NON-DESTRUCTIVE INVESTIGATIONS OF SWISS MUSEUMS OBJECTS WITH NEUTRON AND X-RAY IMAGING METHODS

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Abstract: Many objects of archaeological relevance found in Switzerland are from the Celtic and Roman era. Because of their uniqueness in most cases it is demanded to perform any investigation with such samples non-destructively.

Depending on the structure and size of the objects a transmission experiment performed either with X-ray or neutron can alight inner structures, composition, defects or the principles of the manufacturing procedures. Furthermore, the treatment by conservators and restaurateurs becomes visible in many cases.

This report describes some examples of such investigations. In the case of neutron investigations, beside the transmission imaging as a radiograph the three-dimensional structure was observed with a tomography technique. For X-ray radiography, the images were obtained in the same digital format because the similar experimental method (imaging plates) was applied.

It becomes evident in the described examples that the combination and complementary use of both methods (neutrons and X-ray) brings insights in different aspects of the samples properties and treatment.

This approach to study museums objects stored and exhibit in Switzerland can be extrapolated to other countries where these techniques are also simultaneously available in order to investigate other objects of relevance. The European network COST-G8 entitled "Non-destructive analysis and testing of museum objects" can help to support initiatives in this direction.

Introduction: Objects of historical relevance are often very difficult to analyze due to their age, value and constitution. In most of the cases and when only a limited number of objects is available, the application of non-destructive methods is mandatory. Therefore, most of the larger museums are equipped with installations for X-ray analysis (radiography, diffraction, fluorescence). These devices are not specialized for some dedicated material composition, but applied as pre-scanning for more detailed studies.

Beside the traditional X-ray radiography, similar but complementary information can be obtained when neutron beams are used for transmission analysis. The number of labs able to perform such kind of investigations is limited due to the necessary source, the suited beam line and the adequate detection system. It is well known, that neutron images show more the distribution of light elements, e.g. hydrogen. Neutrons permit deeper penetration through thick layers of metals, even heavier mass ones like lead, uranium or bismuth.

The simultaneous application of both X-ray and neutrons enlarges the information about the content and material distribution in macroscopic samples as museums objects are. There are cases where one of these two methods fails completely, but there are other ones where the obtained information fits well together to a final improved evaluation.

This article describes the investigation of several objects from collections of Swiss museums, where the majority of archeologically relevant samples are from the Celtic and Roman era. The selected examples will demonstrate the possibilities available nowadays, when modern imaging systems are applied, which are based on neutrons and X-ray. The used detection systems are similar and provide the information about the investigated objects in a digital format with a wide dynamic range. Compared to the conventional methods based on film, the modern techniques enable the shift of the valid dynamic range given by both the radiation and the sample attenuation into the human visible scale by image post-processing.

The article wants to encourage other museums and archaeologists to follow the described procedure for a better understanding of the objects in their collections.

Procedure: It was a European initiative called COST-G8 [1], which brought together some scientists from national research centers with archeologists and restaurateurs in order to join their knowledge and facilities for dedicated studies. Although there are activities on European level, the first step towards tests of such kind of collaboration has been initiated nationally in Switzerland.

An important issue is the difficulty occurring during the transportation of objects with historical relevance and value abroad and back (safety, insurance, risk of damage during transportation). On the other side, big research installations are not mobile ones, but only usable at institutions sites. These two reasons motivated to investigate native samples at the installations for NDT at the Paul Scherrer Institute (PSI).

In the five examples described below both neutron and X-ray imaging were applied. The facility for neutron investigations was NEUTRA at the spallation neutron source [2] operating with thermal neutrons, whereas for X-ray inspection a standard tube system was applied. The open field of view was in the order of 40 cm, enabling the study of even larger objects. For much larger samples, a scanning procedure can be applied, where several frames are superimposed by imaging software tools. Due to the applied beam intensity and the high sensitivity of the imaging systems, the needed exposure time was in the order of few seconds only. The risk of an activation of the sample material, which might be possible in the case of neutron irradiation, can be neglected for such low doses of radiation. Only when cobalt is involved the dose rate should be handled as carefully as possible.
The detection system for radiography purpose was in both cases an imaging plate (scanner BAS-2500) enabling spatial resolution in the order of 0.05 mm [3]. For neutron imaging the plates were doped with Gd as converter material.
A neutron tomography was performed in some cases with a camera based setup [4], enabling a variable sample size inspection by changing the lens system. This provides a 3D data volume with voxel size from 0.05 to 0.25 mm. Principles of the neutron tomography method and the setup at PSI are described in [8].
This flexible setup enable the investigation of objects with only few mm (as in the case of the Jewish ring – see below) or up to about 30 cm (as used for the spearhead from Giubiasco).
Results: In the collaboration between PSI and different experts from the museums side several important and interesting objects were investigated non-destructively. This article contains only five typical examples enlightening the options available and the results possible from such kind of studies. There are several other results described elsewhere [5, 6]. This collection of examples should be considered as stimulation for both museums experts and natural scientist to perform similar studies in their countries.

1. Jewish finger ring from Kaiseraugst [7]

This spectacular find has importance because it represents the first indication for Jewish influence to the Roman settlement in North Switzerland. The ring itself is small: the total diameter is only about 22 mm, the plate containing a menorah symbol has a diameter of 11.5 mm. The material was found to be a copper alloy.
The question to answer by non-destructive methods was the bond between the real ring structure and the plate. By visual inspection, no gap between both parts was found. Therefore, a manufacturing process from only one piece was assumed in the beginning.

Fig. 1: Results of neutron investigations of a Jewish finger ring from the Roman era: left: neutron transmission, middle and right: neutron tomography. The right picture shows a virtual slice made by software tools through the object on the level were the both parts are fitted.

A first transmission image delivered very discouraging results: very low contrast due to the low amount of material, which itself is very transparent for thermal neutrons. No structure and material non-homogeneities are visible in these images as shown in Fig. 1 on the left.

In a further attempt, 300 individual projections were taken by stepwise rotation around an axis perpendicular to the image lines towards 180° of the object. These data were used to perform a volume reconstruction as a tomography approach. Fig. 1 (middle and right) demonstrates two of the volume visualizations of the ring, an outer view of the object and a slice through the plate near the bond.
With this neutron tomography data set it becomes possible to handle the sample as a virtual reality with the help of software tools. Any slices through the valuable sample can be made non-destructively. As shown on the right in Fig. 1, the plate can be separated from the ring material obviously and the conclusion can be made that the whole assembly was made from two parts.

2. Coin assembly "Zurich lump"

A big metallic object attributed to the time of the Celts (assumed for about 1st century B.C.) was found in Zurich during excavations for a new building in the beginning of 20th century. Several studies were performed over the years in advance to the current one to find out that the origin should be a coin assembly molten together for ritual reasons. The material was found to be "poitin", a copper based metallic alloy.
No transmission would be able with X-ray based methods through such a thick metallic object (diameter up to 40 cm, weight about 70 kg). Therefore, the attempt was made to apply thermal neutrons to obtain information about the inner content and composition of the object. The detection system was either a neutron sensitive imaging plate [3] or a CCD-camera together with a neutron sensitive scintillator [4], both enabling a wide dynamic rang of 16 bits each.

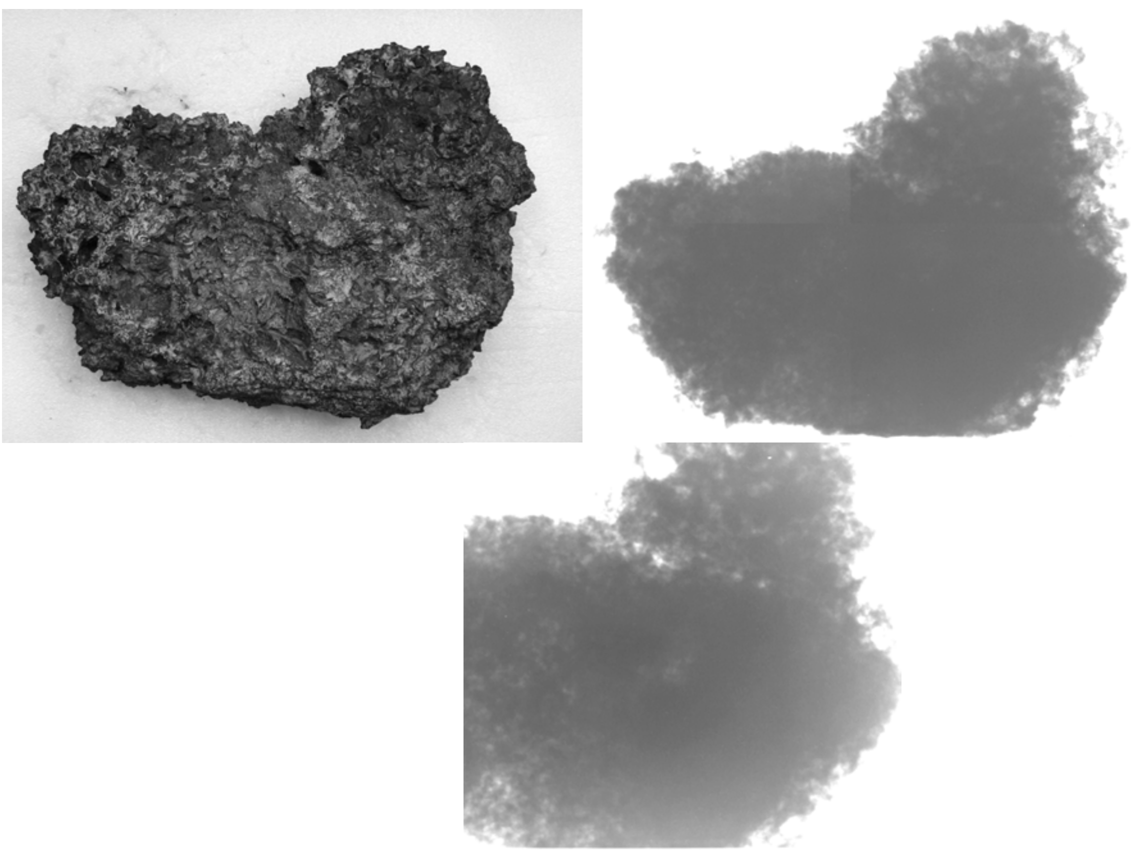

Fig. 2: The „Zurich lump“ (photo on the upper left) with a weight of about 70 kg, identified as an assembly of molten coins of "poitin" metal from the Celtic era was investigated by standard neutron transmission analysis (right) and later with a special method extending the dynamic range of the imaging method. In this way, an insight into this about 40 cm thick sample becomes possible (see the image below).

A simple transmission image already shows some results as indicated in the uper part of Fig. 2. However, to decide about the inner structure needed some enhancement. Therefore, a special image method was applied where 10 individual images were taken and stacked in order to extend the dynamic range as much as possible. With the help of this superimposed data set the sensitivity in the valid range of the histogram was enough to see through all the structure. At most positions of the object where a neutron penetration occurred, no other structures become visible as foamy metal with holes in the order of some mm. It should be emtioned however, the the attenuation in the sample is mainly caused by neutron scattering, blurring the image the thicker the material layer is. Therefore, it is not very surprising that inner structures are not visible with sharp edges.

In conclusion to this study, it can be stated that no individual coins (especially of more attenuating materials like Au or Ag) can be seen in the bulk and the semi-porous structure of the object. The structure visible from the outside seems to continue also inside the object. This non-destructively derived information was a contribution to the understanding of this important exhibit from the Swiss National Museum, Zurich.

3. Spearhead from Giubiasco

This sample was investigated with three different methods: neutron transmission, neutron tomography and X-ray transmission. The results (see Fig. 3) are complementary to each other because the involved materials deliver different contrasts and information. Whereas the metal (mainly iron) is relatively transparent for neutrons, high contrast is delivered for X-ray transmission. On the other hand, there is found some remaining wood inside the lower part of the object as residual form the lance, which has higher visibility with neutrons than with X-ray. Whereas the neutron transmission from this region does not allow to decide about details, the tomography data delivers interesting information about the whole object [8].

In Fig. 3, only one slice in the middle plane of the sample is given showing the structures of the metal and the remained wood as well. Other slices are available and have been used for the archaeological description of the ancient found piece.

4. Roman bronze collection

In the framework of a nationally supported project to describe and to analyze the Swiss finds from the Roman era, a collection of bronze sculptures and other objects have been investigated with the two non-destructive methods mentioned above together with a chemical analysis of the composition. The final aim is the presentation of the results in a dedicated book of a prominent archaeological series. First ever, the images and data of the non-destructive sample analysis will be included into this volume.

To demonstrate the performance of the imaging techniques for such kind of samples, a sculpture named "Merkur from Uster" with a relative thick bronze structure was investigated with both neutron and X-ray transmission. These images (Fig. 4) demonstrate that in such cases the neutron beam is preferable because of the much better transmission. Details inside the object become visible even within material layers of several centimeters. In the case of the X-ray image, only the outer contours can be described. Certainly, the X-ray energy might be increased from the presently used 150 kV, but the relatively high lead content will probably limit the transmission also for higher X-ray energies. Such kind of investigations will be performed in 2004 with tube voltages up to 320 kV.

In cases of relevance, also neutron tomography will be applied enabling a view inside the object, e.g. how the core was made and used during the casting process [8]. Any position of the object can be described by its attenuation coefficient and visualized by suitable slices through the sample volume. This can comfortably be done by advanced software tools as [9].

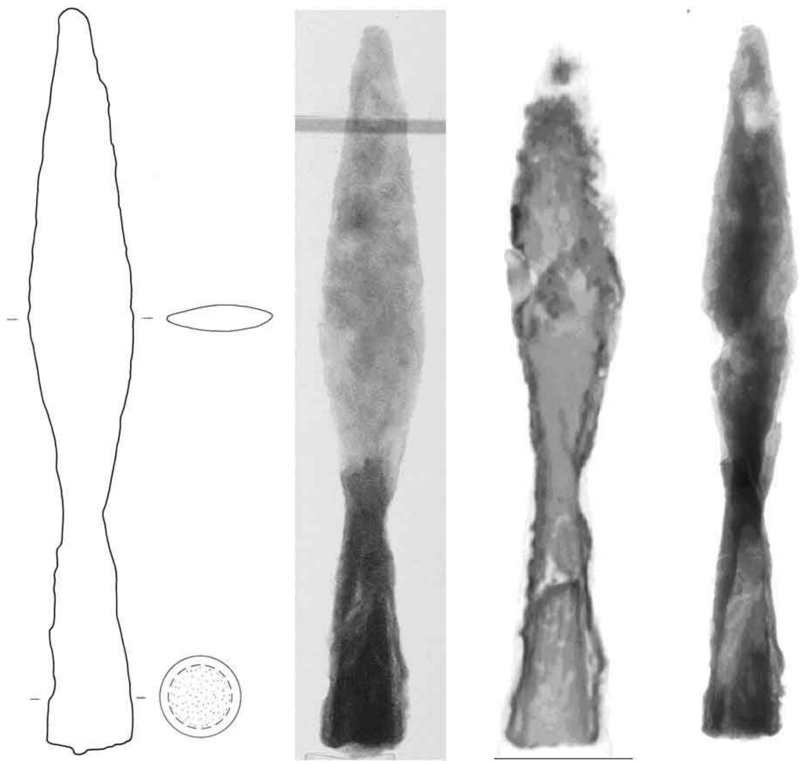

Fig. 3: Results of the investigation of a Roman spearhead (found near Giubiasco (CH)): from left to right– drawings, neutron transmission image, neutron tomography slice through the central plane, X-ray transmission image.

Fig. 4: The bronze sculpture "Merkur from Thalwil" (Photo left) was investigated with thermal neutrons (middle) and X-ray at 150 kV (right). The much higher penetrability by neutrons enables to see inner structures, which is impossible for this applied X-ray energy. This object is about 25 cm high.

5. Imitation of a Roman helmet

A helmet in the collection of a museum in Switzerland was investigated in order to understand the work of restaurateurs in previous time, because major parts were added and strong artificial modifications are assumed. Probably, only the metallic parts were really of Roman origin, but an attribution to a helmet was considered as doubtful. More probably was a former application of theses metallic pieces in a basket or a bucket.
The non-destructive investigations were performed with neutrons and X-ray in vertical and horizontal direction of the helmet. The results are shown in Fig. 5 together with an outer photographic view onto the object. The neutron images are presented on the left side.
The obtained pictures are very different in the respect, that the X-ray ones provide clear information about the metallic parts (metal fittings, nails, …), but neutrons can show wood and leather.

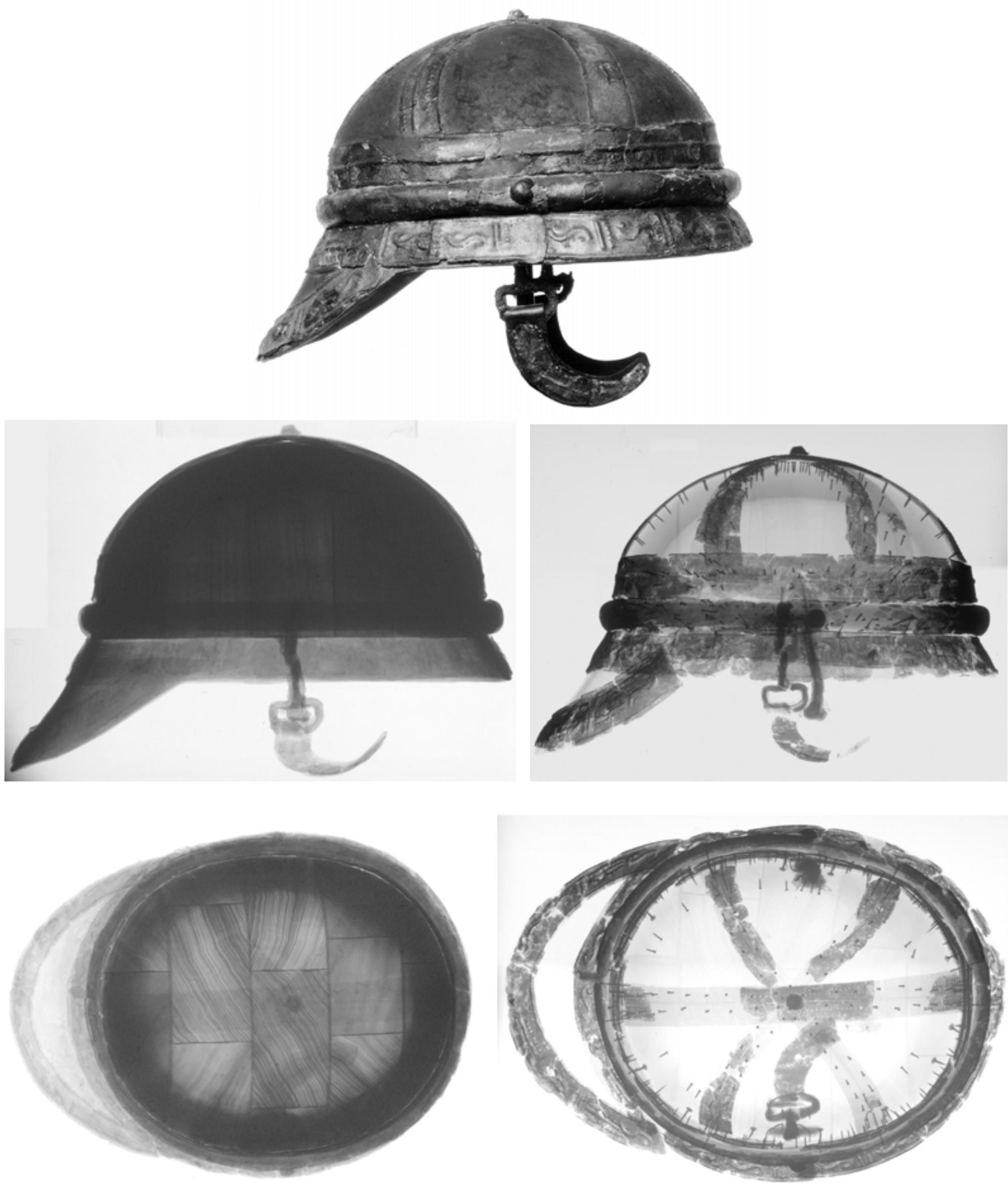

Fig. 5: Results of the transmission of a helmet claimed to be of Roman origin with neutrons (left column) and X-ray. Whereas the metal parts are perfectly shown in the X-ray images, the neutrons are able to visualize the structure of the used wooden material and leather.

Because wood contains a lot of hydrogen in its structure, the neutrons are strongly attenuated and the helmet is not very transparent in the transmission image. In the top view (lower image on the left) , the wooden structure becomes well visible. Obviously, the inner part of the helmet consists of a few centimeters thick wood layer made from several individual pieces fixed together with adhesive. The wood is only hardly visible in the X-ray images, but the nails used to fix the leather layer on it give a high contrast. All metallic bands on the outer surfaces (and also some missing parts inside) can well be analyzed in these images.

Discussion: The few examples shown in the previous chapters demonstrate how useful the non-destructive investigations can be applied to very different questions from the museums experts. Although X-ray imaging is more or less common in some museum research labs, the latest developments towards digital imaging were not followed consequently.

On the other hand, neutron imaging is more “exotic” because the needed neutron sources are large facilities, often located and operated inside specialized research centers. The method is not very well known by the community – but this article intends to make familiar with modern neutron imaging procedures.

The intention is to apply both X-ray and neutron imaging techniques simultaneously to the same object in order to extract as much information as possible in a complementary way. Normally, it depends very much on the composition, which of these two kinds of radiation can provide more useful data. Sometimes, one method is completely useless because either no transmission or no contrast can be obtained. Over the years, there is now sufficient experience to decide how to proceed most efficiently.

Whereas a single transmission image needs only few seconds to get it, a tomography run is obtained over about 200 single frames. The resulting procedure until the structure of the sample can be evaluated is in the order of hours. However, it is justified in many cases to apply this demanding routine as it was wanted to demonstrate in the examples above.

Conclusions: This article demonstrated how neutrons and X-rays can be used for the inspection of museums objects in a non-destructive and non-invasive way. Whereas X-ray imaging is more or less a routine method, the imaging procedures with neutrons are available with high performance at few places only. In the cases where the application of neutron imaging is seen to be mandatory (e.g. if hydrogenous material is involved in suitable amounts), the involved museums specialists should be encouraged to come into contact with partners at neutron imaging facilities. This can either be done directly or via networks like COST-G8 [1] or ISNR [10].

References:

[1] http://srs.dl.ac.uk/arch/cost-g8/

[2] E. Lehmann, G. Kühne, P. Vontobel, G. Frei, The NEUTRA and NCR radiography stations at SINQ as user facilities for science and industry, Proc. 7th World Conf. on Neutron Radiography, Rome, 2002

[3] K. Takahasi et al., Imaging performance of imaging plate neutron detectors, Nuclear Instr. & Meth. In Phys. Research A 377 (1996) 119-122

[4] H. Pleinert, E. Lehmann, S. Körner, Design of a new CCD-camera neutron radiography detector, Nucl. Instr. & Meth. A 399 (1997) 382-390

[5] E. Deschler-Erb, E. Lehmann, L. Pernet, P. Vontobel, S. Hartmann, Complementary use of neutrons and X-rays fort the non-destructive investigations of archaeological objects from Swiss collections, Archaeometry, in press

[6] E. Lehmann, P. Vontobel, S. Hartmann, P. Wyer, