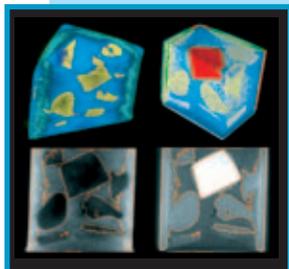




Rivista del  
Consiglio Nazionale  
delle Ricerche

**Cover photo:**

4 pictures of iron black box no. 9 (Fe 9) from the ANCIENT CHARM project.



**NOTIZIARIO**  
Neutroni e Luce di Sincrotrone

published by CNR in collaboration with the Faculty of Sciences and the Physics Department of the University of Rome "Tor Vergata".

Vol. 12 n. 2 Luglio 2007  
Autorizzazione del Tribunale di Roma n. 124/96 del 22-03-96

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GRAPHIC AND PRINTING:

om grafica  
via Fabrizio Luscino 73  
00174 Roma

Finito di stampare  
nel mese di Luglio 2007

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## Carlo Rizzuto will be the new ESFRI Chairman (European Strategy Forum on Research Infrastructures). Hamburg, June 7th 2007

**C**arlo Rizzuto, President of Sincrotrone Trieste, will take the office of Chairman of ESFRI (European Strategy Forum on Research Infrastructures), starting from the beginning of March 2008.

great EU research infrastructures. The Board of European Ministers gave a strongly favourable opinion on the Forum's activity during its last Meeting, held in Wolfsburg. The action plan opened by ESFRI is the essential introduction for dynamic devel-



Carlo Rizzuto

The Forum was funded in 2002 to promote development of a European Infrastructure Research Network, merging the different countries' shares in a common development and innovation strategy. The nomination took place in Hamburg during the plenary meeting held for the IV European Conference on Research Infrastructures.

ESFRI brings together representatives of EU Member States and Associated States, appointed by Ministers of Research in charge, and one representative of the European Commission.

Main objective: to develop coherent policies in order to provide UE the most advanced research instrumentation in every field, from Human and Social Sciences to Environmental and Physical Sciences, with a strong emphasis on Biomedical Sciences. In order to respond in real terms to such a pressing need, in 2006 ESFRI drew up the first "roadmap": an executive programme to assist the laboratories' strategic development, the mobility of the researchers and their common access to the

development of European research, that often lacks a proper coordination structure even though it can boast an ancient tradition and excellent results in science and innovation.

The new Chairman-to-be Rizzuto comments: "There is concrete risk that teams working in different Countries and separate structures could develop in parallel similar projects, without creating synergy and critical mass; this is especially true for collaborations between basic research and industry, so that the economic outcome is limited".

Rizzuto continues: "Only the harmonic combination of efforts through a connection network, can guarantee our continent's competitive future, stimulate innovation and boost technology transfer, in order to make Europe the most competitive and dynamic knowledge-based economy in the world, and to comply with the obligations undertaken by the European countries in the Lisbon Strategy".

**Bibi Palatini**  
*Sincrotrone Trieste*



## 2007 Walter Halg Prize of the European Neutron Scattering Association (ENSA)

It is with great pleasure that we report that Professor Jeffrey Penfold (ISIS, Rutherford Appleton Laboratory, STFC) is to be the fifth recipient of the prestigious Walter Halg prize.

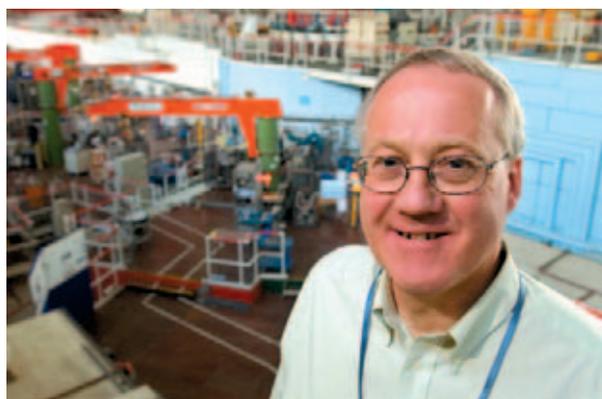
The prize recognises Professor Penfold's ground breaking work on neutron reflection which he developed into an invaluable tool in colloid and interface science. His work has involved both instrument and technique development as well as a large volume of highly cited original research. In particular, he has played a pioneering role in the development of neutron reflection and has exploited this technique, combined with small-angle neutron scattering in order to provide a complete picture, for studies of surface chemistry, which led to the Hayter-Penfold theory to describe the scattering from colloidal dispersions. The quantitative aspects of this theory were ahead of their time and have led to a greatly deepened understanding of the interactions giving rise to colloidal properties. His more recent work with R.K. Thomas, Oxford, has extended all of this to the interactions between biological molecules as well as between biological molecules and surfactants, again revealing unexpected phenomena of both fundamental and practical interest. All these developments have stimulated a huge neutron community, notably industrial companies, to start taking a strong interest in the potential of neutron scattering experiments.

Jeffrey Penfold studied at Brunel University, UK, where he obtained the degree of Bachelor in Technology in 1971 and the Ph.D. degree in 1981 with a thesis entitled "New applications of neutron scattering to problems in surface chemistry". In 1971 he was appointed Scientific Officer in the Neutron

Beam Research Unit at the Rutherford Laboratory. From 1977 to 1979 he was seconded to the Institut Laue-Langevin, Grenoble. From 1980 to 2003 he was Group Leader for Large Scale Structures at ISIS, Rutherford Appleton Laboratory, and since 1981 Group Leader for non-crystalline diffraction at the same institute. Since 2001 he is engaged as the Project Scientist for the target station 2 at ISIS. In 2000 he was appointed Visiting Professor at University of Bristol, UK, and since 2002 he has been Visiting Professor in Physical and Theoretical Chemistry at Oxford University, UK.

The prize has been presented on June 28<sup>th</sup> at a special session of the European Conference on Neutron Scattering in Lund, Sweden. Jeff is the fifth recipient of the Halg Prize, which is awarded every two years to a European scientist for outstanding, coherent work in neutron scattering with long-term impact on scientific and/or technical neutron scattering applications.

*ISIS Facility*



Jeff Penfold

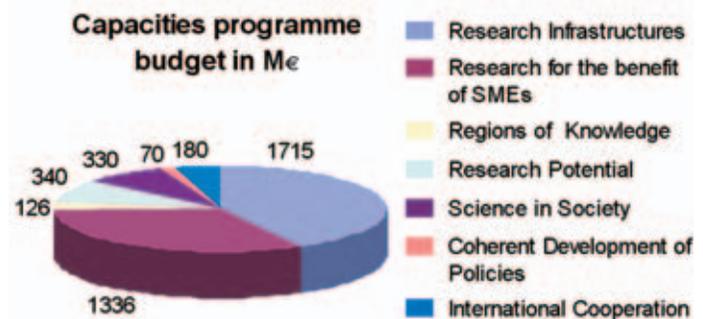
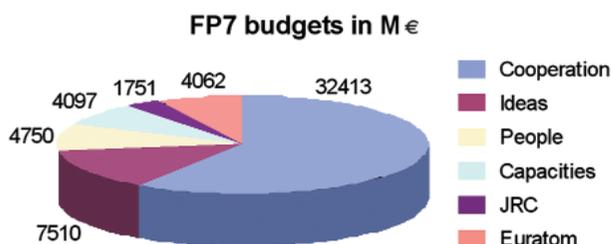


## A rough guide to Research Infrastructures in EU Framework Programme 7



The EU 7th Framework Programme (FP7) was launched at the end of 2006. FP7 will last 7 years, compared to 5 years for FP6. The total budget per year has almost doubled but it is spread over more new activities, for example the European Research Council and (potentially) the European Institute of Technology. Otherwise many of the familiar activities from earlier programmes remain, though the names and other details have changed.

als was focused on young scientists, with the second call being for more established researchers. While surprise has been expressed at the high degree of over-subscription, this was fairly predictable since EU funding has become increasingly directed since FP2 and this is the first significant move since towards the support of basic research. The 'People' activity includes the now familiar Marie Curie actions to support training and mobility.



The bulk of the budget is assigned to the 'Cooperation' activity, which supports research through Networks of Excellence, or networking through Coordination and Support Actions, directed at eleven thematic priorities: Health; Food, Agriculture, Fisheries and Biotechnology; Information and Communication Technologies; Nanoscience and Nanotechnologies; Energy; Environment; Transport; Socio-economic sciences and the Humanities; Space; Security. As in FP6, it can be expected that competition for this funding will be extremely hard.

The 'Ideas' activity is new to FP7 and is directed towards frontier research without any restrictions on topic. It is administered through the European Research Council which acts as an independent agency of the Commission. The first call for propos-

The two main parts of the 'Capacities' activity are support for research involving Small and Medium Enterprises (this contains some interesting new approaches) and for Research Infrastructures (RI), which is the main subject of this article. The budget for RI is roughly the same per year (indexed for inflation) as in FP6.

**Integrated Infrastructure Initiatives (I3):** the I3 concept, bringing together all projects related to a specific type of infrastructure, was started in FP6. These were initially difficult to set up but have generally been successful, so most would expect to continue in FP7 including the NMI3 project for neutron and muon facilities and IA-SFS for synchrotrons and free electron lasers. But there are also some new ideas. 'Bottom up' I3 projects will still be the majority, but there will also be 'top-down'

I3s targeted towards the thematic priorities of the Cooperation programme. An additional concept of 'horizontal' I3 has been suggested, which could bring together different types of RI to solve a common problem, though these might prove difficult to organise within the existing rules. Some of the 'thematic' I3 might be of this type.

The first call for I3 proposals will be in November 2007 with a deadline in February 2008, and first projects starting in autumn 2008. I3 funded in this call would be expected to last 4 years, and there would then be a call for 'top-up' proposals to cover the remaining 2 years of FP7.

concern mainly financial and organizational issues, with only a small amount of technical work. The aim is to achieve signed agreements to construct at least some of the roadmap facilities, and substantial progress in this direction for others. The Commission have also put in place up to 10 billion € of financing (loans) through joint funding of a risk sharing Finance Facility with the European Investment Bank. This could be useful for smoothing out the differences between actual construction costs, which tend to have a strong peak after the middle of the construction phase, and the contributions of individual countries where flat funding is more normal. However, there is a danger of RI entering their operation phase still with loans to be repaid. The typical operation cost of a large RI is the same per year as the average construction cost, so interest payment or loan repayment might mean that the RI either operates under optimal capacity or does not have a regular investment program, i.e. it starts deteriorating from the first day. So it remains to be seen if the EU approach will work.

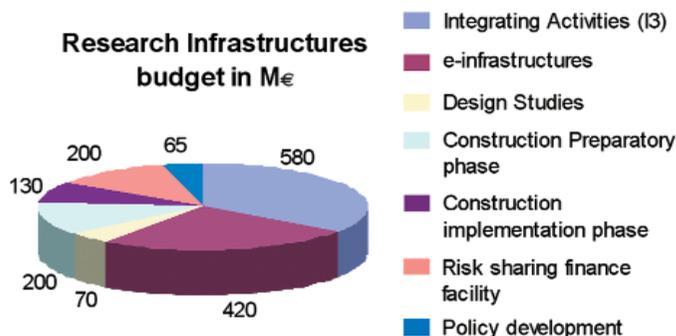
Construction of large RI typically has a major political component and involves agreements ('deals') that may involve non-scientific aspects. These are naturally outside the scope of the EU projects.

CNI projects that are most relevant for Notiziario readers are the ILL 20/20 upgrade, the ESRF upgrade, XFEL, the European Spallation Source (not to be confused with the European Social Survey, which is also ESS) and IRUVX-FEL (a consortium of FELs). The average project funding will be of order 4M €, the maximum being 7M €, and it might be expected that most of these projects would be funded at some level. The first call for proposals closed in May 2007 and these are currently being assessed. Projects might be expected to start towards the end of 2008.

**Robert McGreevy**

*ISIS, Science and Technology Facilities Council*

**Research Infrastructures budget in M€**



**Design Studies:** in FP6 Design Studies were often large projects with a significant technical content. In FP7 the overall budget is much smaller and more aimed at smaller organizational projects, such as 'virtual' distributed RI or Social Sciences and Humanities databases.

**Construction of New Infrastructures (CNI):** Support for CNI is completely different from that in FP6, and is the 'flagship' RI programme for FP7. In FP6 a small amount of financial support (up to 10 %) was given to a few new RI (or major upgrades) that were essentially already funded and under construction. In FP7 'Preparatory Phase' CNI proposals are restricted to the 35 projects on the roadmap produced by the European Strategic Forum on Research Infrastructures (ESFRI), plus projects from the CERN and ESA roadmaps, and will



# A marker-free 3D image registration for the ANCIENT CHARM project. Case study with neutron and X-ray tomography datasets

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University, Belgium

## Abstract

The aim of the ambitious ANCIENT CHARM project is the development of new imaging methods for a non-destructive analysis of archaeological objects using neutron beams: Neutron Resonant Capture Imaging, Prompt Gamma Activation Imaging and Neutron Diffraction Tomography. Together with the well-established Neutron Tomography, these methods will provide a comprehensive and complementary set of position dependent information for the examined objects.

The information they provide includes internal structure, strain, phase and elemental composition. One of the crucial tasks of the project is a detailed comparison of the 3-dimensional information provided by every single method. A precise alignment of the 3D data from each method is an essential prerequisite.

A common approach is to use external markers fixed on the examined object and use them to align the data. In this article we explore the practicability of an alternative method that would precisely align the images without the use of markers, based solely on the information contained in the images. A fully automated registration method used in medical applications (PET and MRI data registration) has been adapted for the characteristic data of the archaeological test objects. The applicability of this registration algorithm is demonstrated on a 3-dimensional registration of X-ray and Neutron Tomography datasets of ANCIENT CHARM test objects.

## Introduction

“Analysis by neutron resonant capture imaging and other emerging neutron techniques: new cultural heritage and archaeological research methods” – the ANCIENT CHARM Project [1] is a three years project funded by the EU to develop 3-dimensional (3D) imaging methods for analysis of archaeological objects by using the available neutron beams in Europe. The objects have been selected as a result of a broad scope archaeological research. An overview description of the full project is given by G.

Gorini in [2]. Neutrons have the ability to penetrate the whole volume of the object of interest and so they provide various kind of information about the complex object without the need of cutting it or destroying it by other means: the internal structure, the residual-strain (e. g. in metallic parts), phase and elemental composition. The yielded information should help to answer questions of archaeologists about production technology, trade routes, provenance etc.

The new methods based on neutron imaging aim to give this information sensitive to the position resulting in a dataset of 3D information.

## New neutron methods

“Neutron Resonant Capture Imaging” combined with “Neutron Resonance Transmission” (NRCI/NRT) is being developed from Neutron Resonance Capture Analysis [3] and uses a spectrum of epithermal neutrons, which exhibit specific resonances at different elements in the sample. The registered signal given by the energy of the resonance identifies the element and its concentration in the sample.

“Prompt Gamma Activation Imaging” combined with “cold Neutron Tomography” (PGAI/NT) is being developed as a special type of the well-established Prompt Gamma Activation Analysis (PGAA) [4] with a collimated cold neutron beam and a collimated detector [5].

By detecting gamma-rays emitted from a sample, chemical elements and their concentrations are determined for a given position. By scanning the sample, a spatial matrix for elements of interest is created. For good reasons, we plan to combine the PGAI method with NT. Having the same geometry as PGAI, neutron tomography provides coordinates of interesting positions within the sample volume and in this way it helps to target the PGAI only on the regions of interest, which speeds the measurement considerably. The neutron tomography also provides data for attenuation coefficients within the samples, which can be used for the correction of the PGAI results in the next step.

“Neutron Diffraction Tomography” (NDT) is a new method that has evolved from the standard Neutron Diffraction [6]. Neutron diffraction provides structural properties: in the archaeological research these can be directly related to the historical fabrication technique and the material treatment. At present the most advanced measurements of this kind provide 2D (radiography-type) maps of strains and phases of rather simple metal objects. NDT is being developed to give this information as a position sensitive 3D image.

#### *Registration of 3D datasets*

One of the important tasks of the ANCIENT CHARM project is a detailed comparison of the 3-dimensional information provided by every single method. Combining the new neutron-based methods with standard neutron techniques will give archaeologists a comprehensive tool for their research, providing a set of complementary position dependent information for the objects of interest. Since the objects are scanned with different devices, the 3D coordinate systems of all acquired data must be precisely aligned before any point-to-point comparison can be attempted.

Thus, the final step after the data acquisition and data reconstruction is inevitably a precise matching of the reconstructed 3D images to each other. This way we obtain the complete set of information from all imaging modalities for every single voxel (pixel in a 3-dimensional space) of the object. A common approach is to use external markers fixed on the examined object and use them to align the data. For this purpose, several markers are fixed on the object and remain there during acquisitions in all imaging devices. Assuming that the markers are visible in all the acquired data, the position of the markers can be detected and used to realign the data into a common coordinate system.

There are several difficulties with this approach in the context of our project. First, putting markers on the archaeological object can be a very delicate business — they must not destroy or otherwise impair the archaeological objects. Next, markers must remain fixed during the transport from one experimental site to the other and of course, during the measurement itself.

Finally, each imaging method prefers a different material for the markers: for example, a strongly neutron absorbing marker made of boron is excellent for NT, but cannot be seen by NRCI. Moreover, if it lies in the direct line with the scanned position for PGAI, it strongly attenuates the pencil neutron beam and the acquired data might be unreliable in case the correction for the attenuation is not known. Thus, finding a material for markers visible by all involved imaging methods can be very problematic. A possibility to use an automatic registration procedure without external markers would un-

doubtedly be of great advantage for the exploration of valuable archaeological objects.

The aim of this study is to demonstrate an automatic procedure for the registration of two 3D datasets with different information onto each other. It is important to mention, that this kind of registration uses only the information contained in the 3D images themselves and needs no external markers.

Since the new imaging methods are still in the phase of development, we have decided to use the already available Neutron Tomography (NT) data and X-ray Tomography (XT) data to show the possibilities of this registration method. The tomography data were acquired and reconstructed in the frame of the ANCIENT CHARM project.

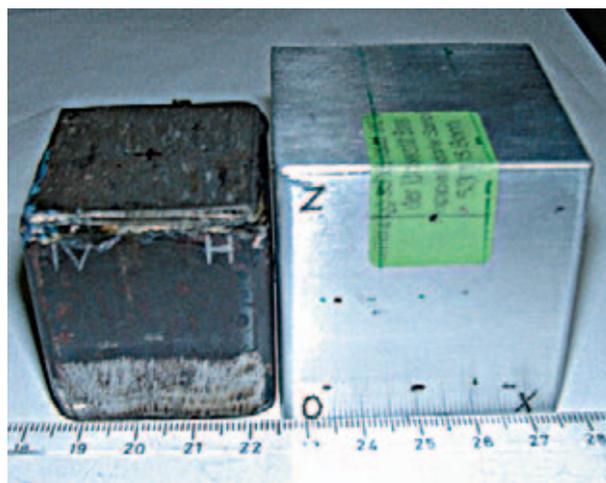


Figure 1. Picture of one iron (left) and one aluminum (right) blackbox.

#### **Experimental data**

##### *Blackboxes – test objects*

For testing during the first phase of development of the new imaging methods, metal cubes with unknown content – called the “blackboxes” – were prepared for the ANCIENT CHARM collaboration by the Hungarian National Museum in Budapest and by the University of Bonn. Care was taken to choose characteristic materials and elements which are representative to the composition of the real archaeological objects. On the other hand, not only suitable chemical elements but also those problematic for each of the new neutron imaging methods were included to allow their thorough testing.

It was decided to first perform the X-ray and neutron radiography of the blackboxes to acquire a 2D projection of their content. Then the X-ray and neutron tomography of selected boxes with more complicated content have been performed. Since the walls of the Hungarian



blackboxes are made of Iron (4 cm x 4 cm x 4 cm, 1.2 mm thick), they are named Fe 1 - Fe 9. The Bonn blackboxes are made of Aluminum (5 cm x 5 cm x 5 cm, 1 mm thick) and are named Al 1 - Al 11.

The iron blackboxes were closed by gluing the iron covers with an epoxy resin. This material contains lots of hydrogen and is therefore not transparent for neutrons, which influences the quality of the neutron tomography result at those parts. An example photo of one iron and one aluminum blackbox is presented in Figure 1.

<b>Date</b>	13 <sup>th</sup> - 14 <sup>th</sup> of September 2006
<b>Neutron beam</b>	thermal + cold neutron flux ~ 2.5 · 10 <sup>7</sup> n/cm <sup>2</sup> s
<b>L/D ratio</b>	800
<b>Tomography of blackboxes</b>	Fe 1, 2, 3, 4, 5, 6, 8 and 9 Al 2, 5, 7, 8, 9 and 10
<b>Dimensions of 1 blackbox</b>	~ 520 x 520 x 520 voxels (Al blackbox)
<b>Resolution (voxel size)</b>	~ 0.1 x 0.1 x 0.1 mm
<b>Number of projections</b>	400
<b>Irradiation time / projection</b>	7 s
<b>CCD camera</b>	16 bit, 2048 x 2048 pixels
<b>Data reconstruction software</b>	"All In One" Reconstruction tool, based on IDL [IDL] software

**Table 1.** Parameters of the Neutron Tomography of the blackboxes

#### Tomography method

The principle of the neutron as well as X-ray tomography is based on the reconstruction of a 3D image from a set of 2D projections of the measured sample. The tomography method was many times and in thorough detail described elsewhere and an overview to both mentioned methods was published by N. Kardjilov and F. G. Moreno in this Journal [7].

In short, a neutron or X-ray beam is transmitted through the examined object and a 2D image (projection) is registered for a given position by a position sensitive detector. Then, the sample is rotated around an axis perpendicular to the beam (usually up to 180° or 360° in 200 - 800 steps, depending on the beam and the tomography set-up characteristics).

From the set of 2D images, a 3D image of the explored sample can be reconstructed using the filtered back-projection (or other reconstruction algorithms). The resulting 3D image can be visualised and examined by various

software packages (e.g. VGStudio [8] or GEHC Microview [9]).

