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International Atomic Energy Agency

Coordinated Research Project on

Application of 3D Neutron Imaging and Tomography in Cultural Heritage Research

Report of the first Research Co-ordination Meeting

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1. FOREWORD

Heritage is our legacy from the past, what we live with today, and what we pass on to future generations. Our cultural and natural heritages are both irreplaceable sources of life and inspiration. Places as unique and diverse as the wilds of East Africa's Serengeti, the Pyramids of Egypt, the Great Barrier Reef in Australia and the Baroque cathedrals of Latin America make up our world's heritage. What makes the concept of World Heritage exceptional is its universal application. World Heritage sites belong to all the peoples of the world, irrespective of the territory on which they are located.

Neutron based techniques, particle induced X-ray- as well as ion probe principles play an important role in both applied research and practical applications. Today, various experimental setups of neutron techniques can be used effectively for imaging purposes. Moreover, recent developments of X-ray methods, which are used primarily for medical applications, like diagnostics or treatment (e.g. X-ray based computer tomography, tomotherapy, image guided radiotherapy, etc.), use advanced imaging principles. However, these techniques do not offer directly analysis of elemental composition of studied entities. On the other hand, non-destructive X-ray fluorescence techniques are often applied for trace element determination but this technique provides information on the surface layers but not on the bulk composition of the samples. In other cases, techniques like Nuclear Magnetic Resonance (NMR) cannot be used, for instance due to the presence of magnetic components in studied samples. Generally, none of the above listed methods can offer bulk elemental analysis. This type of study can be done by the so called large sample neutron activation analysis; however, this technique is not fully developed for imaging purposes. Other neutron techniques, like prompt gamma neutron activation analysis, neutron diffraction or neutron resonant capture analysis, also do not offer all advantages of neutron interactions with matter. From this point of view more complex and sophisticated techniques have to be developed in order to guarantee effective integration and/or simultaneous applications of particular tools. The key application of neutron imaging techniques is foreseen for non-invasive studies on objects from cultural heritage importance, where this tool can bring valuable information. Various research groups as well as potential end-users have been identified and a number of research teams among many Member States are interested in this kind of R&D. Hence these kinds of analytical capabilities are needed, particularly based on bulk-composition and image analysis.

2. EXECUTIVE SUMMARY

Experts from the participating IAEA Member States presented their individual reports on their activities on Neutron Imaging (NI) as well as on Cultural Heritage (CH) studies. The participants also presented an overview of their facilities, ranging from conventional to advanced, and their plans for implementing or improving NI.

From the presentations of the delegates it is evident that the current existing NI technology provides a unique non-destructive bulk analytical capability to the CH community. This technology entails 2-dimensional and 3-dimensional results, and is available at about 16 well equipped facilities throughout the world.The presentations also reported new techniques under development in NI which will be capable to further support the needs expressed by the CH community. These techniques expand the capability of the existing NI technology in the field of structural, chemical and elemental analysis.

The CH-community favours non-invasive techniques to characterize their research objects, which include irreplaceable unique findings recovered from Archaeological-, Palaeontologic-, Human evolution- and Historical sites. Answers needed include identification of ancient manufacturing technology, detection of hidden features and objects, mensuration, authentication, provenance and identification of the best ways of conservation, etc.

The experts welcome the initiation of a CRP to harmonize selected Neutron-based Imaging techniques in order to provide state-of-the-art end user services in the area of CH research. The CRP promotes NI technology utilization in all Member States, especially those in developing countries in order to encourage exploitation of all types of neutron sources for NI through CH research activities. These activities will establish and strengthen collaborations between the NI specialists and researchers from the CH community beyond the 3-year lifetime of this project.

Standardization procedures and methodologies were addressed to achieve synergy among participating laboratories / facilities. This will be enhanced through the development of a database of standard NI-services and solutions, which are typically applied in CH-research. Other enhancements of NI capabilities will be achieved through benchmarking and improvement of available software for data-analysis and simulation.

The CRP members agreed on the importance of continuing communication through web-based portals and workshops. Results related to this CRP will be published in scientific literature, presented at scientific conferences and included in final member state reports within the final report document at the end of this CRP.

A detailed roadmap for the first year activities of this 3-year CRP was developed over the course of the first RCM.

3. INTRODUCTION

The IAEA as a leading supporter of the peaceful use of nuclear technology assists laboratories in its Member States to apply and develop nuclear methods for cultural heritage research for the benefit of socio-economic development in emerging economies. The Agency had in the past initiated several projects to support the application of nuclear techniques for cultural heritage investigations and as a result of a recently completed coordinated research project (CRP) on "Applications of nuclear analytical techniques to investigate the authenticity of art objects", and building up on the expertise of the dedicated experts, decided to compile a technical document to highlight the role of nuclear techniques for cultural heritage research. Although the principle of neutron imaging in this CRP was demonstrated, the art of neutron imaging and the scientific value the technique can offer to the CH community was not demonstrated to its full capacity.

This proposed new IAEA coordinated research project (CRP) aims to provide an advanced and scientifically comprehensive neutron based imaging approach which will be implemented for the imaging of elemental composition of various objects especially focused on end-user applications. These include mostly objects related to cultural history such as archaeological-, geological- and palaeontological artefacts. It is expected that this CRP will stimulate and enhance the utilization of nuclear research reactors and accelerator driven neutron sources as well as the interest of end users from non-nuclear research fields. Moreover, it will also enhance the scientific interaction and direct exchange of experiences between the participating countries in neutron imaging and appropriate dissemination of achieved results and conclusions. It is expected that the CRP activities will also stimulate and foster the scientific front-research in novel and advanced neutron based technology. The development and harmonization of methodologies are also expected to contribute to continuous improvement of quality control (QC) methods in the participating Member States.

The meeting was opened by Mr. Andrej Zeman, Scientific Secretary of the Coordinated Research Project (CRP), he welcomed all CRP members. Afterwards, Mr. Daud Mohammad, IAEA Deputy Director General of Nuclear Sciences and Applications addressed his opening remarks. Then, the director NAPC, Ms. Meera Venkatesh welcomed all CRP members. The opening was concluded by short comments of Mr. M. Haji-Saeid (Section Head NAPC/IACS) and Mr. R.Kaiser (Section Head NAPC/PS) who briefly commented the new CRP and its overall objectives. The participants accepted having the meeting chaired by Mr. FC de Beer (South Africa), whereas Mr. M Lerche (USA) was accepted as the rapporteur.

4. CRP OBJECTIVES

4.1. Objectives of the CRP

The specific research objectives are:

- Adopt Neutron Imaging(NI) technology to enhance its utilization in Cultural Heritage (CH) research activities
- Establish the necessary standardization procedures and methodology to achieve synergy among participating laboratories / facilities
- Strengthen collaboration amongst NI specialists as well as between researchers from NI and CH.
- Develop a database of standard NI services for CH needs
- Evaluate available software for data-analysis and simulations, and develop new software if needed.

Anticipated research outputs (but not limited):

- Enhanced awareness and effective utilization of NI methods by CH end users
- Availability of necessary procedures and methodologies, which will be used by NI laboratories/facilities.
- Intensified collaboration between the NI and CH communities
- Availability of a database on NI services applicable for CH research
- Results of benchmarking on software for data-analysis and simulations.
- Data / information on the design and up grading of existing NI facilities for the purpose of CH research.

The expected outcome of this IAEA Coordinated Research Project is:

- Capability building and effective use of NI in member states.
- Availability of innovative nuclear methodology for specific applications.
- Effective collaboration between participating member states.
- An enhanced capacity to use NI directly for samples of relevance to the CH community.
- Guidelines on infrastructure, technology and trained staff for implementation and utilization of NI facilities in participating member states.
- Broader and deeper awareness of NI as a unique tool in CH studies.
- Increased number of publications as reflected in the proposed database.

4.2. Objectives of 1st RCM meeting

The following are the objectives of the first RCM.

- To review the plan of each participant and the anticipated progress in the framework of the CRP.
- To establish and stimulate new collaborations between member states.
- To establish a mode of communication.
- To examine the possibilities of reaching the objectives of the CRP
- To evaluate the possibility for benchmarking.
- To initiate the development of standardized procedures.
- To initiate the development of a database.

4.3 Working groups:

The executive part of the RCM was organised in the form of working groups (WG). The experts of the RCM meeting discussed a broad range of issues, including the following topics in separated WG's : The topics and responsible coordinators of the WGs are listed below:

(a) Neutron Imaging facilities (WG coordinator: Mr. Jasec Milczarek)
(b) Cultural Heritage (WG coordinator:: Mr. Kilian Anheuser)
(c) Autoradiography with neutrons (WG coordinator: Mr. Frikkie de Beer)
(d) Software (WG coordinator: Mr. Ulf Garbe)
(e) New Methods (WG coordinator: Mr. Nikolay Kardjilov)
(f) Newcomer soft-and hardware (WG coordinator: Mr. Burhard Schillinger)

The following paragraphs describe the basic discussion points within each of the WG's:

4.3.1. Communication with the cultural heritage community (Group Leader: Mr Kilian Anheuser)

Efficient communication between neutron imaging and cultural heritage communities represents a key element to the success of the CRP. Whilst certain CRP participants have already ongoing collaborative projects, others find themselves still at the point of having to establish a network that reaches out beyond the neutron imaging community. Discussion has shown that many successful partnerships have been established through informal, personal transdisciplinary contacts prior to a formal consultation process, underlining the importance of personal networking. Practical experience has shown that in the absence of established personal contacts a promising approach will be to contact groups of people rather than individuals, for example through presentations at conservation or archaeological conferences.

The following cultural heritage target groups have been identified:

- University or museum scientists in archaeometry or conservation science. These can act as mediators and multipliers, promoting further contacts with collection holders.

- Conservators in museums or associated with archaeological projects. These have the advantage of being scientifically trained and with an intimate knowledge of their objects, enabling them to formulate specific conservation or technology questions to be addressed by scientific analysis. A disadvantage may be that in many institutions these important objects specialists are placed at a relatively low hierarchical level. The ConsDist discussion list hosted by the American Institute for Conservation is being read by thousands of conservators worldwide and represents an excellent platform to promote and publicize the present CRP.

- Curators in charge of museum collections. Whilst these people hold responsibility for their collection and need to be approached for approval of any analytical project anyway, they often have a very limited understanding of scientific issues.

- Archaeologists in charge of an excavation. For the investigation of archaeological material it is often easier to be associated directly with an excavation rather than work on existing archaeological collections. Advantages include the fact, that excavation projects include post-excavation conservation treatment and analysis anyway. Neutron imaging may be relatively easily associated with this procedure.

Contacting those responsible for university degrees in archaeometry, where existing, also appears to be a promising option for establishing useful contacts as well as to communicate to future young researchers the possibilities of neutron imaging of cultural objects.

Museums may be interested in using tomographic images for their permanent or temporary exhibitions, benefitting from the high visual impact and the intuitive accessibility of these images to the general public and other non-specialists.

Neutron imaging institutions with a track record of successfully completed cultural heritage projects feel that most efficient use of existing resources is often achieved in smaller size projects where after image acquisition by the research institutions image processing is carried out by users, typically postgraduate or postdoctoral researchers, specifically trained for the purpose. Major grant applications are often disadvantaged by the fact that in many countries scientific analysis of cultural heritage objects does not fall into the remit of any particular category established by grant-providing authorities.

There still exists a widely perceived gap between natural scientists and researchers in the humanities (art history, archaeology, ethnography etc.), resulting in misunderstandings and general lack of communication. Participants in the present CRP are invited and encouraged to take steps to bridge this gap by informing themselves about the cultural background of the objects under investigation, conservation ethics and approaches, as well as alternative analytical methods to their own which may complement neutron imaging. This concerns specifically X-radiography, a technique many conservators and archaeologists are familiar with, and which should always be considered first, before neutron imaging is attempted. Suggested reading to all CRP members includes books by Janet Lang and Andrew Middleton, Radiography of Cultural Material, Butterworth-Heinemann 2nd ed. 2005, Sonia O'Connor and Mary Brooks, X-Radiography of Textiles, Dress and Related Items, Butterworth-Heinemann 2007, or for a more general overview Paul Craddock, Scientific investigation of Copies, Fakes and Forgeries, Butterworth-Heinemann 2009. An introductory must-read for any scientist working on archaeological material would be Janet M. Cronyn, Elements of Archaeological Conservation, Routledge 1990. CRP members are unlikely to establish themselves successfully in the field unless they make a significant effort to learn about working practices in conservation and the science-based investigation of works of art and archaeological finds.

A table with current scientific probes that are being utilised in CH research is being proposed within the Data-base hosted by the International Society for Neutron Radiology (ISNR). www.isnr.de

4.3.2 Autoradiography (Group Leader: Mr. Frikkie de Beer)

For the better understanding of the content, manufacturing or state of conservation of cultural heritage objects museums routinely apply analytical methods and techniques beyond stylistic and historical considerations derived from comprehensive studies of historical sources [1]. There is one essential difference between the analysis of ancient and modern objects in that an objector of ancient artefact is unique; hence, sampling and thus destructive testing is mostly prohibited. Accordingly, the ideal form of analysis would be non-destructive and non-invasive. Many museums regularly use methods based on the use of X-rays, infrared radiation, or UV light. X-ray transmission images indicate the distribution of heavy elements such as lead, e.g.in the pigment lead as white due to absorption of X-rays. Neutron activation autoradiography is able to provide complementary and further information about the painting as neutrons have a high penetration depth as well as being absorbed and scaterred more by light elements : this allows the visualization of structures and layers under the visible surface of paintings and, in addition, enables the identification of the elements contained in the pigments [2]. Often even the individual brush stroke applied by the artist can be made visible, and in addition changes and pentimenti –e.g. a small modification in the position of a hand – introduced during the painting process can be identified as well. The analysis of paintings, which have been reliably authenticated, allows the recognition of the styleor‘‘hand’’of aparticular artist. It is a very effective, non-destructive, but rather an exceptional method..

The need for technology transfer from developed countries with existing facilities for Autoradiography of paintings through neutron activation are being expressed by the South Africa Cultural Heritage community, backed by counterparts in Berlin, to make technology transfer possible. A research program to install such a facility at the neutron radiography facility in South Africa is being envisaged and defined by the CRP.

The immediate aim is to establish an Autoradiography facility, utilizing neutrons, in South Africa. Through thorough description of the needed experimental conditions, set-up and evaluation methodologies, this CRP strives to make the technology available to any member state country who which to impliment similar infrastructure and apply scientific evaluation of paintings in the same manner.

The list of steps to be taken to implement the technology are shortly outlined here:

- Full description of methodologies (reference to previous work)
- Creation of a standardized procedure for AR
- Evaluation of Radiation damage of paintings in a neutron beam (with(out)) gammas.
- Description, evaluation and upgrade initiative for infrastructure development to accommodate paintings.
- A cost evaluation is to be made for the implementation of a experimental bay at the SANRAD facility.
- Clarification of related aspects in the handling of paintings (some national regulations to be followed): (1) Transport to and from SANRAD from Museums and (2) Insurance involved in transport.

The work plan is specified in following steps

- Perform a literature survey and obtain all current proven and available information (Published papers and conference proceedings) on the topic of Autoradiography (with X-rays and Neutrons). Within the description, the following will be addressed:
    - Evaluationof the neutron beam properties ideal for AR
    - Investigation of neutron and gamma damage of pigments that can occur during neutron bombardment.
    - Description of the instrumental and experimental setup
    - Description of the analytical techniques used until date to perform the evaluations
- Evaluation on a Dummy sample at an already established facility in Europe.
    - Development (obtaining current “dummy” sample from FRM-II)
    - Input from CH community in appropriate pigments to be tested
    - Irradiation of pigments / dummy and measurement of radiation damage
- Implementing infrastructure at the SAFARI-1 SANRAD facility
- Report
- Practical verification

Main objective	Sub objectives	Year 1				Year 2				Year 3			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Establish an Autoradiography facility with neutrons in SA	Gather info about technique	X	X	X									
	Preparation (obtain) DUMMY test sample	X	X										
	Overseas visit for hands on experience @ European facilities ON DUMMY				X								
	Theoretical evaluation of Gamma ray and neutron damage of paintings			X	X	X	X	X	X				
	Report on Damage investigations								X				
	Infrastructure development					X	X	X	X	X			
	Infrastructure implementation									X	X	X	
	FULL WORKING AR FACILITY												X

4.3.3 Software (Group Leader: Mr. Ulf Garbe)

Software development for neutron imaging

The main goal is to establish a platform for development and discussion of software related neutron imaging problems, solution or ideas. The ISNR web site is being proposed.

