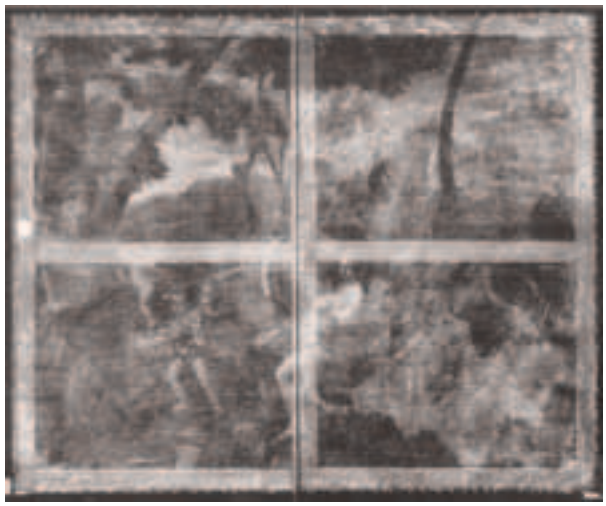

**Figure 2.** Nicolas Poussin, "Armida abducts the sleeping Rinaldo", X-Ray transmission record, Picture Gallery Berlin

**Figure 3.** Nicolas Poussin, "Armida abducts the sleeping Rinaldo", 1st neutron autoradiography assembled from 12 image plate records: In order to investigate the whole picture, two separated irradiations were carried out and finally recomposed.

were processed digitally and assembled afterwards. Already this first record, showing the distribution of the short-lived isotope $^{56}$Mn contained in the brown pigment umber, revealed surprising pentimenti as conceptual changes: additional trees (highlighted in Fig. 3) not present in the final painting. These trees fit in the composition of the painting and contain the same pigments as the other structures. Obviously, these pentimenti are corrections made by the artist himself. A copyist would not have been aware of these changes. Therefore, these pentimenti are strong and important hints that this painting can possibly be ascribed to Nicolas Poussin himself.

b) Investigation of the painting "The Baptism of a Child", by Jan Steen, Berlin Picture Gallery, 85 x 100 cm$^2$, Cat. No. 795D.

The Dutch painter Jan Steen (1625/26 – 1679), a contemporary of Rembrandt, is best known for his humorous genre scenes, animated works in which he treats life as vast comedy of manners. Many of his pictures represent taverns and festive gatherings such as in the painting focused in this experiment. The presented scene shows a genre which demonstrates human misdemeanour according to a saying "The young people twitter as the old people sing" (Fig. 4).

In the course of the restoration of this picture in 2003 diverse structures in the composition of colours were detected by X-rays which disagree with the visible painting. The neutron autoradiography promised a better and deeper understanding of this issue by visualizing pentimentis and other changes.

In the neutron radiography (Fig 5) a lot of pentimenti were revealed which do not display corrections of the visible scene. Originally the platform with the cradle was not provided. At this place a chair was located.

Especially one thematic modification on the right side of the picture is very enlightening: Behind the originally larger archway the view is open to a palace surrounded by a garden and sculptures, which should establish the manorial reference of the content of the picture. The large painting in the middle of Steen's picture changed during the creation shows two struggling cavaliers and indicates a manorial military context.

| Isotope | Half life | Pigment |
|---|---|---|
| $^{56}$Mn | 2.6 h | Brown colours, Umber, Ocre |
| $^{64}$Cu | 13 h | Azurite, Malachite |
| $^{76}$As | 1.1 d | Smalt, Realgar, Auripigmente |
| $^{122}$Sb<br>$^{124}$Sb | 2.7 d<br>60 d | Naples-Yellow |
| $^{32}$P | 14 d | Bone-black |
| $^{203}$Hg | 47 d | Vermilion |
| $^{60}$Co | 5.3 a | Smalt |

**Table 1** Main Isotopes and pigments used in neutron radiography and their half lives

**Figure 4.** Jan Steen, "The Baptism of a Child", Gemäldegalerie zu Berlin, 85 x 100 cm$^2$ Cat No. 795D

With these paintings within the picture the artist wanted to strengthen the thematic statement of this presentation. In the visible composition the pictures hanging at the walls on the left and right hand side strengthen now the moral didactic statement of the painting.
In conclusion by analogy the presentation of struggling cavaliers has to refer to the content of the painting, too. The observed pentimenti indicate that Steen has painted over a picture with completely different content. Especially, he has not made changes within the present composition.
Further image editing is intended to carry out in order to map and to understand the entire content of this underlying picture.

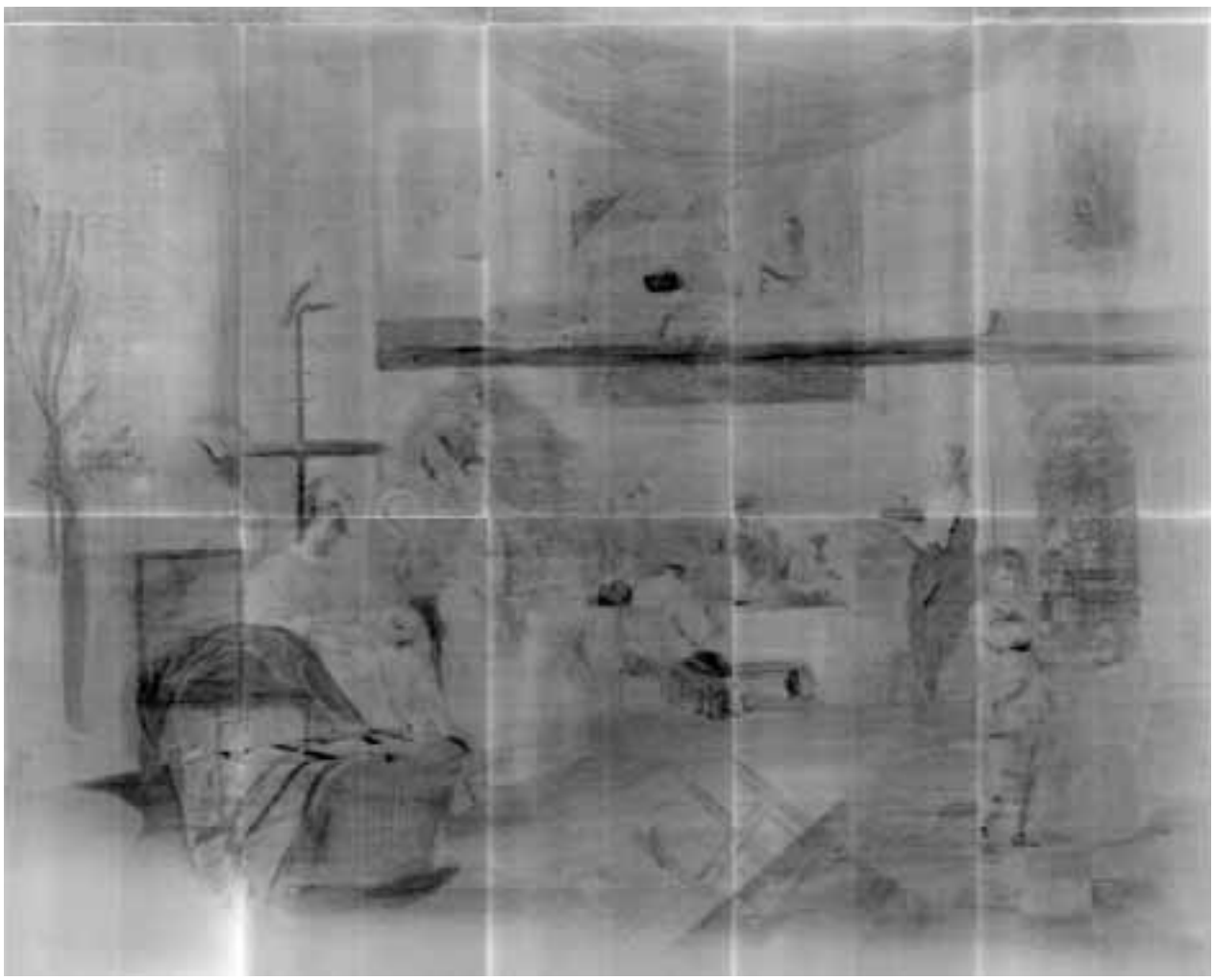

**Figure 5.** Jan Steen, "The Baptism of a Child", 1st autoradiography

# The Swiss Spallation Neutron Source SINQ

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**Abstract**
The continuous spallation neutron source SINQ is located at the Paul Scherrer Institute, Villigen, Switzerland. It delivers a thermal neutron flux of approximately $1.1 \cdot 10^{14}$ n/cm$^2$/s and is equipped with a cold source, supermirror coated neutron guides and a full suite of state-of-the-art instruments for neutron scattering and imaging experiments. SINQ is an open user facility and receives about 200 new proposals per year from the international user community. The facility is part of the EU NMI3 programme 'Access to large scale infrastructures' under Framework Programme 6 and hence is able to support its users from EU member countries and associated states with travel and subsistence funds. Apart from SINQ the Paul Scherrer institute also hosts a third generation synchrotron source (SLS) and the world's most powerful continuous muon source (SμS). More information on the PSI user facilities can be obtained from the Web: http://user.web.psi.ch

## General

The Swiss spallation neutron source SINQ [1] is one out of three user facilities for condensed matter research at the Paul Scherrer Institute (PSI), which is located approximately 35 km northwest of Zurich. Next to SINQ PSI operates a third generation synchrotron source (SLS) and a continuous muon source (SμS). So far PSI is the only place worldwide to offer neutrons, synchrotron X-rays and muons on one campus.
The continuous spallation neutron source SINQ - the first of its kind worldwide - began commissioning in December 1996. Regular user operation started in summer 1998. It is powered by a 590 MeV isochronous proton cyclotron with a current of 1850 μA. SINQ delivers a thermal neutron flux of approximately $1.1 \cdot 10^{14}$ n/cm$^2$/s and hence is a competitive medium flux source. SINQ was consequently designed for and equipped with supermirror coated neutron guides. This together with the fact that the cold $D_2$-source (equipped with a re-entrant hole design) contrary to reactors is placed in the flux maximum, results in a cold neutron flux at the instruments beyond that of neutron sources with a comparable thermal flux. SINQ typically runs six days a week (maintenance shut-downs of the accelerator on Wednesdays) and 8-9 months per year (maintenance shut-downs of the accelerator typically from end of December to middle of April).