#### Neutron tomography

The neutron radiography and tomography with selected blackboxes were performed at the ANTARES Facility [10] at the research reactor FRM II in Garching near Munich [11]. The measurements by the ANTARES group were performed under the conditions and with the parameters presented in Table 1.

<b>Date</b>	1 <sup>st</sup> - 3 <sup>rd</sup> of August 2006
<b>X-ray cone beam + 3 mm thick Cu filter</b>	average energy ~ 80keV; maximum energy ~ 160keV
<b>L/D Ratio</b>	> 10000
<b>Tomography of blackboxes</b>	Fe 6, 8 and 9 Al 8 and 10
<b>Dimensions of 1 blackbox</b>	~ 600 x 600 x 600 voxels (Al blackbox)
<b>Resolution (voxel size)</b>	0.07 x 0.07 x 0.07 mm
<b>Number of projections</b>	500
<b>Irradiation time / projection</b>	10 s
<b>CCD Camera/Image Intensifier</b>	12 bit , 1024 x 1280 pixels
<b>Data reconstruction software</b>	OCTOPUS [XRAYLAB]

**Table 2.** Parameters of the X-ray Tomography of the blackboxes

#### X-ray tomography

The X-ray radiography and tomography with selected blackboxes were performed at the Centre for X-ray Tomography at the Ghent University (UGCT) in cooperation with the group of Prof. Dr. Luc Van Hoorebeke [13]. Parameters presented in Table 2 summarize the conditions of the measurements.

#### Method

Automatic matching of datasets (usually called "registration" in the field of image processing) from different imaging modalities based solely on the information contained in the images has already become an essential tool in the field of medical imaging, for example, for individual anatomical localization of functional processes in human brain using PET (positron emission tomography) and MR (magnetic resonance) or CT (computed tomography) images [15]. In this paper, we make a first at-

tempt to apply this method to the registration of images from X-ray tomography and neutron tomography. New software was developed for this task based on MMM (“Multi-Modality Matching”), an already well established tool for registration of medical images from the Max-Planck-Institute for Neurological Research in Cologne, Germany [16, 17]. The software was further adapted to the specific characteristics of the X-ray and neutron tomography data in the ANCIENT CHARM project. The described method does not use any external markers fixed to the objects of interest. Instead, it uses the complete information content in the two images to estimate and optimize their alignment.

#### Goal

Given two 3D images of the same object acquired with different imaging systems, the goal of the registration procedure is to find a transformation that transforms one of the images so that it is perfectly aligned with the second image. One of the images is static during the registration – we call it the *reference* image. The other one, called the *moving* image, is subjected to various transformations that aim at bringing it into alignment with the reference image.

#### Transformation

Since the images represent the same physical object, we could theoretically just search for a rigid-body transformation, i.e. a rotation and a translation, both in three dimensions. However, only approximate values for the resolution of the X-ray and NT images were known to us a priori. To accommodate for the likely differences in the voxel sizes of the two images we have extended the searched transformation by isotropic scaling in all dimensions.

#### Similarity measure

The registration algorithm basically consists of two main parts. First, we define a “cost function” - a *similarity measure* - that evaluates the alignment of the reference and moving image for a given transformation. It is a function of the transformation parameters and in an ideal case has a global maximum for the transformation that perfectly aligns the two images. Next, we let a suitable optimization method search for a transformation that maximizes this similarity measure. A similarity measure can only be based on the voxel values in the two images since there is no other information available to the algorithm (like positions of markers). If the two images originated from the same imaging modality then we could estimate their “similarity” using the mean of differences between values of all corresponding voxels and try to minimize these differences. In our case, such simple measure would not work because the

images come from different modalities where the same physical objects typically exhibits substantially different intensity values in each imaging modality. This is where *mutual information* comes into play as a convenient measure. In the last years, mutual information gained a lot of attention in the field of medical imaging where it has been proven to be an excellent measure of similarity for medical images, e.g. PET and MR [18] or MR and CT [19]. Mutual information makes no assumption about the type of input images, which makes it a very general criterion, suitable for images from different modalities. It does not directly compare voxel values but rather compares *probability distributions of values* in the images; it measures the statistical dependency or information redundancy between the images, which is assumed to be maximal when the images are geometrically aligned.

Let us denote the reference image as  $R$ , the moving image as  $M$  and let us use  $M(t)$  for the moving image transformed by the currently tested transformation  $t$ . The mutual information of  $R$  and  $M(t)$  is then computed using the normalized marginal intensity histograms ( $H_R$  and  $H_{M(t)}$ ) and the joint intensity histogram ( $H_{R,M(t)}$ ) of the two 3D images as:

$$MI_{R,M(t)} = \sum_{i \in R, j \in M(t)} H_{R,M(t)} \log \frac{H_{R,M(t)}(i, j)}{H_R(i) \cdot H_{M(t)}(j)}$$

where  $i$  and  $j$  are indices of corresponding voxels in  $R$  and  $M(t)$ . The histograms  $H_R$ ,  $H_M$  and  $H_{R,M}$  approximate, respectively, the marginal and joint probability distributions of intensity values in both images.

#### Optimization

Maximization of mutual information can be accomplished by an iterative optimization algorithm that iteratively searches the transformation space for a maximum of the function (7-dimensional in our case: 3 dimensions for translation, 3 for rotation and 1 for isotropic scaling). For this task we use the *downhill simplex* minimization algorithm by Nelder and Mead [20] that already proved good performance in our previous work [16].

#### Multi-resolution

We use a hierarchical multi-resolution approach to improve the speed and robustness of the registration [21]. First, a hierarchy of images with decreasing size is computed for both input images by binning 8 neighbouring voxels into one, reducing the size in each dimension by two. Optimization is then performed first at a low resolution by using the lowest resolution images. The result of this coarse registration is then used as an initial esti-

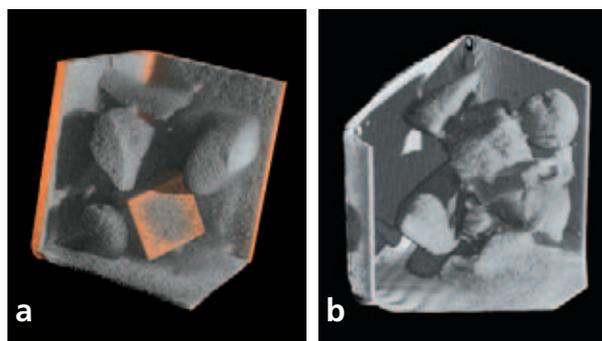
mate at the next higher resolution. In this work we use a 3-level hierarchy for all evaluated data.

#### Downsampling

Input images have dimensions in the order of  $500^3$  voxels which presents a prohibitively large amount of data to process in a reasonable time and the memory capacity of common PCs (~1GB).

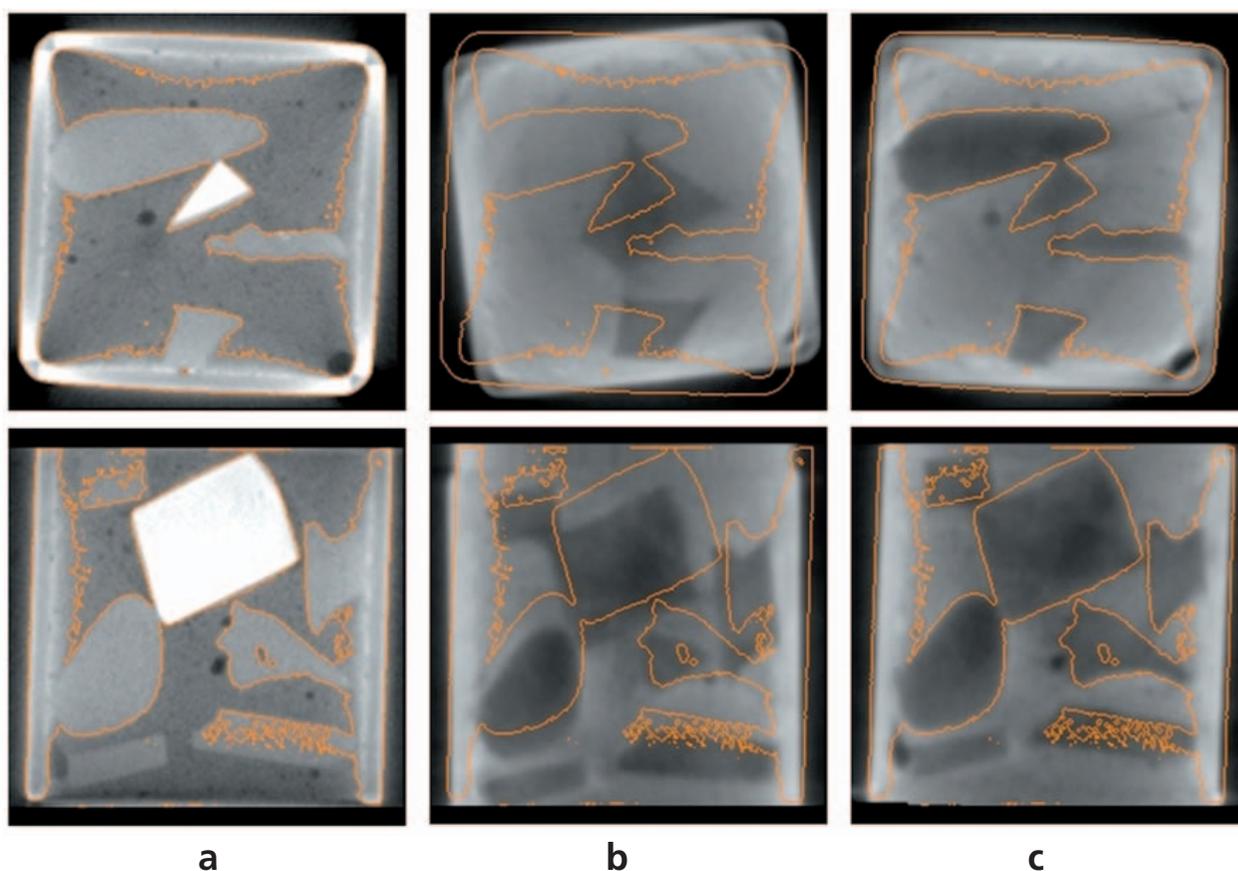
Therefore, the images were cropped to exclude background with no usable information and then downsampled by binning 4 to a dimension of  $160 \times 160 \times 144$  voxels (X-ray), resp.  $128 \times 128 \times 128$  (NT, Al samples) and  $144 \times 144 \times 128$  voxels (NT, Fe samples) with estimated resolution of about 0.3 mm.

After the registration, the resulting transformation can be applied to the original image to retain the high spatial resolution. It has been demonstrated previously in studies with images from Computed Tomography, Magnetic Resonance and Positron Emission Tomography that a mutual information based registration is able to achieve subvoxel accuracy [21, 17].

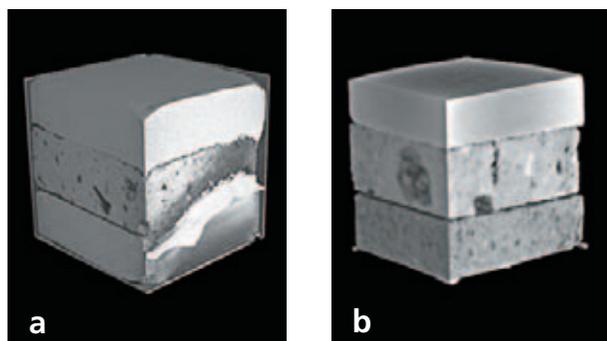


**Figure 2.** 3D rendered X-ray tomography (a) and Neutron Tomography (b) data of the blackbox Fe9.

It means that even the downsampled images could provide a sufficient accuracy for our purposes - all the more that the resolution of the other imaging methods in the ANCIENT CHARM project is by orders of magnitude worse than that of X-ray and Neutron Tomography.



**Figure 3.** X-ray tomography slice of the blackbox Fe9 (a) and the corresponding neutron tomography slice in the initial position (b) and after the automatic registration (c). The upper row shows corresponding horizontal slices of the blackbox (looking “from above”); the bottom row shows vertical slices (looking “from the side”).



**Figure 4.** 3D rendered X-ray Tomography (a) and Neutron Tomography (b) data of the blackbox Al8.

#### *Initial pre-alignment*

The described registration procedure is in its nature *local* - meaning that it can only find the correct global maximum when the initial estimation lies within a certain capture range.

By experience, the capture range is in the order of about  $\pm 20^\circ$  for rotation and about  $\pm 30$  mm for translation. More global optimization methods like simulated annealing are not feasible for this task due to the overwhelming computational complexity.

The initial rotational misalignment of Fe samples exceeded these limits:  $\sim 90^\circ$  by Fe6 and  $\sim 45^\circ$  by Fe 9. Therefore the registration of these samples was started by providing it with an initial rotational estimate of  $90^\circ$  and  $45^\circ$  respectively.

#### **Results and discussion**

We have tested the registration procedure with 4 pairs of reconstructed images from neutron and X-ray tomography. In all cases the procedure succeeded in providing visually precise results. The computation of each pair of images took approx. 3 minutes on a common notebook (Intel Pentium M, 1.7 GHz).

In the following, we present the results on an example of the blackboxes Fe 9 and Al 8.

#### *Blackbox Fe9*

Figure 2 shows a 3D visualization of the reconstructed X-ray data (a) and the corresponding neutron data (b) of the blackbox Fe 9.

Figure 3 shows a horizontal and a vertical slice of the blackbox Fe 9 from the X-ray tomography (a) and from the corresponding Neutron Tomography in the initial position (b) and in the final position after registration (c). Iso-contours from the X-ray slice have been overlaid over the NT-slices to allow for an easier visual validation of the final alignment in comparison with the initial state. The color tables have been chosen so that areas ab-

sorbing less X-rays (resp. neutrons) are darker than the more absorbing areas.

After the volumes have been co-registered, it is possible to perform a point-to-point comparison of voxel values in both volumes.

Neither X-ray nor Neutron Tomography allow to deduce materials or the elementary composition of the scanned object solely from the image content but they often allow to distinguish and separate areas of differing materials and their shapes. However, there might be cases where two materials absorb (for example) X-rays in a similar way which means that they are indistinguishable in an X-ray image only.

Here a comparison with the corresponding NT image can often help providing that these two materials absorb neutrons differently. For example, the NT slices (Fig. 3c) shows several areas in the blackbox that absorb neutrons in a similar way (dark areas), suggesting that these areas might be of the same material.

After a comparison with the corresponding areas in the X-ray image (Fig. 3a) we can see that in reality these objects are of at least two different types (white shining object in the middle, "gray" objects around).

To determine precisely the elemental composition of these objects, PGAI analysis will later be performed directly at their coordinates, provided by the NT image.

#### *Blackbox Al8*

Figure 4 shows a 3D volume visualization of the X-ray Tomography (a) and the corresponding Neutron Tomography (b) of the blackbox Al 8. One can visually distinguish three separate layers of materials. Figure 5 shows slices of the blackbox Al 8 from the X-ray Tomography (a) and from the corresponding NT data in the initial position (b) and the final position after the registration (c). The upper row shows horizontal slices and the bottom row vertical slices through the 3D data set. As in the case of Fe 9, a suitable iso-contour of the X-ray slice helps visualize the initial misalignment of the NT image and its correct alignment after the registration.

This example demonstrates in various ways the value added from the registration and the subsequent point-to-point comparison.

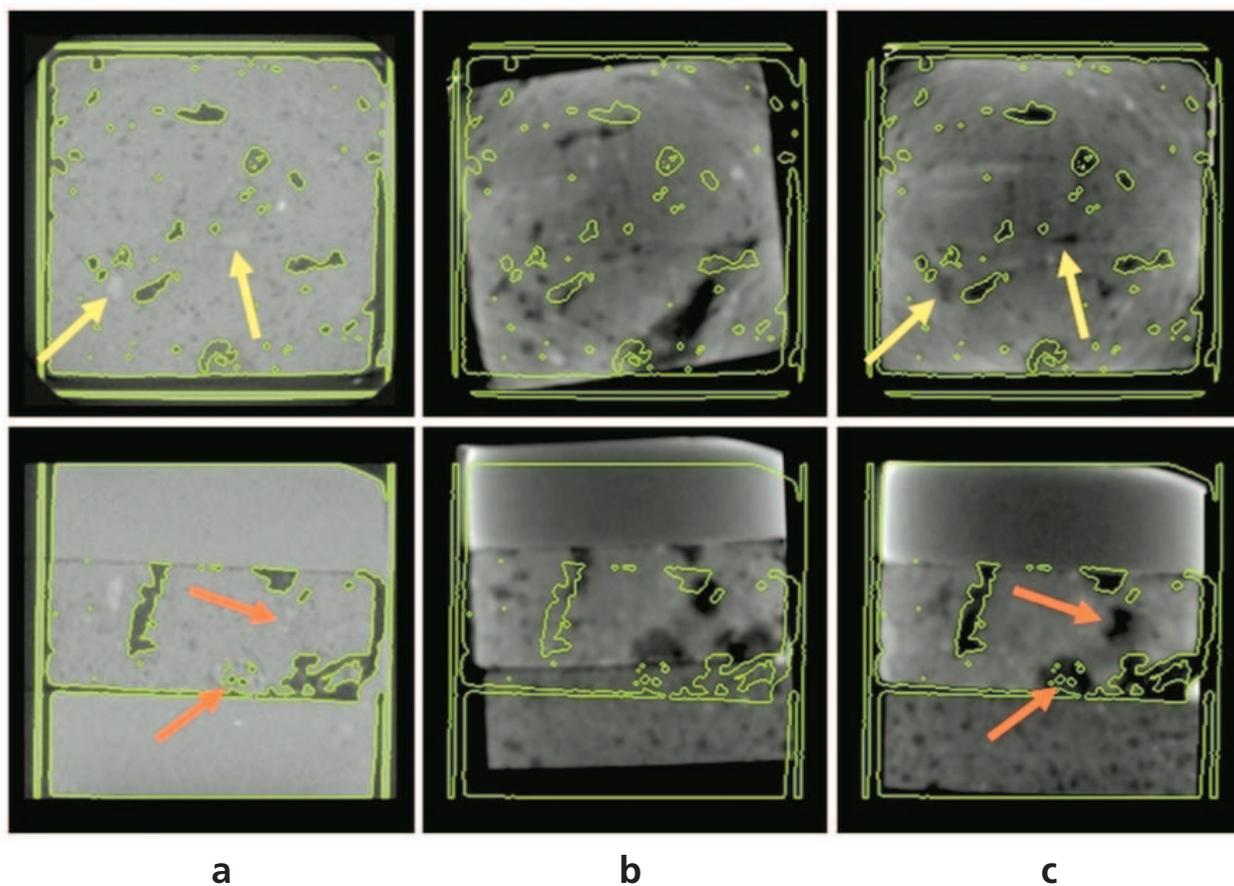
Looking at the vertical slice of the X-ray Tomography image (Fig. 5a), the upper and bottom layer seem to be made of the same homogeneous material. A subsequent comparison with the corresponding slice of the NT image reveals that in reality the two layers are made of different materials. Moreover, the bottom layer is not homogeneous at all, as the X-ray view would suggest, but rather granular. Further we can find areas in the blackbox that absorb more X-rays but fewer neutrons than the surrounding areas (Fig. 5, yellow arrows). More importantly, with the help of the NT slice we can separate areas of differing materials, which are not clearly separable

in the X-ray tomography slice (Fig. 5, red arrows). All image analysis was performed using VINCI [22] (Figures 3 and 5) and VGStudio [8] (Figures 2 and 4). During the evaluation of the registration procedure on the blackboxes we have identified several rules that need to be followed in the future studies in order to increase precision and reduce the complexity of the task. The objects should be placed in the scanning devices in such way that the principal orientation of the output images roughly corresponds (e.g. if the scanned object is “standing” in the first scanner then it should not be “lying” in the other). If this is not possible then at least the orientation of all examined samples should be kept similar in one scanner so that the principal orientation needs to be estimated only once for one sample and then reused for the remaining samples. The knowledge of the exact resolution (or voxel size) of the images would allow using just the rigid-body transformation, resulting in a reduction of computational time and increased accuracy.

The used transformation model assumes that the scanned object in the reconstructed image reflects the physical object geometrically exact (except for scaling). To fulfill this requirement, *geometrical corrections* must typically be applied during the reconstruction process. It is implicitly assumed that the scanned objects are *rigid*. If a part of the object were movable then it cannot be guaranteed that the object does not change its geometrical structure between two scans (e.g. a box partially filled with sand). In such case, an unambiguous registration is impossible.

### Conclusion and outlook

In this article, we have demonstrated the feasibility of an automated registration of X-ray and Neutron Tomography images without the use of external markers. The method makes use of the complete information contained in both images and could present a convenient way of aligning 3D images of archaeological samples for



**Figure 5.** X-ray Tomography of the blackbox A18 (a) and the corresponding Neutron Tomography data sets in the initial position (b) and after the automatic registration (c). The upper row shows corresponding horizontal slices of the blackbox (looking “from above”); the bottom row shows vertical slices (looking “from the side”).

the ANCIENT CHARM project. A possibility to automatically align images without the necessity to use markers would result in a substantial simplification of the experimental analysis of the samples.

In the next steps, we intend to extend the registration method to the other imaging methods in the project. First, the practicability of an automated registration of PGAI and NT images should be examined. The low spatial resolution of PGAI presents a considerable challenge here. Next, the applicability to the remaining imaging methods should be explored.

The first PGAI data is expected to become available in a few months as a result of the planned experiments at the PGAA facility in Budapest [23]. Before these images become available, simulation of low-resolution images from the existing NT data is planned in order to adapt the method for this type of data. For this task, a selected part of an NT image - corresponding to a possible region of interest for PGAI - will be extracted and the voxel values will be modified by a suitable function to simulate different absorption properties. The resolution will be reduced down to the expected dimension of PGAI images (~10 × 10 × 10 voxels) and the applicability of the registration method will be evaluated.

### Acknowledgements

Financial support of the Ancient Charm project by the European Community "New and Emerging Science and Technology" Contract No 15311 is acknowledged.