Setup web page

Offer a collection of free neutron imaging software distributed through the web page
First input to external developed free software expected from
FRM2 ->Burkhard Schillinger, UC Davis (Oliver Kreylos?), Keckcaves.org?, FIJI,
Yoshiaki Kiyanagi combined Imaging and Rietveld?

First internal developed software is expected to be available end 2013 as a beta version.

Developer environment for reconstruction

– define code of ethics for using the platform (seek for legal advice)
– mailing list of registered developer, setup discussion forum (web based)
– mailing list available to registered developer

Start different development platforms:

– Matlab based (Bragg-Edge scanning ANSTO)
– C/C++ based (open)
– IDL based (FRM II?)

Registration of developer through email address and password

Create a generic dataset

Set of different data with certain amount of white spot, rings, tilted rotation axis is required. In addition noisy data and limited projection should be available to develop and test new reconstruction algorithms.

4.3.4. New Methods in NI (Mr. Nikolay Kardjilov)

New methods

Neutron imaging is a non-destructive investigation method with a fast growing application field in materials research and fundamental science. The method is used broadly in the cultural heritage research as complementary technique to X-ray imaging. However, the ability of neutron beam to transmit thick layers of metal and the sensitivity to light elements make the technique unique for detection of organic substances, or even water, in metal and/or stone matrices. Owing to the high penetration power of neutrons, large thick samples, with real dimensions up to about 100 cm^3 can be easily investigated. In Cultural Heritage (CH) artefacts, neutron imaging helps to provide information about manufacturing processes and material properties which is very important for further restoration and conservation of the objects. The development of new methods, like for example energy selective imaging, grating interferometry, laminography and the application of imaging with fast neutrons, increase the potential of the method for characterization of CH samples.

A. Energy selective imaging

For polycrystalline materials, the neutron attenuation coefficient decreases suddenly for well-defined neutron wavelengths where the conditions for Bragg scattering are no more fulfilled – the so-called Bragg edges. Therefore, the position of the Bragg cut-off is related to the corresponding d_{hkl} spacing. In addition, the shift of the Bragg-edge can be used to detect the presence of residual stress in metallurgical samples. Finally, the height of the Bragg edge can be related to the presence of texture, and the shape of the edge depends on the grain size.
Three techniques for beam monochromatisation will be used. Double crystal monochromator (DCM) and velocity selector (VS) will be used at steady neutron sources (reactors) while Time of Flight (TOF) technique will be used at pulsed sources. In the first case, the wavelength resolution $\Delta\lambda/\lambda$ varies between 3 and 10 % (DCM) and between 10 and 30 % (VS), while in case of TOF a resolving power $\Delta\lambda/\lambda \sim 10^{-3}$ can achieved, which is sufficiently accurate to detect residual stresses in samples with simple geometries.

Facility	Technique	Application	Partners
HZB	Double crystal monochromator, Velocity selector	Phase separation (metal alloys, geology) Contrast enhancement Quantification	IBR2, Sofia University,
FRM2	Double crystal monochromator, Velocity selector	Phase separation Contrast enhancement Quantification	
PSI	Double crystal monochromator, Velocity selector, TESI	Phase separation Contrast enhancement Quantification	CNR Uni Zuerich (knifes)?
J-PARC (Hokkaido University)	TOF	Residual stress, Texture Resonance imaging Phase separation Quantification	CNR(certified samples, Fe, Cu, mechanical treatment)
CNR (ISIS)	TOF	Residual stress Texture Crystallographic domain size Phase separation Quantification	J-PARC PSI (Uni Zuerich)
IBR2	TOF	Residual stress Phase separation Quantification	HZB, INR

The energy-selective imaging method allows performing Bragg-edge mapping. Depending on the achieved energy resolution, by the applied monochromatizing technique, different applications are possible:

- *residual stress and texture mapping* – requires high energy resolution $\Delta\lambda/\lambda$ (better than 1 %) which is possible only by TOF technique. This method provides 2D mapping of residual stresses and textures in objects with simple geometries (e.g. thin plates) at moderate resolution (in the range of few millimetres). The technique can be applied on metallic samples: archaeological bronze and iron.

- *phase separation and segregation* – requires moderate energy resolution $\Delta\lambda/\lambda$ (between 1 % and 10 %) which is possible using the double-crystal monochromator or the TESI device. This method provides 3D mapping of phase distribution and segregation in alloys. Variation of elemental concentration in bronze and other alloys could be visualized in 3D. The technique can be applied on bronze samples.
- *contrast enhancement* - requires coarse energy resolution $\Delta\lambda/\lambda$(larger than 10 %) which is possible by a velocity selector. This method provides contrast enhancement in radiographic and tomographic images (e.g differentiate between Cu and Fe in a multi metal sample, or even distinguish between different crystal phases of the same metal). The method can be applied in investigation of complex metal samples.

Applications: Connection to materials science and geology emphasizing the materials characterization.

B. Residual stress, texture mapping:

Samples: ANSTO – set of Al single crystals exposed at different loading conditions for examining of texture, HZB can provide a tensile loading frame

Facilities: J-PARC, CNR(ISIS), IBR2

C. Phase separation and segregation in 3D:

Samples: CNR can provide dendritic bronze samples, PSI will contact the external partners from Zürich University to provide bronze knifes (dummy samples), University of Sofia can provide bronze certified samples

Facilities: HZB, PSI, FRM2

Reference diffraction measurements can be performed at INES(ISIS) and ANSTO

D. Grating interferometry

If a neutron beam has a high spatial and temporal coherence an interferential pattern can be observed at a certain distance behind a phase grating. The structure of the pattern which is beyond the spatial resolution of imaging detectors can be resolved by transverse scanning of an analyser grating through the beam. The presence of a sample distorts the interference pattern locally, as shown in Fig. 1. The spatially resolved detection and analyses of the pattern reveals information about phase effects, small angle scattering and attenuation introduced by the sample. These three signals can be extracted and analysed independently and provide a unique suite of complementary information about the sample material. Rotating the sample and collecting projections at different angles – a tomographic 3D reconstruction of the three signals is possible.

The grating interferomery can be used for investigation of micro and nano heterogeneity of structures in the scale range of 0.1 µm to 10 µm. The goal of the project will be the visualization of microstructural changes in metallurgical samples (archaelogical bronzes and iron). The method can be used for revealing hidden inscriptions on metal plates.

Facility	Technique	Application	Partners
HZB	Grating interferometry (dark-field)	Microstructure in metals, glass and geological samples	
FRM2	Grating interferometry, Phase contrast	Microstructure in metals, glass and geological samples	
PSI	Grating interferometry Phase contrast	Microstructure in metals, glass and geological samples	

Applications: Detection of variation of the carbon content and inclusions in steel/iron, characterization of geological samples and revealing of hidden inscriptions in metals.

E. Microstructure in metals, glass and geological samples:

Samples: archaeological iron samples and Cu coins. CNR and University of Zürich could provide bronze samples. Marble samples can be provide after establishing contact to external experts (Lorenzo Lazzarini – Venice and Bernd Leiss – University of Goettingen)

Facilities: HZB, PSI, FRM2

Reference (U)SANS measurements can be performed at ATI.

F. Laminography

The computed laminography (CL) is developed as a method for high-resolution threedimensional (3D) imaging of regions of interest (ROIs) in all kinds of laterally extended samples. In comparison to computed tomography (CT), the method is based on the inclination of the tomographic axis with respect to the incident neutron beam by a defined angle. With the sample aligned roughly perpendicular to the rotation axis, the integral neutron transmission on the two dimensional (2D) detector does not change exceedingly during the scan. As a consequence, the integrity of laterally extended samples can be preserved. In this respect, CL appears as technique well distinguished from CT, where in some cases ROIs have to be destructively extracted (e.g. by cutting out a sample) before being imaged.

Facility	Technique	Application	Partners
HZB	Laminography and local tomography	Large or flat samples	
FRM2	Laminography and local tomography	Large or flat samples	

Applications: Investigation of large or flat samples.

Laminography and local tomography:

Samples: CNR

Facilities: HZB, FRM2

G. Imaging with epithermal and fast neutrons

The imaging with fast neutrons can be used for tomography investigation of bulky samples, which are difficult to image by thermal neutrons, or even gamma rays. The epithermal neutrons, thanks to their extremely large penetration power, can be used for resonance imaging owing to the selective absorption power of single elements (resonant capture) occurring at a well determined neutron energy. In this case contrast variations becomes possible, also thanks to isotopic substitution.

The method is suitable to investigate complex multi metal samples or organic samples (e.g. wood) covered by metal sheets.

Facility	Technique	Application	Partners
CEADEN	TOF	Resonance imaging	
J-PARC	TOF	Resonance imaging	
FRM2	Continuous source	Tomography with fast neutrons	

Applications: Bulky samples and contrast enhancement in metal samples.

H. Resonance imaging and tomography:

Samples: Wooden samples shielded by metals (CEADEN, CNR)

Facilities: JPARC, FRM2, CEADEN, IBR2

5. OVERVIEW OF INDIVIDUAL RESEARCH PROGRAMS

5.1. Mr Ulf Garbe (Australia)

Introduction

With the ability to analyze and visualize local resolved texture by neutron imaging a great tool is created for better understanding of the history of the material (cultural heritage sample). It is important knowledge for any kind of manufactured material like jewelry, weapons, sculpture … as the texture shows the manufacturing history. In addition archeological samples embedded in rocks and stones will show the history of the environment in terms of deformation, sedimentation and metamorphosis conditions. All the texture information is available nondestructive and in combination with the real space 3D model. In order to establish texture imaging by neutron radiation, the method has to be developed and tested from simple basic textured material (single crystal and single phase) in small steps to more advanced systems like rolled or recrystallizes metal samples and finally geological samples with multiphase systems and large variation in grain size.

A set of wavelength dependent neutron radiography images under certain orientations is needed to calculate the ODF and understand the texture. To determine the sufficient number of single images for ODF calculation several test materials with different known textures are required. This has to be developed in an iterative process from single crystal orientation to polycrystalline multiphase and multitexture material as especially geological samples represent the most complex textures.

As an important outcome a user-friendly software package should be available which should be tested at different facilities with different type of samples. Consistent results from these facilities are strongly required to encourage the cultural heritage community in accepting the method. The typical end user has only basic knowledge of texture and neutron imaging and has to rely on the correctness of the measurement and analyses.

Experimental facility

The new neutron imaging facility DINGO at the OPAL reactor at ANSTO is currently in the construction phase. Completion of the construction phase and start hot commissioning phase with first friendly user commences begin 2013. The general instrument characteristics are based on Monte Carlo simulations by McStas.

Neutron beam characteristics:

- L/D: 500 – 1000
- Flux at sample position: 4.75 x 10^7 n/scm^2
- Beam size: 100 x 100 mm^2 and 200 x 200 mm^2

Specification of DINGO facility
Flight tube Helium filled
Sample stage:

- xyz-travel length: 400mm
- Load: 500kg

Detector:

- IKON-L water-cooled 2048 x 2048 pixel
- Set of different size scintillator screens

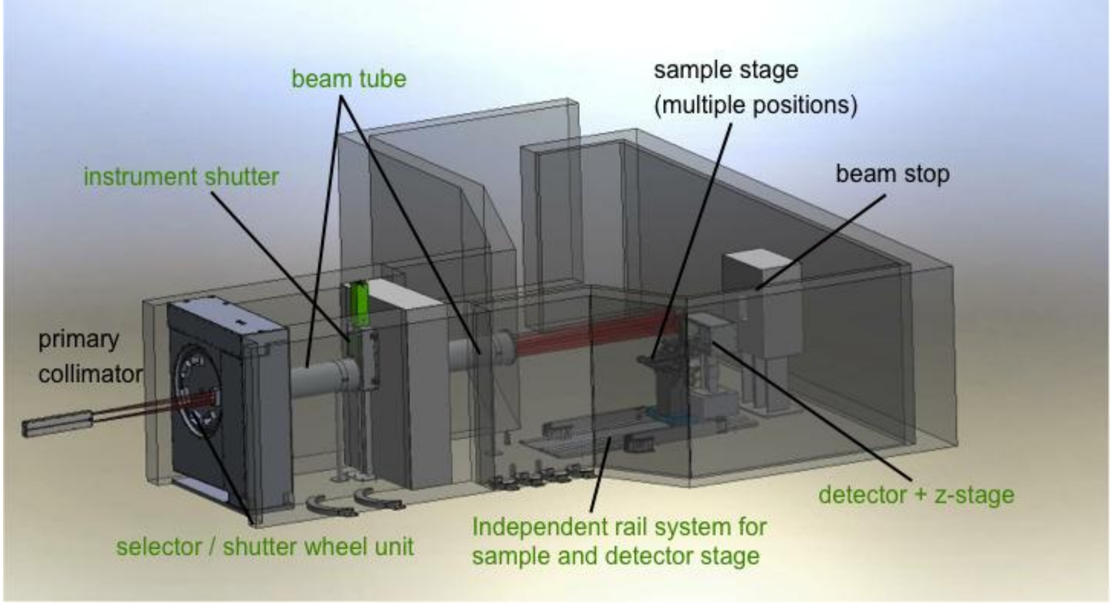


Figure 1 – Schematic view of DINGO facility

Workplan year1:

- Finalize the DINGO imaging station and commence hot commissioning phase with first friendly users
- Start a PhD thesis and hire candidate on texture analyses by neutron imaging Bragg-edge scanning method in cooperation with Helmut Scheaben (Geomathematics and Geoinformatics, TU Bergakademie Freiberg, Germany)
- Develop first theoretical model to describe the texture analysis by Bragg-edge scanning method
- Define set of test sample with known texture (single crystal, large crystal polycrystalline material and strong textured polycrystalline material)
- Apply for beam time at PSI and/ or HZB, FRM II for first test measurements
- Simulate time of flight setup for the neutron imaging instrument DINGO at OPAL as feasibility study to prepare a capital investment case

Main objective	**Sub objectives**	**Year 1**				**Year 2**				**Year 3**			
		Q1	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Build DINGO facility for neutron imaging	Installation of instrument components	X	X										
	Cold commissioning			X	X								
	Hot commissioning					X	X						
Upgrade to TOF neutron imaging	Planning, prepare capital investment case			X	X								
	Design phase					X	X						
	Procurement							X	X				
	Installation								X	X	X		
	Commissioning										X	X	
	Hand over and first experiments											X	X
Software development	Initiate open source platform		X										
	Start PhD project and looking for a candidate on texture analyses by Bragg-Edge scanning neutron imaging		X	X	X								
	Develop theoretical model				X	X	X	X					
	Define set of test samples				X	X							
	Develop first software package for simple textures						X	X	X	X	X		
	Relase software package											X	X

5.2. Mr Fernando Sánchez (Argentina)

Introduction
In Argentina exists a community of researchers of national institutions involved in CH studies and also periodic congresses about the topic since 2007. A new group on neutron imaging is beginning at Bariloche Atomic Center (CNEA).

Experimental facility:
This group consist at the moment by 3 researchers and a working facility with the following characteristics:

- Thermal neutron intensity: 8.6 E6 n/cm^{2}s
- Size of the beam: 20 x 20 cm^2
- L/D: 100 (geometric)
- Filter: 5 cm sapphire (to be changed to 15 cm)
- Radiographic system: scintillating screen ZnS(Ag)+6LiF, cooled CCD camera, lenses 0.95/25 mm and two mirror reflection.
- Useful space: 40x40x40 cm^3 and two ports for long samples (20x20 cm^2)
- Software: Viewfinder and Studio of Pixera Corp., ImageJ and MatLab.

Workplan year 1:
The plan of this group is :
- Characterize the facility: flux, doses, collimation, etc.
- Establish contact with CH researchers for offering neutron imaging
- Demonstrate capabilities of the techique with 2D imaging.
- In the future, will be developed a 3D tomography improvement.

Other participants suggest to change the scintillating screen by one that emits in green, and other offers his expertise for helping the group.

Main objective	Sub objectives	Year 1				Year 2				Year 3			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Characterization of facility	Measure main parameters (flux, L/D, etc)	X	X										
	Radiological aspects		X	X									
	Optimization (if necessary)				X								
Contact with end users	Visit to conservators and researchers	X	X	X	X	X	X	X	X				
	Radiography of samples			x	X	X	X	X	x	x	x		
	Feedback				x	x	x	x	X	x	x	x	x

5.3. Mr Reynaldo Pugliesi (Brazil)

Introduction

The neutron imaging is a set of non - destructive testing techniques commonly employed to inspect the internal structure of objects. Because of the neutron - matter interaction characteristics, these techniques are largely employed to inspect hydrogenous substances (water, organic fibers, adhesives, etc) even wrapped by thick metal layers. The Brazilian culture is surrounded by a rich cultural heritage, mainly left by Indians and slaves. Many of the old objects and tools they have used, were manufactured by using clay, wood, organic fibers as well as bones. These materials and the ones used for their restoration are manufactured of several types of hydrogenous substances and hence the use of neutron imaging techniques are very adequate to study such objects.

The neutron imaging activities at IPEN - CNEN/SP began in 1988 and the primary objective of the working group was to design and to construct an operational facility for neutron imaging, to be installed in the beam-hole - 08 of the 5MW IEA-R1 Nuclear Research Reactor. From 1992 to 1997, the group has developed several 2D imaging techniques.

Experimental facility:

By early 2009 three new imaging techniques to inspect objects with thickness in the range of micra, and three digital systems for image processing were also developed. In the period (1988-2009) four MSc and three PhD theses have been advised by using this same neutron imaging facility. In October 2009 we have installed a neutron tomography setup in the same imaging system which was operational in October 2010. In 2011 the system was transferred to the beam-hole 14 of the same reactor. The new neutron beam is basically defined by a neutron collimator having 3m in length and ~10cm in diameter and by polycrystalline bismuth filters for gamma radiation. The figure 1 shows the external shielding of such system consisting of borated – poly(green) and by a 4tons beam catcher(gray). The characteristics of the neutron beam at the irradiation position and the present 2D imaging techniques available to inspect objects are shown in Tables 1 and 2 respectively.

Table 1. Characterisation of the neutron beam

Beam geometry	Divergent
Flux($ns^{-1}cm^{-2}$)	$8x10^6$
Mean Energy(meV)	7
Beam diameter(cm)	10-15

Table 2. Available techniques for 2D neutron imaging

Detector system	**Processing System**	**Irrad. Time (s)**	**Spatial Resol. (μm)**
X-ray – Gd	Scanner Microscope	20	70
SSNTD – B	Scanner Microscope	900	30 – 50
Video camera LiF	/////////	1	~350
Video camera LiF	//////////	0.03	~350

The tomography setup consists of a LiF(ZnS) scintillator, a high reflectivity(TiO_2) plane mirror, and a ANDOR cooled (-90^0C) CCD digital video camera, installed inside a light tight box. The objects to be inspected are positioned in a rotating table (figure 2). The images are formed in the scintillator and the plane mirror reflects the light of the scintillator 90^0 with respect to the neutron beam. A transparent boron glass filter installed in front of the camera lens, is an additional protection to minimize the damages in the camera CCD. The camera is coupled to a computer and to the rotating table making the system completely automated in such way that after the first image be captured, the table rotates the object 0.9^0 and a new image is captured. A total of 400 individual images are necessary to reconstruct the image and the time required to acquire the images is 400s. The softwares for image reconstruction and for image visualization are the Octopus and the VG Studio respectively.

Figure 1 - Top view (left) of the imaging system

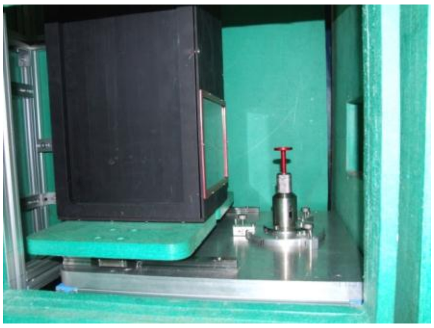


Figure 2 - Detail of therotating table

Examples of 3D images

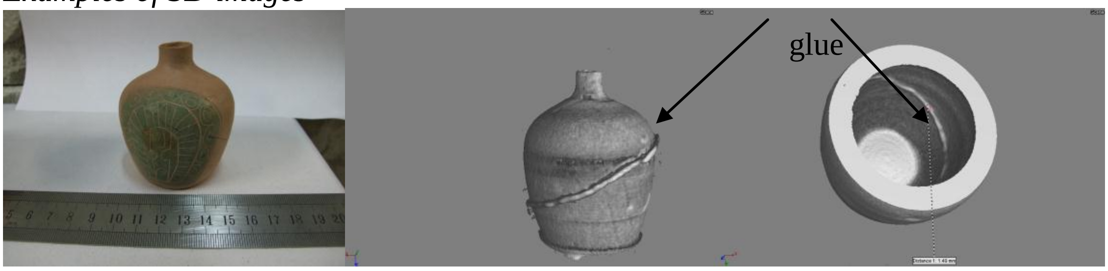


Figure 3 - 3D images of a ceramic vase showing in detail the glue used in restoration

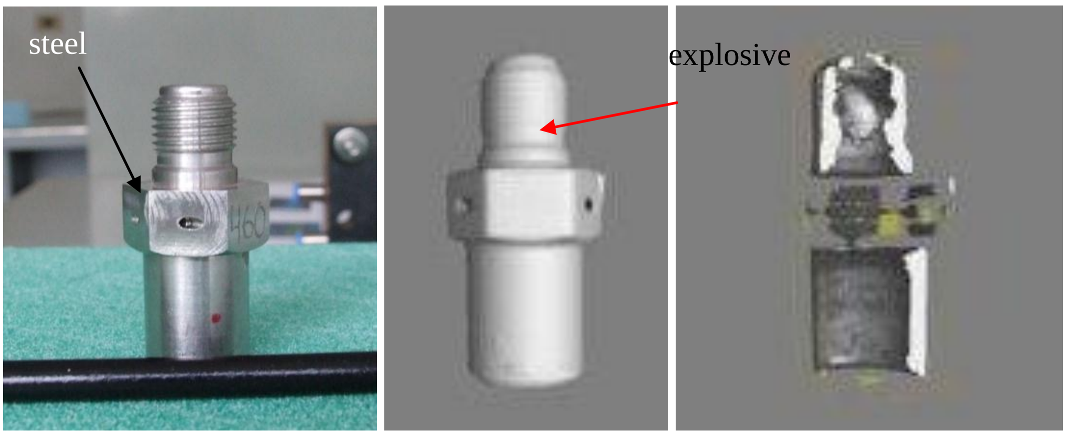


Figure 4 - Explosive screw showing in detail the explosive substance encased in steel

On-going cooperations on cultural heritage.

- Archeometric Study Working Group of IPEN
- Nuclear Technological Institute - ITN - Portugal.

Workplan year 1:

- Upgrade the image system: resolution and camera protection
- Imaging tests to determine the irradiation conditions for this class of materials
- Irradiation of real and restored samples to study the restoration materials
- Use the data from the neutron activation analysis method to catalog the elements used in the manufacturing and in the restoring processes

Main objective	Sub objectives	Year 1				Year 2				Year 3			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Upgrade the image system	Resolution	X	X	X									
	Glass filters		X	X									
	Irradiation tests			X	X								
Fake samples	Acquisition	X	X	X	X								
	Irradiation				X								
	Results analysis				X								
Real and restored samples	Selection					X	X	X	X				
	Sample holders design					X							
	Irradiation tests					X	X	X	X				
	Results analysis						X	X	X				
Results publication									X				
Real samples	Irradiation									X	X	X	X
	Results analysis									X	X	X	X
Use data from TNAA										X	X	X	X
Results publication												X	X

5.4. Ms Rumyana Djingova (Bulgaria)

Introduction

Neutron tomography has recently found new applications in many different fields like for example in Biology, Medicine, Geology, Archaeology and Cultural Heritage. One of the reasons is the fast development in digital image recording and processing, which enables the computation of tomographic reconstructions from high-resolution images at a reasonable timescale. The development of new detectors with better signal-to-noise characteristics and faster read-out electronics has allowed the overcoming of some of the spatial and time resolution limitations of conventional neutron radiography and tomography. Nevertheless the quantification of neutron tomographic data is a challenging task in many cases. The diverse experimental conditions at different facilities (beam spectrum, collimation, background, etc.) hinder the distinct relation between attenuation coefficient and single material. In this case complementary methods should be used for determination of the chemical composition in multicomponent samples which can be related later to the obtained matrix of attenuation coefficients from the neutron tomographic measurement.

Experimental facility:

The analytical chemistry provides various methods which can map the chemical composition on the sample's surface non-destructively (XFR, LA-ICP-MS) or destructively analyse a small part of the sample (ICP-MS and ICP-AES). The application of the non-destructive chemical analytical methods before the exposure of the sample to thermal neutrons will help the detection of critical elements (e.g. Co, Ag, etc.) which have long lived radionuclides and could be a problem for investigation of valuable cultural heritage samples from museums and private collections. The ICP – techniques are already well established for investigation of archaeological materials providing accurate information for a variety of materials and elements. Although ICP-MS and ICP-AES are destructive methods they work with samples of 0.4 – 1 mg which quantity may be taken from most artefacts and used in the standardization experiments. LA-ICP-MS besides non-destructive is also an acknowledged technique for imaging. EDXRF is widely used in archaeometric investigation. Time table with the schedule of the CRP is summarised in following table.

Main objective	Sub objectives	Year 1				Year 2				Year 3			
		Q1	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Quantification of neutron tomography data	Harmonization of ICP-MS; ICP-AES; LA-ICP-MS –analysis of bronze CRM	X	X	X									
	Analysis of bronze CRMs by neutron tomography (Helmholz Zentrum Berlin)			X	X								
	Comparative evaluation of results				X								
	Analysis of bronze artefacts			X	X	X	X						
	Progress report			X									
	Standardization of non destructive approaches (neutron tomography and LA-ICP-MS) for investigation of metal artefacts					X	X	X					
	Investigation of various metal based finds							X	X	X	X	X	
	Progress report							X					
	Scientific communications										X	X	
	Final report												X

5.5. Mr Ivan Padron (Cuba)

Introduction

In the past, some cultural heritage research works have been carried out by the CEADEN, in collaboration with the Arqueology Laboratory of the Cultural Heritage Department, employing techniques as EDXRF, X-ray Difraction, INAA and SEM-EDS for the analysis of Cuban pre-Columbian pottery, painting pigments characterization. Recently, with a modified portable X-ray fluorescence spectrometer were evaluated paintings in restoration process.

Wood is the material that has accompanied the whole development of mankind in various applications, for manufacturing tools and weapons, for buildings and constructions and also as fuel. It has various appearances and is subjected to decomposing changes, so there are sufficient arguments for non-destructive testing of wooden objects in the same way as is common practice with other technologically used materials. However, even today wood is rarely tested. Moreover, artifacts of cultural heritage containing wood are rare and delicate, so dismantling these for studying purposes is undesirable.

Neutrons behave complementarily; they are avidly absorbed by light elements such as hydrogen on the one hand and yet are capable of easily penetrating heavy metals on the other. This provides an alternative for X-ray radiography and tomography when material characteristics are of primary interest rather than structural details, or when shielding with plates or sleeves of heavy metal severely impedes inspections with X-ray or gamma radiation technologies. However, due to the moderating effect of wooden samples it is essential to use fast neutrons for radiography and tomography of voluminous objects. Some typical examples described here will show the difference between neutron and X-ray photon-based radiographic technologies.

Experimental facility:

A novel position sensitive fast neutron detector based on plastic micro-channel plate with a delay-line read-out will be developed for Neutron Resonance Transmission (NRT) application on cultural heritage studies with focus on objects made of wood and metals. That combination was very common on the objects conserved from Spanish colonization of the Americas.

Neutron Resonance Transmission (NRT) reveals the elemental composition of samples by measuring neutron absorption resonances in the transmitted neutron beam. For energy selectivity, needed in NRT analysis we will apply the Time-of-Flight (TOF) method and the associated particle technique (APT).

In order to have an associated helium particle unambiguous identification when D(d, n)3He or 3H(d, n)4He reactions are used for providing mono-energetic neutron beams of know flux and energy, an organic plastic scintillator (NE102A) can be used as associated particle (AP) detector. The neutron cone aperture is determined by the frontal slits which define the solid angle subtended by the AP detector, and in the horizontal plane by the kinematics of the reaction involved. A variable quasi mono-energetic neutron beam is obtained by angular variation using the D(d, n)3He reaction.

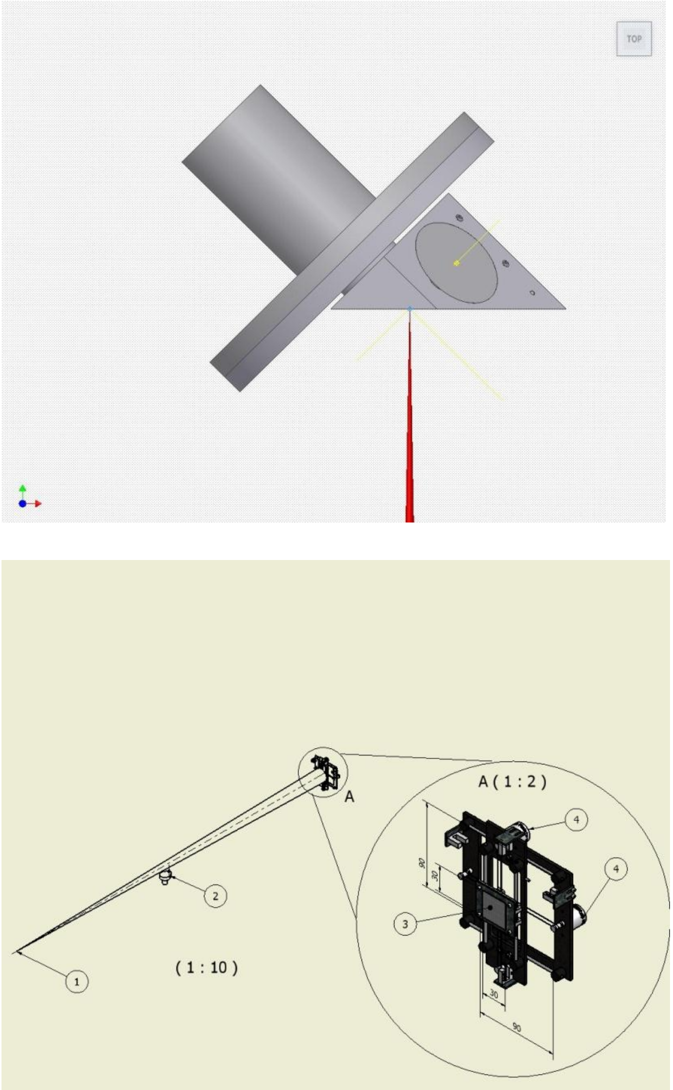


Figure 1 - Geometrical setup designed for Monte Carlo simulations.

The position sensitive fast neutron detector for TOF measurements that we are designing is based on plastic Micro-channel plates (MCP) + two stage stack of lead MCP with a delay-line anode. These novel devices combine the low-noise and high temporal and spatial resolution of MCP with the neutron stopping power of hydrogen rich plastic substrates. Arradiance Inc. of Sudbury is using the atomic layer deposition to add emissive and resistive thin films to the plastic substrates. When a neutron hits a plastic microchannel plate, it interacts with hydrogen, resulting in a recoil proton entering one of its adjacent pores. The proton then hits the walls of the pore, causing a cascade of secondary electrons. The advantage of this technology over the existing fast neutron detectors is the direct conversion of fast neutron into measurable electrical signal and low sensitivity to gammas. Our MCP stack composed of one plastic and two lead MCPs will convert the incoming fast neutrons on 10^3 – 10^6 electrons, providing neutron detection efficiency better than 1%.

Monte-Carlo simulations using the GEANT-4 and MCNP-4C codes will be performed in order to study:

- The performance of a direct neutron conversion in plastic MCP, comparing its resolution and efficiency for fast neutron detection with the silicon MCP.
- The parameters affecting detector performance for its optimization.
- To characterize the intrinsic spatial resolution of MCP neutron detector, a neutron transmission image of archeological object reproductions containing a series of materials like wood, ceramics and different metals will be simulated.

The read-out concept needs to be specially designed to presume that an MCP stack will respond to multiple hits, i.e. it will deliver spatially and timely well defined charge clouds for each particle. However, all common techniques based on phosphor screen read-out can not be applied here as the read-out scheme is much to slow. Pixel anodes with fast and independent read-out electronic channels can handle high rates and multi-hits, but with increasing position resolution demands, such techniques become inefficient as the number of electronic channels increases at least linearly with the position resolution dynamics in each dimension. Also charge integrating read-out schemes as used by the wedge-and-strip or the resistive anodes fail to detect multiple hits as their read-out electronic's shaping times must be in the order of one microsecond to ensure sufficient position resolution.

A promising approach combining most desired features of an MCP read-out scheme, good position and timing resolution at high particle flux, including the ability to analyze multiple-hit events is the delay-line technique.

For reducing the multi-hit dead-time we will investigate the possibility to analyze the pulse shapes of the analogue signals from the delay-line with fast sample-ADCs. The discrimination between single or multiple signals and the generation of the "timing" is than performed by pulse shape analyzing software codes. Thus it should be possible to identify and analyze even double hit events with a pulse pair distance smaller than the individual signal lengths. Such a "digital timing discriminator" in combination with a delay-line anode could improve the multi-hit performance significantly.

Workplan year 1:

- Design of the fast neutron detector based on one plastic MCP and two stage chevron configuration lead MCP with a delay-line position sensitive anode.
- Design and characterization of read-out scheme.
- Design of sample holder and optimization of physical parameters for NRT applications.
- Monte-Carlo simulation and analysis, comparison with GEANT-4 code for detector design and feasibility study for application in cultural heritage research by NRT.
- Investigation of possible discrimination between single and multiple signals and the generation of the "timing" by pulse shape analysis.
- MCP stack acquisition.

Main objective	**Sub objectives**	**Year 1**				**Year 2**				**Year 3**			
		Q1	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Designing of MCP detector	Get information about commercial MCPs	X	X										
	Designing of MCP detector		X	X									
	Designing of readout system				X	X							
Exper. setup optimization	Designing of geometrical setup		X	X									
	Monte Carlo modeling of experimental setup			X	X	X	X						
Detection system optimization	Simulation of direct fast neutron detection on plastic MCP		X	X									
	Estimation of temporal and spatial resolutions			X	X								
1st year Report	Analysis of results				X								
	Writing the report				X								
Exper. setup development	Fabrication of sample holder					X	X						
	Fabrication of detector holder						X	X					
	MCP stack acquisition						X						
	MCP detector fixing							X					
Readout system development	XDL anode acquisition						X						
	XDL anode fixing							X					
	Testing of MCP detector								X				
2nd year Report	Analysis of results								X				
	Writing the report								X				
Software assimilation	Imaging software installation									X	X	X	
Facility testing	Imaging different artifacts										X	X	
	Data analysis										X	X	
	Comparison with X-ray radiography											X	X
3rd year Report	Analysis of results												X
	Writing the final report												X

5.6. Mr Tarek Mongy (Egypt)

Introduction
Egypt Second Research Reactor (ETRR-2) is a pool-type reactor with an open water surface and variable core arrangement. The core power is 22 MW_{th} cooled by light water, moderated by water and with beryllium reflectors. The design concept is based on the requirement of being a reactor of versatile utilizations, It has been mainly designed for:

Basic and applied research in reactor physics and nuclear engineering, neutron radiography for research and industrial purpose, radioisotope production for medical and industrial purposes, beam hole experimentation for neutron scattering experiments and neutron radiography, material testing, material irradiation, activation analysis and training of scientific and technical personnel.

Experimental facility:
ETRR-2 has neutron radiography facility has the following characterization parameters:

γ rate intensity at beam outlet is 3.3 Sv/hr at 13.3 Mwatt thermal, thermal neutron flux at nominal power, 22 MWatt, is 1.5×10^7 n/cm^2. sec., fast neutron flux is at nominal power, 22 MWatt, is 1.6×10^6 n/cm^2. Sec., n/γ ratio is $0.132*10^6$ $n.cm^{-2}$ $.mR^{-1}$, Cd ratio is 10, L/D ratio is 117, Facility resolution is 188 μm (Agfa Stucturix D7).

Previous work had been done toward culture heritage reservation, as; determine of hydrogenous contents in soil and porous construction materials with high accuracy, detect the underground water for ancient Egyptian and Islamic heritage protection, test the soil for preventing water migration inside.

The present Status is Commissioning of ETRR-2 neutron radiography facility in1998 by using nitrocellulose film as a first step, in 1999 Agfa Structurix D7 photographic film was used rather than nitrocellulose film to get high quality image formation, in 2012 the commissioning of dynamic system neutron radiography/tomography is in process according to TC project between AEA and IAEA.

Workplan year 1-4:
The activities will be carried out under the framework of the CRP involve; First year activity, to protect monuments from migration of underground water by stat-of-the-art non-destructive tool, use neutron imaging technology for elemental and chemical analysis, and use computer software to detect hidden objects and study of material characterization and properties. Second year activity; for data analysis and imaging processing using different software, collaboration with Egyptian museums for mummies investigation, neutron tomographic investigation of cultural heritage objects to get information about the manufacturing techniques in the past, developing of restoration strategies and estimation of the degradation state of the samples by using neutron tomographic data, investigation of water penetration in cultural heritage building materials (marble, concrete and wood), and optimize of impregnation techniques by using dynamic neutron radiographic method. Third year activity; dedicated for examination of the internal structures of ancient Egyptian artifacts and make contacts with cultural heritage institutions (e.g. museums, archaeological institutes and universities) and collect samples. Fourth year activity**;** for Implement the necessary standardization procedures and methodology to achieve synergy between ETRR-2 NR Facility and international laboratories/facilities, develop a database of NR/T in ETRR-2 and

standard neutron imaging services for culture heritages needs, technology transfer between the specialist of NR/T in ETRR-2 and researcher from culture heritage communities, use of available software for data analysis and simulations, enhance awareness and effective utilization of ETRR-2 NR/T technique by culture heritages activities. The expected results are promising and verify technology transfer and data analysis between ETRR-2 and international facilities, more training, more experiences and more education is extremely added and is the main future challenge, also, in the near future, development of computer software is planned towards imaging processing and elemental analysis.

The employed software is summarized in the following table:

Software	**Functions**
Camware software	For camera control, image acquisition and archiving of images in various file formats (PCO2000),
ImageJ	- Display, edit, analyze, process, save, and print 8-bit color and grayscale, - Can read images with many different formatting,
LabVIEW	For data acquisition and motion control.
Octopus	- Image processing, 3D viewer, reconstruction and image analysis program, - Can read images with different formatting,
VGStudioMax	- 3D Image processing, - Animation capability, - Data analysis and measurement, - Support interactive analysis of three dimensional/volumetric data to characterize a volume element, - Visualization of interior structure with high-quality detail representations are applicable.

Main objective	**Sub objectives**	**Year 1**				**Year 2**				**Year 3**			
		Q1	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Database	Get information		X	X									
	Compile info			X	X								
	Send info				X	X							
Rosseta National Museum	Planning				X	X	X						
Islamic Museum in Cairo	Round Robin				X	X	X	X					
Copts Museum in Cairo	Results								X	X	X		
	Report									X	X	X	X

5.7. Mr Nikolay Kardjilov (Germany)

Introduction

Neutron imaging is a non-destructive investigation method with a fast growing application field in materials research and fundamental science. The method is used broadly in the cultural heritage research as complementary technique to x-ray imaging. The ability of neutron beam to transmit thick layers of metal and the sensitivity to light elements makes the technique unique for detection of organic substances in metal and stone matrices. The high penetration power of neutrons allows for investigation of samples with real dimensions of about 100 cm^3. The neutron imaging in cultural heritage helps to provide information about manufacturing processes and material properties which is very important for further restoration and conservation of the objects. The development of new methods like energy selective imaging and grating interferometry and the application of autoradiography increase the potential of the method for characterization of cultural heritage samples.

The neutron tomography instrument CONRAD has been in operation since 2005 at the Hahn-Meitner research reactor at Helmholtz-Zentrum Berlin (HZB). Over the last 5 years, significant development work has been performed to expand the radiographic and tomographic capabilities of the beamline. New techniques have been implemented, including imaging with polarized neutrons, Bragg-edge mapping, high-resolution neutron imaging and grating interferometry. These methods together with the autoradiography have been provided to the user community as tools to help address scientific problems particularly in the field of cultural heritage and palaeontology. Descriptions and parameters of the facilities are given below.

Experimental facility:

Imaging facility CONRAD at HZB: the neutron tomography station at the Hahn-Meitner research reactor at HZB is installed at the end of curved neutron guide. The guide has a radius of curvature of 750 m, which provides a flux density of $2x10^9$ $n/cm^2/s$ while minimizing thermal neutron and gamma radiation noise to the instrument. The cold neutron beam is used beside the conventional absorption contrast radiography and tomography for imaging with polarized neutrons, energy-selective mapping, grating interferometry and high-resolution imaging. The flexibility of the instrument allows for switching between different modes in a matter of only a few hours. Beam collimation is performed by means of pinhole geometry, using a pinhole exchanger which is placed at the end of the neutron guide. The distance from pinhole to the downstream sample position is 5m. Using circular pinholes with diameters of 1 cm, 2 cm and 3 cm, mounted in 5 mm B_4C neutron absorbing plastic, beam collimation ratios (L/D) rates achieved are respectively 1000, 500 and 333. A neutron imaging detector system based on a CCD camera was implemented at the CONRAD instrument. The CCD camera used is an Andor DW436N-BV 16-bit CCD camera with 2048×2048 pixels and a pixel size of 13.5 µm × 13.5 µm. Conventional scintillating screens (^{6}LiF/ZnS:Cu,Al,Au) were used. The entire detector assembly is situated in a light-tight box. This detector system allows for a range of imaging capabilities, from a maximum field of view (FOV) of 20 cm x 20 cm at a spatial resolution of 250 µm, to a high resolution of 70 µm with a FOV of 6 cm x 6 cm.

Facility for neutron autoradiography B8: The instrument B8 allows to irradiate and activate artistic, technical or geological items (foils, stones etc.) and other materials with cold neutrons and to investigate them by imaging plate technique and/or to analyse it by gamma-spectroscopy. In the main the instrument is used for paintings but also for other purposes (neutron activation analysis). The painting is fixed on a support in front of a neutron guide end with an open area of 3.5 x12.5 cm^2. The surface of the painting is adjusted under a small angle (< 3°) with respect to the axis of the guide. Thus a 12.5 cm wide strip of the painting is illuminated by the neutrons. The main free path of the neutrons within the paint layer is much longer than in the case of perpendicular transmission. The support is moved up and down with a velocity of a few cm/s in order to receive a uniform activation of the total area of the panel. The facility is installed in a secure closed container. The basic area of the container is 250 x 450 cm^2. On a special table in a shielded room in the basement the film exposure and the gamma spectroscopy can be performed for the suitable times (up to more than 4 weeks) depending on the half-lives of the isotopes.

Workplan year 1:
– Establishment of contacts with partners from cultural heritage institutions (museums, archaeological and paleontological groups).
– Identification of interesting scientific questions and definition of scientific projects with different partners.
– Conventional neutron tomographic and autoradiographic experiments on target objects.
– Data evaluation and decision if innovative methods are needed for further investigation.

Main objective	**Sub objectives**	**Year 1**				**Year 2**				**Year 3**			
		Q1	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Contact with CRP partners and museums	CRP partners	X											
	Museums		X										
	Identification of samples			X	X								
Measurements by conventional tomography	Quantification				X	X							
Measurements by energy-selective imaging	Quantification					X	X						
	Phase separation						X	X					
Measurements by grating interferometry	Metals						X	X					
	Glass							X	X				
	Geological samples								X	X			
Measurements by laminography	Large samples									X	X		
	Flat samples										X	X	
Autoradiography	Test samples				X			X		X		X	
Reporting and publish the results	Report											X	
	Publications												X

5.8. Mr Burkhard Schillinger (Germany)

Introduction

The ANTARES facility for neutron imaging is currently completely refurbished and will restart operation in summer 2012. ANTARES will again provide the combination of highest flux and highest resolution worldwide in neutron imaging. Additional methods include energy-dependent measurements (Bragg edges) for the identification of different elements and phases as well as (soon) phase gratings for linear phase contrast.

With the collaboration partners The University of Queens (Canada), The Archäologisches Landesamt für Denkmalpflege in Esslingen, Germany, and Archäologische Staatssammlung of Bavaria, Germany, research at ANTARES will focus on the examination of organic materials in combination with metal artefacts.

- The University of Queens (Canada) possesses a huge collection of Roman and other coins that need to be identified and restored, often to give contextual information about their place of discovery. Research at ANTARES will include radiographical and tomographical examination of a large part of this collection.
- The Archäologisches Landesamt für Denkmalpflege in Esslingen will provide artifacts of cloth stuck to metal objects for further examination with Neutron computed tomography to analyse different organic materials out of early medieval burials in Southern Germany. The measurements will help to get some very new detailed information about their usage and ancient manufacturing techniques. The results will also be important for investigation of original functions, reconstruction of early medieval clothes and for studies of ancient funeral rites.
- Archäologische Staatssammlung of Bavaria is involved in many bronze or iron age excavations in South Germany that lie underwater, in swamps or moist soil. Artifacts found there often contain small remains of textile cloth attached to leather or metal artifacts. Neutron computed tomography will be used to examine artifacts made of composed anorganic and organic materials, like corroded swords in scabbards. Another aspect is the shifting of the contrast by impregnating the objects with different organic substances e.g. resins during the conservation process. This phenomenon should be observed as a side effect of the study.

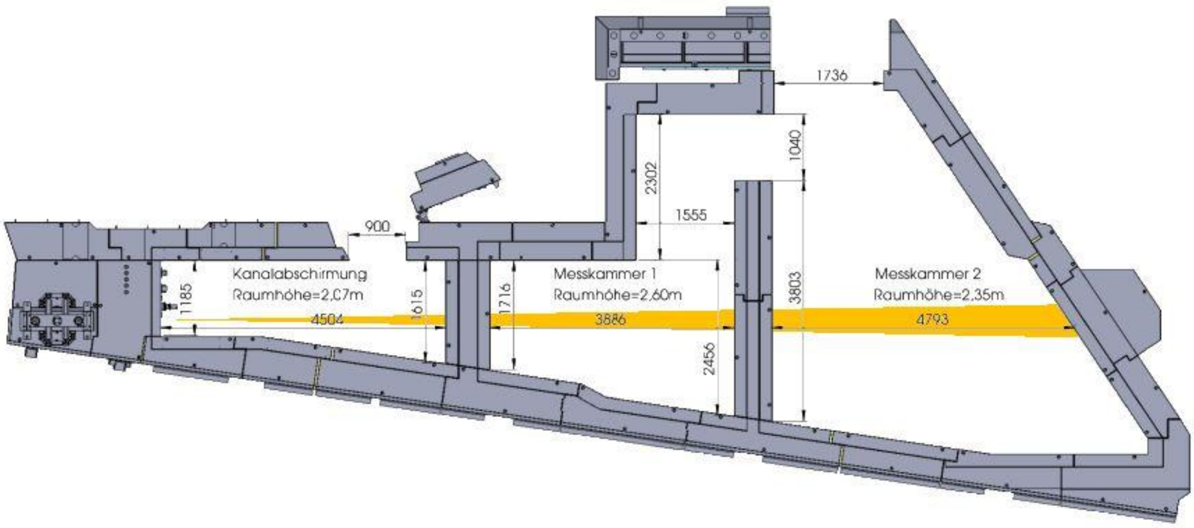


Figure 1 - The ANTARES facility:

Experimental facility:

Chamber 2:

- Large & heavy samples (manipulator load capacity: 500kg)
- Beam size: 350 x 350mm
- Same beam properties as old ANTARES
- L/D ratio 200 … 7100
- All components movable on rail system

Chamber 1:

- L/D ratio 100 … 3600
- 1.6 * 109 n/cm^{2}s (@L/D=100)
- Smaller beam size / small samples (<15cm)
- Low background
- Higher initial intensity (closer to reactor) for low count ratre measurements:
- Polarized Imaging
- Monochromatic Imaging
- Grating Interferometry
- Roof elevation for cryostats

Beam formation area:

- Separately accessible
- 6 collimators in a drum
- Fast shutter
- Filters
- Double Crystal Monochromator
- Velocity Selector
- Polarizer
- Periscopes
- All flight tubes are He-filled, Non-magnetic

Detection systems: 2k x 2k cooled CCD, 4k x 4k cooled scientific CMOS, 1k x 1 k CCD with gated image intensifier, 30 fps video camera with image intensifier

Workplan year 1:

- Re-establishment of the ANTARES facility and its control and work parameters, as control software, tomographic reconstruction software and 3D raytracing software.
- Radiography and tomography measurements of first batch of coins and textiles.
- Standardization of measurement parameters.
- Exchange with other international groups.
- Grant access for other groups.
- Also: Provide hardware and software information, especially free software, for beginners about to install tomography setups at their reactors.

5.9. Mr Marco Zoppi (Italy)

Introduction

Materials characterization, through non-invasive techniques, represents an important strategic tool in the non-destructive quantitative analysis of artefacts of archaeological and historical interest. In fact, thanks to the high penetration power of thermal neutrons in dense matter, bulk analysis of massive findings, characteristic of archaeological activity, can be nowadays carried out in an almost straightforward way, especially on metal samples. By means of neutron diffraction, it is possible to obtain, without any need of sampling, the average bulk phase composition of the specimen and to reveal the hidden presence of mineralisation phases, which, in turn, gives a deep information on its preservation status. Moreover, a detailed analysis of the peak shape, can shed light on smelting and smithing methods, as well as on the amount of mechanical work that was originally carried out on the sample. Neutron imaging techniques, have developed to such an extent that, today, it is possible to reconstruct tomographic images down to ≅30 μm space resolution. In addition, thanks to the developing techniques of energy selective neutron imaging and tomography the scenario opens over a wealth of futuristic applications, thanks to the enhanced contrast inherent in this technique. At present, these energy selective techniques are only limited by the performances of the device needed to select the energy (and wavelength) of the incident neutron beam: i.e. a rotating disk velocity selector and double monochromator. The possibility of enhancing this technique by fully exploiting the Time of Flight technique could improve dramatically the energy resolution and consequently the range of possible “contrast enhancement” possibilities. What we propose is a research activity using energy selective neutron imaging, applied to cultural heritage metal artefacts, to study the historical evolution of iron production on a world basis, i.e. including European, middle-east, Indian, and far-east specimens provided by museum institutions with whom we are already collaborating. At the same time, we are planning to collaborate with Hokkaido University (Sapporo, Japan) to enhance the energy resolving power of ToF instruments, fully exploiting the Bragg Edges analysis technique, by the development of a bi-dimensional detector with the best possible space resolution.

Experimental facility:

Name:	INES (Italian Neutron Experimental Station)
Location:	ISIS (UK)
Responsible:	Marco ZOPPI (marco.zoppi@isc.cnr.it)
	Francesco Grazzi (francesco.grazzi@isc.cnr.it)
	web site: www.isis.stfc.ac.uk/instruments/ines/
Local Contact:	Antonella Scherillo (antonella.scherillo@stfc.ac.uk)

Mission: INES is mainly intended to work as a training facility for the Italian community and testing station for new materials and techniques. As such, 50% of the beam time is reserved for exploratory experiments of italian users (mainly young researchers and newcomers), while the remaining 50% is open to the international community. The primary use is mainly dedicated to Cultural Heritage artefacts, but also material science experiments (especially at a primary level testing stage) are welcome.

Description: INES main equipment is constituted by a powder diffractometer. The installation is complemented by several ancillary equipments:

- LASER sample aligner
- X-Y translation table (max weight 50 Kg)
- goniometers (for texture analysis)
- neutron beam shaper

– neutron imaging sample aligner
– high efficiency transmission monitor
– NRCA detector

Radiographic / tomographic camera: a movable radiographic camera can be mounted on the output port of the instrument for neutron radiography analysis. This is equipped with a rotating sample holder allowing tomographic measurements. The main parameters are:

- Beam Size: 40x40 mm^2
- Primary beam path: 23.60 m
- L/D (measured) = 100

Reference: Nuclear Instruments and Methods in Physics Research A **595** (2008) 643

The main objective of the present project is to develop an integrated protocol of measurements including Neutron Diffraction (ND), Neutron Imaging (NI), and position sensitive Bragg-Edge Neutron Transmission (BENT) analysis. In order to tune the proposed integrated techniques to its best performance, we plan to apply it to historical metal artefacts, which represent a good example of complex and interesting samples. The contemporary application of ND, NI, and BENT techniques, will permit to obtain a complete set of information and to fully characterize the samples. In this context, we plan to use the diffraction data and the imaging results to optimise the effectiveness of the software analysis tool developed, by the Hokkaido University, for the BENT experiments. To this aim we propose to use museum artefacts, originating from Museums in Florence and in London, with whom CNR-ISC has established collaborations. We are presently working to stimulate the corresponding Japanese counterparts to join the project activities.

In order to fulfil the project objectives, we propose the following tasks:

1. Measuring a number of reference certified samples for a preliminary calibration of the CNR facility setup.

2. Measuring a selected number of Iron and Steel samples from:
    a. Europe, Middle Age and Renaissance period
    b. India, Mogul period
    c. Japan, Muromachi and Edo periods

This choice is based on the rationale that the three different production and working techniques are very different from each other, depending on the different cultural and environmental conditions. In order to fulfil these tasks, we will perform neutron diffraction and imaging at the Italian Neutron Experimental Station (INES@ISIS), as well as at other European neutron facilities. Within the collaboration work with Japan, there will be an exchange of samples, which will be measured by the Hokkaido University team using the neutron transmission technique.

Workplan year 1:
– Test and optimisation of the INES transmission monitor. Instrument calibrations using standards
– INES experiments on selected Japanese cultural heritage artefacts from Edo period (swords, tsubas, armours components, etc.)
– Meeting in Florence with the Japanese colleagues to analyse preliminary results and plan the following research activity.

Main objective	Sub objectives	Year 1				Year 2				Year 3			
		Q1	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Database (measure of a number of certified reference samples)	Get samples	X											
	Run Diffraction/transmission experiments on INES		X	X									
	Data Analysis		X	X	X								
	Selection of a few representative samples			X	X								
	Run transmission experiment in Sapporo/J-parc			X	X								
	Critical comparison of results (joint meeting)				X								
Measurements of selected iron&steel samples (Europe, India, Japan)	INES experiments					X		X		X			
	Hokkaido University / J-parc experiments						X		X		X		
	Data Analysis						X	X	X	X	X		
	Critical comparison (meeting)										X	X	
Report	Meeting												X

5.10. Mr Yoshiaki Kiyanagi (Japan)

Introduction

The pulsed neutron imaging using the time-of-flight method can give structural information on materials by using the characteristic features of the wavelength dependent neutron transmission. The crystal structure (lattice spacing), crystallite size, and preferred orientation in metal materials are investigated by analyzing the Bragg edge shapes and the elements by the resonance absorption peaks. Such information is important for characterizing the steels and other metal products, and only our group has the data analysis code for deducing such information. It is useful to apply the pulsed neutron imaging to the cultural heritages since the method helps to understand smithing and smelting processes of the specimens. The transmission method gives position dependent information and the diffraction gives complemental and more detailed data for the crystal structures and the textures. Therefore, the combined use of these methods is very useful for studying rigorously the crystal structure of cultural heritage samples. We have already collaborated with the Italian group for this direction, since the group has been performing the diffraction study. Therefore, we promote the research collaboratively for comprehensive and rigorous understanding of the crystallographic characteristics of the cultural heritages and archeological specimens.

The main object of this study is to obtain comprehensive crystallographic information of the cultural heritages and archaeological samples, and to understand the historical or regional difference of the smithing and the smelting. To obtain such outcomes we are planning to perform mainly the pulsed neutron imaging using NOBORU at J-PARC, HUNS at Hokkaido University and INES at ISIS. We are the only group that can obtain the crystallographic images by using the pulsed neutron experiments coupled with the data analysis code we developed. In parallel we improve the Bragg edge analysis code and develop the data analysis code for the resonance absorption.

Experimental facilities

J-PARC spallation neutron source: high power spallation neutron source at MLF (Material and Life science experimental Facility) at J-PARC in Japan. We can perform the neutron transmission experiments using the instrument called 'NOBORU', a test experimental beam line. The present power is about 200kW. In this instrumental area we can put relatively large equipments for the transmission experiments and get high statistics and high wavelength resolution data (about 0.3% at 15m). The maximum beam size now is 10x10 cm^2, and L/D of 140, 190, 600 and 1875 are obtainable. The Maximum intensity is about $5x10^7$n/sec/cm^2 at 1MW.

Hokkaido University neutron source (HUNS): There is an electron linac based neutron source at Hokkaido University. This is a pulsed neutron source applicable to various fields of neutron experiments. The source neutron intensity is $1.6x10^{12}$n/sec. L/D is about 50 for cold neutron experiments and about 100 for resonance measurement. Time resolution is about 4% for cold neutron region. We also have various neutron detectors such as pixel-type detector, RPMT detector and GEM detector. This facility can be operated by users, so the on-demand use is possible and easy. We perform various kinds of transmission experiments which are sprouting and do not need high wavelength resolution.

Cooperation

For this study the collaborated work with the Italian group (Dr. M. Zoppi group) is essential since they have valuable experiences on the neutron diffraction study on the cultural heritages. The comparison between the transmission data depending on the position and the diffraction data on the large area is very important to understand the crystallographic feature of the samples.

Main objective	**Sub objectives**	**Year 1**				**Year 2**				**Year 3**			
		Q1	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Soft ware development	Bragg edge	X	X	X	X	X	X	X	X				
	Resonance			X	X	X	X	X	X	X			
Detector development	GEM	X	X	X	X								
	Neutron color I.I.			X	X	X	X	X	X				
Database (measure of a number of certified reference samples)	Run Diffraction/transmission experiments on INES		X	X									
	Data Analysis		X	X	X								
	Selection of a few representative samples			X	X								
	Run transmission experiment in Sapporo/J-parc			X	X								
	Critical comparison of results (joint meeting)				X								
Measurements of selected iron&steel samples (Europe, Indian, Japan)	INES experiments					X		X		X			
	Hokkaido University / J-parc experiments						X		X		X		
	Data analysis						X	X	X	X	X		
	Critical comparison (meeting)										X	X	
Report	**Meeting**												**X**

5.11. Mr Muhammad Rawi Mohamed Zin (Malaysia)

Introduction

Inspection of cultural heritage artifact by neutron imaging becoming interesting and important research area since its able to sees internal structure non-destructively. Therefore advanced neutron imaging capability to conduct this kind of inspection is needed. Associated with this needs, TRIGA MARK II PUSPATI reactor has neutron imaging facility, NUR-2 which capable for radiography and tomography usage. Details parameters of current set up is given in Table 1. Neutron radiography capability at this facility has been relied on direct method technique by the usage of SR-45 KODAK film technology. Current set-up has been used by university student through-out the country to conduct their research in various levels of educations.

Table 1 - NUR-2 parameters and characteristics

Collimator type	Step divergence
Length of Collimator	200 cm
Inlet aperture (collimator)	5.4 cm
L/D ratio	37 ~ 100 (normally L/D ~ 75)
Thermal neutron flux (outlet of collimator)	1.04×10^5 n cm^2 s^{-1}
Gamma dose rate (outlet of collimator)	36.7 R/hr
Beam size at sample position	10 cm x 25 cm

Presently, there is an interest to use present facility for artifact sample from cultural heritage site. Focus for this inspection is to obtain three dimensional images with the ability to view internal structure in any directions. In order to do this, some modernization should be made on the current facility. Therefore, the aim is new ability for obtaining sufficient number of neutron tomographic projections is crucially needed. In order to achieve this aim, the workplan is specified in following table

Objectives	**Year 1**				**Year 2**				**Year 3**			
	Q1	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Design of sample positioning system	X	X	X	X								
Construction of neutron camera shielding	X	X	X									
Design of shielding for exposure room			X	X								
Fabrication and installation of sample positioning system				X	X	X						
Procurement of image acquisition and analysis Software				X	X	X						
Improve thermal neutron flux at sample				X	X	X	X	X	X	X		
Improve L/D ratio at least to150				X	X	X	X	X	X	X		
Construction of shielding for exposure room					X	X	X	X	X	X		
Testing for Radiographic Image Acquisition and Tomographic reconstruction												X

5.12. Mr Jacek J. Milczarek (Poland)

Introduction

Due to heavy losses during last war austerities the public opinion in Poland is very conscious on the preservation of the national cultural heritage objects. The preservation of cultural heritage in Poland is supervised and financed by the Ministry of Ministry of Culture and National Heritage with the Department of Cultural Heritage and the National Heritage Board established in Warsaw. There are over 400 museums in the country, from which 110 museums are the registered ones. The 12 national museums and 12 archaeological ones exist in major Polish cities. There are approximately 1000 excavation sites in Poland explored for 6 months in year. The archaeological research currently well developed and the X-ray radiography is widely used for investigation of excavation findings.

Experimental facilities

Since 2001 the neutron and gamma radiography facility (NGRS) has been working at the nuclear research reactor MARIA at Świerk, 25 km form the Warsaw centre. The MARIA is a water pool reactor of nominal 30 MWth power. Besides water pool each fuel element has its own separate cooling system.

The NGRS facility is a standard white beam neutron radiography station located at the reactor experimental hall at one of the neutron horizontal beams. The system consists of two neutron beam collimators, scintillation screens (250×250 mm), mirror, optical zoom lenses and high sensitive CCD camera. The linear resolution of the registered neutron radiograms was approximately 0.1 mm, The main parameters of the station: $100 < L/D < 200$, Cd ratio = 20, and the neutron flux $1.1 \cdot 10^7$ cm $^{-2}$s^{-1} at the sample position for L/D=150. The commercially available components: AST NDg 6Li:ZnS:Cu,Al,Au screens, Hamamatsu ORCA-ER camera (1280×1024 pixels, 12 bit) and LUCIA software were used.. The exposure times of 0.6–2.5 s are applied. The station is equipped with the mobile sample support/carrier, enabling the remote control tuning of the position of the investigated object with respect to the radiation beam and converter screen. The sample support can hold objects with mass to 100 kg.

Most of the activities carried out with the NGRS facility have been basically of scientific character. In particular the processes of water migration in various porous media have been studied for imbibition and drying.

Our invitations directed to some of the archaeological institutes and museums were met with positive responses mainly from researchers active in the investigations of the objects found currently at the excavation sites. Some parts of early mediaeval shield and swords were offered as first objects for neutron radiography analysis.

There are four main objectives of the Polish participation in the CRP:

1. Development of NR facility for efficient investigations of archaeological artefacts with thermal neutron tomography.
2. Examination of archaeological artefacts delivered by Polish museums and institutes.
3. Examination of excavated objects before cleaning.
4. Development of Web accessible database for the NI investigated artefacts.

Workplan year 1:

1. Design and construction of computer controlled rotation table for performing the tomographic projections.
2. Choice and purchase of software for computer tomography
3. Neutron projections for components of mediaeval shields and sword hilts.

4. Dissemination of information on availability of the NI technique for Polish museum and archaeological institutions.

Main objective	**Sub objectives**	**Year 1**				**Year 2**				**Year 3**			
		Q1	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Facility development at MARIA reactor	Rotation computer controlled table		X	X	X								
	Software for CT			X	X	X							
	Projections for shields and swords		X	X	X								
	Information on NI availability for Polish CH institutions		X	X	X								
Neutron radiography examination of artifacts from Polish institutions	Development of protocols and forms					X	X						
	Collection of artefacts					X	X	X	X	X			
	Examination of chosen items					X	X	X	X	X	X		
	SANS investigation of bronze elements							X	X	X	X		
Development of web accessible database of the NI results for Polish artifacts	Information on Czersk excavation findings									X	X	X	
	Database implementation									X	X	X	
	Final reports and publications									X	X	X	X

5.13. Mr Ion Ionita (Romania)

Introduction

The group will investigate Dacian statues of clay and Dacian treasure pieces of silver from the Arges County Museum of History. This collaboration will help curators to reveal the internal structure and composition of the objects. This could be a good beginning for the dissemination of the investigation methods based on neutrons for cultural heritage and beyond this area.

We will used the capabilities of our facilities, specifically: dry neutron radiography (DNR) facility, prompt gamma-ray activation analysis (PGAA) facility, neutron activation analysis (NAA) facility and the focusing crystal neutron high resolution diffractometer (HRD) facility.

The ACPR TRIGA reactor from INR Pitesti, the source of thermal neutrons and gamma radiations, is a pool type research reactor without solid reflector with two operation modes having in steady state a maximum power of 500 kW and being capable of a pulse to the peak power of 20000 MW. The ACPR was used for neutron radiography more in steady state (100-300 kW) and rarely in pulsing mode (4000 – 5000 MW).

Experimental facilities

DNR facility was designed to have a neutron collimator system, a gamma shutter, a holder for investigated objects with horizontally, vertically and rotational remote control movements, a neutron imaging system based on two scintillators (for thermal neutrons and gamma radiations) and two CCD cameras, biological protection and surveillance system. DNR has in collimator, before the aperture, a lifting Bi mono-crystal filter to change the neutron/gamma ratio.

Finally a detector system has been developed based on two interchangeable scintillators, one for neutron detection (6LiF-ZnS) and the other one for gamma radiation detection (Gd2O2S) and two interchangeable CCD cameras. The experiments performed in 2006 with first CCD camera, a SXV-H9 from STARLIGHT XPRESS with a XD-4 type image intensifier, have shown the potential for high resolution static image acquisition with neutrons and gammas. Neutron radiography experiments with second EM-CCD Hamamatsu C9100-02 camera, intended for real time imaging, were perform in 2011. It is estimated a three times rise of the thermal neutron current intensity at the exit of the collimator after a transfer improvement of the thermal neutron flux from reactor core to tangential channel. It is supposed to have about 106 n cm-2s-1 in the plane of the investigated object on a 300 mm diameter.

DNR facility offers 2-D neutron and gamma imaging and at the end of 2012 will offer 3-D imaging.

The prompt gamma-ray activation analysis activity is performed at the facility placed at radial channel of the ACPR adjacent to the dry neutron radiography facility at a thermal current of 7.6x105n cm-2.s-1 and 50 mm diameter. A mono-crystal of silicon (450 mm length and 100mm diameter) is used in collimator to cut the fast neutrons. The facility was used for the determination of the isotopic abundance for B and Gd and for impurities of B, Gd, Sm, Cd, Pb, Hg in different samples. Sensitivity of the method is: B – 8 imp/sec/mg; Gd – 10 imp/sec/mg; Sm – 8 imp/sec/mg. This facility uses a detector for gamma spectrometry from ORTEC.

Another detector for gamma spectrometry is used for neutron activation analysis. The samples are activated both in TRIGA-SSR and TRIGA-ACPR using a pneumatic post.

The high resolution diffractometer with Si pneumatically bent monochrystal as monochromator is intalled at the radial channel of the TRIGA-SSR reactor. This instrument is aimed to analyze the structure of different materials including texture, stress/strain, ageing, phase composition etc. The main characteristics are:

- monochromator : pneumatically bent Si perfectcrystal in asymmetric reflection (331).
- diffraction on polycristalline samples.
- wavelength : 2.05 A
- angular resolution: 15-25 minutes
- detector: 3 position sensitive detectors, each of 30 cm length, 1mm resolution, disposed vertically
- field angle: 2θ < 1200

For PGAA and NAA are used two HpGe detectors. The detector from PGAA will be used at DNR to capture prompt gamma rays simultaneously with neutron imaging to put in evidence elements like H, B, Cl, Cd, Sm, Gd, Eu, Mn, C, N, P, S, Pb etc. A special holder for HpGe detector and two collimators for gamma rays will be designed and fabricated for DNR facility. A collimator will provide an average elemental composition for a large area of the object and the other collimator for some narrow parts from object will be used to achieve a rough 3-D distribution of the elements in object. A software is needed to reconstruct a 3-D image. Detector will have a fixed position and the investigated object will be moved controlled in the radiation beams of neutrons and gammas. Some areas of the object will be scanned by HpGe detector for 3-D element distribution after capturing of image that reveals the interested areas for further elemental investigation. If it is permitted to take a sample of tens of µg from an object a NAA could be accomplished.

In order to perform a neutron resonance capture analysis (NRCA) for evidence of Cu, Ag, As, Zn, Sb, Sn etc., we will be purchased a D-D fast neutron generator that will target the investigated object. A special arrangement will be designed after modeling with MCNP code. Neutrons moderated at proper energies for different resonances of the isotopes from investigated object will be extracted to hit the object.

Also, a scintillator for fast neutrons will be bought to made available fast neutron radiography. The D-D generator and scintillator optically coupled to one of the available CCD cameras will put in function a mobile neutron radiography with fast neutrons for in-situ investigations. Application of this method could have impact in industry and archaeology too.

Expected Outputs:

- First of all will be a good opportunity for all specialists from TRIGA department with specific expertise at using neutrons and gamma radiations for investigations of the materials to collaborate at a common plan.
- At the end of this project will be in place techniques and methodologies for a large area of scientific studies and industrial applications for structural and composition determination of the materials that form objects.
- This project gather all nuclear techniques and methodologies from TRIGA department of the INR to contribute at a complex plan for an integral structural and

composition analysis of the materials. This sets the limits of every method, assures a easier future dissemination of every method among possible beneficiaries and sets a methodology to perform the proper investigation to obtain as simple as possible the required result for the structure and the composition of an object.

– The focus on cultural heritage will help to establish a way of collaboration between specialists that put in place the nuclear techniques and the specialists that can use these techniques. This collaboration can be a good feed-back for involved techniques and an open way for collaboration with specialists from other fields.
– The project assures a permanent exchange of information among the participants to CRP. In the period of the deployment of the project some initial ideas could be changed with better ones after planned meetings. The total outcome of the CRP will be a real progress for neutron radiography that will be improved with other techniques used complementary in the same installation.

Main objective	**Sub objectives**	**Year 1**				**Year 2**				**Year 3**			
		Q1	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Database	Get information - update of the 2006 version of the OCTOPUS reconstruction software	X											
	Compile info concerning OCTOPUS reconstruction software		X	X									
	Send info												
Facility improvements	- Improvement of the thermal neutrons transfer from reactor core to tangential channel by placing aluminum pins in empty holes of the reactor grid	X											
	- A new design and building of the radiological protection for dry neutron radiography facility												
	- Finalization of the hardware and software for remote control of the different displacements		X										
	- a special holder for HpGe detector												
	- a special holder for HpGe detector			X									
	- will be purchased a D-D fast neutron generator that will target the investigated object					X	X						
	-. A special arrangement will be designed after modeling with MCNP code									X	X		
	- The D-D generator and a scintillator for fast neutrons optically coupled to one of the available CCD cameras will put in function a mobile neutron radiography with fast neutrons even for in-situ investigations.											X	
Sample 1 Dacian statues of clay	Planning		X	X		X							
	-Neutron radiography						X				X		
	-Diffraction							X			X		
	-Tomographic investigations												
	-Elemental composition analysis of the objects								X		X		
Sample2 Dacian treasure pieces of silver	-Round Robin Diffraction measurements INR, JINR Dubna			X								X	
	- Tomographic investigations						X						X
	- Elemental composition analysis of the objects							X			X		
	Results				X				X	X			
	Report				X				X		X		

5.14. Mr Denis Kozlenko (Russia)

Introduction

The development of neutron imaging techniques as a tool for non-destructive analysis of the internal structure, defects and processes in industrial products, functional materials, objects of cultural heritage attracts considerable attention at the present time. The dedicated instruments are available at the many neutron sources. The IBR-2M high flux pulsed reactor is one of the most powerful pulsed neutron sources in the world with the average power 2 MW, power per neutron pulse 1850 MW and neutron flux in pulse of $5 \cdot 10^{15}$ n/cm^2/s. During the period December 2006 – December 2010 the reactor was on modernization for replacement of the reactor vessel and fuel elements. During 2011, the successful physical and power start-up of IBR-2M were performed. Now reactor is operational and can be used for research and development activities using neutron scattering techniques in next 25 years prospective. However, no instruments dedicated for neutron imaging is installed at IBR-2M so far. Moreover, in Russian Federation there is no dedicated neutron imaging facility for cultural heritage research at the moment.

Experimental facilities

First activities for establishing prospects of neutron imaging development at IBR-2M were made in 2011. Using the experimental setup based on the CCD camera and beamline 12 with mirror neutron guide, it was shown that appropriate quality neutron images can be obtained in rather short time of 10 s with white neutron beam. The main goal of this project is to develop neutron imaging facility at the IBR-2M high flux pulsed reactor, which can be used for cultural heritage research purposes.

Table 1 - Technical parameters of the neutron imaging facility at the IBR-2M reactor

Neutron flux at the sample position	~10^6 n/cm^2/s
Incoming beam apertures	50, 30, 20, 10 mm
L/D ratio for given apertures	240, 400, 600, 1200
Fields of view for given L/D	341, 298, 276, 255 mm
CCD-camera parameters	Active pixels: 4008×2672 Pixel size: 9×9 μm Image area 36×24 mm Digitization: 12 bit Cooling (Peltier) to -25 C

Cooperation:

- Helmoltz Zentrum Berlin (Germany),
- Paul Scherrer Institute (Switzerland),
- National Research Center “Kurchatov Institute” (Russia),
- Institute of Paleontology RAS (Russia).

Workplan year 1:

- The development of the neutron imaging facility with CCD camera-based detector at the one of available beamlines of the IBR-2 reactor. Design and fabrication of the main units - vacuumed collimator, box for CCD camera with larger field of view (15*15 cm) than presently available (1*5cm), purchasing of sample manipulator, material for X-ray filter.

– Nondestructive analysis of the Brachiopods and other objects from Institute of Paleontology (Moscow) by neutron imaging at IBR-2 reactor. It is planned to use white neutron beam and energy selection by polycrystalline filters.

Main objective	**Sub objectives**	**Year 1**				**Year 2**				**Year 3**			
		Q1	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Development of Neutron Imaging Facility	Planning	X	X										
	Design and fabrication of main units, including vacuumed collimator parts, box for CCD camera		X	X	X	X	X	X	X				
	Purchase of the sample manipulator, material for X-ray filter			X	X								
Research cooperation	Promoting of contacts with neutron imaging and cultural heritage community		X	X	X	X	X						
Sample 1 - Brahiopods	Planning			X									
	Experimental measurements				X		X	X					
	Results								X				
	Report									X	X		

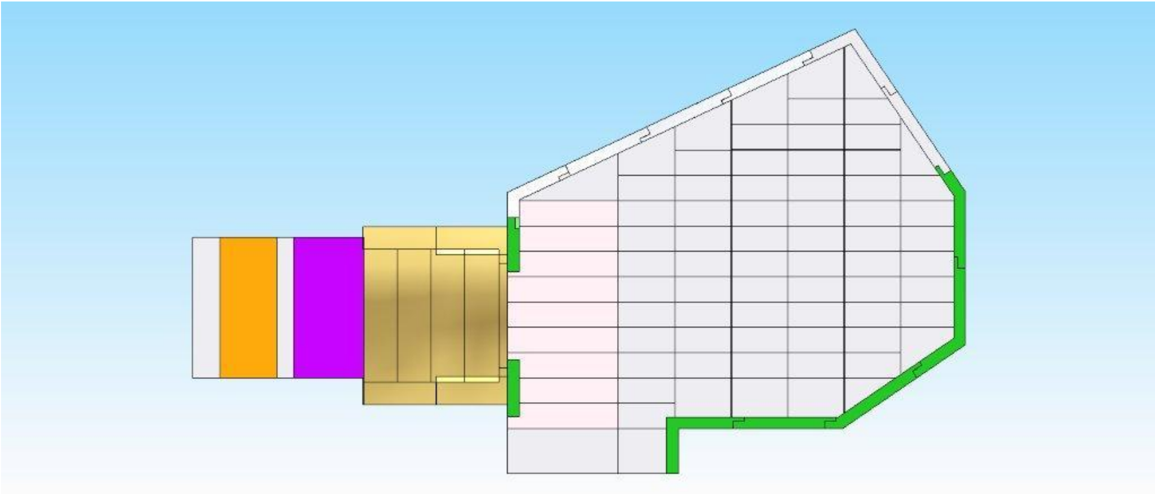
5.15. Mr Frikkie De Beer (South Africa)

Introduction
South Africa has a rich cultural history with ample opportunities for Neutron Imaging to be applied in Archaeological and Palaeontological studies as depicted in the references. Through this collaboration the NI and CH communities are united to introduce neutron induced Autoradiography of paintings as new analytical technique to South Africa. The outcome is foreseen to be a database on NI techniqeus and applications in CH as well as and exhibition at a museum to showcase the scientific collaborations.

Experimental facilities
The SAFARI-1 Nuclear research reactor with the SANRAD facility located at beam line #2, main parameters are:

- Thermal neutron beam flux : 10^7
- with L/D = 125 and

Field of View of 25cm x 25cm. Andor Camera with Neutron sensitive Scintilator screen in light tight box and rotation table completes the imaging infrastructure. Will be in operation till June 2012 and upgraded till July 2013. A new upgraded facility will be in operation from July 2013 – a schematic layout (Top View) of the new facility is being depicted in the figure below.



Cooperation:
The following Cooperation within the scope of the CRP is being envisaged:

- Database: All participants of CRP and all NI facilities globally
- Autoradiography: Helmholtz Berlin : Dr. Nikolay Kardjilov and FRMII – Garching: Dr. Burkhard Schillinger.
- Tomography: Helmholtz Berlin : Nikolay Kardjilov and FRMII – Garching: Burkhard Schillinger.
- PSI: David Mannes
- Museum exhibition: DITSONG museum group in South Africa, Leon Jacobson & Dirk Oegema

Workplan year 1-4:

Year 1 - The establishment of an International database on the International Society for Neutron Radiology website: (www.ISNR.de) on:

- Current approved and available neutron imaging methods applied in Cultural Heritage samples
- Available and characteristics of available neutron imaging facilities for cultural heritage studies
- Literature and references of work reported in previous international Conferences on the subject
- Imaging results of recent publications on cultural heritage samples.

Year 2 - The establishment of an Auto-neutron-radiography capability in South Africa through:

- Theoretical and methodological knowledge transfer from Germany on:
  - Preparation of samples-specially on paintings
  - Neutron scanning
  - Evaluation instrumentation set-up
  - Evaluation techniques and principles
- Practical hands on demonstration at existing facilities overseas for practical knowledge transfer
- establishment of an instrument list to manufacture and install similar and functional infrastructure at the SANRAD facility in South Africa.
- Preliminary investigations on paintings:
  - Development and Manufacturing of phantoms for calibration and standardization.
  - Exposure of phantoms and evaluation
  - Report on findings – especially the critical safety aspects in terms of safety and possible damage to paintings
- Application of neutron tomography and Autoradiography on: Rock art samples, Gold plated artefacts, Glass, Palaeontology samples, Other Archaeological samples
- Planning of Museum exhibition.
  - Determination of needed infrastructure through liaison with the museum community.
  - Planning of museum exhibition layout.
  - Purchasing of necessary infrastructures.

The detailed 3 year workplan for autoradiography and the database can be found in the separate working groups

5.16. Mr. Kilian Anheuser (Switzerland)

Introduction

Traditional X-radiography is widely used by conservation scientists in the investigation of cultural objects to assess structural problems and other technological conservation issues. In practice, however, X-radiography is sometimes unsuitable for the purpose, for instance when objects made of organic materials (wood, plastic, textile fibres) are covered by sheet metal. In these particular cases neutron radiography may present an interesting alternative.

The proposed project will be closely associated with the day-to-day activities and requirements of the conservation laboratory of Geneva Ethnographic Museum (MEG), ensuring the practical relevance of the proposed research.

The project follows on from an exploratory study of an Indonesian dagger from the MEG collection, using neutron imaging and tomography facilities at Paul Scherrer Institute (PSI) at Villigen, Switzerland. Results were presented by co-applicant Eberhard Lehman (PSI) in a paper entitled "Wood investigation by means of radiation transmission techniques in the analysis of cultural heritage objects" on the 16th November 2011 at the joint COST-action meeting IE0601/MP0601 "Photon technologies for conservation of wooden cultural heritage" in Paris, France.

Whilst the selection of objects will be made at Geneva Ethnographic Museum, the state-of-the-art facilities at Paul Scherrer-Institute will be used for neutron imaging. PSI's extremely versatile NEUTRA and ICON beamlines, both linked to the SINQ spallation neutron source, provide beams of thermal and cold neutrons for analysis as required. Large and heavy objects up to 500 kg can be accommodated by the existing experimental setup. The facilities also allow microtomography at high resolution for the analysis of small objects. X-radiography and –tomography for reference purposes can be carried out either also on the NEUTRA beamline for direct comparison of the results, or locally in Geneva (X-radiography only).

Designed for a period of initially three years, the study of objects using X-radiography and neutron imaging will follow on-going conservation and restoration campaigns in preparation of the re-opening of Geneva Ethnographic Museum in 2014. Imaging will be carried out as and when requried during investigation and treatment of objects, ensuring its practical relevance for ordinary
day-to-day museum activities. It is envisaged to present and publish results at relevant scientific and/or conservation conferences, for example at future IAEA-coordinated research project meetings.

5.17. Mr David Mannes (Switzerland)

Introduction

Historical bronze objects play an important rule in cultural heritage research as this material was used for a broad variety of different purposes (tools, weapons, jewellery, cult objects,…) since more than 5000 years in most parts of the world (Africa, Asia, Europe). Furthermore this group of copper alloys shows high durability and has low susceptibility for corrosion, which explains the large number of objects, which have stand the test of time and wait to be studied. For the study of cultural heritage objects non-destructive testing methods are in many cases required and generally preferred. Neutron imaging provides a unique opportunity to thoroughly characterize bronze objects and to provide information on the inner structure also from larger objects while other conventional methods such as X-ray methods are restricted to surface regions of such metal objects.

In the scope of this CRP we propose an interdisciplinary platform for non-destructive investigations of historical bronze objects using neutrons. The platform will provide a forum and link users from the cultural heritage area with partners from the neutron imaging community. As outcome we anticipate a document listing the possibilities and limitations of neutron imaging (such as neutron-radiography, -tomography, energy selective imaging,…) and other neutron based techniques (e.g. diffraction, PGAA,...) to investigate certain questions and problems from the cultural heritage area regarding bronze objects. The document should also contain possible methodical approaches (i.e. how to perform certain investigations) and list partners from the neutron imaging community, which could help in the planning and realization of investigations.

The platform will intensify the collaboration and strengthen the connections between the involved research institutes from both areas neutron physics and cultural heritage and result in a long-lasting synergetic effect.

Experimental facilities

The neutron imaging facilities at the Paul Scherrer Institut include two beam-lines, NEUTRA and ICON, the first with neutrons in the thermal spectrum the latter with a cold neutron spectrum, which are both fed by the spallation neutron source SINQ. Both beamlines dispose over a variety of different detector systems (mostly scintillator-CCD camera systems), which can be chosen accordingly to the requirements of the respective investigation (object size, spatial resolution, sensitivity, temporal resolution,…). Large samples (up to 500 kg) can be scanned with a maximum field of view of 30 cm x 30 cm; the highest spatial resolution can be reached for small samples resulting in a pixel size of 13.5µm/px. The NEUTRA beamline is equipped with an optional X-ray tube allowing reference measurements with similar beam geometries and thus direct pixelwise comparison of the resulting images. ICON is equipped with devices for energy selective imaging and differential phase contrast imaging.

Table 1 – Basic specification of available neutron imaging instruments

NEUTRA specification (neutron energy: 25 meV thermal Maxwellian spectrum)

Position for experiments	**2**	**3**
Distance from the n-aperture L [mm]	7292	10547
Neutron flux / cm^2 / sec / mA	$9.8\ 10^6$	$5.1\ 10^6$
Collimation ratio L/D	350	550

ICON (Mean neutron energy 8.53 meV / 3.1Å)

Position for experiments	**2**	**3**
Distance from the n-aperture L [mm]	6864	12083
Neutron flux / cm^2 / sec / mA	1.3 10^7	3.9 10^6
Collimation ratio L/D	343	604

Table 2 – Typical CCD imaging parameters

Position	**Lens**	**Field of view [mm]**	**Nominal pixe size [mm]**	**Exposure time [sec]**
NEUTRA 2	Macro	65 x 65	0.032	60
NEUTRA 2	Normal	150 x 150	0.104	12
NEUTRA 3	Macro	131 x 131	0.064	50
NEUTRA 3	Normal	306 x 306	0.15	8
ICON 2 (Midi)	Normal	150 x 150	0.104	12
ICON 2 (Micro)	Normal	27	13.5	90
ICON 3	Normal	306 x 306	0.15	8

Instrument References:

– NEUTRA: E. Lehmann et al, Nondestr. Test Eval. 16, 191-202 (2001), doi:10.1080/10589750108953075
– ICON: Kaestner et al., NIMA , 659(1), pp 387-393, doi:10.1016/j.nima.2011.08.022

Cooperation:

- Swiss national Museum
- Ethnographic museum Geneva
- Rietberg Museum Zurich
- University Zurich, Institute for Archaeology

Workplan year 1:

The project will be embedded in the regular operational plan of the neutron imaging beamlines at PSI. Two PhD-projects will partially be integrated in the project, one dealing with the evaluation of the manufacturing processes of bronze age knives (University of Zurich) and the other one dealing with energy selective neutron imaging (PSI & EPFL). The scope of the second thesis will be to optimise and improve the method with regards to the topic for example by developing a double-detector setup allowing for simultaneous acquisition of transmission and diffraction images.

Beside the already existing project it is planned to actively identify and invite possible partners from the cultural heritage area and to expand the number of evaluated applications within the project.It is envisaged to present and publish results at relevant scientific and/or conservation conferences, for example at future IAEA coordinated research project meetings. Other events, which will be used to further promote the platform idea of the project are the International conference for experimental archaeology EXAR 2012 in Brugg, Switzerland and the 18th International Congress on Antique Bronzes, to be held in Zurich in 2013 and will be co-organised by PSI.

Main objective	**Sub objectives**	**Year 1**				**Year 2**				**Year 3**			
		Q1	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Demonstrate / Scrutinize possible application of neutron imaging for historical bronze objects	Bronze age knives → structures / textures	X	X	X	X								
	Historical bronze objects	X	X	X	X	X	X	X	X	X	X	X	X
Publications	Publications / conferences	X	X	X	X	X	X	X	X	X	X	X	X
Improvement of imaging methods (e.g. → double detector setup)	planning	X	X	X									
	Testing / measurements		X	X	X	X	X						
	Results and publication				X	X	X	X	X	X	X		
Document listing possibilities / limitations of neutron imaging for CH objects (bronze)	Gather info	X	X	X	X	X	X	X	X	X	X	X	X
	Compile methods	X	X	X	X	X	X	X	X	X	X	X	X
	Compile contact lists (CH partners)	X	X	X	X	X	X	X	X	X	X	X	X
	Report									X	X	X	X

5.18. Ms Sasiphan Khaweerat (Thailand)

Introduction

Undoubtedly, neutron imaging is one of the best investigation techniques for cultural heritage researches. Cultural heritage is what we obtain from the past and pass on to future generation. It contains unique and irreplaceable record that is important to fulfill our understanding about the past. Recently, many cultural heritages remain untouched and historical records are ambiguous because scientific method of proof is difficult to make without destruction. Fortunately, the neutron imaging technique allows property of neutron that can penetrate through object providing non-invasive characterization. The intensity of transmitting neutron varies upon neutron flux at exposing position and elemental composition in particular objects. Consequently, the object's provenance, manufacturing technology, authentication, and hidden structure can be determined. To achieve a high quality image and further service for cultural heritage research, good facility and practice are of significant concerns.This CRP provides great opportunity to develop neutron facility and to standardize methodology in Thailand. After official meeting between Thailand Institute of Nuclear Technology (TINT) and Office of National Museum (ONM), Fine Arts Department on 24^{th} January 2011, we are agreed to collaborate in CRP- F11018. With supporting from IAEA, the neutron imaging technology will be sustainable developed and the strengthen collaboration between TINT and ONM will be established. TINT scientists will work in an appropriate channel to meet the state-of-the-art end user's requirements. Since the hidden historical records will be revealed, we strongly believe that the adapted neutron imaging technique will help answer questions regarding ancient Thais.

The utilization of neutron imaging technology in Thailand is limit as a result of a few numbers of neutron facilities; a research reactor and a neutron spallation sources. Neutron radiography has been developed since 1991 when a radiography facility was constructed at 8”x8” south beam tube of Thai research reactor (TRR-1/M1). Collaboration between Office of Atoms for Peace and Chulalongkorn University has been performed continuously. In 1995, ZnS(Ag) plate was invented and tested for in-house using. During 2005-2007, a Fuji BAS-ND 2040 neutron imaging plate and a Kodak MX125 X-ray film/Gd neutron converter screen combination were tested for comparison. The optimum conditions for neutron imaging plate applied for diversity of samples have been studied. More recently, we use neutron imaging technology to look inside plants, to evaluate pearl structure, to search hidden parts in some electronic devices and to investigate sculpture manufacturing technology. The current neutron imaging utilization in Thailand, however, provides unsatisfied image quality with less resolution because of uncertain and low neutron flux at exposing position and relatively high background radiation. Therefore, we have an energetic attempt to develop and enhance our neutron imaging facility for cultural heritage analysis and can be extent further for servicing diversity of samples.

Experimental facilities

– Neutron radiography beam tube at (TRR-1/M1)
– Dark room
– Radiographic film and film processing facility
– Neutron imaging plate ND 2040
– Image reader BAS 2500

Workplan year 1:

- Official cooperation between Thailand Institute of Nuclear Technology and Thai National Museum has been initiated and MOU will be signed by the end of 2012
- Collect information of proper cultural objects for neutron imaging
- Significant Thai cultural objects are exhibited at Thai National Museum, however, most pieces are well stored and undetermined. For the first phase, we aim to take image of movable objects that can fit well with our neutron beam. The focused objects should be less than 20x20 sq cm in size. The objects may be made of wide ranges of materials, for example, bronze, alloy, wood and clay.
- Develop neutron imaging facility at 8”x8” south beam tube of Thai research reactor (TRR-1/M1)
- The exposing position should be modified for easy accessing. The slot for placing imaging plate should be well designed and can be adjustable for different size of objects.
- Attend the first RCM

Main objective	**Sub objectives**	**Year 1**				**Year 2**				**Year 3**			
		Q1	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Data collection	Get information	X	X										
	Compile info		X										
	Develop neutron radiography facility including sample exposure station			X	X	X							
Experiment	Planning					X	X						
	Neutron radiography							X	X	X	X		
	Results											X	
	Documentation											X	X

5.19. Mr Michael Lerche (USA)

Introduction

Neutron imaging is an ideal tool in cultural heritage applications: It is a non-destructive technique that can penetrate several cm of metal. These features allow, for example, to investigate metal cast sculptures by exposing their inner structure. This way manufacturing procedures could be revealed, which may also provide information about knowledge transfer between different cultures. The University of California, Davis (UCD) operates the McClellan Nuclear Research Center (MNRC), a nuclear reactor-based research facility. MNRC is a 2 Megawatts (MW) TRIGA™ (Training, Research and Isotope Production General Atomic) reactor, originally built and operated by the United States Air Force for the primary purpose of detecting low-level corrosion and hidden defects in aircraft structures using non-destructive testing techniques. In 2000, the center was acquired by UCD for continuing operations to support nuclear education, research, and applications.

Experimental facilities

Both, two-dimensional radiography and three-dimensional tomography are available at the MNRC, the Center has the capability to image samples as large as 10 m long, 3.6 m high, and weighing up to 2.25 metric tons (radiography only).

We want to implement suggestions and standards established in this CRP and by the International Society of Neutron Radiography (ISNR) in to our procedures, to allow for state of the art neutron imaging in cultural heritage (CH).

We also established a collaboration with UC Davis' Institute for Data Analysis and Visualization, a group working on interdisciplinary problems in visualization, geometric modeling, computer graphics, computational geometry, graphics architecture, and immersive technologies. This group also operates the "W. M. Keck Center for Active Visualization in the Earth Sciences" (KeckCAVES), a high-end immersive visualization facility that is equipped with cutting-edge software for interactive exploration and analysis of complex 3D data. CH related tomography data can be visualized using these techniques, providing new ways of investigating and understanding the data.

The MNRC has four bays to perform neutron radiography: Two large enclosures that can accommodate samples up to 10m x 3.6m x 2.5m, weighing up to 2.25 tons and two smaller enclosures that also provide tomography capabilities. Most of the work would be done in the smaller research oriented bays using conversion screens and CCD cameras, but one of the larger bays will be available if needed. Techniques available in all bays are imaging plates, film and conversion screens with CCD camera readout.

Workplan year 1:

- Participation in the discussion to standardize procedures for CH applications
- Evaluation of current capabilities at MNRC.
- Actively pursue funding opportunities to upgrade and update our equipment if necessary.
- Foster collaborations with researchers in the field of data visualization

Main objective	Sub objectives	Year 1				Year 2				Year 3			
		Q1	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Standardize procedures		X	X										
Evaluation of current capabilities (Note: the timeline depends on the availability of standards!)	Receive standardization procedures	X	X										
	Accumulate data			X	X								
	Evaluate data				X	X							
	Make results available					X	X						
Pursue funding opportunities					X	X	X	X	X	X	X	X	X
Foster collaborations				X	X	X	X	X	X	X	X	X	X

6. OTHER RELEVANT ACTIVITIES

6.1. Newcomers to NI – Software & Hardware (Burkhard)

A collection of links to free software and to simple hardware for radiography and computed tomography will be built and later hosted either at www.isnr.de (see below) with the database, or at the future CRP site at ANSTO. The software will allow for first radiography and tomography data processing, the hardware descriptions will contain a master thesis about building a simple radiography/tomography starter system which had originally been intended for IAEA, then built at FRM II of Technische Universität München as a beam monitoring device and adjustment aid.

6.2. Database

The need to establish a database where aspects (proven NI techniques / published references / etc) of the interaction(s) of past, current and future activities between NI techniques in CH research are being compiled for the benefit of both scientific groups.

Aim of the database is to establish and maintain an international database on the Web-site of the International Society for Neutron Radiology (ISNR) (Site : www.isnr.de) on:

– Current proven and available imaging methods applied in CH
– NI facilities – Availability / Characteristics
– Full reference of published papers in journals (past WCNR-series)
– www-links to: (1) Software available in the analysis of CH objects, (2) CH sites, (3) NI available sites for Cultural heritage studies and (4) Applicable Conferences on CH & NI.
– Thesis's: Full documents

The goals of the database are to maintain the updated database which will be accessible to any researcher in the field of NI or CH and others to know about the current status of research conducted in this field.

The schedule for development and implementation of database is summarised in attached table.

Main objective	Sub objectives	Year 1				Year 2				Year 3			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Database	Format of database	X	X										
	Liaise with web site curator and format of database	X	X	X									
	Compile references from WCNR-series		X	X	X								
	Populate database for use by community and trials			X	X								
	WORKING DATABASE					X							
	Update					X	X	X	X	X	X	X	∞

Additional requirements for such a database and specifications include also the following features;

- Opening page (Welcome)
- Must be searchable in terms of (1) Keyword and (2) Author
- Must be user friendly

6.3 Conferences and other scientific events

- 2012/06/16 – 21: ITMNR-7: International Topical Meeting on Neutron radiography, Kingston, Canada.
- 2014/10 : WCNR-10: 10th World Conference on Neutron Radiography, Switzerland

6.4 Scientific publications

The CRP members agree to publish as many joint peer-reviewed papers as possible in order to stimulate and demonstrate the high level of cooperation. Furthermore they will also put acknowledgment on the IAEA CRP in order to publicise this specific activity.

All RCM participants precompiled the liet of available publication which are a very good starting point for new comers in the area of 3D neutron imaging and application in cultural heritage research. This list is available in ANNEX 2

6.5 Identified web-sites

www.isnr.de : web page of the International Society for Neutron Radiology

www.bcin.ca : "Bibliographic Database of the Conservation Information Network", conservation bibliography hosted by the Canadian Heritage Information Network, contains publications relating to technological studies of cultural heritage artefacts from a conservation point of view.

http://aata.getty.edu : "Art and Archaeology Technical Abstracts", conservation bibliography hosted by the Getty Conservation Institute, contains publications relating to technological studies of cultural heritage artefacts.

7. RECOMMENDATIONS

The following proposal for hosting an international conference and RCM-2 is being made for evaluation by the IAEA:

7.1 International Conference

Date: Week 1 of Sept 2013

Venue: Munich, Germany (Technische Universität München (TUM - Garching))

Hosted by TUM: An international conference for Neutrons in Cultural Heritage Research (including other neutron methods) in conjunction with a CRP meeting (2013 or 2014)

Invite existing and potential Museum and Archaeology users from Europe and all over the world.

Preliminary assent exists from the press office of TUM to host the conference under the auspices of The President of the University and IAEA

7.2 Next RCM meeting

The CRP participantsa agree that next RCM meetign should take place in Munich, Germany (hoted by TUM). Suggested period of the meeting should be following week of the the conference (ref. 7.1).

8. CONCLUSIONS

The participants concluded that all objectives of first RCM meeting were accomplished, specifically:

- The plans of all participants have been reviewed. An overview of the status of NI facilities and the CH needs has been given.
- Numerous new collaborations were triggered by the RCM.
- An address list was created and a web portal has been initiated.
- The objectives of the CRP were scrutinized. All objectives as put forward in the CRP are achievable.
- The proposed website will provide a platform for the benchmarking of software and procedures. Participants with existing facilities confirmed their availability for use by others within the frame of the CRP.
- The development of a database was initiated to be jointly hosted by International Society For Neutron Radiology (ISNR) homepage (Germany) and Australian Nuclear Science and Technology Organisation (ANSTO), (Australia).

The 2nd RCM is estimated to be by approximately September 2013. Each participant is expected by then being ready to start validation tests, intercomparison and/or benchmarking.

ANNEX 1 - NEUTRON IMAGING INSTALLATIONS

Country	Name of the facility	Name and address of the contact person	Techniques	Accesibility/proposal system	Max. size/weight of the object	Technical parameters			
						Neutron flux at sample position [cm-2s-1]	L/D	Typical linear resolution [µm]	remarks
Argentina	Reactor RA-6 Centro Atomico Bariloche	Fernando Ariel Sanchez Centro Atomico Bariloche R8402AGS Bariloche Argentina	Radiography	No proposal system contact directly via email	30 x 30 x30 cm3 or 20 x20 x 100 cm3	8 10^7	100	0.1 mm	
Australia	DINGO	Ulf Garbe Australian Nuclear Science and Technology Organisation New Illawara Road Lucas Heights, 2234 Australia ulf.garbe@ansto.gov.au +61 297177217	Neutron Radiography., Tomography,	User office and proposal system available end 2013	2.5m 500kg	$4.75x10^{7}$@L/D=500	Two beam setup: L/D=500 L/D=1000	50-200 um	Friendly user starts begin 2013
Brasil	IEA-R1 Research Reactor	Reynaldo Pugliesi IPEN-CNEN/SP Sao Paulo Brazil	Radiography Neutron induced radiography(*) Real-time Tomography	contact directly pugliesi@ipen.br	15cm 10Kg	8x10^6	100	300	(*)capability to inspect very thin samples
Cuba	CEADEN Neutron Generator NG-12-I	Ivan Padron Diaz CEADEN Calle 30 No.502, Miramar, Playa, La Habana, Cuba	Fast neutron imaging (TOF; MCP detector)	contact directly (ipadron@ceaden.edu.cu)		$1x10^{6}$			under development
Germany	ANTARES	Burkhard Schillinger TU Muenchen FRM II Lichtenberstr.1 D-85748 Garching, Germany Burkhard.Schillinger@frm2.tum.de +49 89 28912185	Neutron Radiography., Tomography, polarized magnetic imaging, pinhole phase contrast, liner phase contrast, stroboscopic imaging, fast continuous imaging	User office and proposal system on user.frm2.tum.de (Button for English available)	1m, 500 kg	1.6 x 10^9 @L/D=100, 2.6 x10^7 @L/D=800	Six different collimators, two positions L/D=100 to L/D=7100	80 um with standard screen, 10-20 um with thinned screen	in commissioning, available summer 2012, proposals can be submitted

Germany	CONRAD	Nikolay Kardjilov Helmholtz Zentrum Berlin Hahn-Meitner Platz 1 14109 Berlin Germany	Neutron Radiography., Tomography, polarized magnetic imaging, Grating interferometry, energy-selective imaging	User office and proposal system on www.helmholtz-berlin.de	50 cm, 200 kg	1x10^7@L/D=300 3x10^6@L/D=500	3 different collimators, two positions L/D=150 to L/D=1000	80 um with standard screen, 10-20 um with thinned screen	in commissioning, available summer 2012, proposals can be submitted
Italy	INES	Marco Zoppi CNR-ISC Via Madonna del Piano 10 50019 Sesto Fiorentino Italy, marco.zoppi@isc.cnr.it	Diffraction, imaging testing facility	www.isis.stfc.ac.uk/apply-for-beamtime/apply-for-beamtime217.html	50 Kg	ISIS pulsed surce, TS1, 22.8 m from Water moderator	~100	100	Preliminary prototype for testing radiographiec techniques on a pulsed source
Japan	J-PARC	Yoshiaki Kiyanagi Hokkaido University Kita-13, Nishi-8, Kita-ku, Sapporo, Hokkaido, 060-8628, Japan http://is.j-parc.jp/vo/index_e.html	TOF radiography	User office and proposal system available (Button for English available)	~30x30x30cm^3 Max. beam size 10x10cm^2	4.7x107@L/D=140 @1MW	140,190,600, 1875	0.055mm (Detector dependent)	
Malaysia	Neutron Radiography 2 (NUR-2)	Muhammad Rawi Mohamed Zin Block 34, Malaysian Nuclear Agency, 43900 BANGI, Selangor, MALAYSIA	Neutron Radiography (direct method film technique, CCD neutron camera method), Neutron Tomography	-NotApplicable	At present 5 100 kg (concrete base platform)	10^5	Geometrical L/D 75 Measurement varies ~30 to 100	120, 50	
Poland	NGRS National Centre for Nuclear Research, 05-400 Otwock	Jacek J. Milczarek, +48 605633998 jjmilcz@cyf.gov.pl	transmission radiography	3500 h/year	20 cm/100 kg	10^7	100 - 200	150	
Romania	Institute for Nuclear Research Pitesti(INR),115400-Mioveni, Arges County, Romania	M.Dinca, +0248 213400, fax +40248262449	Transmission radiography	600h/year	10 cm/10kg	10^6		0.1-033	
Russia	Frank Laboratory of Neutron Physics, Joint Institute for Nuclear Research,141980 Dubna Moscow Reg, Russia	Gizo Bokuchava +7 49621 65273 gizo@nf.jinr.ru	Transmission radiography/ tomography	2100 h/year, http://flnp.jinr.ru	27 cm/35 kg	10^6	200-1900	150	Estimated parameters are given, facility is in development stage

South Africa	SouthAfricanNuclearEnergyCorporation (Necsa) PO Box 582, Pretoria,South Africa SANRAD facility	Frikkie deBeer Building1500, Necsa, POBox 582, Pretiria, 0001, South Africa Email: frikkie.debeer@necsa.co.za +27 12 3055258	Thermal neutron radiography & Tomography Micro-focus X-ray Radiography & Tomography (Future) Gamma ray Radiography & Tomography	Thermal Neutrons: Accessable till End July 2012. Upgrade and offline from until July 2013 MicroFocus X-rays: Available Gamma Ray: Planned – Not Accessable2012	Thermal neutrons 20kg After upgrade 100kg	Thermal neutrons: Before Upgrade: 10^6 After upgrade: 10^8	65, 250, 400 800	100	Thermalneutron radiography in upgrade from June 2012 till July 2013
Switzerland	Paul Scherrer Institut (PSI) CH-5232 Villigen PSI Switzerland	Eerhard Lehmann +41 56 310 2963 eberhard.lehmann@psi.ch	Transmission radiography / tomography, Neutron grating interferometry, Energy selective imaging, dynamic measurements	Research proposals via digital user office (duo.psi.ch)	500 kg	10^6-10^7	343 - 600	13.5 - 150	Parameters for typical / standard settings; values can differ considerably (confer PSI-Homepage)
Thailand	Thai Research Reactor(TRR 1/M1)	Sasiphan Khaweerat 16 Vibhavadeerangsit Rd, Ladyao, Chatuchak, Bangkok, 10900 Thailand	- Thermal neutron radiography,	approximately 300 days/year	30x30x30 cm^3	10^5	100	25-50 um	
USA	McClellan Nuclear Research Center	Michael Lerche University of California Davis MNRC 5335 Price Avenue McClellan, CA 95656, USA mlerche@ucdavis.edu	Radiography and Tomography	No proposal system contact directly via email	10m, 2,2tons for radiography 1m, 200kg for radiography	$5x10^6$@L/D=200, $1x10^7$@L/D =170 $6x10^5$@L/D=350		100 um, 50um 50um	

ANNEX 2 - TABLE 1. TYPES OF SAMPLES TO BE ANALYZED BY PARTICIPANTS

Country	Facility available for testing	Type of neutron Beam Thermal Cold Fast	Technique	Sample type	Sample shape	Reason for analysis Foreign material Mensuration Authenticity Manufacturing
South Africa	FRMII HelmH-Berlin ANTARES PSI	Thermal Cold	Autoradiography	Test samples of Paintings Real paintings	Plate	Authenticity
Malaysia	Hokkaido Univ. (J-PARC) CNR (ISIS) HZB	Fast Thermal Cold	Bragg-Edged Diffraction High Resolution Tomography	Test samples: Knife – Kris	Curved	Composition and manufacturing technology
Romania	DNR – Romania Dubna – JINR (Russia)	Thermal	Radiography/Tomography Diffraction SANS	Clay statues Silver ornaments	Pottery shape	Composition Manufacturing
Egypt	ETTR-2 (Egypt)	Thermal	Tomography	Ancient Egyptian Artefacts (Mummified plant and animals)	All shapes	Mummification process/method
Brazil	IEA-R1 (Brazil)	Thermal / Cold	Radiography/Tomography	Pottery	All shapes	Manufacturing and restoring materials
Bulgaria	HZB	Cold	Bragg-Edge & Other non neutron	Bronze materials	All	Standardization
Italy	HZB (Germany) CNR (ISIS) NCBJ (Poland) Hokkaido Univ. (J-PARC) PSI FRMII (ANTARES)	Thermal Cold	Bragg Edge (Transmission Rietveld Analysis) Tomography Grating Laminography SANS	Bronze Iron Wood	All	Standardization

Country	Facility available for testing	Type of neutron Beam Thermal Cold Fast	Technique	Sample type	Sample shape	**Reason for analysis** Foreign material Mensuration Authenticity Manufacturing
Cuba	IEA-R1 (Brazil)	Thermal	Radiography /Tomography	Pre-Colombian artefact Bronze pottery	Any	Restoration Manufacturing
Poland	NCBJ (Poland)	Thermal	Radiography /Tomography	Bronze/Iron swords and shields	Knife Plate Spherical	Manufacturing
Switzerland	PSI	Cold	Bragg-Edge Radiography /Tomography Grating interferometry Diffraction	Bronze knifes experimentally manufactured Originals	Knife	
Germany	ANTARES (FRMII)	Cold	Tomography	Coins Textiles Burial objects	All	Corrosion state Restoration Weaving techniques
Thailand	TRR-M1 (Thailand) Hokkaido Univ. (J-PARC)	Thermal	Radiography	Pottery Buddha sculpture	Sculpture	Hidden Structure Manufacturing
Argentinia	RA-6 Bariloche Atomic Center (Argentinia)	Thermal	Radiography	Pottery Wood Metals	Any	Structure Manufacturing

ANNEX 3 – LIST OF PUBLICATIONS (TO BE INCLUDED IN THE DATABASE)

2005

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ethylsilicates in porous material by neutron radiography"Journal of Cultural Heritage, Volume 8, Issue 4, September-December 2007, Pages 331-338

2008

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[11] F.C. de Beer, H. Botha, E. Ferg, R. Grundlingh, A. Smith, "Archaeology benefits from neutron tomography investigations in South Africa", Nuclear Instruments and Methods in Physics Research A 605 (June 2009) 167–170.

2010

[12] R. Schulze, L. Szentmiklósi, Z. Kis, Archeologia e Calcolatori 21 (2010) 281-299.

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[15] I. Masiteng, F de Beer, R Nshimirimana, P Segonyana, "X-ray tomography, neutron tomography and energy dispersive X-ray spectroscopy investigations of selected ancient Egyptian artefacts.", Ditsong NMCH Research Journal, Vol 5, 2010, P1-18.

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ANNEX 4 - SUMMARY OF ACTIVITIES

Overview of individual Member States participation in working groups of RCM meeting.

	Autoradiography	Software	New Methods	Newcomer Soft/Hard	NI	CH
Aus		x				
Arg		x		x		x
Bra		x	x	x	x	
Bul			x			x
Cub		x	x			
Egy		x		x	x	x
Ger-H	x		x		x	x
Ger-M	x	x	x	x	x	
Ita	x	x	x	x		
Jap			x			x
Mal		x		x	x	
Pol		x		x	x	
Rom						
Rus			x			
SA	x				x	
Swit-MEG						
Swit-PSI	x		x			x
Thai				x		x
USA		x	x	x	x	

ANNEX 5 - SUMMARY OF NEW COLLABORATIONS ESTABLISHED AMONGST PARTICIPANTS

	Aus	Arg	Bra	Bul	Cub	Egy	Ger-H	Ger-M	Ita	Jap	Mal	Pol	Rom	Rus	SA	Swit-MEG	Swit-PSI	Thai	USA
Aus																			
Arg																			
Bra		x																	
Bul																			
Cub																			
Egy																			
Ger-H	x	x	x	x		x													
Ger-M	x	x	x				x												
Ita	x						x												
Jap	x						x	x	x										
Mal			x					x	x										
Pol			x					x	x										
Rom																			
Rus							x				x								
SA							x	x			x								
Swit-MEG							x		x					x					
Swit-PSI	x						x	x	x	x		x		x	x	x			
Thai								x		x	x					x			
USA	x						x	x							x				
	COUNTRY COLLABORATE WITH																		

The overview of the presentations is summarised in the following paragraphs:

ANNEX 6 – LIST OF PARTICIPANTS

1st RCM on "Application of 3D Neutron Imaging andTomography in Cultural Heritage Research"7-11 May 2012 - Vienna, Austria

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