## Instrumental capabilities

SINQ offers a complete suite of state-of-the-art neutron instrumentation to its users. The facility is equipped with 6 thermal beam ports, 2 cold beam tubes, and 7 neutron guides which - except for the SANS-I-guide - are fully coated by supermirrors. Presently 10 instruments dedicated to neutron scattering are scheduled for user operation. These instruments are run by the Laboratory for Neutron Scattering (LNS), a joint venture between ETH Zurich and PSI. In addition, PSI operates non-diffractive instruments such as irradiadion facilities and both cold and thermal radiography instruments. In particular the following instrument specifics are unique at SINQ:

**a) Diffractometers:**
**DMC,** funded by ETHZ, is one of the very few powder diffractometers worldwide using cold neutrons. Hence especially in combination with a dilution cryostat it is very well suited for solving magnetic structures with its 400 detectors. An upgrade programme of the secondary instrument and the detector is presently on its way. The second powder diffractometer **HRPT** uses thermal neutrons and is a high resolution instrument competitive to world class instruments at the ILL. It makes use of 1600 detectors covering 160º of scattering angle simultaneously. Furthermore, its high (30cm) vertically focusing Germanium-monochromator allows for the use of different hkk-reflections. Both powder diffractometers are equipped with radial collimators. **TriCS** is the only thermal neutron single crystal diffractometer that uses three 2-dimensional area detectors. The strain scanner **POLDI** operated on a thermal beam port is designed as a multiple pulse overlap TOF diffractometer. It is dedicated to measurements of internal strain and stress in engineering components. Special features are the capability of highly active and heavy weight samples.

**b) Spectrometers:**
**FOCUS**, partially funded by German BMBF, through University of Saarbrücken, is the only crystal time-of-flight spectrometer worldwide where the range of incident energies can be continuously tuned between 0.3 and 30meV. It can be used in time and monochromatic focusing mode

and its intensity is comparable to the world's top-instrument IN6/ILL. In the framework of the cooperation with Risø National Laboratory the cold triple-axis spectrometer **RITA-II** was installed at a guide end position. Its area sensitive detector enables the use of several analyser reflections simultaneously, which causes a significant intensity gain. **TASP** is a highly versatile triple-axis spectrometer (also at an end position of a cold guide) equipped for polarization analysis. Presently the thermal triple-axis spectrometer **EIGER** is being constructed in the neutron target hall (available for user operation in 2007) to extend the dynamic range of the SINQ spectrometers to the thermal range of about 100 meV. Furthermore the inverted geometry time-of-flight backscattering spectrometer **MARS** will be commissioned early 2006. With its mobile MICA analyzer banks MARS will allow for monitoring energy transfers in the μeV range.

**c) SANS/Reflectometry:**

The **SANS-I** facility (2x20m) is mechanically a twin instrument of D22/ILL. Beside its unique non-magnetic sample surrounding that allows for magnetic fields of 11T the instrument offers the option to polarize the incident beam and to perform time resolved experiments. Furthermore, an in-situ add-on for simultaneous light scattering is being implemented. **SANS-II** – as RITA-II - has been acquired from Risø and was upgraded with a new (Astrium-type of) velocity selector. The instrument (2x6m) that ran successfully with a very active user community at Risø for more than 10 years is highly flexible and can adapt the full SINQ and Risø sample environment. Since its installation the extreme overload (>3) of the SANS-I facility could be reduced using SANS-II for less demanding experiments. The reflectometer **AMOR** can be operated either in time-of-flight or in θ/2θ-mode. Special features are polarization analysis, vertical scattering plane, multi-detector, and special vibration damping units for the sample table. **MORPHEUS** is a highly flexible two-axis diffractometer, which is mainly used for instrument development such as testing of neutron optical components or for crystal alignment. A special feature on MORPHEUS is the ultra small angle scattering option called ECHO.

**d) Non-diffractive instruments:**

The most prominent representative of the non-diffractive use of SINQ is the Neutron Radiography and Tomography Station **NEUTRA** for thermal neutrons, which recently has been complimented by a second station at a cold neutron beam (**ICON**) [15].

SINQ has a dedicated sample environment group on site that is responsible for operating the respective devices like cryostats, furnaces, magnets, etc during the experiments. Presently, temperatures between 50mK and 1800K, magnetic fields up to 15T vertical and 1.8T horizontal for large scattering angles, 11T horizontal for SANS, as well as hydrostatic pressures up to 15kbars can be realized. Almost all devices are completely computer controlled and are integrated into the instrument control software such that the parameters can be easily changed in a user friendly manner. A full documentation of all available devices can be found on the SINQ webpages [2].

Recently, a new chemistry laboratory for sample preparation has been installed in the extension of the SINQ guide hall next to the neutron instruments. The lab is especially equipped for the preparation, handling and storage of soft condensed matter and biological samples, since the share of soft matter beam time as well as the users' request for such facilities rose significantly during the last years. Due to this location the handling of active and irradiated samples is also possible.

**In-house research**

The in-house research activities within the neutron scattering group are mainly focused on the following subjects: quantum spin systems, CMR manganates and cobaltates, intermetallic compounds with d- and f-elements, multilayers, high-temperature superconductors, large scale objects and materials science. Although most experiments are performed at SINQ, when necessary, other European facilities (ILL, ISIS, BENSC, Saclay…) are used as well.

A large effort of our activities is related to the investigation of materials with novel electronic properties. Amongst the best candidates are the 3d-metal complexes, which, as illustrated by their complex phase diagrams, posses remarkable physical properties. It is not rare to observe a metal-insulator phase transition accompanied by orbital, magnetic, structural and/or charge instabilities. Since many years, this class of materials has attracted much attention from scientists working at the research front on both basic and applied topics (Spintronics, Quantum communication, Superconducting devices, Random Access Memories, vibration damping, …). However, due to the intrinsic complexity of these compounds, large combined experimental and theoretical efforts are still required to get a deeper understanding of the relevant interactions controlling their macroscopic properties. Scientists at the Laboratory for Neutron Scattering in collaboration with partners at various research institutes worldwide, are currently working on a variety of 3d-transition metal complexes, whose most prominent examples are probably given by the high-$T_c$ cuprate-perovskite superconductors, colossal magneto-resistive manganites of ferro-electrics. In the following a few selected recent examples are given.

In a pioneering work at LNS, the existence of a magnetic field-induced phase transition of the vortex-lattice

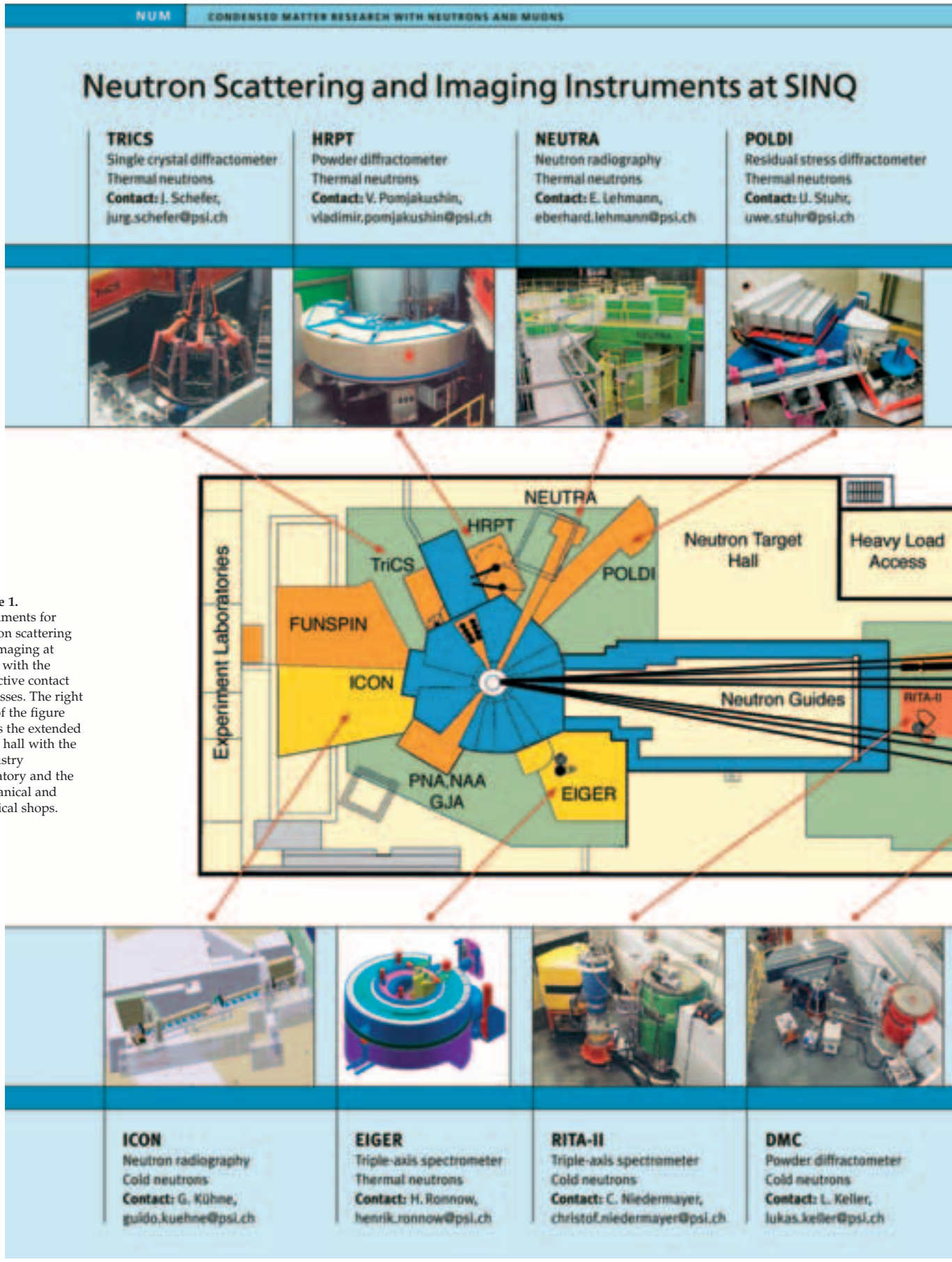


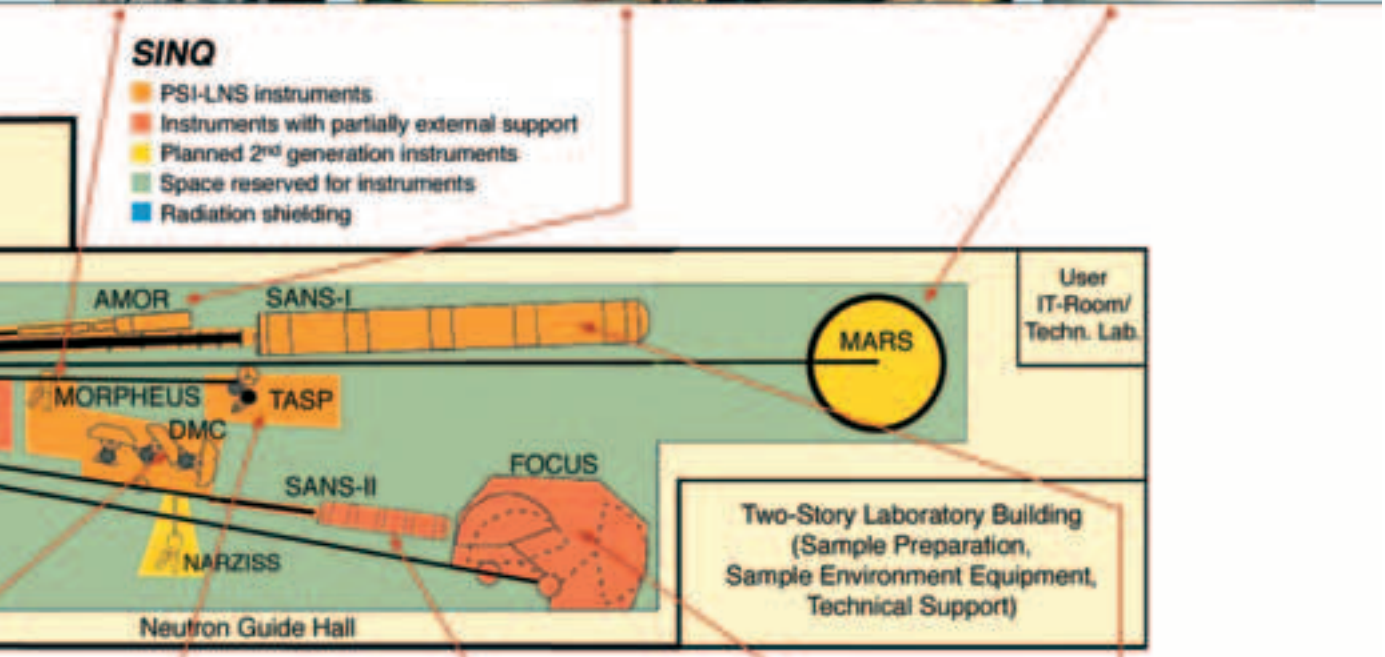

**Figure 1.**
Instruments for neutron scattering and imaging at SINQ with the respective contact addresses. The right part of the figure shows the extended guide hall with the chemistry laboratory and the mechanical and electrical shops.

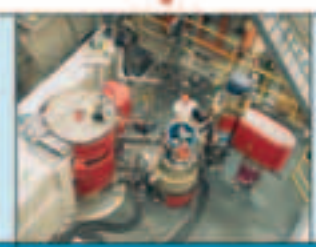
**Further information:** http://sinq.web.psi.ch/sinq/instruments.html

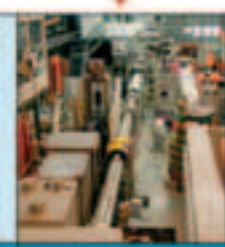
**MORPHEUS**
Two-Axis diffractometer
Cold neutrons
**Contact:** J. Stahn,
jochen.stahn@psi.ch

**AMOR**
Reflectometer
Cold neutrons
**Contact:** T. Gutberlet,
thomas.gutberlet@psi.ch

**MARS**
Backscattering spectrometer
Cold neutrons
**Contact:** P. Tregenna-Piggott,
philip.tregenna@psi.ch





**TASP**
Triple-axis spectrometer
Cold polarized neutrons
**Contact:** B. Roessli,
bertrand.roessli@psi.ch

**SANS-II**
12 m SANS-facility
Cold neutrons
**Contact:** T. Geue,
thomas.geue@psi.ch

**FOCUS**
Time-of-flight spectrometer
Cold neutrons
**Contact:** T. Straessle,
thierry.straessle@psi.ch

**SANS-I**
40 m SANS-facility
Cold neutrons
**Contact:** J. Kohlbrecher,
joachim.kohlbrecher@psi.ch

could be demonstrated by means of small angle neutron scattering, thus providing important information about the underlying electronic structure of these materials [3]. It was furthermore shown that the Cu-spin dynamics in $La_{2-x}Sr_xCuO_4$ couples in a highly unusual and unexpected manner to the vortex-dynamics [4].

Relaxor ferroelectrics form another sub-group of complex perovskites, which possess a remarkable dielectric anomaly over a broad range of temperatures and frequencies. In order to shine light on the microscopic mechanism controlling the unique physical properties of these important materials for technological applications, high-resolution neutron experiments have been recently initiated [5].

Further studied oxides materials are the magneto-resistive manganites and related compounds [6] and Co–based oxides showing complex spin-state transitions [7].

Neutron scattering studies of quantum spin systems allow for a deeper understanding of the microscopic mechanisms controlling the magnetic properties of systems relevant for future applications in the field of quantum computing. While in $NH_4CuCl_3$ quantized magnetization plateaus could be understood on the basis of high-resolution neutron diffraction experiments [8], the existence of Bose-Einstein condensation of spin-triplets was recently demonstrated using inelastic neutron scattering [9]. Furthermore, neutron diffraction investigations on the recently discovered Cu-tellurate, a system possibly lying on the verge of a quantum phase transition, indicate the existence of highly frustrated and degenerate magnetic ground-states [10]. In LiHoF it was shown that the coupling between the electronic- and nuclear-spins prevents the system to reach, under the application of a magnetic field, the predicted quantum critical point [11].

Very promising candidates in the field of spintronics include materials with strongly correlated charge carriers, whose mobility is linked to the exchange coupling between magnetic ions and spin degree of freedom. Recent neutron reflectometry data taken on multilayers of high-$T_c$ cuprates and ferromagnetic manganites show evidences for strong mutual interaction of the superconducting and ferromagnetic order parameters [12].

Beside the traditional fields of magnetism and strongly correlated electrons, it was recently decided to develop, in the future, as well the soft-matter research at LNS. Specifically this effort will aim on subjects as hybrid biomembrane structures [13], nanostructured polymer films [14], surfactant systems, aggregation and gelation in colloidal suspensions.

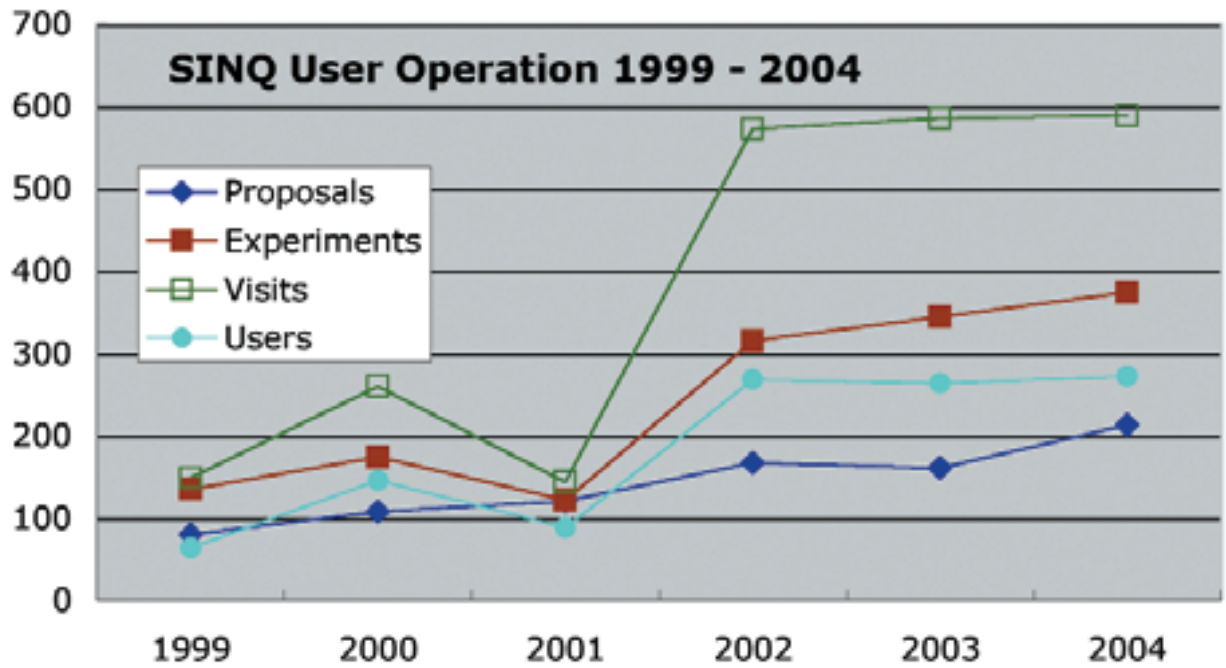



**Figure 2.** Evolution of key numbers for the user programme at SINQ since 1999. Some users make multiple visits to the facility over a year, hence the number of visits exceeds the number of individual users. The huge impact of the start of the EU access programmes in 2002 is clearly visible.

Investigations of the residual strains and stresses in large specimens can be performed with the strain scanner POLDI, a high-resolution time-of-flight diffractometer. The two main projects of the last year were the investigation of the development of residual strains in railway wheels during their lifetime and the determination of the stresses close to a weld in a reactor vessel in dependence of the level of irradiation.
Neutron imaging and neutron radiography serves a variety of programmes from different disciplines in science and technology, partly strongly supported by industrial partners. Actual research projects are the in-situ investigation of electric fuel cells, the investigation of aerosol filters for diesel engines, moisture distribution and exchange processes in wood-based materials and soil assemblies, fuel injection investigation in combustion engines and many more [15].

### International User facility

SINQ is not only the home base for the very active Swiss neutron scattering community but moreover an international user facility embedded into various international networking activities. SINQ is a full partner of the NMI3 access activity within the 6$^{th}$ Framework Programme of the European Commission and hence is able to support its users from EU member countries and associated states by the reimbursement of travel and subsistence funds. Over the last years SINQ received between 160 and 210 new proposals per year. Approximately 600 annual visits from 300 different users are counted. The number of experiments is in the order of 350 per year (Figure 2). Every year a users' meeting is organized. The 2005 meeting was attended by more than 100 participants from all over the world. The next meeting will be organized at PSI on May 10, 2006.
Proposals can be submitted at two deadlines per year (May 15 and November 15) either as short term or long term proposals. Short term proposals ask for beam time just for the next SINQ cycle, whereas a long term proposal defines a coherent research programme for a typical duration of two years. Long term proposals are frequently used for Ph.D. theses or postdoctoral works and have the major advantage that beam time once allocated is guaranteed over the full duration of the project. The proposals are evaluated by an external scientific committee before beam time is allocated. The third option to request for beam time at SINQ is the 'fast access' or 'director's discretion time'. That option should be used if a project is very urgent or important samples with a restricted lifetime should be investigated. Those requests can be submitted all over the year directly to the SINQ management. A certain share of urgent beam time is held back on all instruments such that access within a few weeks time or even less is enabled. All contact addresses and access possibilities are summarized on the SINQ Web pages [16].
Recently an online tool for the proposal submission and the management of the experiments was installed. This project is part of the general PSI User Office, which is in operation since mid 2004. The User Office serves as a central contact point [17] not only for the SINQ users but also for the other PSI user facilities SLS, SμS and the particle physics. The goal is to synchronize and unify the user operation at the various facilities as far as possible and also to trigger the use of complementary techniques over the PSI campus.
Finally it should be mentioned that the Paul Scherrer Institute is fully equipped to serve as a user laboratory. A guesthouse, a restaurant and various catering facilities are available on site. The PSI library and the various mechanic and electric shops are open to be used by the visitors as well. But the most attractive feature PSI can offer to its user community is the high quality of the instruments and the know-how and enthusiasm of the PSI staff members, who will help make experiments at SINQ a success.

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# ESRF Users' Meeting 2006

The ESRF will hold is annual USERS' MEETING on 7 and 8 February 2006. The meeting will largely be dedicated to a discussion of options for a Long Term Strategy for the facility. Users are warmly encouraged to contribute with their views on new and emerging areas, techniques and instrumentation. A Long Term Strategy paper will then be prepared and submitted to ESRF's funding partners for approval during Spring 2006. The Users' Meeting will be followed by two topical workshops, to be held in parallel on 8 and 9 February: "High Pressure and Synchrotron Radiation", and "Dynamical Phenomena in Soft Matter". Further details can be found at:
www.esrf.fr/NewsAndEvents
Conferences/UsersMeeting2006/
ESRF also invites prospective Users to submit proposals for beamtime. The deadlines for these applications are 1 March and 1 September 2006. ESRF recently increased the number of Review Committees that evaluate proposals for their scientific excellence or technical relevance. This has helped to cater to the increasing interest from scientists working in the areas of materials research and cultural heritage issues.
Details of the number of proposals submitted in September 2005 and accepted, per Review Committee, are shown in the table below.

| REVIEW COMMITTEES | Proposals submitted | Proposals accepted |
|---|---|---|
| Chemistry | 96 | 36 |
| Chemistry | 96 | 36 |
| Hard Condensed Matter: Electronic & Magnetic Properties | 125 | 56 |
| Crystals and Ordered Structures | 118 | 52 |
| Disordered Systems | 57 | 19 |
| Applied Materials and Engineering | 124 | 45 |
| Environmental & Cultural Heritage Matters | 68 | 24 |
| Macromolecular Crystallography | 64 | 55 |
| Medicine | 39 | 14 |
| Methods and Instrumentation | 29 | 10 |
| Soft Condensed Matter | 102 | 46 |
| Surfaces and Interfaces | 72 | 30 |
| Totals | **894** | **387** |

**R. Mason**

## News from ILL

# Welcome to Hungary !!

On 30 August 2005, a Scientific Cooperation Agreement and a Memorandum of Intent were signed between the Research Institute for Solid State Physics and Optics (RISP) in Budapest - acting on behalf of the Hungarian Academy of Sciences - and the ILL. Under the terms of the Memorandum of Intent, Hungary undertakes to accede to full scientific membership of ILL by not later than October 2007, probably as partner of a consortium with other Central European countries.
As of September 2005, Hungary has already obtained the status of interim scientific member, which conveys, in particular, the right to access scheduled beamtime in return for payment of a temporarily reduced contribution. A similar arrangement was concluded with Sweden in April 2005 and other countries have also expressed interest in joining the ILL through interim membership.
Hungary is particularly interested in cooperating on the construction of a next generation Neutron Spin Echo instrument.
The ILL management is organising our second ILL MILLENNIUM SYMPOSIUM and European Users Meeting (26-29 April 2006). Since the first ILL Millennium Symposium held in 2001, our Millennium Programme not only has started, but has been moving on at high speed, delivering much improved instrumentation and infrastructure to the benefit of ILL's users. We therefore feel that it is timely to review what has been achieved, but also to look towards the future. The Refit Programme of securing our high-flux reactor is coming to a close in 2006/07 and following the public instrument review new projects have emerged with the need of having more cold and ultra-

cold neutrons. These projects include the site development plans together with ESRF and EMBL, a high magnetic field laboratory, and new facilities for material science and soft condensed matter. A new ILL Roadmap is on the way and will be available at the Symposium.
We would like to invite you therefore to attend the meeting and to join the discussion and to give your input and advice on such matters as the past and future directions in neutron science, and the future scientific and instrumental choices for neutron science at ILL.

### Next standard proposal round

The deadline for proposal submission is **Tuesday, 14 February 2006, midnight (European time).**
Proposal submission is **only possible electronically**. Electronic Proposal Submission (EPS) is possible via our Visitors' Club (www.ill.fr, Users & Science, Visitors' Club, or directly at http://vitraill.ill.fr/cv/), once you have logged in with your personal username and password.

*Colin Carlile welcomes His Excellency André Erdös (Ambassador of Hungary to France) to the ILL.*

The detailed guide-lines for the submission of a proposal at the ILL can be found on the ILL web site: www.ill.fr, Users & Science, User Information, Proposal Submission, Standard Submission.
The web system will be operational from ***1 January 2006***, and it will be closed on ***14 February, at midnight (European time)***. You will get full support in case of computing hitches. If you have any difficulties at all, please contact our web-support (club@ill.fr). For any further queries, please contact the Scientific Co-ordination Office:
ILL-SCO, 6 rue Jules Horowitz
BP 156, F-38042 Grenoble Cedex 9
phone: +33 4 76 20 70 82,
fax: +33 4 76 48 39 06
email: sco@ill.fr, http://www.ill.fr

### Instruments available

The following instruments will be available for the forthcoming round:

- powder diffractometers: D1A, D1B*, D2B, D20, SALSA
- liquids diffractometer: D4
- polarised neutron diffractometers: D3, D23*
- single-crystal diffractometers: D9, D10, D15*, VIVALDI
- large scale structure diffractometers: D19, DB21, LADI
- small-angle scattering: D11, D22
- reflectometers: ADAM*, D17
- small momentum-transfer diffractometer: D16
- diffuse-scattering spectrometer: D7
- three-axis spectrometers: IN1, IN3, IN8, IN12*, IN14, IN20, IN22*
- time-of-flight spectrometers: IN4, IN5, IN6
- backscattering and spin-echo spectrometers: IN10, IN11, IN13*, IN15, IN16
- nuclear-physics instruments: PN1, PN3
- fundamental-physics instruments: PF1B, PF2

* Instruments marked with an asterisk are CRG instruments, where a smaller amount of beam time is available than on ILL-funded instruments, but we encourage such applications. You will find details of the instruments on the web: www.ill.fr/index_sc.html.

### Scheduling period

Those proposals accepted at the next round, will be scheduled during the THREE CYCLES foreseen in 2006 (150 days).

**REACTOR CYCLES FOR 2006*:**

| | | |
|---|---|---|
| **Cycle n° 143** | From | **14/06/2006** |
| | To | **03/08/2006** |
| **Cycle n° 144** | From | **31/08/2006** |
| | To | **20/10/2006** |
| **Cycle n° 145** | From | **31/10/2006** |
| | To | **20/12/2006** |

**Table 1.** The ILL reactor cycles in 2006. Start-ups and shut downs are planned at 8:30 am

* Please note that these dates might change. We therefore encourage you to consult the ILL website, where possible changes will be indicated.

### Report from the ILL Scientific Council

The 73rd meeting of the Scientific Council was chaired by Dieter Richter, the new Chairman, and it was fully devoted to looking to the future of the ILL. In his introduction, Dieter Richter referred to the new instruments being developed at ILL and the scientific partnerships being shaped while insisting upon growing competition from new MW spal-

lation sources in Europe and in other parts of the world. He agreed that the ILL has taken the right strategy which is to build on its own strengths. Partnerships for science are vital in that they enable laboratories/institutes to expand to other activities.

The subcommittee meetings – initially planned in November 2005 – and related proposal deadline were cancelled because, after the 2005-2006 winter shutdown, the reactor will not restart before June 2006, which would have caused a 9-10 months delay between the submission of a proposal and the schedule of the allocated beam time.

The **next Scientific Council** will be on 30-31 March 2006. The subcommittee meetings will be held on 28-29 March.

**G. Cicognani**

**668 pp**
**ISBN 981-256-013-0**
**Pub. date: Jun 2005**
**US$98 / £60**

*www.worldscibooks.com/chemistry/5628.html*

# VIBRATIONAL SPECTROSCOPY WITH NEUTRONS

## With Applications in Chemistry, Biology, Materials Science and Catalysis

by **Philip C.H. Mitchell** *(University of Reading, UK)*, **Stewart F. Parker, Anibal J. Ramirez-Cuesta & John Tomkinson** *(Rutherford Appleton Laboratory, UK)*

Inelastic neutron scattering (INS) is a spectroscopic technique in which neutrons are used to probe the dynamics of atoms and molecules in solids and liquids. This book is the first, since the late 1960s, to cover the principles and applications of INS as a vibrational-spectroscopic technique. It provides a hands-on account of the use of INS, concentrating on how neutron vibrational spectroscopy can be employed to obtain chemical information on a range of materials that are of interest to chemists, biologists, materials scientists, surface scientists and catalyst researchers. This is an accessible and comprehensive single-volume primary text and reference source.

**Contents:**
• The Theory of Inelastic Neutron Scattering Spectroscopy • Instrumentation and Experimental Methods • Interpretation and Analysis of Spectra Using Molecular Modelling • Analysis of INS Spectra • Dihydrogen and Hydrides • Surface Chemistry and Catalysis • Organic and Organometallic Compounds • Hydrogen Bonding • Soft Condensed Matter - Polymers and Biomaterials • Non-Hydrogenous Materials and Carbon • Vibrational Spectroscopy with Neutrons - The Future

**Readership:** Users and potential users of neutron scattering spectroscopy (academics, staff of neutron scattering institutes, researchers and graduate students); solid state vibrational spectroscopists.

## The personal view of the reviewer

**Carla Andreani**
*University of Rome Tor Vergata, I*

The book provide a very good account of principles and applications of Inelastic Neutron Scattering (INS) as a vibrational spectroscopic technique, without assuming a high level of background knowledge. It is a piece of work factually novel and done properly, which meets needs of graduate students as well as both users and potential users of inelastic neutron spectroscopy, belonging to academic and research institutions. On the whole the book is quite clearly written, the subject matter rather well developed and the applications of the INS well described in a wide range of materials and problems.

# SNS Nears Completion

The Spallation Neutron Source (SNS), is a 1.4 MW pulsed neutron spallation source under construction at Oak Ridge National Laboratory (ORNL) for the U.S. Department of Energy.
The SNS will deliver a 60 Hz, 1.4 mA average current, 1GeV proton beam to a liquid mercury target for short-pulse neutron scattering experiments. The SNS has been planned as dedicated user facility for neutron scattering research. As such, it is expected eventually to accommodate 1000 to 2000 national and international users per year, carrying out research in diverse fields such as condensed matter physics, materials science, chemistry, biology, and mineralogy and geology.
To achieve this goal, a collaboration of six Department of Energy national laboratories is responsible for design and construction of the various subsystems: ion source (Lawrence Berkeley), room temperature linear accelerator (Linac) (Los Alamos), superconducting Linac (Thomas Jefferson), accumulator ring (Brookhaven), target (Oak Ridge), and instruments (Argonne and Oak Ridge).
The project is in the seventh year of a seven-year construction phase, with facility operations scheduled to begin in 2006. Following a two-year period of commissioning and ramping up of power level, we anticipate being able to operate in user mode (defined at >90% availability) in the megawatt-level power range. As experience with operation is gained, we plan to approach the ultimate goal of 5000 full power hours per year at 95% reliability.

Key to the performance of SNS is its accelerator which has the following components. An $H^-$ ion source provides a 65 keV beam of 50 mA peak current to the Linac.
This beam is accelerated in four separate accelerating structures, and each is optimized for a particular energy range. First, a Radiofrequency Quadrupole accelerates the beam to 2.5 MeV. Second, a Drift-Tube-Linac accelerates the beam to 87 MeV. Third, a Coupled-Cavity-Linac accelerates the beam to 186 MeV. Fourth a Superconducting Linac accelerates the beam to 1GeV.
An RF pulse is applied to the Linac accelerating structures to provide a 1 msec long beam pulse. The 1 msec beam pulse is continuously injected into the accumulator ring (after the electrons are removed) and the re-


**Photo 1.** The site aerial of the Spallation Neutron Source and the Center for Nanophase Materials Sciences at Oak Ridge National Laboratory. Photo credit: ORNL

sulting proton beam pulse length is compressed to 700 nsec.
Once accumulation is complete, this beam of high-energy protons is extracted and hits mercury nuclei in a target of 20 tons of flowing liquid mercury.
Neutrons are the spallation product of these collisions and are slowed by one ambient water and three liquid hydrogen moderators. The neutrons are guided to the instrument hall where up to 24 instruments can be accommodated. The acceleration, accumulation and delivery cycle operates at 60 Hz.
To date, 17 instruments have been assigned beamlines, including one for fundamental physics research, two reflectometers, seven diffractometers and seven spectrometers. The general user program is expected to begin in 2008 for a small group of these instruments and will be preceded by a period for initial users to assist SNS instrument scientists in the commissioning of these instruments during the ramp-up of power, predictability, and reliability.
With the SNS construction phase ending, SNS, the Joint Institute of Neutron Sciences (JINS) and other members of the U.S. neutron community are working with the European Community to chart new research opportunities through NMI3 (EU Framework Programme 6 - Integrated Infrastructure Initiative for

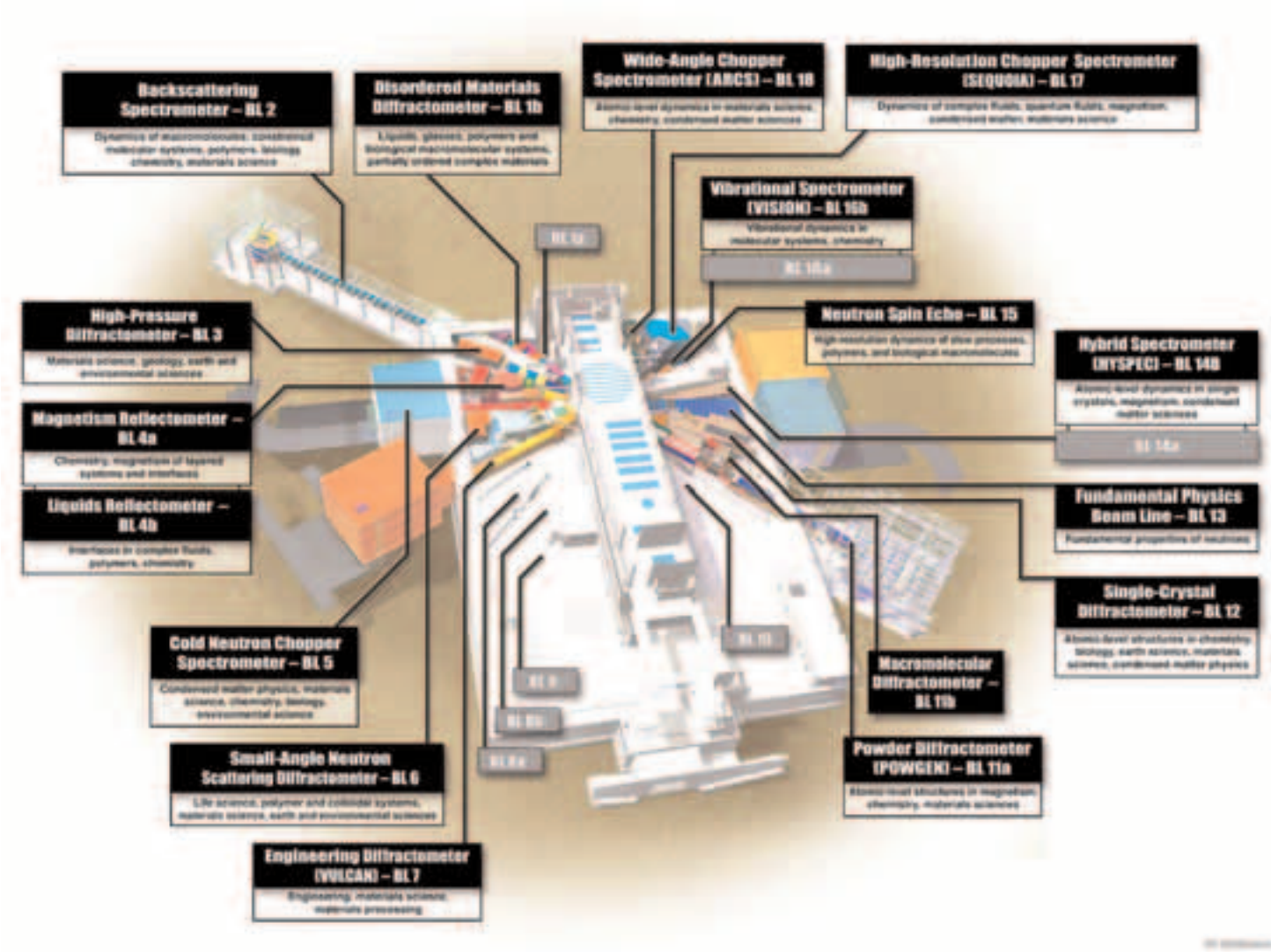


**Photo 2.** In this image of the Target building, protons enter from the top. SNS will have room for 24 instruments. Five instruments are part of the initial construction project and others will be added at a rate 1-2 per year.

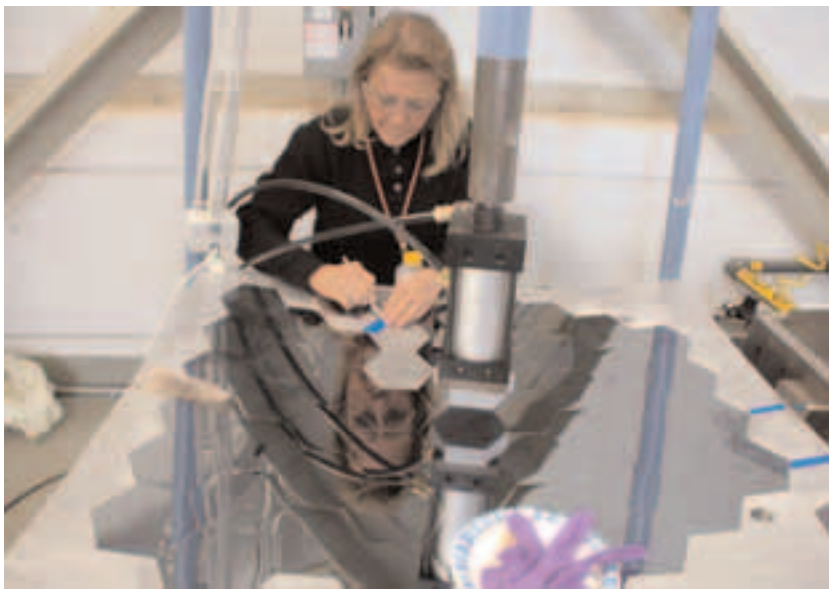

**Photo 4.** Waynette Dawkins is attaching one of 1500 analyzer crystals to aluminum plates prior to mounting in the evacuated tank.

Neutron Scattering and Muon Spectroscopy).
The *BioMaN- Biomaterials & Neutrons* session at the American Vacuum Society Meeting introduced neutron scattering to the biomaterials community. This followed JINS-NMI3 supported collaborations of foresight studies on *Neutrons and Energy for the Future*, June 2004, and *Symposium on Neutrons at the Frontier of Earth Sciences and Environment – NESE*, April 2005.
These collaborations continue with a small group meeting in February 2006 to identify research that will support advances in neutron instrumentation needed over the next several decades.
Research at the SNS will be complemented by opportunities available elsewhere at Oak Ridge National Laboratory.
Together with the expanded capabilities of the High Flux Isotope Reactor, the synthesis and characterization facilities in the new Center for Nanophase Materials Science, biodeuteration capabilities of the Center for Structural Molecular Biology, and the resources of the Center for Computational Sciences, we believe these are unparalleled opportunities for the study of structure and properties of materials. For more information on the SNS, please visit our website at www.sns.gov.

**A.E. Ekkebus**

**Photo 3.** The Backscattering Spectrometer is a near-backscattering, crystal-analyzer spectrometer designed to provide extremely high energy resolution. The design requires a long initial guide section of 84 m from moderator to sample in order to achieve the timing resolution necessary to achieve the desired energy resolution. The tank is 7 m in diameter and 4 m high.

**Photo 5.** This curved portion of the 84 m of neutron guides directs low energy neutrons from the target to the sample.
Photo credits: ORNL

# New high-throughput crystallization facility at EMBL-Hamburg

**Abstract**

The European Molecular Biology Laboratory (EMBL) has established a new high-throughput crystallization facility at its Outstation located on the campus of the German Synchrotron Radiation Facility (DESY) in Hamburg, Germany, with major funds from the German Ministry for Science and Education (BMBF). This is Europe's largest facility of its kind with access to the general user community. The facility combines technological advances in new ways to automate every step along the crystallization process.

Progress in life science has been extraordinary over the past years. The amount of data deposited in GenBank (www.ncbi.nlm.nih.gov/Genbank) for example has increased almost 10-fold since 1999 for a total of more than 46 Million entries. As a consequence, researchers worldwide now have access to the complete inventories of cells from multiple organisms. While bioinformatics has brought classification and systematization to this plethora of information, scientists still have to translate the genetic information into knowledge about the cell's inner workings.

One almost immediate response to close the gap between information and knowledge was Structural Genomics [1]. It is founded on the realization that the three-dimensional structure of biological macromolecules is the fundamental principle behind function. X-ray crystallography is the natural choice for structure determination by virtue of its accuracy, speed, potential for further speed gains and absence of limits on the sample size. Bio-crystallography contributes 85% of all structures deposited in the Protein Data Bank (PDB, www.rcsb.org/pdb).

Despite numerous improvements in X-ray crystallography (e.g. the use of powerful synchrotrons and better detectors) it is still a slow method in comparison to DNA sequencing, for example. There are currently two major bottlenecks in crystallography: the production of sufficient amounts of soluble sample and its subsequent crystallization. The reason crystallization is a bottleneck lies in the inability to predict successful conditions or construct designs that lead to the formation of well formed crystals. Therefore one is forced to set up a very large number of crystallization experiments (~500 at 2 temperatures) for a large number of constructs. Fortunately, crystallization is very suitable for automation [2,3].

We have established Europe's largest high-throughput crystallization facility at the EMBL-Hamburg Outstation, which will be open to the general user community. The facility has the capacity to generate 10,000 crystallization experiments in an 8 hour working day and it can store and image a total of 1,000,000 such experiments. With this facility, the EMBL has added a critical component to its already existing services for structural biologists. Users of the EMBL-Hamburg outstation now have the possibility to take advantage of a highly automated crystallography pipeline that comprises sample crystallization, data collection at a synchrotron and model building.

In the future, the high-throughput crystallization facility will become part of the Integrated Center for Life Science at the new 3rd generation synchrotron beamline of PETRA III (http://petra3.desy.de). This center will accommodate state of the art sample purification and characterization facilities (e.g. MS, ITC, DLS/SLS etc.) as well as the world's most advanced PX and SAXS beamlines under one roof. Brining together all of these facilities will give researchers a unique tool to tackle the scientific challenges ahead.

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**Matthias Wilmanns**
*EMBL Outstation Hamburg,*
*c/o DESY*
*Notkestr. 85, Bldg. 25A*
*D-22603 Hamburg, Germany*
*Email:*
*jochenmd@embl-hamburg.de*
*wilmanns@embl-hamburg.de*

## Call for proposals for
# Neutron Sources

### BENSC
Deadlines for proposal submission are:
**15th March 2006**
www.hmi.de/bensc

### BNC
Deadlines for proposal submission are:
**15th June 2006**
www.bnc.hu

### FZ Juelich
Deadline for proposal submission is:
**1st February 2006**
www.fz-juelich.de

### GeNF
Deadline for proposal submission is:
**Anytime during 2006**
www.gkss.de/index

### ILL
Deadlines for proposal submission are:
**14th February 2006**
www.ill.fr

### ISIS
Deadlines for proposal submission are:
**16th April and 16th October 2006**
www.isis.rl.ac.uk

### LLB-ORPHEE-SACLAY
Deadlines for proposal submission are:
**1st April 2006**
www-llb.cea.fr

### NFL
Deadlines for proposal submission are:
**15th May and 15th September, 2006**
www.studsvik.uu.se

### NPI-Rez
Deadline for proposal submission is:
**15th May and 15th September 2006**
www.ujf.cas.cz

### SINQ
Deadlines for proposal submission are:
**15th May and 15th November 2006**
sinq.web.psi.ch/

## Call for proposals for
# Synchrotron Radiation Sources

### ALS
Deadlines for proposal submission are:
**1st June 2006**
www-als.lbl.gov/als/quickguide/independinvest.html

### BESSY
Deadlines for proposal submission are:
**15th February 2006**
www.bessy.de/boat/

### DARESBURY
Deadlines for proposal submission are:
**1st May and 1st November 2006**
www.srs.ac.uk/srs/userSR/user_access2.html

### ELETTRA
Deadlines for proposal submission are:
**28th February and 31st August 2006**
www.elettra.trieste.it/UserOffice/index.php?n=Main.ApplicationForBeamtime

### ESRF
Deadlines for proposal submission are:
**1st March 2006 and 1st September 2006**
www.esrf.fr/UsersAndScience/UserGuide/GeneralGuidelines

### GILDA
Deadlines for proposal submission are:
**1st May and 1st November 2006**
www.lnf.infn.it/esperimenti/puls/gilda.html

### HASYLAB
Deadlines for proposal submission are:
**1st March and 1st September 2006**
www-hasylab.desy.de/user_infos/projects/3_deadlines.htm

### LURE
Deadline for proposal submission is:
**30th October 2006**
www.lure.u-psud.fr

### MAX-LAB
Deadline for proposal submission is:
**February 2006**
www.maxlab.lu.se

### NSLS
Deadlines for proposal submission are:
**31st May and 31st September, 2006**
www.nls.bnl.gov/

**February 8-9, 2006** — **GRENOBLE, FRANCE**

**Dynamic Phenomena in Soft Matter**
ESRF, Auditorium
e-mail: soft_matter_workshop@esrf.fr
http://www.esrf.fr/NewsAndEvents/Conferences/UsersMeeting2006/SoftCondensedMatterWS/

**February 8-10, 2006** — **GRENOBLE, FRANCE**

**Workshop on High Pressure and Synchrotron Radiation**
CNRS Grenoble Auditorium
http://www.esrf.fr/NewsAndEvents/Conferences/UsersMeeting2006/HiPressureWorkshop/

**February 13-14, 2006** — **VILLIGEN, SWITZERLAND**

**International Workshop on Present Status and Future of Very Cold Neutron Applications**
Paul Scherrer Institut
http://sinq.web.psi.ch/sinq/instr/psts/vcn-workshop.html

**February 16-17, 2006** — **JÜLICH, GERMANY**

**Symposium for the Inauguration of the 'Juelich Centre for Neutron Science JCNS' and European Users Meeting**
Forschungszentrum
http://www.jcns.info/

**February 20-21, 2006** — **CAMPINAS, SP, BRAZIL**

**LNLS 16th Annuak Users Meeting**
LNLS Campus
http://www.lnls.br/formularios/eventos/DetalhesEvento.asp?idEvento=51&idioma=2

**February 20-21, 2006** — **VILLIGEN PSI, SWITZERLAND**

**Workshop on X-ray absorption spectroscopy and micro-spectroscopic techniques**
Paul Scherrer Institut
http://xas06.web.psi.ch/

**February 20-26, 2006** — **ST. LOUIS, MISSOURI, USA**

**AAAS Annual Meeting**
http://www.aaas.org/meetings/Annual_Meeting/

**February 21-23, 2006** — **TOKYO, JAPAN**

**Nano Tech 2006 - "International Nanotechnology Exhibition & Conference"**
Tokyo Big Sight (Tokyo International Exhibition Center)
e-mail: nanotech@ics-inc.co.jp
http://www.ics-inc.co.jp/nanotech/index_e.html

**March 1-4, 2006** — **VILLIGEN, SWITZERLAND**

**Swiss-Russian Workshop on 'Quantum Magnetism and Polarised Neutrons'**
PSI
http://lns00.psi.ch/sinqwiki/Wiki.jsp?page=WorkshopQM

**March 7-8, 2006** — **HARIMA, JAPAN**

**The Fourth International Workshop on X-ray Damage to Biological Crystalline Samples**
Spring8
http://www.spring8.or.jp/e/conference/rd4/

**March 12-16, 2006** — **SAPPORO, JAPAN**

**The 8th International Conference on the Physics of X-Ray Mutlilayer Structures**
e-mail: pxrms@esrf.fr
http://www.esrf.fr/NewsAndEvents/Conferences/pxrms06/

**March 13-17, 2006** — **BALTIMORE, MD, USA**

**American Physical Society Meeting**
Convention Center
http://www.aps.org/meet/MAR06/

**March 16-18, 2006** — **GRENOBLE, FRANCE**

**AP.G.RA.D(E) 2006 Applications of Gamma-Ray Diffraction**
Institut Laue Langevin,
http://www.ill.fr/apgrade/First-Announce.htm

**March 23-26, 2006** — **GRENOBLE, FRANCE**

**3rd International Workshop on Dynamics in Coninement**
Institut Laue Langevin
http://www.ill.fr/YellowBook/IN6/confit2006/confit_2006.html

**March 26-30, 2006** — **ATLANTA, GA, USA**

**231st American Chemical Society Meeting**
http://acswebcontent.acs.org/nationalmeeting/atlanta2006/home.html

**March 30-31, 2006** — **DARESBURY, CHESHIRE, UK**

**3rd Network Meeting - ESF Future Advanced Light Sources(FALS)**
Daresbury Laboratory
email: a.m.hannah@dl.ac.uk
http://www.srs.ac.uk/meetings/esf_fals/

**April 17-21, 2006** — **SAN FRANCISCO, CA, USA**

**MRS Spring Meeting - Materials Research Society Spring Meeting**
Moscone West
http://www.mrs.org/s_mrs/sec_mtgdetail.asp?CID=2072&DID=92004

**April 22-25, 2006** — **DALLAS, TX, USA**

**American Physical Society Meeting**
Hyatt Regency Hotel
http://www.aps.org/meet/APR06/

**April 27-29, 2006** — **GRENOBLE, FRANCE**

**ILL Millenium Symposium and European Users Meeting**
Institut Laue Langevin,
http://vitraill.ill.fr/symposium/welcome.jsp

**May 5-10, 2006** — **VAALBEEK (BELGIUM)**

**Neutron scattering - an introductory course for the biosciences and materials sciences**
La Foresta

**May 10, 2006** — **VILLIGEN, SWITZERLAND**

**8th SINQ Users' Meeting**
PSI
http://sinq.web.psi.ch/sinq/usmeet_8/meet8.html

**May 13-19, 2006** — **MUROL, PUY-DE-DOME**

**14th Journées de la Diffusion Neutronique**
http://www.sfn.asso.fr/JDN/JDN14

**May 15-19, 2006** — **HAMBURG, GERMANY**

**FLS 2006 - 37th ICFA Advanced Beam Dynamics Workshop on Future Light Sources**
http://fls2006.desy.de/

**May 16-19, 2006** — **KYOTO, JAPAN**

**LPM 2006 - 7th International Symposium on Laser Precision Microfabrication 2006**
Kyoto Research Park
http://www.jlps.gr.jp/lamp/lamp2006/

**May 21-26, 2006** — **GRENOBLE, FRANCE**

**HSC1: Synchrotron Radiation X-ray Imaging**
ESRF
e-mail: hsc@esrf.fr
http://www.esrf.fr/NewsAndEvents/Conferences/HSC/HSC1/

**May 28 - June 3, 2006** — **DAEGU, KOREA**

**SRI2006 - Ninth International Conference on Synchrotron Radiation Instrumentation**
Exco Center
http://www.sri2006.org/about/info.php

**June 10-17, 2006** — **GIRONDE, FRANCE**

**8th Bombannes School - European School on Scattering Methods Applied to Soft Condensed Matter**
RelaiSoleil Aquitaine , "Les Bruyères" Bombannes
http://whisky.ill.fr/Events/bombannes/

**June 13-14, 2006** — **ITHACA, NY, USA**

**CHESS Users Meeting**
http://meetings.chess.cornell.edu/Usermeeting2006

**June 14-17, 2006** — **BLOOMINGTON, IN, USA**

**The Eighth International Quasi-Elastic Neutron Scattering Conference (QENS2006)**
Bloomington Convention Center
http://www.iucf.indiana.edu/events/qens2006

**June 16-18, 2006** — **SASKATOON, SASKATCHEWAN, CANADA**

Saskatchewan, Canada
**CLS 9th Annual Users Meeting**
University of Saskatchewan
http://www.lightsource.ca/uac/meeting2006

**June 18-22, 2006** — **ST. CHARLES, IL, USA**

**2006 American Conference on Neutron Scattering**
e-mail: ajschultz@anl.gov
http://acns2006.anl.gov

**June 18-22, 2006** — **SAN DIEGO, CA, USA**

**AAAS Pacific Division 87th Annual Meeting**
San Diego University Campus
http://www.sou.edu/aaaspd/SanDiego2006/Index.html

**July 9-13, 2006** — **KYOTO, JAPAN**

**13th International Conference on Small-Angle Scattering (SAS2006)**
Kyoto International Conference Hall
http://sas2006.scphys.kyoto-u.ac.jp

**July 9-13, 2006** — **KYOTO, JAPAN**

**SAS2006 Kyoto - XIII International Conference on Small-Angle Scattering**
Kyoto International Conference Hall
http://sas2006.scphys.kyoto-u.ac.jp

**July 9-14, 2006** — **STANFORD, CA, USA**

**XAFS13 - 13th International Conference on X-ray Absorption Fine Structure**
Stanford University campus.
http://www-ssrl.slac.stanford.edu/xafs13

**July 12-18, 2006** — **MANCHESTER, UK**

EPS-HEP2007
**European Physical Society Conference on High Energy Physics**
http://www.hep.man.ac.uk/HEP2007

**July 16-20, 2006** — **TAIPEI, TAIWAN**

**9SXNS - Ninth International Conference on Surface X-Ray and Neutron Scattering**
Academia Sinica
http://web11.nsrrc.org.tw/9sxns

**July 23-28, 2006** — **KOBE, JAPAN**

**19th General Meeting of the International Mineralogical Association - "New Frontiers in Mineral Sciences"**
e-mail: SAS2006@alloy.polym.kyoto-u.ac.jp
http://www.congre.co.jp/ima2006/index_e.html

**July 30 - August 2, 2006** — **CHICAGO, IL, USA**

**SRMS-5 - Fifth International Conference on Synchrotron Radiation in Materials Science**
Drake Hotel
http://www.aps.anl.gov/News/Conferences/2006/SRMS/index.html

# NEUTRON SOURCES

## NEUTRON SCATTERING WWW SERVERS IN THE WORLD (http://neutron.neutron-eu.net/n_news/n_calendar_of_events)

**Atominstitut Vienna (A)**
Facility: TRIGA MARK II
Type: Reactor. Thermal power 250 kW.
Flux: 1.0 x 1013 n/cm2/s (Thermal);
1.7 x 1013 n/cm2/s (Fast)
Address for information:
1020 Wien, Stadionallee 2 - Prof. H. Rauch
Tel: +43 1 58801 14111; Fax: +43 1 58801 14199
E-mail: boeck@ati.ac.at; http://www.ati.ac.at
Wap: wap.ati.ac.at

**NRU Chalk River Laboratories**
The peak thermal flux 3x1014 cm-2 sec-1
Neutron Program for Materials Research
National Research Council Canada
Building 459, Station 18
Chalk River Laboratories
Chalk River, Ontario - Canada K0J 1J0
Phone: 1 - (888) 243-2634 (toll free)
Phone: 1 - (613) 584-8811 ext. 3973
Fax: 1- (613) 584-4040
http://neutron.nrc-cnrc.gc.ca/home.html

**Budapest Neutron Centre BRR (H)**
Type: Reactor. Flux: 2.0 x 1014 n/cm2/s
Address for application forms:
Dr. Borbely Sándor, KFKI Building 10,
1525 Budapest - Pf 49, Hungary
E-mail: Borbely@power.szfki.kfki.hu
http://www.iki.kfki.hu/nuclear

**FRJ-2 Research Reactor in Jüelich (D)**
Type: Dido reactor. Flux: 2 x 1014 n/cm2/s
Prof. D. Richter, Forschungszentrums Jüelich GmbH,
Institut für Festkörperforschung,
Postfach 19 13, 52425 Jüelich, Germany
Tel: +49 2461161 2499; Fax: +49 2461161 2610
E-mail: neutron@fz-juelich.de
http://www.neutronscattering.de

**FRG-1 Geesthacht (D)**
Type: Swimming Pool Cold Neutron Source.
Flux: 8.7 x 1013 n/cm2/s
Address for application forms and informations:
Reinhard Kampmann, Institute for Materials Science,
Div. Wfn-Neutronscattering, GKSS, Research Centre,
21502 Geesthacht, Germany
Tel: +49 (0)4152 87 1316/2503; Fax: +49 (0)4152 87 1338
E-mail: reinhard.kampmann@gkss.de
http://www.gkss.de

**HMI Berlin BER-II (D)**
Facility: BER II, BENSC
Type: Swimming Pool Reactor. Flux: 2 x 1014 n/cm2/s
Address for application forms:
Dr. Rainer Michaelsen, BENSC,
Scientific Secretary, Hahn-Meitner-Insitut,
Glienicker Str 100, 14109 Berlin, Germany
Tel: +49 30 8062 2304/3043; Fax: +49 30 8062 2523/2181
E-mail: michaelsen@hmi.de; http://www.hmi.de/bensc

**IBR2 Fast Pulsed Reactor Dubna (RU)**
Type: Pulsed Reactor.
Flux: 3 x 1016 (thermal n in core)
Address for application forms:
Dr. Vadim Sikolenko,
Frank Laboratory of Neutron Physics
Joint Institute for Nuclear Research
141980 Dubna, Moscow Region, Russia.
Tel: +7 09621 65096; Fax: +7 09621 65882
E-mail: sikolen@nf.jinr.dubna.su
http://nfdfn.jinr.ru/flnph/ibr2.html

**ILL Grenoble (F)**
Type: 58MW High Flux Reactor.
Flux: 1.5 x 1015 n/cm2/s
Scientific Coordinator
Dr. G. Cicognani, ILL, BP 156,
38042 Grenoble Cedex 9, France
Tel: +33 4 7620 7179; Fax: +33 4 76483906
E-mail: cico@ill.fr and sco@ill.fr; http://www.ill.fr

**IPNS Intense Pulsed Neutron at Argonne (USA)**
for proposal submission by e-mail
send to cpeters@anl.gov or mail/fax to:
IPNS Scientific Secretary, Building 360
Argonne National Laboratory,
9700 South Cass Avenue, Argonne,
IL 60439-4814, USA
Phone: 630/252-7820; Fax: 630/252-7722
http://www.pns.anl.gov/

**IRI Interfaculty Reactor Institute in Delft (NL)**
Type: 2MW light water swimming pool.
Flux: 1.5 x 1013 n/cm2/s
Address for application forms:
Dr. A.A. van Well, Interfacultair Reactor Institut,
Delft University of Technology, Mekelweg 15,
2629 JB Delft, The Netherlands
Tel: +31 15 2784738; Fax: +31 15 2786422
E-mail: vanWell@iri.tudelft.nl; http://www.iri.tudelft.nl

**ISIS Didcot (UK)**
Type: Pulsed Spallation Source.
Flux: 2.5 x 1016 n fast/s
Address for application forms:
ISIS Users Liaison Office, Building R3,
Rutherford Appleton Laboratory, Chilton,
Didcot, Oxon OX11 0QX
Tel: +44 (0) 1235 445592; Fax: +44 (0) 1235 445103
E-mail: uls@isis.rl.ac.uk; http://www.isis.rl.ac.uk

**JAERI (J)**
Japan Atomic Energy Research Institute,
Tokai-mura, Naka-gun,
Ibaraki-ken 319-11, Japan.
Jun-ichi Suzuki (JAERI);
Yuji Ito (ISSP, Univ. of Tokyo);
Fax: +81 292 82 59227; Telex: JAERIJ24596
http://www.ndc.tokai.jaeri.go.jp/

**JEEP-II Kjeller (N)**
Type: D2O moderated 3.5%
enriched UO2 fuel.
Flux: 2 x 1013 n/cm2/s
Address for application forms:
Institutt for Energiteknikk
K.H. Bendiksen, Managing Director
Box 40, 2007 Kjeller, Norway
Tel: +47 63 806000, 806275; Fax: +47 63 816356
E-mail: kjell.bendiksen@ife.no; http://www.ife.no

**LLB Orphée Saclay (F)**
Type: Reactor. Flux: 3.0 x 1014 n/cm2/s
Laboratoire Léon Brillouin (CEA-CNRS)
Submissio by email at the following address :
experience@llb.saclay.cea.fr
http://www-llb.cea.fr/index_e.html

**NFL Studsvik (S)**
Type: 50 MW reactor. Flux: > 1014 n/cm2/s
Address for application forms:
Dr. A. Rennie, NFL Studsvik
S-611 82 Nyköping, Sweden
Tel: +46 155 221000; Fax: +46 155 263070/263001
E-mail: user.admin@studsvik.uu.se
http://www.studsvik.uu.se

**NIST Research Reactor, Washington, USA**
National Institute of Standards
and Technology-Gaithersburg,
Maryland 20899 USA
Center Office:
J. Michael Rowe, 6210, Director
NIST Center for Neutron Research
E-mail: mike.rowe@nist.gov
http://www.ncnr.nist.gov/

**NRI Rez (CZ)**
Type: 10 MW research reactor.
Address for informations:
Zdenek Kriz, Scientif Secretary
Nuclear Research Institute Rez plc,
250 68 Rez - Czech Republic
Tel: +420 2 20941177 / 66173428; Fax: +420 2 20941155
E-mail: krz@ujv.cz / brv@nri.cz; http://www.nri.cz

**PSI-SINQ Villigen (CH)**
Type: Steady spallation source.
Flux: 2.0 x 1014 n/cm2/s
Contact address: Paul Scherrer Institut
User Office, CH-5232 Villigen PSI - Switzerland
Tel: +41 56 310 4666; Fax: +41 56 310 3294
E-mail: sinq@psi.ch; http://sinq.web.psi.ch

**SPALLATION NEUTRON SOURCE, ORNL (USA)**
http://www.sns.gov/

**TU Munich FRM, FRM-2 (D)**
Type: Compact 20 MW reactor.
Flux: 8 x 1014 n/cm2/s
Address for information:
Prof. Winfried Petry,
FRM-II Lichtenbergstrasse 1 - 85747 Garching
Tel: 089 289 14701; Fax: 089 289 14666
E-mail: wpetry@frm2.tum.de
http://www.frm2.tu-muenchen.de

# SYNCHROTRON RADIATION SOURCES

## SYNCHROTRON SOURCES WWW SERVERS IN THE WORLD (http://www.esrf.fr/navigate/synchrotrons.html)

**ALS Advanced Light Source**
Berkeley Lab, 1 Cyclotron Rd, MS6R2100, Berkeley, CA 94720
tel: +1 510.486.7745 - fax: +1 510.486.4773
http://www-als.lbl.gov/

**ANKA**
Forschungszentrum Karlsruhe Institut für Synchrotronstrahlung Hermann-von-Helmholtz-Platz 1 76344 Eggenstein-Leopoldshafen, Germany
tel: +49 (0)7247 / 82-6071 - fax: +49-(0)7247 / 82-6172
http://hikwww1.fzk.de/iss/

**APS Advanced Photon Source**
Bldg 360, Argonne Nat. Lab. 9700 S. Cass Avenue, Argonne, Il 60439, USA
tel:+1 708 252 5089 - fax: +1 708 252 3222
http://epics.aps.anl.gov/welcome.html

**ASTRID**
ISA, Univ. of Aarhus, Ny Munkegade, DK-8000 Aarhus, Denmark
tel: +45 61 28899 - fax: +45 61 20740
http://www.aau.dk/uk/nat/isa

**BESSY Berliner Elektronen-speicherring Gessell.für Synchrotron-strahlung mbH**
BESSY GmbH, Albert-Einstein-Str.15, 12489 Berlin, Germany
tel +49 (0)30 6392-2999 - fax: +49 (0)30 6392-2990
http://www.bessy.de

**BSRL Beijing Synchrotron Radiation Lab.**
Inst. of High Energy Physics, 19 Yucuan Rd.PO Box 918, Beijing 100039, PR China
tel: +86 1 8213344 - fax: +86 1 8213374
http://solar.rtd.utk.edu/~china/ins/IHEP/bsrf/bsrf.html

**CAMD Center Advanced Microstructures & Devices**
Louisiana State University, Center for Advanced Microstructures & Devices, 6980 Jefferson Hwy., Baton Rouge, LA 70806
tel: (225) 578-8887 - fax: (225) 578-6954 Fax
http://www.camd.lsu.edu/

**CHESS Cornell High Energy Synchr. Radiation Source**
Wilson Lab., Cornell University Ithaca, NY 14853, USA
tel: +1 607 255 7163 - fax: +1 607 255 9001
http://www.tn.cornell.edu/

**CLS**
Canadian Light Source, University of Saskatchewan, 101 Perimeter Road, Saskatoon, SK., Canada. S7N 0X4
http://www.cls.usask.ca/

**DAFNE**
INFN Laboratori Nazionali di Frascati, P.O. Box 13, I-00044 Frascati (Rome), Italy
tel: +39 6 9403 1 - fax: +39 6 9403304
http://www.lnf.infn.it/

**DELTA**
Universität Dortmund,Emil Figge Str 74b, 44221 Dortmund, Germany
tel: +49 231 7555383 - fax: +49 231 7555398
http://prian.physik.uni-dortmund.de/

**DIAMOND**
Diamond Light Source Ltd, Rutherford Appleton Laboratory, Chilton, Oxon OX11 0QX
http://www.diamond.ac.uk/

**ELETTRA**
Sincrotrone Trieste S.C.p.A., Strada Statale 14 - Km 163,5 in AREA Science Park, 34012 Basovizza, Trieste, Italy
tel: +39 40 37581 - fax: +39 40 226338
http://www.elettra.trieste.it

**ELSA Electron Stretcher and Accelerator**
Nußalle 12, D-5300 Bonn-1, Germany
tel:+49 288 732796 - fax: +49 288 737869
http://elsar1.physik.uni-bonn.de/elsahome.html

**ESRF European Synchrotron Radiation Lab.**
BP 220, F-38043 Grenoble, France
tel: +33 476 882000 - fax: +33 476 882020
http://www.esrf.fr/

**EUTERPE**
Cyclotron Lab.,Eindhoven Univ. of Technol, P.O.Box 513, 5600 MB Eindhoven, The Netherlands
tel: +31 40 474048 - fax: +31 40 438060

**HASYLAB**
Notkestrasse 85, D-2000, Hamburg 52, Germany
tel: +49 40 89982304 - fax: +49 40 89982787
http://www-hasylab.desy.de/

**INDUS**
Center for Advanced Technology, Rajendra Nagar,
Indore 452012, India
tel: +91 731 64626
http://www.ee.ualberta.ca/~naik/accind1.html

**KEK Photon Factory**
Nat. Lab. for High Energy Physics, 1-1, Oho,
Tsukuba-shi Ibaraki-ken, 305 Japan
tel: +81 298 641171 - fax: +81 298 642801
http://www.kek.jp/

**Kurchatov**
Kurchatov Inst. of Atomic Energy, SR Center,
Kurchatov Square, Moscow 123182, Russia
tel: +7 95 1964546

**LNLS Laboratorio Nacional Luz Sincrotron**
CP 6192, 13081 Campinas, SP Brazil
tel.: (+55) 0xx19 3287.4520 - fax: (+55) 0xx19 3287.4632
http://www.lnls.br/

**LURE**
Bât 209-D, 91405 Orsay ,France
tel: +33 1 64468014 - fax: +33 1 64464148
http://www.lure.u-psud.fr

**MAX-Lab**
Box 118, University of Lund, S-22100 Lund, Sweden
tel: +46 46 109697 - fax: +46 46 104710
http://www.maxlab.lu.se/

**NSLS National Synchrotron Light Source**
Bldg. 725, Brookhaven Nat. Lab., Upton, NY 11973, USA
tel: +1 516 282 2297 - fax: +1 516 282 4745
http://www.nsls.bnl.gov/

**NSRL National Synchrotron Radiation Lab.**
USTC, Hefei, Anhui 230029, PR China
tel +86-551-5132231,3602034 - fax: +86-551-5141078
http://www.nsrl.ustc.edu.cn/en/enhome.html

**Pohang**
Pohang Inst. for Science & Technol., P.O. Box 125
Pohang, Korea 790600
tel: +82 562 792696 - fax: +82 562 794499
http://pal.postech.ac.kr/english.html

**Siberian SR Center**
Lavrentyev Ave 11, 630090 Novosibirsk, Russia
tel: +7 383 2 356031 - fax: +7 383 2 352163
http://ssrc.inp.nsk.su/english/load.pl?right=general.html

**SLS**
Swiss Light Source
Paul Scherrer Institut, User Office, CH-5232 Villigen PSI,
Switzerland
tel: +41 56 310 4666 - fax: +41 56 310 3294
E-mail slsuo@psi.ch - http://sls.web.psi.ch

**SPring-8**
2-28-8 Hon-komagome, Bunkyo-ku ,Tokyo 113, Japan
tel: +81 03 9411140 - fax: +81 03 9413169
http://www.spring8.or.jp/top.html

**SOLEIL**
Centre Universitaire - B.P. 34 - 91898 Orsay Cedex
http://www.soleil.u-psud.fr/

**SOR-RING Inst. Solid State Physics**
S.R. Lab, Univ. of Tokyo, 3-2-1 Midori-cho Tanashi-shi,
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