Our thanks belong to the Max-Planck Institute for neurological Research in Cologne, Germany, for providing the visualization software VINCI.

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# Dynamic interplay between biomolecules and glassy environments – New insights from neutron scattering

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Proteins perform a plethora of essential functions in living systems. They serve as enzymatic catalysts, are used as transport molecules (hemoglobin transports oxygen) and storage molecules (iron is stored in the liver as a complex with the protein ferritin); they are used in movement (proteins are the major component of muscles); they are needed for mechanical support (skin and bone contain collagen—a fibrous protein); they mediate cell responses (rhodopsin is a protein in the eye which is used for vision); antibody proteins are needed for immune protection; control of growth and cell differentiation uses proteins (hormones).

These are just a few examples of the many, many tasks carried out by proteins. The key to appreciating how different proteins function in a number of different ways lies in an understanding of both their structure and dynamics. In fact the early view of proteins as relatively rigid structures has been gradually replaced by a dynamic model by which the internal motions play an essential role in their function [1].

The most mentioned evidence of that comes from myoglobin, the first protein whose structure has been solved ever since 1958 by X-ray crystallography and that gives muscles their red colour.

As far as we know, in Mb's role as an oxygen-repository protein, O<sub>2</sub> enters the protein, stays some time in a cavity called Xe1, then binds at the iron of the heme group, which is the red active centre where the O<sub>2</sub> is stored [2].

This is an apparently quite simple picture, but there is a not negligible problem: the structure of Mb shows no permanent channel that leads from the outside to either Xe1 or the heme pocket or from Xe1 to the heme pocket. Thus, structural fluctuations are necessary for function [3]. The internal dynamics of proteins is a real puzzle, as internal motions occur over a wide time window, ranging from the picosecond window of rapid librations and vibrations, up to the microsecond and millisecond slower motions of protein subunits and subdomains [4].

Such an outstanding dynamical variety results from the structural complexity of these biomolecules.

In fact, proteins may assume a huge number of different conformations, also called conformational substates [5], which are points of the 3*N*-dimensional protein potential energy hypersurface, where *N* is the number of atoms of protein and hydration shell. Within this picture, structur-

al fluctuations are depicted as jumps between conformational substates.

Fast relaxations in the picosecond time scale at ambient temperature seem to be crucial for biological activity [1,6], as they guarantee a prompt response of side chains to biological events such as, for instance, the approaching of a substrate molecule through the milieu toward the protein surface.

The complex scenario of protein internal motions can appear, if possible, even more tangled if one considers that a massive body of experimental [1,7] and theoretical [8] evidences show that there is an intimate and not yet completely understood dynamical coupling between the protein and the molecular environment surrounding its surface. With this respect, incoherent neutron scattering (INS) technique, which makes use of the large incoherent cross section of hydrogen nuclei (much larger than the cross section of other elements), provides invaluable information on all internal molecular motions on the picosecond time scale.

As hydrogen atoms are abundantly and almost uniformly distributed through the protein, this method allows one probing the average protein dynamics.

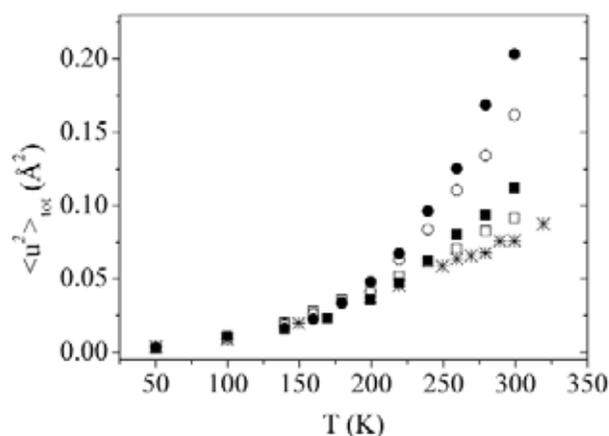
In addition, if the molecular environment around the protein is deuterated, its contribution to the measured signal can be neglected and one can directly investigate the dynamical behaviour of proteins as affected by different environments.

The INS signal from the investigated samples is extremely rich of detailed information on the protein dynamics. In a very concise scheme the elastic, inelastic and quasi-elastic intensities allow us to quantify respectively the amplitude of atomic thermal fluctuations, their vibrational density of states and the characteristic times, geometry and populations of diffusive motions.

In this paper we will show only some results obtained through the inspection of the INS elastic intensity measured at the backscattering spectrometer IN13 (ILL, Grenoble), however there is plenty of data also on the vibrational and relaxational behaviour of proteins as affected by the environment [9-12].

The first step in this kind of study is to quantify the amplitude of protein structural fluctuations when the environment surrounding the protein surface consists of water molecules, which is the usual physiological milieu.

Lysozyme, a very well known model enzyme, is the system we chose. The elastic neutron scattering intensity from samples of lysozyme hydrated with heavy water is described in terms of the double-well model by which the protein hydrogen atoms, that are supposed to be dynamically equivalent, may jump between two distinct sites of different free energy [9]. Within this approximation the total hydrogen mean square displacements



**Figure 1.** Hydrogen total mean square displacements as a function of temperature for lysozyme hydrated with  $D_2O$  samples at  $0h$ , cross;  $0.1h$ , open squares;  $0.2h$ , full squares;  $0.3h$ , open circles;  $0.4h$ , full circles.

$\langle u^2 \rangle_{tot}$  are quite easily evaluated, and decomposed in two components coming from, respectively, vibrations at the bottom of the well  $\langle u^2 \rangle_{vib}$  and jumps between the two sites  $\langle u^2 \rangle_{2w}$  [13].

In Fig. 1 we show  $\langle u^2 \rangle_{tot}$  of lysozyme at different hydration degree  $h$  ( $h = \text{g water/g dry lysozyme}$ ).

The  $\langle u^2 \rangle_{tot}$  of dry lysozyme exhibit a quite regular trend in the whole investigated temperature range, while in the case of hydrated samples the  $\langle u^2 \rangle_{tot}$  display a significant anharmonic deviation from the dry behaviour at a certain temperature  $T_d$ .

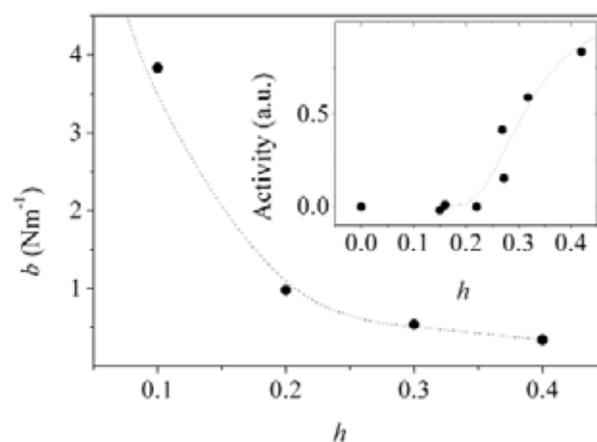
This phenomenon, which is called protein dynamical transition in analogy with the glass transition, is due to the onset of large-amplitude anharmonic motions that play a key role on increasing the intrinsic protein flexibility to achieve functional configurations [9].

As the dynamical transition is not visible in the dry system and  $T_d$  shifts to lower values when the water content increases, one can infer that the water environment around the surface of the biomolecule acts as a plasticizer by activating the protein thermal fluctuations.

In fact, the solvent could alter the free energy of the protein to create an effective potential energy surface, or it could have more direct dynamic effects as a result of col-

lisions between solvent molecules and the protein atoms. What is the biological consequence of this hydration-induced dynamical activation? An interesting suggestion to this key question comes from Fig. 2, where it is reported the protein rigidity  $b$  vs.  $h$ .

The protein rigidity quantifies the linear response of protein fluctuations and is proportional to the inverse of the configurational mean square displacements [6, 13].



**Figure 2.** Protein rigidity  $b$ . Inset: enzymatic activity of lysozyme [7]. Lines are guide to the eye.

Quite strikingly  $b$  steeply decreases in the hydration range from  $0h$  to  $0.2h$  and then attains an almost constant value.

Directly from the inset of Fig. 2 we can observe that the enzyme is biologically inactive [7] at low hydration levels where the macromolecular rigidity is large, while the enzymatic activity starts just above the threshold value  $0.2h$  where the protein rigidity becomes quite low.

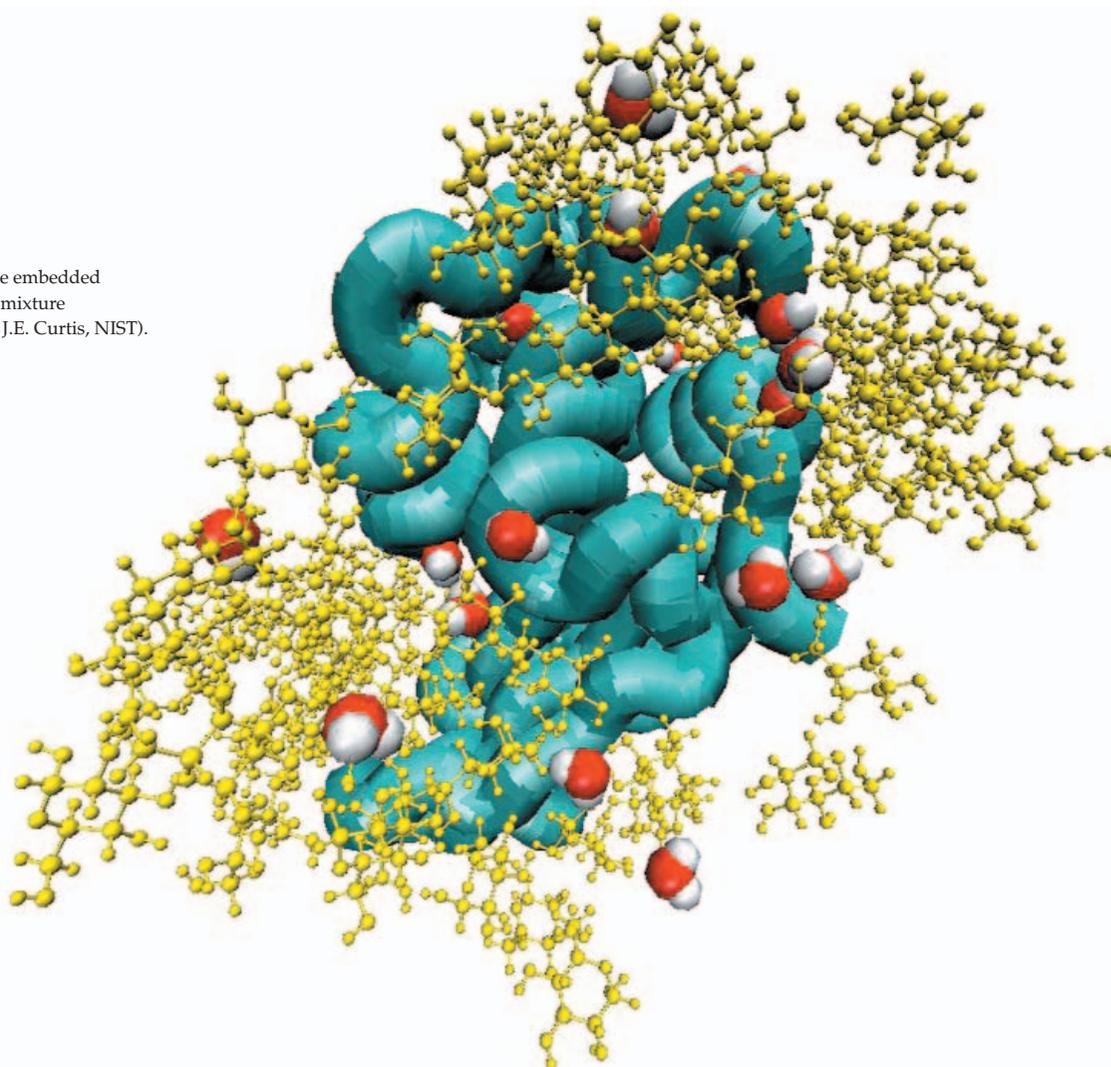
This evidence suggests that the increased flexibility induced by hydration is related to biological activity. In other words enzymes need flexibility to properly work. One may now wonder how the protein internal dynamics evolves when the molecular wrapping changes, always providing indeed that the biomolecule retains its native structure.

To answer this question we performed a detailed investigation on the molecular mobility of lysozyme embedded in glycerol or glucose, at different water contents, as a function of temperature.

In Fig. 3 we show how the investigated sample should appear at an atomic level. Glycerol and glucose belong to the family of polyols and are part of the so-called stabilizers or bioprotectant substances. These substances make glassy matrices which show an outstanding ability



**Figure 3.**  
Lysozyme molecule embedded  
in a glucose-water mixture  
(by courtesy of Dr. J.E. Curtis, NIST).



in preserving structure and functionality of biomolecules, which has been often largely exploited in food, pharmaceutical and biotechnology sciences to optimize lyophilization and long-term storage of biological samples [14].

Glassy matrices of simple carbohydrate are of capital importance in protecting biological molecules and cells against stresses induced by potentially detrimental freezing, drying and heating processes.

Despite this importance, the nanoscopic mechanisms through which such matrices act as stabilizers are still unclear. Bioprotectant glassy matrices were proven not only to induce a noticeable retardation of protein molecular movements [15], but also to reduce their extent [16]. The degree of fragility of the glassy matrices where the protein is embedded has been suggested to be a key parameter to quantify their bioprotectant aptitude [17].

In Fig. 4 and Fig. 5 we show the total mean square displacements of lysozyme when the molecular environment is respectively a glycerol-water and a glucose-water glassy matrix. These figures, taken together with Fig. 1, confirm that the amplitude of  $\langle u^2 \rangle_{tot}$ , i.e. the internal mo-

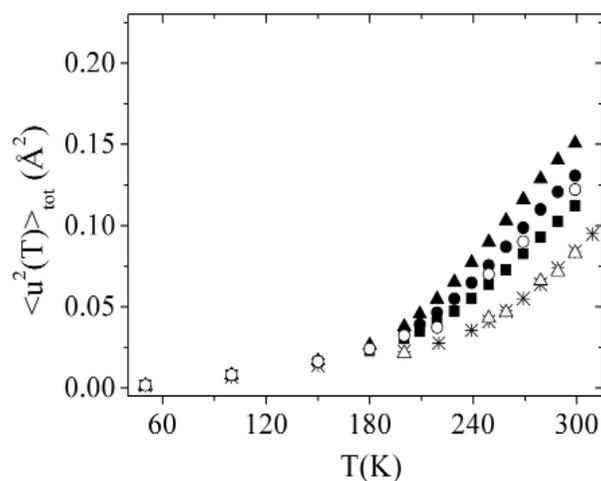
bility of lysozyme, progressively grows when the water content increases, even in presence of glycerol and glucose. Actually, when lysozyme is embedded in polyol-water glassy matrices, the plasticizing action of water is somehow counterbalanced by the stabilizing character of the polyol molecular network.

As a consequence, the internal mobility of lysozyme is more and more reduced when we pass from pure water (Fig. 1), to glycerol-water (Fig. 4) and then to glucose-water (Fig. 5) molecular environments.

We may speculate that this constraining action of bioprotectant substances is one of the key ingredients to preserve life in extreme and adverse conditions.

Another striking feature is that the dynamical transition temperature  $T_d$  of lysozyme in all the environments displays a remarkable decrease when hydration increases, as it can be clearly seen in Fig. 6. In this figure we report as well the estimated critical temperatures  $T_c$  of the glycerol-water and glucose-water environments [18,19], i.e. the temperature predicted by the idealized Mode Coupling Theory below which relaxations in glass-forming systems are arrested.

Quite interestingly there is a nice superposition of  $T_d$  and  $T_c$ , thus suggesting that the molecular network around the protein, despite its high viscosity, is nevertheless able to support the protein structural relaxations, but only when the network itself may sustain density relaxations ( $T_d > T_c$ ). In other words, the environment would drive the protein dynamics that can be modulated by properly choosing the plasticizing or stabilizing degree of the enclosing matrix.



**Figure 4.** Hydrogen total mean square displacements as a function of temperature for lysozyme in glycerol-water mixtures at the hydration degree 0h, star; 0.1h, open triangles; 0.2h, closed squares; 0.35h, open circles; 0.42h, closed circles; 0.83h, closed triangles.

This result is crucial in view of the practical consequences it may have on the biological and pharmaceutical fields [20,21].

We notice that similar findings have been reported as well for other biomolecules very different from lysozyme, such as DNA [22], thus suggesting that the conditioning action of the environment on biomolecules is a quite general hallmark.

Despite the evidences that support this strong conditioning action, the precise mechanisms by which internal motions of biomolecules are affected by the surrounding molecular network remain a mystery.

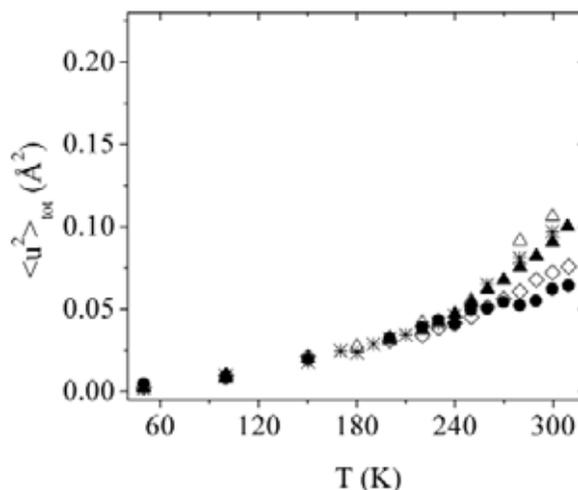
Very little is known on the relationship between the protein dynamics and a key macroscopic solvent property such as the viscosity, that plays a pivotal role in affecting functional, i.e. reaction rates, features of biomolecules [7]. We recently proved the existence of a simple relationship between the picosecond-timescale thermal fluctuations of lysozyme and the viscosity of the glassy matrix where it is embedded [23].

In Fig. 7 we represent the logarithm of the bulk viscosity of water, glycerol-water and glucose-water mixtures vs.

the inverse of  $\langle u^2 \rangle_{2w}$  (the configurational mean square displacements, see above) of lysozyme in the corresponding matrices.

Quite surprisingly we observe that a linear relationship exists in the whole investigated temperature range in all the systems we studied.

It should be remarked that the linear relationship between the logarithm of the viscosity vs. the inverse of the relaxational mean square displacements is satisfied also



**Figure 5.** Hydrogen total mean square displacements as a function of temperature for the samples at for lysozyme in glucose-water mixtures at the hydration degree 0h, full circles; 0.15h, empty rhomb; 0.4h, full triangles; 0.6h, stars and 0.7h, empty triangles.

in some glass formers, such as selenium, poly-butadiene, glycerol and sugar-water mixtures [23]. Anyway, in these materials it is the bulk viscosity and the fast dynamics of the same system that are correlated.

What's the meaning of the relationship we found in a complicated system such as protein in glassy environments? The existence of a linear dependence tells us that protein relaxational mean square displacements show a temperature critical behaviour that is tightly linked with that of bulk solvent viscosity, with crucial changes just in proximity of the glass transition.

Indeed, the internal dynamics of proteins is strongly determined by the ability of the surface protein side-chains to move. If we describe the picosecond timescale motions of a particle (a solvent molecule or a protein side-chain exposed to solvent) in terms of Brownian diffusion, then the Stokes-Einstein law leads to an inverse relationship between the relevant MSD and bulk viscosity  $\langle u^2 \rangle \sim \eta^{-1}$ , for a fixed experimental temporal window.

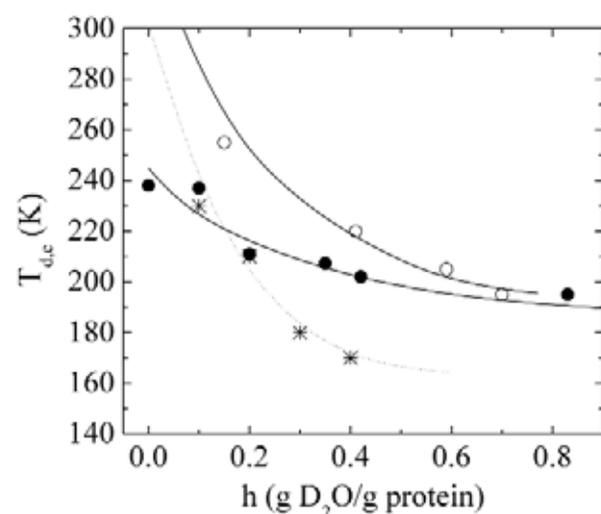
Actually, from our results it follows that  $\langle u^2 \rangle \sim (\log \eta)^{-1}$ . This weaker dependence by the solvent viscosity could be due to the fact that it is the microviscosity sensed by



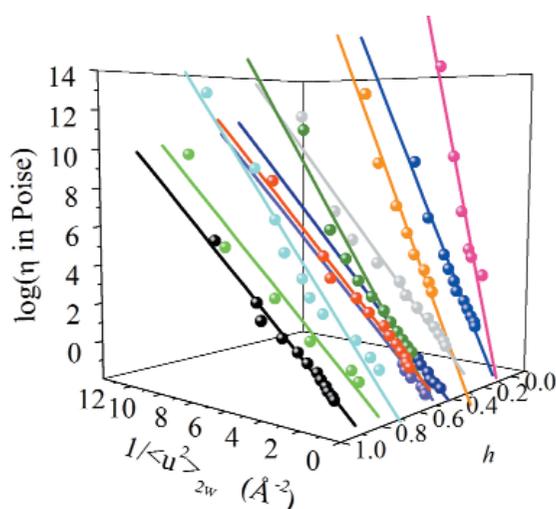
the particle, possibly different from bulk viscosity, which is related to the corresponding dynamics.

Moreover, in the case of protein side-chains such a microviscosity is also strongly affected by preferential hydration effects, by which cosolvents like glucose and glycerol are preferentially excluded from the protein domain, thus giving rise to a surface viscosity with a much weaker increase than bulk viscosity.

Besides the quite entangled physical relationship between the protein dynamics and solvent bulk viscosity,



**Figure 6.** Dynamical transition temperatures of  $D_2O$ -hydrated lysozyme powders (stars), lysozyme embedded in glycerol-water mixtures (closed circles) and lysozyme embedded in glucose-water mixtures (empty circles). In the latter two samples the continuous line is an estimate of the solvent  $T_c$  [18,19].



**Figure 7.** Linear relationship between the logarithm of the solvent bulk viscosity and the inverse of  $\langle u^2 \rangle_{2w}$  for the investigated systems. For details see Ref. [23].

the evidence that both solvent and protein MSD are related to bulk solvent viscosity by the same functional dependence indicates that the protein local dynamics is closely coupled with that of the host.

This finding supports the hypothesis that it is just the molecular network immediately around the protein surface to drive protein fast fluctuations.

#### Acknowledgements

I would like to acknowledge all the collaborators who participated actively in this research line, in particular Dr. E. Cornicchi, Dr. A. De Francesco, Dr. M. Marconi and Prof. G. Onori.

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## HiFi – A new Muon Spectrometer for ISIS

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This year, the ISIS Pulsed Muon Facility celebrates its 20<sup>th</sup> birthday. Since first muons were produced in March 1987, over 800 separate muon experiments have been performed at the facility, resulting in about the same number of publications. The ISIS Muon Facility is unique in Europe, providing complementary facilities to the only other European muon source, the continuous facility at PSI in Switzerland. It is used by over sixty research groups from eighteen countries, often in combination with neutron and other techniques which provide complementary information. It is appropriate that, as the ISIS Muon Facility celebrates 20 years of successful muon experiments, it is also looking to develop its capabilities by provision of a new muon spectrometer to further extend its range of science applications.



Figure 1. The ISIS muon beamlines

### The Muon Technique and Applications

The muon method involves following the behaviour of 100% spin-polarised muons once they have been implanted into a sample. Muons live on average for 2.2  $\mu$ s, after which they decay to produce a positron and two neutrinos. Detection of the decay positrons provides information on the direction of the muons' spins at time of decay – allowing the behaviour of the muon polarisation

in the sample to be followed as a function of time after implantation. This in turn tells us about the muons' local magnetic environment and behaviour. The technique is known as  $\mu$ SR, which stands for muon spin rotation, relaxation and resonance (for an introductory review, see S.J. Blundell, *Contemporary Physics*, 40 (1999) 175).

Muon studies include a wide variety of magnetic systems, with muons being used to explore magnetic transitions, ordering and spin dynamics, and with the technique being sensitive to very small magnetic fields (down to  $10^{-5}$  T) and appropriate for investigations where the magnetism is short-range, random, or dilute. In superconducting systems, muons can be used to explore the flux-line lattice generated when a field is applied to a type-II material, and can be used to determine fundamental superconducting parameters. Muons are also used for investigation of ion mobility in ionic conductors, charge carrier motion in conducting polymers and molecular dynamics. Muons have a mass of one ninth that of the proton, and in some systems it is useful to think of the muon as a light proton isotope. Observation of muon behaviour then enables models to be built up of analogous hydrogen behaviour, and this is particularly useful in semiconducting systems, as well as in proton conductors and hydrogen storage materials.

### A New Muon Spectrometer

The existing ISIS muon instruments allow applied fields of up to 0.45 T to be generated at the sample position. This is insufficient for many studies, and a new instrument being constructed at present – called HiFi – seeks to provide an order of magnitude increase in this, generating up to 5 T. This new instrument is being funded by the CCLRC Facility Development Board through a grant to the ISIS Muon Group and Prof. Stephen Blundell of Oxford University.

From a neutron point of view 5 T may sound like only a moderate applied field. However, muon experiments deal with charged particles – both the incoming muon beam and the outgoing decay positrons are profoundly affected by applied fields in the Tesla region. For example, the radius of curvature of a typical positron emitted in a muon experiment in 5 T is only 2 cm. This means that designing a detector array for the decay positrons that will work in these fields is a significant challenge. Muon experiments also require a very homogeneous



field at the sample position – for some measurements, as good as 20 ppm. This, together with the requirement for a very low stray field (2 G at only a few metres from the magnet, so as not to interfere with the other muon instruments and beamlines) means that the design of the main applied field magnet is also not a simple exercise. However, at time of writing, a suitable magnet system is being designed and built by Cryogenic Ltd, and prototype detectors are also being constructed prior to manufacture of the full detector array.



Figure 2. The ISIS muon beamlines and spectrometers

### New Science with ISIS Muons

So what new scientific opportunities will HiFi provide? An order of magnitude increase in applied field will produce a step-change in facility capabilities for many systems. Benefits will be found in four primary areas:

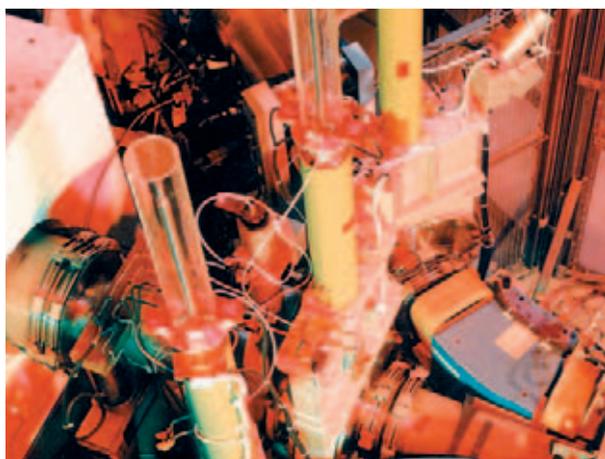


Figure 3. Part of the ISIS muon beamlines where an electrostatic kicker divides the beam, feeding it to three different muon spectrometers

### Correlations, fluctuations, diffusion and dynamics

For investigations of magnetic and superconducting materials (including organic systems), charge carrier motion in conducting polymers and ionic materials, molecular dynamics and modelling the electrical activity of hydrogen in semiconductors, it is the ability to characterise atomic-level fluctuations of the magnetic environment that is important. Here, the field dependence of the muon spin relaxation rate is essentially a one-to-one map of the power spectrum of the fluctuations and, in the simplest cases, the average correlation time can be measured directly. Extending the applied field range up to 5 T will give an order of magnitude increase in capability in this area.

### Spectroscopy and molecular dynamics

Higher fields are needed for observation of resonances between muon energy levels and those of the muons' surroundings. Such 'level crossing resonances' are known in a large variety of systems including organic donors and acceptors, liquid crystals and biologically-relevant molecules, and can be used, for example, to study co-surfactant partitioning within surfactant lamella phases. However, most lie in a band of fields between 1 T – 3 T which is presently inaccessible at ISIS. Their observation will allow the extraction of detailed spectroscopic data and molecular dynamics information and will be widely applicable to a variety of areas of Physics, Chemistry and Biochemistry.

### State preparation

Higher fields will also enable specific regions of a magnetic phase diagram to be accessed. Here, field is a controlling parameter, breaking symmetries, lifting degeneracies, closing spin gaps or inducing new phases. Re-entrant phase diagrams, frustrated magnetic systems, field-induced orbital or quadrupole ordering, and multiferroics (coexistent ferro-electricity and ferromagnetism) are all topical examples requiring fields of several Tesla.

### Pulsed environment development

One of the specialities of a pulsed source such as ISIS is the ability to use external sample (or muon) stimulation timed to the arrival of the muon pulses. Analysis of some systems, for example proton and ionic conductors or superconductors, can benefit from radio-frequency stimulation of both sample atom nuclei and implanted muons. However, a field range up to around 1.5 T is required to make most nuclei of interest available for this method.

As can be seen, studies of a wide variety of systems will benefit from the new instrument and the order of magnitude increase in applied field that it will provide. HiFi will be ready for operation by Autumn 2008, and we are looking forward to new science from ISIS Muons.

# The EMBL Integrated Facility for Structural Biology at PETRA III

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**Figure 1.** Artists impression of the new PETRA III hall. The approximate locations of the SAXS and MX beamlines are indicated in red; sample preparation facilities will be located in the area marked in green; data evaluation will take place in the parts of the PETRA III hall shown in blue.

Starting in July 2007, the PETRA storage ring at DESY in Hamburg will be converted into a dedicated low-emittance source for synchrotron radiation.

The new storage ring, PETRA III, will have a circumference of 2.304 km and will be run at a particle-energy of 6 GeV. The emittance will be 1 nrad, a value so far unrivaled by storage rings run at comparable particle energies. On one octant of the new storage ring, an experimental hall will be constructed (Figure 1). In this hall, a total of nine straight sections will be available for placing insertion devices.

Four of the straight sections will contain single undulators, while the remaining five straight sections will be equipped with pairs of canted undulators resulting in a total of 14 independent beams of synchrotron radiation.

EMBL Hamburg is in charge of building three beamlines on PETRA III, two for macromolecular crystallography (MX) and one for small angle X-ray scattering on biological samples (SAXS).

The beamlines will be embedded in an integrated facility for structural biology uniting sample preparation and characterization, data collection using synchrotron radiation, and data processing and structure determination. The construction of the three beamlines has been funded by the German Ministry for education and research (BMBF) with a total of 8.8 million EURO for a period of four years.

These funds are complemented by contributions from EMBL. In the operational phase, access to the beamlines will be based on scientific criteria only.



While the basic parameters of the beamlines have been described in the Technical Design Report on the PETRA III project ([http://petra3.desy.de/general/tdrindex\\_eng.html](http://petra3.desy.de/general/tdrindex_eng.html)), we are now refining and finalizing both the scientific case and the design of the beamlines. Towards this, two beamline design workshops were held (SAXS: October 31 to November 1, 2006, MX: April 23 to April 25, 2007). These workshops brought together experts of the fields and provided guidance and a number of new ideas.

For small angle X-ray scattering, the very low emittance of PETRA III will allow to produce a high-intensity beam that at the same time has a small divergence and a small focal size. While the small divergence will improve the measurable signal, the small focal size can be exploited to drastically reduce the amount of sample required for individual measurements.

Given that the experiments will also be accelerated by the high intensities, novel systems for moving small amounts of liquids in and out of the beam quickly and automatically are currently being developed.

For achieving very high X-ray fluxes, the SAXS beamline will have a large bandpass (several percent) monochromator; the projected intensities will be sufficiently high to push the duration of a measurement into the milli-second time regime enabling time-resolved measurements of structural transitions accompanying biochemical reactions. The two beamlines for macromolecular crystallography will fulfill different roles.

While one will be geared towards collecting diffraction data from  $\mu\text{m}$ -sized crystals, the other will provide extended wavelength-tunability, in particular towards long wavelengths.

Given the importance of accurate measurement of weak anomalous signals from macromolecular crystals both for phasing and the unambiguous interpretation of electron densities, we plan to implement a wide wavelength range from 0.35 to 3.0 Å (36 to 4 keV) covering most of the absorption edges of interest in biology.

To reduce the technical complications in building a single beamline with a very large wavelength range, the accessible energies will be divided between the two MX beamlines. The low emittance of PETRA III will enable us to produce very small (10-50  $\mu\text{m}$ ) low-divergence (0.1-0.2 mrad) beams at the sample position allowing to perform diffraction experiments on small crystals, or multiple experiments on single crystals to circumvent the effects of radiation damage.

By using focusing optics on one of the beamlines, we will be able to reduce the beam size to 1-5  $\mu\text{m}$  enabling experiments on micro-crystals.

To improve sample-handling in crystallographic applications, we are continuing the development of a robotic sample changer already available at EMBL Hamburg. Our goal is to construct an instrument that will be able

to not only pick up cryogenic sample mounts following the present standard but will also allow massive *in situ* screening (hundreds of samples) exploiting novel microfluidic technologies in crystal growth and crystal handling. Both SAXS and MX beamlines will be supported by upstream-facilities for sample preparation.

In particular, the existing high-throughput crystallization facility at EMBL Hamburg will be moved to a new location very close to the beamlines allowing a direct coupling of crystallization and diffraction-based screening. Other biophysical methods for sample characterization such as isothermal calorimetry, mass-spectrometry, analytical ultra-centrifugation, dynamic light scattering etc. will be available in the direct vicinity of the beamlines (Figure 1).

Building on the traditional strength of EMBL Hamburg in developing new methods for structure determination from both SAXS and MX data, we will provide a state-of-the-art computing environment together with powerful software for immediate interpretation of the collected data. We are very excited about building the new facilities and plan to offer first access to the experimental stations in 2010.

More information about the EMBL@PETRA-III project is available at: [www.embl-hamburg.de/services/petra3](http://www.embl-hamburg.de/services/petra3)

#### INFORMATION ON:

Conference Announcements and Advertising for Europe and US, rates and inserts can be found at:

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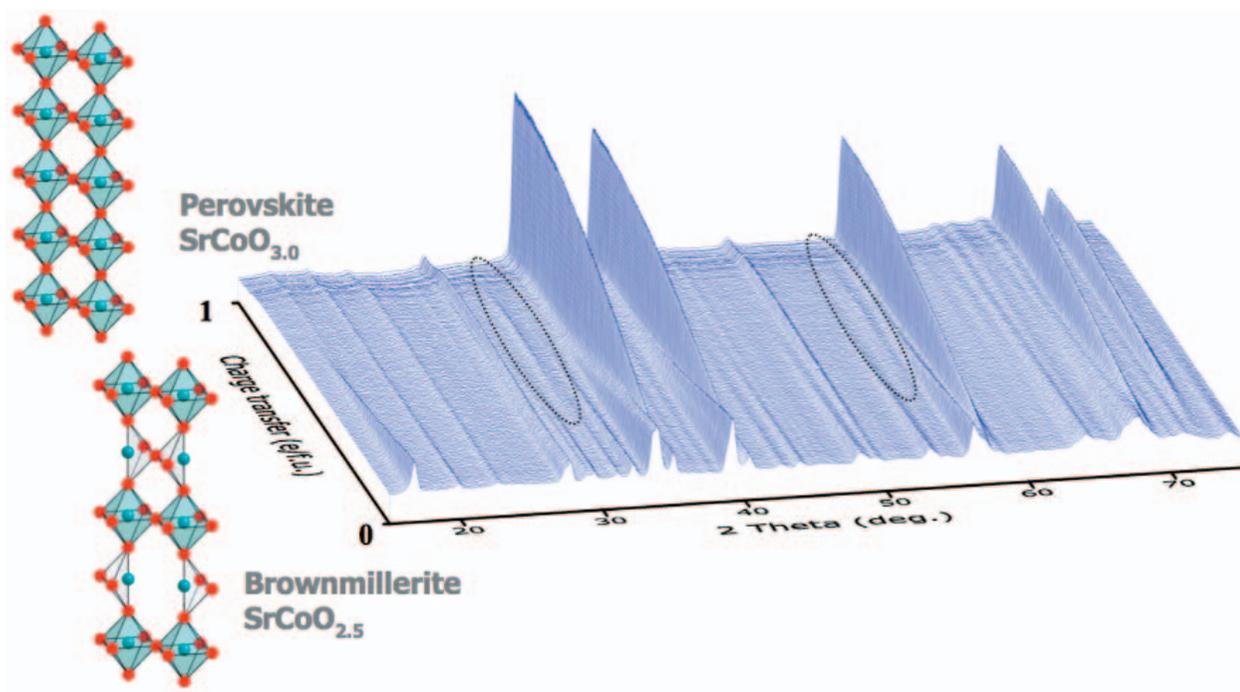
## News from ILL

# Engineering Oxygen Transport

The requirements for new and clean energy sources, such as solid-oxide fuel cells (SOFC), have stimulated considerable research activities in the last decade on solid oxygen ion conductors operating at moderate temperatures.

In particular, three-dimensional oxygen ordering and evidence of the formation of  $O^-$  species during the intercalation were observed for the first time. Ion conduction in solids is normally described in terms of a thermally activated hopping process

calated reversibly at ambient temperature using 'gentle' electrochemical methods or other soft chemistry synthesis. At present two structure types are known to show such behaviour: the first one is the  $La_2MO_{4+x}$  ( $M=Cu, Ni, Co$ ) system with  $K_2NiF_4$



**Figure 1.** Right: neutron powder diffraction patterns obtained *in situ* on D20 during the electrochemical oxidation of  $SrCoO_{2.5}$  vs. charge transfer. The diffractogram of the brownmillerite  $SrCoO_{2.5}$  is represented at the bottom, whereas the one of the perovskite  $SrCoO_{3.00}$  is at the top. The outlined ellipsoids indicate the positions of the superstructure reflection corresponding to  $SrCoO_{2.82\pm 0.07}$ ; left: schematical transformation of the brownmillerite to the perovskite structure.

SOFCs would offer enormous ecological benefit, provided that suitable materials with high oxygen permeability can be developed to operate at moderate temperatures.

In order to better understand low-temperature oxygen diffusion mechanisms, the oxygen intercalation into  $SrCoO_{2.5}$  was investigated by *in situ* neutron diffraction and X-ray absorption spectroscopy at ambient temperature.

with ions jumping from occupied into vacant sites. Oxygen ions are doubly charged and have a rather large radius of about 1.4 Å.

The energy barriers to overcome during jumping are therefore high, requiring elevated temperatures for diffusion to set in, even in structures possessing rather large vacancy sites. In this context, it is rather surprising that there exist compounds into which oxygen ions can be inter-

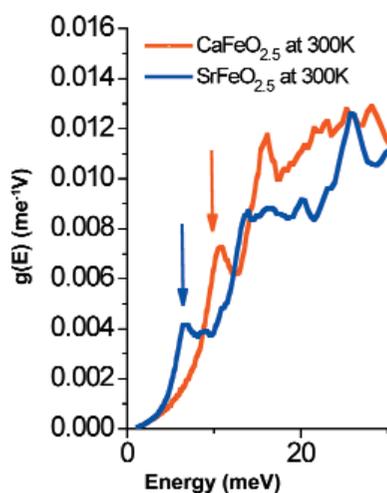
calated reversibly at ambient temperature using 'gentle' electrochemical methods or other soft chemistry synthesis. At present two structure types are known to show such behaviour: the first one is the  $La_2MO_{4+x}$  ( $M=Cu, Ni, Co$ ) system with  $K_2NiF_4$

calated reversibly at ambient temperature using 'gentle' electrochemical methods or other soft chemistry synthesis. At present two structure types are known to show such behaviour: the first one is the  $La_2MO_{4+x}$  ( $M=Cu, Ni, Co$ ) system with  $K_2NiF_4$



oxygen octahedra. Extracting rows of oxygen ions (see figure 1, left) in such a way as to create channels of parallel vacancies would lead to the Brownmillerite structure type.

In the case of  $\text{SrCoO}_{2.5}$  these channels can be electrochemically re-oxidised at room temperature, thus coming back to the ordered  $\text{SrCoO}_3$  mother compound. In a first step to understand what makes  $\text{SrCoO}_{2.5}$  so special, the structural and magnetic



**Figure 2:** Density-of-states of  $\text{SrFeO}_{2.5}$  (blue) and  $\text{CaFeO}_{2.5}$  (red) obtained on IN6 at 300 K. The low energy modes were found for  $\text{SrFeO}_{2.5}$  at 7 meV and for  $\text{CaFeO}_{2.5}$  at 12 meV and are indicated by arrows.

changes were monitored during electrochemical oxidation. Electrochemistry is in this context a very useful tool, as it allows controlling directly the charge transfer, i.e. the oxygen stoichiometry and also the reaction kinetics.

*In situ* neutron diffraction, using a specially adapted electrochemical cell on the instrument D20, turned out to be the method of choice for this experiment.

Neutrons are simply more suitable than X-rays when it comes to determine the oxygen ordering and stoichiometry. In the first stage of the

oxidation the original  $\text{SrCoO}_{2.5}$  phase coexists with  $\text{SrCoO}_{2.75}$ , a cubic deficient perovskite structure (see figure 1, right). Further oxygen uptake does, however, not proceed continuously to the cubic  $\text{SrCoO}_3$  but yields in an additional intermediate phase,  $\text{SrCoO}_{2.82\pm 0.07}$  establishing 3D oxygen ordering [4].

The latter phase is isostructural to the homologous  $\text{SrFeO}_{2.875}$  phase with tetragonal symmetry, which is related to the perovskite unit cell by  $a = b \approx 2a\sqrt{2}$  and  $c \approx 2a$ . This is the first time that oxygen ordering has been detected during controlled intercalation at ambient temperature, i.e. far away from thermodynamic equilibrium.

This implies the important message that solid oxides can indeed relax towards new ordered structures already at ambient temperature.

The general assumption that good ionic conduction is always accompanied by structural disorder and that, reciprocally, structural disorder always favours ionic conduction, is thus a questionable concept.

Complementary studies by X-ray absorption spectroscopy carried out *in situ* on the beamline BM29 at the ESRF have evidenced the formation of  $\text{O}^-$  species during the intercalation reaction [4]. This indicates that the oxygen sub-band is energetically higher than the cobalt band and further underlines the importance of possible valence fluctuations to support oxygen ion conduction following  $\text{Co}^{4+} + \text{O}^{2-} \leftrightarrow \hat{1} \text{Co}^{3+} + \text{O}^-$  which has in this sense more than only academic impact.

The fact that  $\text{CaFeO}_{2.5}$  is unable to intercalate oxygen by electrochemical oxidation while  $\text{SrFeO}_{2.5}$  does, demonstrates that the simple existence of vacancy channels solely is unable to explain the conduction mechanism. It becomes evident that also the lattice motion must play a decisive role.

Inelastic neutron scattering (IN6) shows significant differences in the

density-of-states for the homologous compounds  $\text{SrFeO}_{2.5}$  and  $\text{CaFeO}_{2.5}$  (figure 2). Using these neutron data to validate numerical simulations, we obtain first evidence for a delicate interplay of structure and lattice dynamics.

In particular, very small changes in the cell parameters may trigger instabilities, i.e. soft-going modes leading to dynamic disorder. According to our numerical simulations, the conduction channels in  $\text{SrFeO}_{2.5}$ , even at room temperature, are anything but rigid tubes. The tetrahedra, constituting the walls of these channels, display a very complex motion in a way to promote dynamically transport of oxygen ions along the channels.

The equivalent motions do not exist in  $\text{CaFeO}_{2.5}$  thus offering an explanation why oxygen cannot be intercalated at ambient conditions.

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## ILL next standard proposal round: call for proposals

The deadline for proposal submission is

**Tuesday, 18 September 2007, midnight (European time)**

Proposal submission is **only possible electronically**.

Electronic Proposal Submission (EPS) is possible via our Visitors Club (<http://club.ill.fr/cv/>), once you have logged in with your personal username and password.

The detailed guide-lines for the submission of a proposal at the ILL can be found on the ILL web site: [www.ill.fr](http://www.ill.fr), Users & Science, User Information, Proposal Submission, Standard Submission.

The web system will be operational from **1 July 2007**, and will be closed on **18 September at midnight** (European time).

**Please allow sufficient time for any unforeseen computing hitches.**

You will receive full support from the Visitors Club team. If you have any difficulties at all, please contact our web-support ([club@ill.fr](mailto:club@ill.fr)).

For any further queries, please contact the Scientific Co-ordination Office: [sco@ill.fr](mailto:sco@ill.fr)

### Scheduling period

Those proposals accepted at the next round will be scheduled during the last two cycles in 2007.

### Reactor Cycles for 2007:

Cycle n° 146 (071)	from <b>20/02/2007</b>	to <b>11/04/2007</b>
Cycle n° 147 (072)	from <b>24/04/2007</b>	to <b>13/06/2007</b>
Cycle n° 148 (073)	from <b>28/08/2007</b>	to <b>17/10/2007</b>
Cycle n° 149 (074)	from <b>30/10/2007</b>	to <b>19/12/2007</b>

Start-ups and shut downs are planned at 8:30 am.



## News from Scientific Coordination Office

### EASY access

A new application has been put in place on the ILL Visitors Club, for granting quick and easy access to ILL beamtime. The Easy Access System (EASY) will grant diffraction beamtime to scientists from ILL member countries, who need a rapid structural characterisation of samples and data analysis. Access will be open all year long, and it will not be necessary to go through the ILL standard proposal round

and consequent peer review system. The system – already operational in other neutron scattering facilities such as ISIS – will offer two neutron days per cycle, on four instruments (D1A, D2B, VIVALDI and ORIENT-EXPRESS) to perform very short experiments (a maximum of 4h per cycle) at room temperature. The users will not be invited to the ILL, but will send their samples to one of two designated ILL scientists (one for

powder and one for single-crystal experiments), who will be responsible for the measurements, sample radiological control, and shipping back the sample.

More information is available at [www.ill.fr/dif/easy/](http://www.ill.fr/dif/easy/)

**G. Cicognani**  
*Communication and  
Scientific Support  
Institut Laue-Langevin*



## New ILL PhD programme

In the light of the essential role played by PhD students in the ILL's scientific life the Institute has decided to raise to 25 the total number of PhD grants awarded to students interested in preparing their thesis at the world's leading facility in neutron science.

The new ILL PhD programme aims at promoting four scientific fields: Nanoscience, Soft Condensed Matter, Biology and Magnetism, but some high quality proposals from other fields will also be considered.

The award of a grant depends essentially on the quality of the proposals.

### Who can apply?

Academics belonging to a university or an affiliated institution in one of the ILL's Associate or Scientific Partner countries, with responsibility for supervising PhD students. He/she must already have identified a student motivated to carry out the research project. The student may be of any nationality.

### When to apply?

There are two calls for proposals each year. The next deadlines are 15 April and 15 September 2007.

More information is displayed on the 'Jobs and careers' page on [www.ill.fr](http://www.ill.fr).



## Engineering Users Warm to SALSA

*SALSA, the ILL instrument for engineering and materials science came on line at the end of 2005 and the three reactor cycles for users of 2006 have shown its excellent performance.*

*A surprisingly wide range of experiments have included stress determination in superconducting wires at a temperature of 4 K, investigation of welded steel joints used in the construction industry, understanding fatigue in nickel single crystal tensile specimens and near-surface stress determination in a 120 kg bearing used in the shaft of a wind-powered electricity generator.*

In 2006 SALSA has evolved into the world-leading instrument for residual stress determination in engineering components using neutrons. During the last year significant strides forward have been made. Behind the scenes, SALSA has also benefited from the refurbished neutron guide H22 which now provides a 'raw' flux gain of a factor of  $\approx 3$ . When the instrument was commissioned the beam defining optics were incident and detector slits. These provide a high-flux solution to many bulk measurement experiments. From the last cycle of 2006 radial-focussing oscillating collimators were available as an option.

These allow better definition of small measuring volumes with high peak-to-background ratios whilst also suppressing spurious effects arising when measurements are made through surfaces [1].

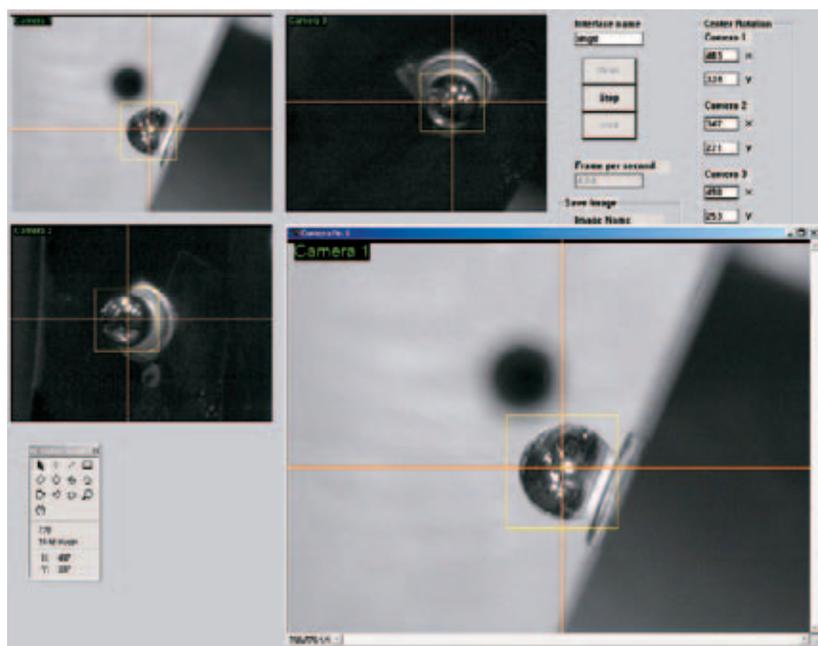
Users are therefore able to perform detailed peak-shape analysis even near surfaces. One of the principal challenges when measuring strain in complex samples is the location of the measuring volume with respect to the sample. To assist sample alignment we have developed a 3D-camera assisted metrological system (Mario Urbina).

A set of three cameras are focused on the measurement location, providing a spatial resolution of  $\approx 20 \mu\text{m}$ .

Intelligent pattern-matching routines allow the simple determination of the centre-of-rotation for the instrument, a very important tool for instrument alignment.

The same technique is applied to locate reference marks on the sample.

system; installation of a portable laser scanner at the instrument to digitise the sample surface and determine the absolute position of the sample relative to the translation stage; providing a more flexible range of beam definition optics (slits/collimators/supports).



**Figure 1.** Alignment of a turbine section on SALSA. The screen shot shows steel balls of 4 mm diameter, used for alignment, automatically detected by the pattern matching routine. The crosses mark the gauge volume position.

Measurements of distances, angles and positions can be performed on screen. Figure 1 shows a screen shot during the alignment of a complex shaped aircraft engine turbine ring section.

The specimen had first been digitised using the co-ordinate measuring machine (CMM) in the FaME38 laboratory.

Continued developments are planned for the 2007 including: further improvements to the camera

### Experimental highlights

Ultrasonic Impact treatment (UIT) is a novel mechanical surface treatment, capable of introducing a layer of deep compressive residual stress into engineering materials. The technique is particularly suited to the protection of known failure locations at welded joints in the aerospace industry.

UIT has been shown to be highly effective in increasing fatigue strength and damage tolerance. The UIT



treatment involves the deformation of the surface of the treated material by impacts of a free needle indenter vibrating at  $\approx 27$  kHz.

These impacts create severe plastic deformation of the near surface region (depth 1-3 mm typically for steel) and an ultrasonic stress wave that propagates deep into the material (10-12 mm).

As part of a project to investigate the effectiveness of this treatment, the full thickness residual stress distrib-

central axis roller bearing.

The sheer scale of wind turbines combined with the near-constant running the often remote location, sometimes offshore, poses some difficult engineering questions.

The central bearing of the drive axis is a key component which experiences complex stress states both in the bulk and on the surfaces in contact with the shaft on one side and the rollers on the other.

Conventional surface treatments to

## References

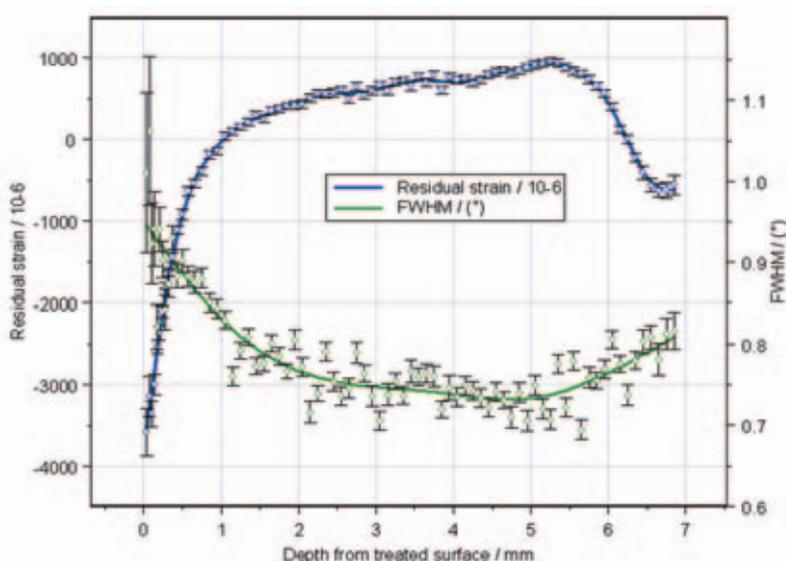
1. ILL annual report, 2000, p. 86

Further Information:

*First impressions of SALSA: The new engineering instrument at ILL.* D.J. Hughes, G. Bruno, T. Pirling and P.J. Withers. Neutron News 17, 3 (2006), 28-32

**T. Pirling and D.J. Hughes**

ILL



**Figure 2.** Longitudinal residual strain and peak width evolution in an UIT treated steel sample. Data analysis is in progress, but it can already be seen from the peak width that the plastically deformed region is well correlated with the region of compressive stresses. This analysis is only possible with the radial focussing collimator set-up.

ution was measured on SALSA (Alex Evans).

The results show a 1 mm deep region of beneficial compressive residual strain produced by the process (figure 2), accompanied by plastic deformation as can be seen from peak broadening.

With the current drive to lower emission energy sources, increasing focus is falling upon electricity generation by wind power. A recent study (Matthew Peel) using SALSA attempted to measure the residual stress in the wall of a wind turbine

impose compressive surface stresses have lead to unexpected failures, probably due to the occurrence of balancing tensile stresses in other locations. An ongoing project in collaboration with Swedish company SKF intends to fully characterise the residual stresses in a complete bearing of 60 cm diameter and 120 kg weight (figure 3).

The measurements required flexible sample positioning, high spatial resolution and substantial penetration for which the hexapod and the beam optics on SALSA are very effective.



**Figure 3.** Wind turbine and bearing mounted on the SALSA hexapod. The roller bed is positioned vertical by tilting the hexapod.



## News from ISIS

# Extra Terrestrial Research at ISIS

When voters cast their ballot in Schaerbeek in Brussels in May 2003 they expected their vote to count, but what they did not expect was extra terrestrial invaders to disrupt proceedings by casting an additional 4096 votes. This is not an absurd plot from a science fiction story, but scientific fact - but how can this be true? The answer lies in their use of electronic voting machines for this election. Despite some extensive testing the machines were, in fact, vulnerable to an unforeseen but growing problem that is now being investigated at ISIS; the disruption of the micro-electronic systems by cosmic rays. It is not just voting machine electronics that are vulnerable to cosmic rays either - virtually all the integrated electronics that have found their way our lives can be affected by these extra terrestrial invaders and documented cases show that many electronic systems which includes the latest sophisticated supercomputers have fallen foul of their effects<sup>1</sup>.

The menace that lies at the heart of this phenomenon is the neutron. Neutrons are generated by cosmic rays interacting with the Earth's upper atmosphere in a process that is somewhat akin to a planet-sized spallation neutron source<sup>2</sup>. The number of neutrons generated is far too small to have a serious effect on human health and can be thought of as a gentle neutron 'rain' at the Earth's surface. The problem with the neutron 'rain' or flux is that it interacts with the silicon, boron, indium and other materials commonly found in integrated circuits to disrupt them. The very high energy and highly penetrating nature of the neutrons involved means that they are able to get to the very heart of the electronic devices and take part in nuclear re-

actions that generate unwanted electrical discharge. This unwanted extra charge can change the basic operation of the electronics by changing the stored binary information in a memory chip or by altering the logical function of another. These effects, known as 'soft errors', are often hard to track down as they are not permanent; they do not tend to make the device fail completely or burn out but cause unpredictable random errors - a true and dangerous 'ghost' in the machine.

Whilst many mainstream electronic manufacturers are now beginning to wake up to the potential threat that cosmic-ray neutrons can cause to the reliability of their devices, these neutrons have been of great concern to the aerospace and avionics industry for many years<sup>3</sup>. At typical commercial flight altitudes of 30,000 - 35,000 feet the intensity of the cosmic-ray neutron flux is several hundred times higher than at ground level as the shielding effect of the lower atmosphere diminishes. When this is coupled with the fact that aircraft manufacturers are incorporating ever increasing numbers of computers and electronic systems into their products, all of which are potentially vulnerable to the neutrons' effects, you can begin to see why they are concerned. In fact, such radiation effects are now accepted as one of the dominant reliability threat to aircraft electronics operating at normal cruising altitudes. The answer to this threat is, of course, to test the effects of the cosmic-ray neutrons on electronic components and systems, and for that you need an accelerator-based neutron source.

The ISIS Neutron Source where neutron production is driven by an 800MeV proton accelerator is just such a facility, and is ideal for micro-

chip testing as it is able to generate high intensity neutron beams with a spectrum close to the atmospheric neutron spectrum created by cosmic rays. The intensities of the neutron beam at ISIS are such that an hours exposure on VESUVIO is equivalent to many tens of thousands of hours in the real natural environment.

This 'accelerated' testing makes it feasible to carry out an assessment of the errors created by atmospheric neutrons in a wide variety of electronic devices.

The value of ISIS for accelerated testing for the avionics industry has recently been demonstrated by SPAESRANE<sup>4</sup>, a UK consortium of industrial and academic research groups specifically set up to address the threat posed by atmospheric radiation. Another leading group involving several Italian universities<sup>5</sup> has also been testing electronics at ISIS. They, however, have also been extending studies to electronics that have applications at ground level. Although the lower levels of radiation at ground level make the likelihood of disruption to a single constituent component less than it is at altitude, the race towards rapidly decreasing size, ever increasing speed and the sheer number of components being packed into modern electronics means that the incidents of 'soft errors' resulting from cosmic-ray neutrons at ground level is on the increase<sup>6</sup>.

Predicting where the problems may occur is difficult and exacerbated by the fact that devices doing very similar things can have quite different sensitivities to cosmic-ray neutrons. Experts agree that the problem is likely to get worse and is certainly not going to go away. As we increase our dependence on electronics, not only for safety critical applications



such as ground based transport and medicine but also in a whole host of social and economic ones, the reliability of those electronics and the potential threat from cosmic-ray neutrons will become of increasing concern to the industries involved<sup>7</sup>.

The problem for the electronics industry is that accelerator-based neutron sources that are suitable for electronic testing are not that widely available, particularly in Europe. The opening of the micro-chip testing facility at ISIS and its future developments in collaboration with leading groups from the UK, Italy and Europe is therefore a step forward for European industries and academic researchers in this field.

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## INES Takes Off: Update on the First Year of User Program

During 2006, the Italian Neutron Experimental Station (INES), whose construction you have already heard about in this journal, started its first user program.

The Station is equipped with a general purpose powder diffractometer, characterised by good resolution and simple versatile design.

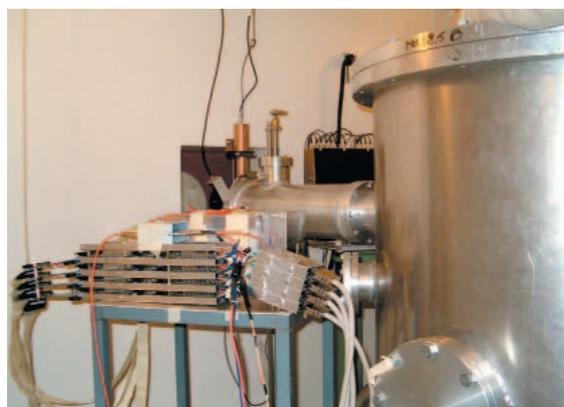
The INES project was sponsored by the CNR Neutron Spectroscopy Advisory Committee, who stressed the importance of realizing an experimental station with beam-time partially reserved for the Italian community at the world most powerful pulsed neutron source (ISIS, Rutherford Appleton Laboratory, UK) and identified the strategic value that such a Test Station would take for the Italian neutron scattering community, given the absence of neutron sources in our country. A powder diffractometer seemed a good initial choice, given the vast exploitation of this technique by various branches of science, such as Chemistry, Material Science, Earth Science or Crystallography. Indeed, neutron powder

diffractometer plays a fundamental role in these fields, typically either in the determination of structural and magnetic transitions, with the employment of furnaces and cryostats, or in the routine characterization of samples, an application whose importance is sometimes neglected.

Besides, neutrons are a highly non-destructive probe for condensed matter, thus neutron techniques have become very popular recently in archaeological applications, and neutron diffraction proved to be particularly

effective for the characterization of archaeological samples, such as bronzes or ceramics.

This fact is particularly relevant for the Italian community, given the continuously increasing importance attributed to this kind of study in our country. Archaeometry has in fact become a very popular discipline in Italy in the recent years, and the reason for this, besides the support from funding institutions, has to be seen in the great availability of archaeological sites, in a country



**Figure 1.** A portion of the INES block-house: the incoming beam direction can be seen in the background, the sample tank on the right hand side. The  $^{144}\text{He}$  INES detectors are hidden on the other side of the tank. In front, a prototype detection device can be seen while it is being tested by the ISIS detector group.



with such a rich cultural heritage. With this in mind, the Test Station INES has been designed with a particular eye for archaeological applications; from an almost full detector coverage of the scattering angles (from  $9^\circ$  to  $171^\circ$ ) for easier texture analysis to a large sample container tank (80 cm diameter by 90 cm height), ready to host big samples such as a statue or an amphora.

During the first 2 cycles of 2006, some fraction of the beam-time has been reserved for completing the commissioning of the instrument and making calibration measurements, in order to assess its capabilities and performances.

A new turbo-molecular pump has been installed, closed-cycle refrigerators and furnaces tested, and the data reduction and analysis procedures have been set up and tested, in collaboration with the Crystallography group at ISIS. Different standard samples have been measured, in order to calibrate the geometry and resolution of the diffractometer on an absolute scale and in comparison with other instruments. The instrument proved to have a good resolution (down to  $\Delta d/d=0.002$ ), and low background, although it is hampered by a low count rate. During this first year of operation, we have been able to allocate beam-time for almost all of the experiments proposed, with a steady increase in requests from potential users and a really packed final cycle.

In this initial period, we have established a friendly access mechanism without deadlines. However, at the

same time, the instrument has been inserted into the ISIS on-line proposal system and, starting with the 1<sup>st</sup> round in 2007, the access to INES follows the same rules as the other ISIS instruments, with on line submission of proposals through the ISIS website. The interests of the INES users of the first year, together with their national provenance can be seen in the charts below.

Archaeometry and magnetism are popular subjects these days, while good old chemistry is still not out of fashion. With regards to the first item, INES has been employed to measure samples such as Roman bronzes, among which an important piece of ancient bureaucracy: a metallic lamina, an indestructible certificate stating that the roman soldier *Aemilius Flavi* (son of *Flavus*) from *Tingi* (Tangier, Morocco), is finally a free man and a citizen of the Empire.

A very peculiar set of samples is represented by metallic retrievals from a shipwreck, still covered with calcareous concretions and still smelling of sea. Here the sample has almost disappeared, due to corrosion from the salty water, and the surrounding concretion is very important because it retains the shape of the object and, in some cases, some heavily corroded residual. Thus, the concretion, instead of being something to be removed in order to be able to access the object, contains the relevant information about it. Hence the importance of having a highly penetrating particle to investigate matter!

As already mentioned, the test station has an open design, with space available for neutron instrumentation tests such as new detectors and/or ancillary equipment. It is worth mentioning that, thanks to the water moderator on the beamline, high energy incident neutrons are available on INES.

At the moment, we are working to improve the detectors' stability. In addition, a new collimation device has been installed after the beam shutter for pin-pointing selected portions of the beam over different positions on the sample.

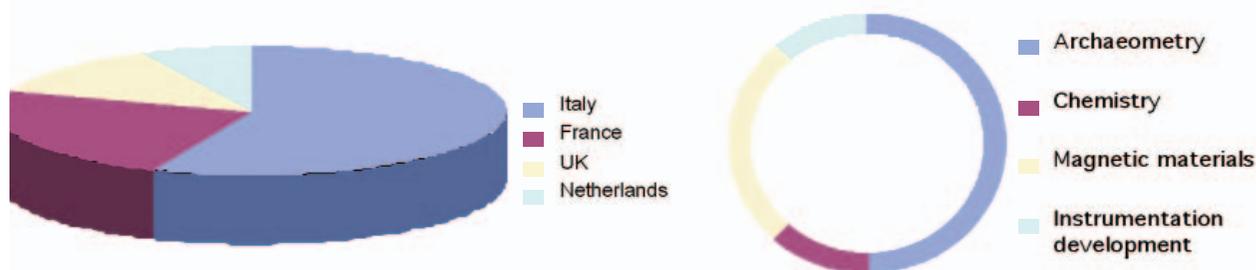
The data acquisition system is being changed to the new ISIS DAE II standard, which will make easier the control of specific pieces of sample environment equipment, such as remote controlled sample holders.

Finally, we are producing new pieces of equipment: a new goniometer for texture analysis of small objects and a small xyz table for positioning of large samples. We are confident that the community of INES users will increase in number and variety, and we hope to be able to offer more and more opportunities for producing good science.

For updated information we suggest to check our website: [www.isis.rl.ac.uk/molecularspectroscopy/ines](http://www.isis.rl.ac.uk/molecularspectroscopy/ines).

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First year of user program on INES: national provenance of the users (on the left) and topics investigated (on the right)



## News from NIST Center for Neutron Research

### Polarized $^3\text{He}$ neutron spin filters for NCNR instruments

Polarized neutron scattering (PNS) is a powerful probe for a wide range of research fields from physics to biology. Although it is useful for many applications, the lack of optimal polarizing and analyzing devices still precludes many PNS experiments. Nuclear spin polarized  $^3\text{He}$  gas, produced by optical pumping, can be used to polarize or analyze neutron

broadband and can polarize cold, thermal or hot neutrons effectively; 2) they can polarize large area and large divergence neutron beams without adding beam divergence; and 3) they can efficiently flip the neutron polarization by reversing the  $^3\text{He}$  nuclear polarization. This last capability can be performed using the adiabatic fast passage nu-

devices have been applied to diffuse reflectometry [2], small-angle neutron scattering (SANS) [3], and to a thermal triple-axis spectrometer (TAS) having a double focusing monochromator [4].

For thermal TAS, the  $^3\text{He}$  spin filters can provide significantly better neutronic performance and greater versatility in the selection of energy and polarization compared to Heusler crystals.

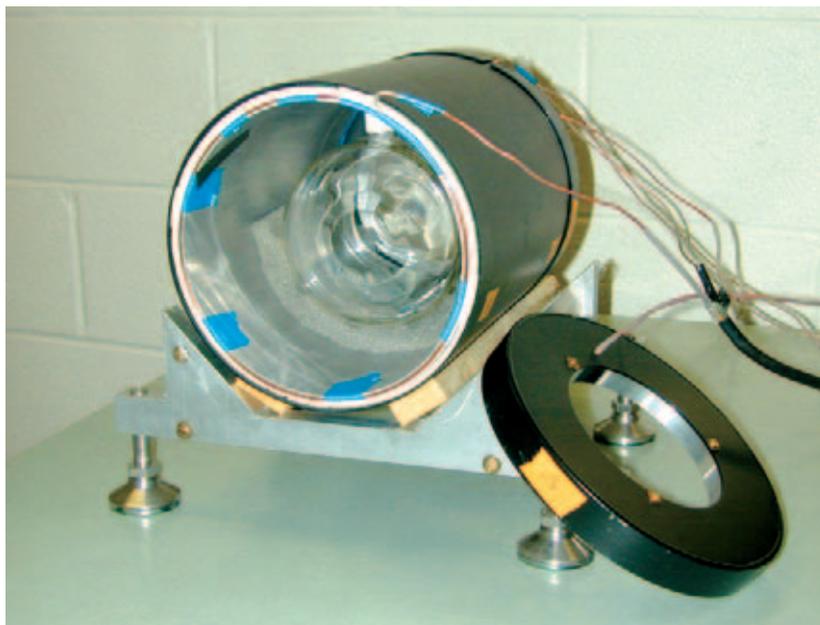
We have successfully performed several polarized beam experiments on the BT-7 TAS using  $^3\text{He}$  polarizers and analyzers. A  $^3\text{He}$  NSF in conjunction with a large double focusing pyrolytic graphite monochromator on the BT-7 TAS has yielded an initial polarized beam intensity about a factor of 20 higher than the recently decommissioned BT-2 TAS that used Heusler crystals.

For polarization analysis in diffuse reflectometry, the  $^3\text{He}$  spin filter allows much more efficient collection of off-specular scattering for a broad range of reciprocal space.

The use of a  $^3\text{He}$  spin filter makes polarization analysis practical in SANS. As a long-term goal, we plan to implement wide-angle polarization analysis for some other instruments.

User-friendly data reduction software is also under development to interface with these  $^3\text{He}$  NSFs. There exist two optical pumping methods to polarize the  $^3\text{He}$  gas, spin-exchange (SEOP) and metastability exchange (MEOP). Both SEOP and MEOP techniques can routinely provide polarized  $^3\text{He}$  gas at a polarization of 75%.

For our current  $^3\text{He}$  NSF applications, the  $^3\text{He}$  gas is polarized off-line by the SEOP method, transported to neutron scattering instruments, and stored on the beam line using a uniform magnetic field provided by a magnetically shielded solenoid



**Figure 1.** A compact  $^3\text{He}$  spin filter device (20 cm in diameter and 25 cm long) used for a thermal triple axis spectrometer.

beams because of the strong spin dependence of the neutron absorption cross section for  $^3\text{He}$ . Due to significant improvements in their performance during the last several years, polarized  $^3\text{He}$  neutron spin filters (NSF) have been of growing interest to the neutron scattering community worldwide. Compared to commonly used polarizers such as supermirrors and Heusler crystals, NSFs have the following advantages: 1) they are

clear magnetic resonance technique [1], thus integrating the polarizer and the flipper into a single device. The NIST Center for Neutron Research (NCNR) initiated a polarized  $^3\text{He}$  neutron spin filter program in 2006. The goal is to polarize and/or analyze neutron beams for neutron scattering instruments where other neutron-polarizing techniques are inadequate.

At the NCNR, polarized  $^3\text{He}$  NSF



(Fig. 1). The development of online optical pumping of  $^3\text{He}$  gas to maintain time-independent neutronic performance is underway for a few instruments.

The key technical challenges in applying  $^3\text{He}$  spin filters to neutron scattering are 1) producing a large volume of highly polarized  $^3\text{He}$  gas and 2) minimizing the  $^3\text{He}$  polarization decay.

We have constructed two SEOP systems capable of producing 75 % polarized  $^3\text{He}$  gas at pressures of (1 to 2)  $\times 10^5$  Pa in cells having volumes

approaching 1 L. To reduce polarization relaxation arising from field gradients inside magnetically shielded solenoids, we have optimized the field homogeneity by modeling and mapping the field, and most usefully, by measuring the polarization relaxation of the sealed low-pressure MEOP cells.

We have built a few compact magnetically shielded solenoids that yield field-gradient induced relaxation times up to 3000 h for a  $^3\text{He}$  pressure of  $10^5$  Pa over a cell volume of 1 L.

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## News from SNS ORNL Neutron Sciences Update

Both Oak Ridge National Laboratory neutron scattering facilities completed safety reviews in April 2007.

These successes enable the High Flux Isotope Reactor (HFIR) and the Spallation Neutron Source (SNS) to continue preparations for users to perform neutron scattering experiments. A recently developed web-based proposal submission process enables both facilities to coordinate beam time on the neutron scattering in-

struments through a combined user program. The Integrated Proposal Tracking System is undergoing beta testing. It will track proposals throughout the experimental process, including proposal submission, safety and science reviews, and beam time scheduling. The High Flux Isotope Reactor passed a formal review assessing readiness for restart of operations. Neutron production is expected to begin again in early May

2007. It is anticipated that the initial cycles will be devoted to testing of instruments and operational parameters, with general users arriving later this summer. Four HFIR instruments will be initially available following restart of the reactor: three triple-axis spectrometers and the residual stress diffractometer. Future capabilities at world-class levels will be enabled by a new cold source for two small-angle neutron scattering



**Figure 1.** A 24-ton portion of the 65m<sup>3</sup> ARCS scattering tank is lifted into position.  
*Photo credit:* Mark Loguillo/ORNL.



**Figure 2.** The POWGEN3 powder diffractometer team has completed installation of neutron guide.  
*Photo credit:* Luke Heroux/ORNL.



beam lines; these will be directed to the biomaterials, pharmaceutical, and polymer communities. In comments referring to the re-start of HFIR operations, ORNL group leader Greg Smith said "Neutron scatterers are anxious to start doing experiments using the facilities now available at HFIR. In particular, the cold neutrons will give us new capabilities almost immediately to study complex molecules and biological samples using the new SANS instruments in the guide hall. These instruments, combined with our state-of-the-art spectrometers already in the beam room, will certainly usher in a new era of scientific productivity for ORNL researchers and users from around the world". The most recent SNS operation cycle was completed April 15, 2007. A review was held April 2007 to assess readiness for accelerator operations at proton beam power above our present 100 kW ap-

proved limit up to the design capability of 2 MW. Power of the accelerator will be increased beyond 100kW as the predictability and reliability of neutron production also increases. In the most recent SNS operations cycle, proton beam power routinely delivered to the target achieved the goal of approximately 60 kW at an operating frequency of 15 Hz. The accelerator also operated for four hours at 90 kW. In another test of the accelerator system, the operating frequency was increased to 30 Hz for several hours of neutron production at 30 kW; this is in preparation for increasing the power during the next operations cycle. A new world energy record for proton beam acceleration in a linear accelerator was set on February 19, 2007. SNS accelerated the proton beam to 1.01 GeV, breaking the previous record of 0.95 GeV, which SNS achieved in December 2005, and reaches the intended de-

sign energy of 1.0 GeV. The first three SNS instruments continue their commissioning with the goal of welcoming general users in October 2007: BASIS – Backscattering Spectrometer, and the Magnetism and Liquids Reflectometers.

This involves testing major components such as the data acquisition system, neutron choppers, incident beam monitor, and neutron detectors. Test measurements of various samples have been performed. Testing of this equipment including selected sample environments and polarizers will continue during the next operations cycle. Advances continue in the construction of other instruments at SNS with an extremely busy period of commissioning and user activity beginning in fall 2007 (see accompanying table).

The POWGEN3 powder diffractometer finished guide installation and is installing shielding over the

## Schedule of ORNL Instruments through 2008

High Flux Isotope Reactor	Spallation Neutron Source
<b>Scheduled for General User Program in 2007</b>	
HB-1, Polarized Triple-Axis Spectrometer	BL 2 , BASIS - Backscattering Spectrometer
HB-1A, Ames Lab Triple-Axis Spectrometer	BL-4a, Magnetism Reflectometer
HB-3, Triple-Axis Spectrometer	BL-4b, Liquids Reflectometer
HB-2B, Residual Stress Diffractometer	
<b>Commissioning Scheduled for 2007, General Users in 2008</b>	
CG-2, 40m SANS	BL-18, ARCS - Wide Angular Range Chopper Spectrometer
CG-3, 35m BIOSANS	
<b>Commissioning Scheduled for 2008, General Users in 2009</b>	
	BL-3, High Pressure Diffractometer
	BL-5, CNCS – Cold Neutron Chopper Spectrometer
	BL-6, EQ-SANS – Extended Q-Range Small Angle Neutron Diffractometer
	BL-7, VULCAN – Engineering Diffractometer
	BL-11a, POWGEN3, Powder Diffractometer
	BL-13, Fundamental Physics Beam Line
	BL-17, SEQUOIA – Fine Resolution Fermi Chopper Spectrometer



guide sections. Large sample vessels for ARCS - Wide Angular Range Chopper Spectrometer [volume of 65 m<sup>3</sup>] and SEQUOIA - Fine Resolution Fermi Chopper Spectrometer [volume of 250 m<sup>3</sup>] have been received and installed.

Construction of the external instrument buildings for the CNCS - Cold Neutron Chopper Spectrometer and

### ORNL User Meeting October 8-12, 2007

Four ORNL user facilities - SNS, HFIR, the Center for Nanophase Materials Sciences, and the Shared Research Equipment user facilities - are coordinating a program for a combined User Week, October 8-12, 2007, to be held at ORNL. The first goal of this meeting is to increase in-

Oak Ridge facilities. Second, we wish to receive feedback on needed advances in areas such as developing pump-probe techniques to study non-equilibrium phenomena at microsecond timescales, combining sample environment stages (perhaps high magnetic fields, high pressure, and low temperature simultaneously), and combining characterization techniques (x-ray and neutron) on the same instrument. Third, there is an opportunity to acquaint new users with capabilities of some of the major techniques used at SNS and HFIR through small workshops.

More information on this combined user meeting, including registration, agenda, and lodging, can be found at <http://neutrons.ornl.gov> or by email to [neutronusers@ornl.gov](mailto:neutronusers@ornl.gov).



**Figure 3.** This UV image is used to assess optical alignment of neutron guide sections of the VULCAN engineering diffractometer. Note the continuous smooth lines from the corners with no breaks or jumps where glass sections meet.

*Image credit:* Marc Shoemaker/ORNL.

VULCAN - Engineering Diffractometer is scheduled for completion in summer 2007.

terest and awareness of the important scientific research challenges that are being addressed at these

**A.E. Ekkebus**

*Neutron Scattering Science Division  
Oak Ridge National Laboratory*

## Judges come to Lawrence Berkeley National Lab to learn about Science

In late March, 55 state and federal judges came to Lawrence Berkeley National Laboratory for a week-long conference designed to give the judges an orientation to the emerging fields of nanotechnology, synthetic biology, and environmental biotechnology, and enhance their ability to preside over complex cases



Judges get an orientation to emerging scientific fields from Lab microbial ecologist Terry Hazen.

involving novel scientific evidence. They toured the Advanced Light Source, focusing on its protein and cellular imaging capabilities.

They also toured a nanotechnology research center, met with Berkeley Lab Director Chu and several other Lab scientists, isolated DNA fragments and examined spectroscopy images, and dissected imaginary cases involving nanoparticles, radionuclide releases, and bioremediation. "They came to Berkeley Lab because we are known as the center for science, and they need to know how science works", says Terry Hazen, a microbial ecologist in the Earth Sciences Division who has helped judges bone up on the fundamentals of science for the past eight years.

Hazen organized the March 25 to March 30 conference under the auspices of the Advanced Science &

Technology Adjudication Resource Center (ASTAR), a non-profit corporation that seeks to improve the capacities of the nation's courts in resolving highly technical cases. Judges who attended the conference were certified by ASTAR and will provide case-related leadership later this year at the group's national conferences.

ASTAR's mission over the next two years is to provide an orientation on the fundamentals of emerging scientific disciplines to every court jurisdiction in the U.S.

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## Call for proposals for Neutron Sources

<http://pathfinder.neutron-eu.net/idb/access>

### **BENSC**

Deadlines for proposal submission:  
**15th September 2007**  
[www.hmi.de/bensc/user-info/call-bensc\\_en.html](http://www.hmi.de/bensc/user-info/call-bensc_en.html)

### **BNC**

#### **Budapest Neutron Centre**

Deadlines for proposal submission:  
**15th November 2007**  
[www.bnc.hu/modules.php?name=News&file=article&sid=39](http://www.bnc.hu/modules.php?name=News&file=article&sid=39)

### **FRJ-2 Fz-Julich**

Deadlines for proposal submission:  
**Autumn 2007**  
[www.jcms.info/jcms\\_proposals/](http://www.jcms.info/jcms_proposals/)

### **FRM-II**

Deadlines for proposal submission:  
**17th August and 14th September 2007**  
<http://user.frm2.tum.de/modules.php?name=News&file=article&sid=11>

### **GeNF**

#### **Geesthacht Neutron Facility**

Deadline for proposal submission:  
**At anytime during 2007**  
[www.gkss.de/index\\_e\\_js.html](http://www.gkss.de/index_e_js.html)

### **ILL**

Deadlines for proposal submission:  
**18th September 2007**  
[www.ill.fr](http://www.ill.fr)

### **ISIS**

Deadlines for proposal submission:  
**16th October 2007**  
[www.isis.rl.ac.uk](http://www.isis.rl.ac.uk)

### **LLB**

#### **Laboratoire Léon Brillouin**

Deadlines for proposal submission:  
**1st October 2007**  
[www-llb.cea.fr](http://www-llb.cea.fr)

### **NPL**

#### **Neutron Physics Laboratory**

Deadline for proposal submission:  
**15th September 2007**  
<http://neutron.ujf.cas.cz/>

### **RID**

#### **Reactor Institute Delft**

Deadlines for proposal submission:  
**31st December 2007**  
[www.rid.tudelft.nl/live/pagina.jsp?id=c36aa5a4-fe11-418d-89f9-6b200851bd05&lang=en](http://www.rid.tudelft.nl/live/pagina.jsp?id=c36aa5a4-fe11-418d-89f9-6b200851bd05&lang=en)

### **SINQ**

#### **Swiss Spallation Neutron Source**

Deadlines for proposal submission are:  
**15th November 2007**  
[http://sinq.web.psi.ch/sinq/sinq\\_call.html](http://sinq.web.psi.ch/sinq/sinq_call.html)

### **SμS**

#### **Swiss Muon Source**

Deadlines for proposal submission:  
**5th December 2007**  
<http://lmu.web.psi.ch/eu-muons/>



## Call for proposals for Synchrotron Radiation Sources

[www.lightsources.org/cms/?pid=1000336#byfacility](http://www.lightsources.org/cms/?pid=1000336#byfacility)

### **APS** **Advanced Photon Source**

Deadlines for proposal submission:  
**13th July 2007**  
[www.aps.anl.gov/Users/Scientific\\_Access/General\\_User/GUP\\_Calendar.htm](http://www.aps.anl.gov/Users/Scientific_Access/General_User/GUP_Calendar.htm)

### **BESSY**

Deadlines for proposal submission:  
**15th August 2007**  
[www.bessy.de/boat/www/](http://www.bessy.de/boat/www/)

### **BSRF** **Beijing Synchrotron Radiation Facility**

Deadlines for proposal submission:  
**Proposals are evaluated twice a year**  
[www.ihep.ac.cn/bsrf/english/userinfo/beamtime.htm](http://www.ihep.ac.cn/bsrf/english/userinfo/beamtime.htm)

### **CHESS** **Cornell High Energy Synchrotron Source**

Deadlines for proposal submission:  
**31st October 2007**  
[www.chess.cornell.edu/proposals/index.htm](http://www.chess.cornell.edu/proposals/index.htm)

### **CLS** **Canadian Light Source**

Deadlines for proposal submission:  
**1st October 2007**  
[www.lightsources.ca/uso/call\\_proposals.php](http://www.lightsources.ca/uso/call_proposals.php)

### **ELETTRA**

Deadlines for proposal submission:  
**31st August 2007**  
<https://vuo.elettra.trieste.it/pls/vuo/guest.startup>

### **ESRF** **European Synchrotron Radiation Facility**

Deadlines for proposal submission:  
**1st September 2007**  
[www.esrf.eu/UsersAndScience/UserGuide/News/ProposalDeadline/](http://www.esrf.eu/UsersAndScience/UserGuide/News/ProposalDeadline/)

### **FELIX** **Free Electron Laser for Infrared eXperiments**

Deadlines for proposal submission:  
**1st December 2007**  
[www.rijnh.nl/molecular-and-laser-physics/felix/n4/f1234.htm](http://www.rijnh.nl/molecular-and-laser-physics/felix/n4/f1234.htm)

### **HASYLAB** **Hamburger Synchrotronstrahlungslabor at DESY**

Deadlines for proposal submission:  
**1st September 2007**  
[www-hasylab.desy.de/user\\_infos/projects/3\\_deadlines.htm](http://www-hasylab.desy.de/user_infos/projects/3_deadlines.htm)

### **ISA** **Institute for Storage Ring Facilities**

Deadlines for proposal submission:  
**31st December 2007**  
[www-hasylab.desy.de/user\\_infos/projects/3\\_deadlines.htm](http://www-hasylab.desy.de/user_infos/projects/3_deadlines.htm)

### **SOLEIL**

Deadlines for proposal submission:  
**15th September 2007**  
[www.synchrotron-soleil.fr/anglais/users/index.html](http://www.synchrotron-soleil.fr/anglais/users/index.html)

### **SRC** **Synchrotron Radiation Center**

Deadlines for proposal submission:  
**1st August 2007**  
[www.src.wisc.edu/users/index.htm](http://www.src.wisc.edu/users/index.htm)

### **SRS** **Synchrotron Radiation Source**

Deadlines for proposal submission:  
**1st November 2007**  
[www.srs.ac.uk/srs/userSR/user\\_access2.html](http://www.srs.ac.uk/srs/userSR/user_access2.html)

### **SSRL** **Stanford Synchrotron Radiation Laboratory**

Deadlines for proposal submission:  
**1st November and 1st December 2007**  
[www-ssrl.slac.stanford.edu/users/user\\_admin/deadlines.html](http://www-ssrl.slac.stanford.edu/users/user_admin/deadlines.html)



**July 22-26, 2007**

**ERICE, SICILY, ITALY**

**Structure and Dynamics of Free and Supported Nanoparticles Using Short Wavelength Radiation**  
41st Course International School of Solid State Physics  
52nd IUVSTA Workshop  
<http://pccluster.mi.infn.it/erice-2007/>

**July 23-31, 2007**

**SERPONG & BANDUNG, INDONESIA**

**International Conference on Neutron and X Ray Scattering**  
<http://centrin.net.id/~nslbatan/>

**July 25-31, 2007**

**FREIBURG, GERMANY**

**XXV ICPEAC – International Conference on Photonic, Electronic and Atomic Collisions**  
[www.mpi-hd.mpg.de/ICPEAC2007/](http://www.mpi-hd.mpg.de/ICPEAC2007/)

**July 26-27, 2007**

**ABINGDON, OXFORDSHIRE, UK**

**Theoretical and Experimental Magnetism Meeting**  
[www.iop.org/activity/groups/subject/mag/Events/file\\_22170.pdf](http://www.iop.org/activity/groups/subject/mag/Events/file_22170.pdf)

**July 29 - August 3, 2007**

**BERLIN, GERMANY**

**VUV XV – 15th International Conference on Vacuum Ultraviolet Radiation Physics**  
[www.bessy.de/VUVXV/front\\_content.php](http://www.bessy.de/VUVXV/front_content.php)

**August 5-10, 2007**

**NEW LONDON, NH, UK**

**Gordon Research Conference on X-ray Physics**  
[www.grc.org/programs.aspx?year=2007&program=xray](http://www.grc.org/programs.aspx?year=2007&program=xray)

**August 10-12, 2007**

**SAINT AUBIN, FRANCE**

**III BioXAS Study Weekend**  
Satellite meeting BSR2007  
[www.synchrotron-soleil.fr/workshops/2007/Third-BioXAS-SWE/](http://www.synchrotron-soleil.fr/workshops/2007/Third-BioXAS-SWE/)

**August 13-17, 2007**

**MANCHESTER, UK**

**BSR2007 – 9th International Conference on Biology and Synchrotron Radiation**  
[www.srs.ac.uk/bsr2007/](http://www.srs.ac.uk/bsr2007/)

**August 18-25, 2007**

**ZUOZ, SWITZERLAND**

**Correlated Electron Materials**  
6th PSI Summer School on Condensed Matter Research  
<http://sls.web.psi.ch/view.php/science/events/Conferences/2007/Zuoz2007/Scope.html>

**August 19-23, 2007**

**BOSTON, MA, USA**

**234th American Chemical Society National Meeting**  
[www.chemistry.org/portal/a/c/s/1/acdisplay.html?DOC=meetings%5cboston2007%5chome.html](http://www.chemistry.org/portal/a/c/s/1/acdisplay.html?DOC=meetings%5cboston2007%5chome.html)

**August 22-27, 2007**

**MARRAKECH, MOROCCO**

**ECM24 – XXIV European Crystallographic Meeting**  
[www.ecm24.org/index.php?option=com\\_frontpage&Itemid=57](http://www.ecm24.org/index.php?option=com_frontpage&Itemid=57)

**August 26-30, 2007**

**SASKATOON, CANADA**

**Medical Applications of Synchrotron Radiation**  
Saskatoon, Saskatchewan, Canada  
[www.lightsource.ca/masr2007/](http://www.lightsource.ca/masr2007/)

**September 2-6, 2007**

**MELBOURNE, AUSTRALIA**

**COMS2007 – 12th International Conference on the Commercialisation of Micro and Nano Technologies**  
[www.mancef-coms2007.org/](http://www.mancef-coms2007.org/)

**September 3-5, 2007**

**BEIJING, CHINA**

**Materials Today Asia 2007**  
[www.materialstodayasia.elsevier.com/location.htm](http://www.materialstodayasia.elsevier.com/location.htm)

**September 3-14, 2007 JULICH / GARCHING, GERMANY**

11th JCNS Laboratory Course - Neutron Scattering  
[www.fz-juelich.de/iff/wns\\_lab07](http://www.fz-juelich.de/iff/wns_lab07)

**September 24-26, 2007 WIEN, AUSTRIA**

MECASSENS IV  
<http://mecasens2007.mpie.de/?type=1>

**September 4-14, 2007 OXFORD, UK**

10th Oxford Summer School on Neutron Scattering  
University of Oxford  
<http://www.oxfordneutronschool.org/>

**September 24-28, 2007 TRIESTE, ITALY**

WAO2007 – 6th International Workshop  
on Accelerator Operations  
[www.elettra.trieste.it/wao07/](http://www.elettra.trieste.it/wao07/)

**September 11-13, 2007 VILLIGEN, SWITZERLAND**

8th SLS Users' Meeting  
Villigen PSI  
<http://user.web.psi.ch/sls07/>

**September 25-29, 2007 AWAJI CITY, HYOGO, JAPAN**

WIRMS2007 - International Workshop on Infrared  
Microscopy and Spectroscopy with Accelerator Based  
Sources  
[www.spring8.or.jp/en/users/meeting/2007/wirms2007](http://www.spring8.or.jp/en/users/meeting/2007/wirms2007)

**September 12-13, 2007 MOTZEN, GERMANY**

CorMic2007 – 1st European Workshop on Correlative  
Microscopy for 3-D Cell Imaging  
[www.bessy.de/cms.php?idcatart=874](http://www.bessy.de/cms.php?idcatart=874)

**September 26-28, 2007 GARCHING, GERMANY**

Advances of Neutron Scattering in Correlated  
Electron Systems  
[http://neutron.neutron-eu.net/n\\_news/n\\_calendar\\_of\\_events/n-events-2007](http://neutron.neutron-eu.net/n_news/n_calendar_of_events/n-events-2007)

**September 13-14, 2007 CHILTON, OXFORDSHIRE, UK**

UK Synchrotron Radiation User Meeting 2007  
[www.diamond.ac.uk/ForUsers/SRUser07/default.htm](http://www.diamond.ac.uk/ForUsers/SRUser07/default.htm)

**September 26-28, 2007 GOTTINGEN, GERMANY**

SKIN2007 - Studying Kinetics with Neutrons  
[http://neutron.neutron-eu.net/n\\_nmi3/n\\_networking\\_activities/SKIN2007/#Programme](http://neutron.neutron-eu.net/n_nmi3/n_networking_activities/SKIN2007/#Programme)

**September 17-21, 2007 SCHUBERG, GERMANY**

Application of Neutrons and Synchrotron Radiation in  
Engineering Materials Science  
Schüberg, near Hamburg, Germany  
[www.hmi.de/events/PNAM\\_school/anmeldung\\_en.html](http://www.hmi.de/events/PNAM_school/anmeldung_en.html)

**October 1-2, 2007 KARLSRUHE, GERMANY**

6th ANKA Users' Meeting  
<http://ankaweb.fzk.de/conferences/users-meeting-2007/first%20page.html>

**September 17-21, 2007 WARSAW, POLAND**

New Opportunities and Challenges in Material  
Research using Synchrotron and Free Electron  
Laser Sources - Symposium  
E-MRS Fall Meeting  
[www.e-mrs.org/meetings/fall2007/I.html](http://www.e-mrs.org/meetings/fall2007/I.html)  
[www.esrf.fr/NewsAndEvents/Conferences/HSC/HSC1/](http://www.esrf.fr/NewsAndEvents/Conferences/HSC/HSC1/)

**October 1-2, 2007 MENLO PARK, CA, USA**

SSRL 34th Annual Users' Meeting

**October 4-6, 2007**      **BERKELEY, CA, USA**

ALS Users' Meeting

**October 30 - November 1, 2007**      **HSINCHU, TAIWAN**

NSRRC Thirteenth Users' Meeting &amp; Workshops

**October 12-13, 2007**      **STOUGHTON, WI, USA**

SRC Users' Meeting

**November 1, 2007**      **HYOGO, JAPAN**

SPRING-8 Users' Meeting

**October 14-19, 2007**      **BEIJING, CHINA**

13th International Workshop on RF Superconductivity

**November 2-3, 2007**      **HSINCHU, TAIWAN**Asia/Oceania Forum for Synchrotron  
Radiation Research**October 15-26, 2007**      **TRIESTE, ITALY**School on Pulsed Neutrons: Characterization  
of Materials**November 4-7, 2007**      **TAIPEI, TAIWAN**8th Conference of the Asian Crystallographic  
Association (AsCA'07)**October 22-23, 2007**      **GRENOBLE, FRANCE**Total scattering PDF analysis using X-rays and  
neutrons: powder diffraction and complementary  
techniques - Workshop  
[www.esrf.eu/events/conferences/PDFPowderDiffraction](http://www.esrf.eu/events/conferences/PDFPowderDiffraction)  
Announcement**November 15, 2007**      **POHANG, KOREA**

PAL Users' Meeting

**October 23-26, 2007**      **VILLIGEN, SWITZERLAND**International school for "Scattering for Biologists"  
Paul Scherrer Institut, Switzerland**December 3, 2007**      **TRIESTE, ITALY**

ELETTRA Users' Meeting

**October 28 - November 3, 2007**      **HONOLULU, HAWAII, USA**2007 IEEE Nuclear Science Symposium and Medical  
Imaging Conference  
[www.nss-mic.org/2007/](http://www.nss-mic.org/2007/)**December 4-7, 2007**      **KOBE, JAPAN**

The 10th Pacific Polymer Conference

**December 6, 2007**      **BERLIN, GERMANY**

BESSY Users' Meeting



## NEUTRON SOURCES

### NEUTRON SCATTERING WWW SERVERS IN THE WORLD

(<http://idb.neutron-eu.net/facilities.php>)

#### **BNC - Budapest Research reactor**

Budapest Research Centre, Hungary  
Type: Swimming pool reactor, 10MW  
Email: [tozser@sunserv.kfki.hu](mailto:tozser@sunserv.kfki.hu)  
[www.bnc.hu/](http://www.bnc.hu/)

#### **BENSC - Berlin Neutron Scattering Center**

Hahn-Meitner-Institut  
Glienicker Strasse 100  
D-14109 Berlin, Germany  
Phone: ~49/30/8062-2778; Fax: ~49/30/8062-2523  
E-mail: [bensc@hmi.de](mailto:bensc@hmi.de)  
[www.hmi.de/bensc/index\\_en.html](http://www.hmi.de/bensc/index_en.html)

#### **Budapest Neutron Centre**

Budapest Research Reactor  
Type: Reactor. Flux:  $2.0 \times 10^{14}$  n/cm<sup>2</sup>/s  
Address for application forms:  
Dr. Borbely Sándor  
KFKI Building 10, 1525 Budapest - Pf 49, Hungary  
E-mail: [Borbely@power.szfk.kfki.hu](mailto:Borbely@power.szfk.kfki.hu)  
[www.iki.kfki.hu/nuclear](http://www.iki.kfki.hu/nuclear)

#### **CNF**

Canadian Neutron Beam Centre  
National Research Council of Canada  
Building 459, Station 18  
Chalk River Laboratories, Chalk River, Ontario  
CANADA K0J 1J0  
Phone: 1- (888) 243-2634 (toll free) / 1- (613) 584-8811  
ext. 3973; Fax: 1- (613) 584-4040  
<http://cnf-ccn.gc.ca/home.html>

#### **FRG-1 Geesthacht (D)**

Type: Swimming Pool Cold Neutron Source.  
Flux:  $8.7 \times 10^{13}$  n/cm<sup>2</sup>/s  
Address for application forms and informations:  
Reinhard Kampmann, Institute for Materials Science,  
Div. Wfn-Neutronsattering, GKSS, Research Centre,  
21502 Geesthacht, Germany  
Phone: +49 (0)4152 87 1316/2503;  
Fax: +49 (0)4152 87 1338  
E-mail: [reinhard.kampmann@gkss.de](mailto:reinhard.kampmann@gkss.de)  
[www.gkss.de](http://www.gkss.de)

#### **FRJ-2**

Forschungszentrum Jülich GmbH  
Jülich  
Type: DIDO (heavy water), 23 MW  
Research Centre Jülich, D-52425, Jülich  
E-mail: [info@fz-juelich.de](mailto:info@fz-juelich.de)  
[www.fz-juelich.de/iff/wms/](http://www.fz-juelich.de/iff/wms/)

#### **FRM, FRM-2 (D)**

Technische Universität München  
Type: Compact 20 MW reactor.  
Flux:  $8 \times 10^{14}$  n/cm<sup>2</sup>/s  
Address for information:  
Prof. Winfried Petry,  
FRM-II Lichtenbergstrasse 1 - 85747 Garching  
Phone: 089 289 14701  
Fax: 089 289 14666  
E-mail: [wpetry@frm2.tum.de](mailto:wpetry@frm2.tum.de)  
[www.frm2.tum.de/en/index.html](http://www.frm2.tum.de/en/index.html)

#### **HFIR**

Oak Ridge National Lab.  
Oak Ridge, USA  
Phone: (865)574-5231; Fax: (865)576-7747  
E-mail: [ns\\_user@ornl.gov](mailto:ns_user@ornl.gov)  
<http://neutrons.ornl.gov/>

#### **HIFAR**

ANSTO Australia  
New Illawarra Road, Lucas Heights NSW, Australia  
Phone: 61 2 9717 3111  
E-mail: [enquiries@ansto.gov.au](mailto:enquiries@ansto.gov.au)  
[www.ansto.gov.au/ansto/bragg/hifar/nshifar.html](http://www.ansto.gov.au/ansto/bragg/hifar/nshifar.html)  
[www.ansto.gov.au/natfac/hifar.html](http://www.ansto.gov.au/natfac/hifar.html)

#### **IBR2 Fast Pulsed Reactor Dubna (RU)**

Type: Pulsed Reactor.  
Flux:  $3 \times 10^{16}$  (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.  
Phone: +7 09621 65096; Fax: +7 09621 65882  
E-mail: [sikolen@nf.jinr.dubna.su](mailto:sikolen@nf.jinr.dubna.su)  
<http://nfdfn.jinr.ru/ibr-2/index.html>

**ILL Grenoble (F)**

Type: 58MW High Flux Reactor.  
 Flux:  $1.5 \times 10^{15}$  n/cm<sup>2</sup>/s  
 Scientific Coordinator  
 Dr. G. Cicognani, ILL, BP 156,  
 38042 Grenoble Cedex 9, France  
 Phone: +33 4 7620 7179; Fax: +33 4 76483906  
 E-mail: cico@ill.fr and sco@ill.fr  
 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  
 www.pns.anl.gov

**ISIS Didcot (UK)**

Type: Pulsed Spallation Source.  
 Flux:  $2.5 \times 10^{16}$  n fast/s  
 Address for application forms:  
 ISIS Users Liaison Office, Building R3,  
 Rutherford Appleton Laboratory, Chilton,  
 Didcot, Oxon OX11 0QX  
 Phone: +44 (0) 1235 445592; Fax: +44 (0) 1235 445103  
 E-mail: uls@isis.rl.ac.uk  
 www.isis.rl.ac.uk

**JRR-3M**

Tokai-mura, Naka-gun,  
 Ibaraki-ken 319-11, Japan.  
 Jun-ichi Suzuki,  
 JAERI - Japan Atomic Energy Research Institute  
 Yuji Ito (ISSP, Univ. of Tokyo)  
 Fax: +81 292 82 59227  
 Telex: JAERIJ24596  
 E-mail: www-admin@www.jaea.go.jp  
 http://cispyon.tokai-sc.jaea.go.jp/english/index.cgi

**JEEP-II Reactor Kjeller**

Type: D<sub>2</sub>O moderated 3.5%  
 enriched UO<sub>2</sub> fuel.  
 Flux:  $2 \times 10^{13}$  n/cm<sup>2</sup>/s  
 Address for application forms:  
 Institutt for Energiteknikk  
 K.H. Bendiksen, Managing Director  
 Box 40, 2007 Kjeller, Norway  
 Phone: +47 63 806000, 806275  
 Fax: +47 63 816356  
 E-mail: kjell.bendiksen@ife.no  
 www.ife.no

**KENS**

Institute of Materials Structure Science  
 High Energy Accelerator research Organisation  
 1-1 Oho, Tsukuba-shi, Ibaraki-ken, 305-0801, JAPAN  
 E-mail: kens-pac@nml.kek.jp  
 http://neutron-www.kek.jp/index\_e.html

**KSR - Nuclear Science Research Facility**

Institute for Chemical Research (ICR) and Kyoto  
 University  
 Gokasho, Uji Kyoto 611, Japan  
 Fax: +81-774-38-3289  
 www.al.kuicr.kyoto-u.ac.jp/www/index-e.htmlx

**KUR - Kyoto University Research Reactor Institute**

Kumatori-cho Sennan-gun,  
 Osaka 590-0494, Japan  
 Phone: +81-72-451-2300  
 Fax: +81-72-451-2600  
 www.rri.kyoto-u.ac.jp/en/

**LANSCE - Los Alamos Neutron Science Center**

TA-53, Building 1, MS H831  
 Los Alamos National Lab, Los Alamos, USA  
 505-665-8122  
 E-mail: tichavez@lanl.gov  
 www.lansce.lanl.gov/index.html

**LLB Orphée Saclay (F)**

Type: Reactor. Flux:  $3.0 \times 10^{14}$  n/cm<sup>2</sup>/s  
 Laboratoire Léon Brillouin (CEA-CNRS)  
 E-mail: experience@llb.saclay.cea.fr  
 www-llb.cea.fr/index\_e.html

**NFL – Studsvik Neutron Research Laboratory**

Uppsala University  
 Studsvik Nuclear AB, Stockholm, Sweden  
 Type: swimming pool type reactor, 50 MW,  
 with additional reactor 1 MW  
 http://idb.neutron-eu.net/facilities.php

**NCNR – NIST Center for Neutron Research**

National Institute of Standards and Technology  
 100 Bureau Drive, MS 8560  
 Gaithersburg, MD 20899-8560, USA  
 Patrick Gallagher, Director  
 Phone: (301) 975-6210  
 Fax: (301) 869-4770  
 E-mail: pgallagher@nist.gov  
 http://rrdjazz.nist.gov

**NPL – NRI**

Type: 10 MW research reactor.  
Address for informations:  
Zdenek Kriz, Scientific Secretary  
Nuclear Research Institute Rez plc,  
250 68 Rez - Czech Republic  
Phone: +420 2 20941177 / 66173428  
Fax: +420 2 20941155  
E-mail: krz@ujv.cz and brv@nri.cz  
www.nri.cz

**NRU Chalk River Laboratories**

The peak thermal flux  $3 \times 10^{14}$  cm<sup>-2</sup> sec<sup>-1</sup>  
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>

**PSI-SINQ Villigen (CH)**

Type: Steady spallation source.  
Flux:  $2.0 \times 10^{14}$  n/cm<sup>2</sup>/s  
Contact address: Paul Scherrer Institut  
User Office, CH-5232 Villigen PSI - Switzerland  
Phone: +41 56 310 4666; Fax: +41 56 310 3294  
E-mail: [sinq@psi.ch](mailto:sinq@psi.ch)  
<http://sinq.web.psi.ch>

**RID Reactor Institute Delft (NL)**

Type: 2MW light water swimming pool.  
Flux:  $1.5 \times 10^{13}$  n/cm<sup>2</sup>/s  
Address for application forms:  
Dr. M. Blaauw, Head of Facilities and Services Dept.  
Reactor Institute Delft, Faculty of Applied Sciences  
Delft University of Technology, Mekelweg 15  
2629 JB Delft, The Netherlands  
Phone: +31-15-2783528  
Fax: +31-15-2788303  
E-mail: [m.blaauw@tudelft.nl](mailto:m.blaauw@tudelft.nl)  
[www.rid.tudelft.nl](http://www.rid.tudelft.nl)

**SNS – Spallation Neutron Source**

ORNL, Oak Ridge, USA  
Address for information:  
Allen E. Ekkebus  
Spallation Neutron Source,  
Oak Ridge National Laboratory  
One Bethel Valley Road, Bldg 8600  
P.O. Box 2008, MS 6460  
Oak Ridge, TN 37831-6460  
Phone: (865) 241-5644  
Fax: (865) 241-5177  
E-mail: [ekkebusae@ornl.gov](mailto:ekkebusae@ornl.gov)  
[www.sns.gov/](http://www.sns.gov/)



# SYNCHROTRON RADIATION SOURCES

## SYNCHROTRON SOURCES WWW SERVERS IN THE WORLD

(<http://www.lightsources.org/cms/?pid=1000098>)

### ALBA – Synchrotron Light Facility

CELLS - ALBA Edifici Ciències. C-3 central.  
Campus UAB  
Campus Universitari de Bellaterra.  
Universitat Autònoma de Barcelona  
08193 Bellaterra, Barcelona – Spain  
Phone: +34 93 592 43 00 - fax: +34 93 592 43 01  
[www.cells.es/](http://www.cells.es/)

### ALS - Advanced Light Source

Berkeley Lab, 1 Cyclotron Rd, MS6R2100,  
Berkeley, CA 94720  
Phone: +1 510.486.7745 - fax: +1 510.486.4773  
E-mail: [alsuser@lbl.gov](mailto:alsuser@lbl.gov)  
[www-als.lbl.gov/](http://www-als.lbl.gov/)

### ANKA

Forschungszentrum Karlsruhe Institut  
für Synchrotronstrahlung  
Hermann-von-Helmholtz-Platz 1,  
76344 Eggenstein-Leopoldshafen, Germany  
Phone: +49 (0)7247/82-6071 - fax: +49-(0)7247/82-6172  
E-mail: [info@fzk.de](mailto:info@fzk.de)  
<http://hikwww1.fzk.de/iss/>

### APS - Advanced Photon Source

Argonne Nat. Lab. 9700 S. Cass Avenue,  
Argonne, IL 60439, USA  
Phone: (630) 252-2000 - fax: +1 708 252 3222  
[www.aps.anl.gov](http://www.aps.anl.gov)

### AS - Australian Synchrotron

Level 17, 80 Collins St Melbourne, VIC 3000, Australia  
Phone: +61 3 9655 3315 - fax: +61 3 9655 8666  
E-mail: [contact.us@synchrotron.vic.gov.au](mailto:contact.us@synchrotron.vic.gov.au)  
[www.synchrotron.vic.gov.au/content.asp?Document\\_ID=9](http://www.synchrotron.vic.gov.au/content.asp?Document_ID=9)

### BESSY – Berliner Elektronenspeicherring Gesellschaft.für Synchrotronstrahlung

BESSY GmbH, Albert-Einstein-Str.15,  
12489 Berlin, Germany  
Phone: +49 (0)30 6392-2999 - fax: +49 (0)30 6392-2990  
E-mail: [info@bessy.de](mailto:info@bessy.de)  
[www.bessy.de](http://www.bessy.de)

### BSRF - Beijing Synchrotron Radiation Facility

BEPC National Laboratory, Institute of High Energy  
Physics, Chinese Academy of Sciences  
P.O.Box 918 Beijing 100039 – P. R. China  
Phone: +86-10-68235125 - fax: +86-10-68222013  
E-mail: [houbz@mail.ihep.ac.cn](mailto:houbz@mail.ihep.ac.cn)  
[www.ihep.ac.cn/bsrf/english/main/main.htm](http://www.ihep.ac.cn/bsrf/english/main/main.htm)

### CAMD - Center Advanced Microstructures & Devices

CAMD/LSU 6980 Jefferson Hwy. – Baton Rouge,  
LA 70806 USA  
Phone: +1 (225) 578-8887 - fax : +1 (225) 578-6954  
E-mail: [leeann@lsu.edu](mailto:leeann@lsu.edu)  
[www.camd.lsu.edu/](http://www.camd.lsu.edu/)

### CANDLE - Center for the Advancement of Natural Discoveries using Light Emission

Acharyan 31 375040, Yerevan, Armenia  
Phone/fax: +374-1-629806  
E-mail: [baghiryan@asls.candle.am](mailto:baghiryan@asls.candle.am)  
[www.candle.am/index.html](http://www.candle.am/index.html)

### CFN - Center for Functional Nanomaterials

User Administration Office  
Brookhaven National Laboratory  
P.O. Box 5000, Bldg. 555  
Upton, NY 11973-5000, USA  
Phone: +1 (631) 344-6266  
Fax: +1 (631) 344-3093  
[www.bnl.gov/cfn/facilities/](http://www.bnl.gov/cfn/facilities/)

### CHESS - Cornell High Energy Synchrotron Source

Cornell High Energy Synchrotron Source  
200L Wilson Lab Rt. 366 & Pine Tree Road  
Ithaca, NY 14853 – USA  
Phone: +1 (607) 255-7163 , +1 (607) 255-9001  
E-mail: [useradmin@mail.chess.cornell.edu](mailto:useradmin@mail.chess.cornell.edu)  
[www.tn.cornell.edu/](http://www.tn.cornell.edu/)

### CLIO - Centre Laser Infrarouge d'Orsay

CLIO/LCP  
Bat. 201 - P2  
Campus Universitaire  
91405 ORSAY Cedex, France  
[www.lcp.u-psud.fr/cliio/cliio\\_eng/cliio\\_eng.htm](http://www.lcp.u-psud.fr/cliio/cliio_eng/cliio_eng.htm)  
[www.lcp.u-psud.fr/cliio/cliio\\_fr/cliio\\_fr.html](http://www.lcp.u-psud.fr/cliio/cliio_fr/cliio_fr.html)

**CLS - Canadian Light Source**

Canadian Light Source Inc. University of Saskatchewan  
101 Perimeter Road Saskatoon, SK, Canada. S7N 0X4  
Phone: (306) 657-3500 - fax: (306) 657-3535  
E-mail: [clsuo@lightsource.ca](mailto:clsuo@lightsource.ca)  
[www.lightsource.ca](http://www.lightsource.ca)

**CNM - Center for Nanoscale Materials**

Argonne National Laboratory  
9700 S. Cass Avenue. Bldg. 440  
Argonne, IL 60439, USA  
Phone: (630) 252-2000  
<http://nano.anl.gov/facilities/index.html>

**CTST - UCSB Center for Terahertz Science and Technology**

University of California, Santa Barbara (UCSB), USA  
<http://sbfel3.ucsb.edu/>

**DAFNE Light**

INFN – LNF  
Via Enrico Fermi, 40, I-00044 Frascati (Rome), Italy  
fax: +39 6 94032597  
[www.lnf.infn.it/esperimenti/sr\\_dafne\\_light/](http://www.lnf.infn.it/esperimenti/sr_dafne_light/)

**DELSY - Dubna Electron SYNchrotron**

JINR Joliot-Curie 6 141980 Dubna, Moscow region, Russia  
Phone: + 7 09621 65 059 - fax: + 7 09621 65 891  
E-mail: [post@jinr.ru](mailto:post@jinr.ru)  
[www.jinr.ru/delsy/](http://www.jinr.ru/delsy/)

**DELTA - Dortmund Electron Test Accelerator**

**FELICITA I (FEL)**  
Institut für Beschleunigerphysik und  
Synchrotronstrahlung Universität Dortmund  
Maria-Goeppert-Mayer-Str. 2,  
44221 Dortmund Germany  
fax: +49-(0)231-755-5383  
[www.delta.uni-dortmund.de/home\\_e.html](http://www.delta.uni-dortmund.de/home_e.html)

**DFELL - Duke Free Electron Laser Laboratory**

Duke Free Electron Laser Laboratory  
PO Box 90319 Duke University Durham,  
North Carolina 27708-0319 USA  
Phone: 1 (919) 660-2666 - fax: +1 (919) 660-2671  
E-mail: [beamtime@fel.duke.edu](mailto:beamtime@fel.duke.edu)  
[www.fel.duke.edu/](http://www.fel.duke.edu/)

**Diamond Light Source**

Diamond Light Source Ltd  
Diamond House, Chilton, Didcot OXON OX11 0DE UK  
Phone: +44 (0)1235 778000 - fax: +44 (0)1235 778499  
E-mail: [dlsenquiries@diamond.ac.uk](mailto:dlsenquiries@diamond.ac.uk)  
[www.diamond.ac.uk/](http://www.diamond.ac.uk/)

**ELETTRA Synchrotron Light Lab.**

Sincrotrone Trieste S.C.p.A  
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34012 Basovizza, Trieste, Italy  
Phone: +39 40 37581 - fax: +39 (040) 938-0902  
E-mail: [useroffice@elettra.trieste.it](mailto:useroffice@elettra.trieste.it)  
[www.elettra.trieste.it](http://www.elettra.trieste.it)

**ELSA - Electron Stretcher Accelerator**

Physikalisches Institut der Universität Bonn  
Beschleunigeranlage ELSA, Nußallee 12,  
D-53115 Bonn, Germany  
Phone: +49-228-735926 - fax +49-228-733620  
E-Mail: [roy@physik.uni-bonn.de](mailto:roy@physik.uni-bonn.de)  
[www.elsa.physik.uni-bonn.de/elsa-facility\\_en.html](http://www.elsa.physik.uni-bonn.de/elsa-facility_en.html)

**ESRF - European Synchrotron Radiation Lab.**

ESRF 6 Rue Jules Horowitz BP 220, 38043 Grenoble  
Cedex 9 FRANCE  
Phone: +33 (0)4 7688 2000 - fax: +33 (0)4 7688 2020  
E mail: [useroff@esrf.fr](mailto:useroff@esrf.fr)  
[www.esrf.fr](http://www.esrf.fr)

**FELBE – Free-Electron Lasers at the ELBE radiation source at the FZR/Dresden**

Bautzner Landstrasse 128 – 01328 Dresden, Germany  
[www.fz-rossendorf.de/pls/rois/Cms?pNid=471](http://www.fz-rossendorf.de/pls/rois/Cms?pNid=471)

**FELIX - Free Electron Laser for Infrared eXperiments**

FOM Institute for Plasma Physics 'Rijnhuizen'  
Edisonbaan, 14 3439 MN Nieuwegein, The Netherlands  
P.O. Box 1207 3430 BE Nieuwegein, The Netherlands  
Phone: +31-30-6096999 - fax: +31-30-6031204  
E-mail: [B.Redlich@rijnh.nl](mailto:B.Redlich@rijnh.nl)  
[www.rijnh.nl/felix/](http://www.rijnh.nl/felix/)

**HASYLAB - Hamburger Synchrotronstrahlungslabor DORIS III, PETRA II / III, FLASH**

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Notkestrasse 85 22607 Hamburg, Germany  
Phone: +49 40 / 8998-2304 - fax: +49 40 / 8998-2020  
E-mail: [hasylab@desy.de](mailto:hasylab@desy.de)  
[www-hasylab.desy.de/](http://www-hasylab.desy.de/)

**HSRC - Hiroshima Synchrotron Radiation Center HiSOR**

Hiroshima University  
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739-8526 Japan  
Phone: +81 82 424 6293 - fax: +81 82 424 6294  
[www.hsrx.hiroshima-u.ac.jp/index.html](http://www.hsrx.hiroshima-u.ac.jp/index.html)

**iFEL**

Institute of Free Electron Laser Graduate School of Engineering, Osaka University  
2-9-5 Tsuda-Yamate Hirakata Osaka 573-0128 Japan  
Phone: +81-(0)72-897-6410  
[www.fel.eng.osaka-u.ac.jp/english/index\\_e.html](http://www.fel.eng.osaka-u.ac.jp/english/index_e.html)

**INDUS -1 / INDUS -2**

Centre for Advanced Technology Department of Atomic Energy Government of India  
P.O : CAT Indore M.P - 452 013 India  
Phone: +91-731-248-8003 - fax: 91-731-248-8000  
E-mail: [rvn@cat.ernet.in](mailto:rvn@cat.ernet.in)  
[www.ee.ualberta.ca/~naik/accind1.html](http://www.ee.ualberta.ca/~naik/accind1.html)

**IR FEL Research Center****FEL-SUT**

IR FEL Research Center, Research Institutes for Science and Technology  
The Tokyo University of Science, Yamazaki 2641, Noda, Chiba 278-8510, Japan  
Phone: +81 4-7121-4290 - fax: +81 4-7121-4298  
E-mail: [felsut@rs.noda.sut.ac.jp](mailto:felsut@rs.noda.sut.ac.jp)  
[www.rs.noda.sut.ac.jp/~felsut/english/index.htm](http://www.rs.noda.sut.ac.jp/~felsut/english/index.htm)

**ISA – Institute for Storage Ring Facilities****ASTRID-1**

ISA, University of Aarhus Ny Munkegade, bygn. 520 DK-8000 Aarhus C – Denmark  
Phone: +45 8942 3778 - fax: +45 8612 0740  
E-mail: [fyssp@phys.au.dk](mailto:fyssp@phys.au.dk)  
[www.isa.au.dk/](http://www.isa.au.dk/)

**ISI-800**

Institute of Metal Physics  
National Academy of Sciences of Ukraine  
Phone: +(380) 44 424-1005 - fax: +(380) 44 424-2561  
E-mail: [metall@imp.kiev.ua](mailto:metall@imp.kiev.ua)

**Jlab - Jefferson Lab FEL**

12000 Jefferson Avenue Newport News, Virginia 23606 USA  
Phone: (757) 269-7767  
[www.jlab.org/FEL](http://www.jlab.org/FEL)

**Kharkov Institute of Physics and Technology****Pulse Stretcher/Synchrotron Radiation**

National Science Center KIPT, 1 Akademicheskaya St., Kharkov, 61108 Ukraine  
Phone: 38 (057) 335-35-30 - fax: 38 (057) 335-16-88  
[www.kipt.kharkov.ua](http://www.kipt.kharkov.ua)

**KSR Nuclear Science Research Facility Accelerator Laboratory**

Gokasho, Uji, Kyoto 611  
fax: +81-774-38-3289  
[www.wal.kuicr.kyoto-u.ac.jp/www/index-e.html](http://www.wal.kuicr.kyoto-u.ac.jp/www/index-e.html)

**KSRS - Kurchatov Synchrotron Radiation Source Siberia-1 / Siberia-2**

Kurchatov Institute 1 Kurchatov Sq. Moscow 123182 Russia  
[www.kiae.ru/eng/wel/alb/illus6.htm](http://www.kiae.ru/eng/wel/alb/illus6.htm)

**LCLS - Linac Coherent Light Source**

Stanford Linear Accelerator Center (SLAC)  
2575 Sand Hill Road, MS 18 Menlo Park, CA 94025 USA  
Phone: +1 (650) 926-3191 -fax: +1 (650) 926-3600  
E-mail: [knotts@ssrl.slac.stanford.edu](mailto:knotts@ssrl.slac.stanford.edu)  
[www-ssrl.slac.stanford.edu/lcls/](http://www-ssrl.slac.stanford.edu/lcls/)

**LNLS - Laboratorio Nacional de Luz Sincrotron**

Caixa Postal 6192 CEP 13084-971 Campinas, SP Brazil  
Phone: +55 (0) 19 3512-1010 - fax: +55 (0)19 3512-1004  
E-mail: [sau@lnls.br](mailto:sau@lnls.br)  
[www.lnls.br](http://www.lnls.br)

**LURE - Laboratoire pour l'Utilisation du Rayonnement Electromagnétique**

Bât 209D Centre Universitaire Paris-Sud B.P. 34 - 91898 Orsay Cedex France  
Phone: +33 (0)1 6446 8000  
E-mail: [useroffice@lure.u-psud.fr](mailto:useroffice@lure.u-psud.fr)

**MAX-Lab**

Box 118, University of Lund, S-22100 Lund, Sweden  
Phone: +46-222 9872 - fax: +46-222 4710  
[www.maxlab.lu.se/](http://www.maxlab.lu.se/)

**Medical Synchrotron Radiation Facility**

National Institute of Radiological Sciences (NIRS)  
4-9-1, Anagawa, Inage-ku, Chiba-shi, 263-8555, Japan  
Phone: +81-(0)43-251-2111  
[www.lightsources.org/cms/?pid=1000161](http://www.lightsources.org/cms/?pid=1000161)

**MLS - Metrology Light Source**

Physikalisch-Technische Bundesanstalt  
Willy-Wien-Laboratorium  
Magnusstraße 9, ?12489 Berlin, ?Germany  
Phone: +49 30 3481 7312 ?- Fax: +49 30 3481 7550  
Email: [Gerhard.Ulm@ptb.de](mailto:Gerhard.Ulm@ptb.de)  
[www.ptb.de/mls/](http://www.ptb.de/mls/)

**NSLS - National Synchrotron Light Source**

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Brookhaven National Laboratory P.O. Box 5000, Bldg.  
725B Upton, NY 11973-5000 USA  
Phone: +1 (631) 344-7976 - fax: +1 (631) 344-7206  
E-mail: [nslsuser@bnl.gov](mailto:nslsuser@bnl.gov)  
[www.nsls.bnl.gov/](http://www.nsls.bnl.gov/)

**NSRL - National Synchrotron Radiation Lab.**

University of Science and Technology China (USTC)  
Hefei, Anhui 230029, PR China  
Phone: +86-551-5132231,3602034 - fax: +86-551-5141078  
E-mail: [zdh@ustc.edu.cn](mailto:zdh@ustc.edu.cn)  
[www.nsrll.ustc.edu.cn/en/enhome.html](http://www.nsrll.ustc.edu.cn/en/enhome.html)

**NSRR - National Synchrotron Radiation Research Center**

National Synchrotron Radiation Research Center  
101 Hsin-Ann Road, Hsinchu Science Park, Hsinchu  
30076, Taiwan, R.O.C.  
Phone: +886-3-578-0281  
E-mail: [user@nsrrc.org.tw](mailto:user@nsrrc.org.tw)  
[www.nsrrc.org.tw/](http://www.nsrrc.org.tw/)

**NSSR - Nagoya University Small Synchrotron Radiation Facility**

Nagoya University  
4-9-1, Anagawa, Inage-ku, Chiba-shi, 263-8555 Japan  
Phone: +81-(0)43-251-2111  
<http://nssr.xtal.nagoya-u.ac.jp>

**PAL - Pohang Accelerator Lab.**

San-31 Hyoja-dong Pohang Kyungbuk 790-784 Korea  
Phone: +82 562 792696 - fax: +82 562 794499  
<http://pal.postech.ac.kr/eng/index.html>

**PF - Photon Factory**

KEK 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan  
Phone: +81 (0)-29-879-6009 - fax: +81 (0)-29-864-4402  
E-mail: [users.office2@post.kek.jp](mailto:users.office2@post.kek.jp)  
<http://pfwww.kek.jp/>

**RitS Ritsumeikan University SR Center****MIRRORCLE 6X/MIRRORCLE 20**

Ritsumeikan University (RitS) SR Center,  
Biwako-Kusatsu Campus  
Noji Higashi 1-chome, 1-1 Kusatsu,  
525-8577 Shiga-ken, Japan  
Phone: +81 (0)77 561-2806 - fax: +81 (0)77 561-2859  
E-mail: [d11-www-adm@se.ritsumei.ac.jp](mailto:d11-www-adm@se.ritsumei.ac.jp)  
[www.ritsumei.ac.jp/acd/re/src/index.htm](http://www.ritsumei.ac.jp/acd/re/src/index.htm)

**SAGA-LS - Saga Light Source**

Kyushu Synchrotron Light Research Center  
8-7 Yayoigaoka, Tosu, Saga 841-0005, Japan  
Phone: +81-942-83-5017; fax: +81-942-83-5196  
E-mail: [riyou@saga-ls.jp](mailto:riyou@saga-ls.jp)  
[www.saga-ls.jp/english/index.htm](http://www.saga-ls.jp/english/index.htm)

**SESAME Synchrotron-light for Experimental Science and Applications in the Middle East**

E-mail: [hhelal@mailier.eun.eg](mailto:hhelal@mailier.eun.eg)  
[www.sesame.org.jo/](http://www.sesame.org.jo/)

**SLS - Swiss Light Source**

Paul Scherrer Institut reception building PSI West CH-  
5232 Villigen PSI Switzerland  
Phone: +41 56 310 4666 - fax: +41 56 310 3294  
E-mail: [slsuo@psi.ch](mailto:slsuo@psi.ch)  
<http://sls.web.psi.ch>

**SOLEIL**

Synchrotron SOLEIL  
L'Orme des Merisiers  
Saint-Aubin - BP 48 91192 GIF-sur-YVETTE CEDEX  
FRANCE  
Phone: +33 1 6935 9652 - fax: +33 1 6935 9456  
E-mail: [frederique.fraissard@synchrotron-soleil.fr](mailto:frederique.fraissard@synchrotron-soleil.fr)  
[www.synchrotron-soleil.fr/anglais/index.html](http://www.synchrotron-soleil.fr/anglais/index.html)

**SPL - Siam Photon Laboratory**

The Siam Photon Laboratory of the National  
Synchrotron Research Center  
111 University Avenue, Muang District, Nakhon  
Ratchasima 30000, Thailand  
PO. BOX 93, Nakhon Ratchasima 30000, Thailand  
Phone: +66-44-21-7040  
Fax: +66-44-21-7047, +66-44-21-7040 ext 211  
[www.nsrc.or.th/eng/](http://www.nsrc.or.th/eng/)

**Spring-8**

Japan Synchrotron Radiation Research Institute (JASRI)  
Kouto, Sayo-cho, Sayo-gun, Hyogo 679-5198, Japan  
Phone: +81-(0) 791-58-0961 - fax: +81-(0) 791-58-0965  
E-mail: [sp8jasri@spring8.or.jp](mailto:sp8jasri@spring8.or.jp)  
[www.spring8.or.jp/en/](http://www.spring8.or.jp/en/)

**SRC - Synchrotron Radiation Center**

Univ. of Wisconsin at Madison, 3731 Schneider Drive,  
Stoughton, WI 53589-3097 USA  
Phone: +1 (608) 877-2000 - fax: +1 (608) 877-2001  
[www.src.wisc.edu](http://www.src.wisc.edu)

**SSLS - Singapore Synchrotron Light Source****Helios II**

National University of Singapore (NUS)  
Singapore Synchrotron Light Source, National  
University of Singapore  
5 Research Link, Singapore 117603, Singapore  
Phone: (65) 6874-6568 - fax: (65) 6773-6734  
<http://ssls.nus.edu.sg/index.html>

**SSRC - Siberian Synchrotron Research Centre  
VEPP3/VEPP4**

Lavrentyev av. 11, Budker INP, Novosibirsk 630090,  
Russia  
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<http://ssrc.inp.nsk.su/>

**SSRL - Stanford Synchrotron Radiation Lab.**

Stanford Linear Accelerator Center, 2575 Sand Hill  
Road, Menlo Park, CA 94025, USA  
Phone: +1 650-926-4000 - fax: +1 650-926-3600  
E-mail: [knotts@ssrl.slac.stanford.edu](mailto:knotts@ssrl.slac.stanford.edu)  
[www-ssrl.slac.stanford.edu](http://www-ssrl.slac.stanford.edu)

**SRS - Synchrotron Radiation Source**

CCLRC Daresbury Lab.  
Warrington, Cheshire, WA4 4AD, U.K.  
Phone: +44 (0)1925 603223 - fax: +44 (0)1925 603174  
E-mail: [srs-ulo@dl.ac.uk](mailto:srs-ulo@dl.ac.uk)  
[www.srs.ac.uk/srs/](http://www.srs.ac.uk/srs/)

**Stanford Picosecond FEL Center**

USA  
[www.stanford.edu/group/FEL/](http://www.stanford.edu/group/FEL/)

**SuperSOR Synchrotron Radiation Facility**

Synchrotron Radiation Laboratory  
Institute for Solid State Physics,  
University of Tokyo  
5-1-5 Kashiwa-no-ha, Kashiwa, Chiba 277-8581, Japan.  
Phone: +81 (0471) 36-3405  
E-mail: [mailto:kakizaki@issp.u-tokyo.ac.jp](mailto:mailto:kakizaki@issp.u-tokyo.ac.jp)  
[www.issp.u-tokyo.ac.jp/labs/sor/project/MENU.html](http://www.issp.u-tokyo.ac.jp/labs/sor/project/MENU.html)

**SURF-II / SURF-III - Synchrotron Ultraviolet Radiation Facility**

NIST, 100 Bureau Drive, Stop 3460 Gaithersburg, MD  
20899-3460 USA  
Phone: +1 301 975 6478  
<http://physics.nist.gov/MajResFac/surf/surf.html>

**TNK \_ F.V. Lukin Institute**

State Research Center of Russian Federation  
103460, Moscow, Zelenograd  
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Fax: +7(095) 531-4656

**TSRF - Tohoku Synchrotron Radiation Facility  
Laboratory of Nuclear Science**

Tohoku University  
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E-mail: [koho@LNS.tohoku.ac.jp](mailto:koho@LNS.tohoku.ac.jp)  
[www.lns.tohoku.ac.jp/index.php](http://www.lns.tohoku.ac.jp/index.php)

**UVSOR - Ultraviolet Synchrotron Orbital Radiation Facility**

UVSOR Facility, Institute for Molecular Science,  
Myodaiji, Okazaki 444-8585, Japan  
[www.uvsor.ims.ac.jp/defaultE.htm](http://www.uvsor.ims.ac.jp/defaultE.htm)

**VU FEL – W. M. Keck Vanderbilt Free-electron Laser Center**

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Nashville, TN 37235 USA  
[www.vanderbilt.edu/fel/](http://www.vanderbilt.edu/fel/)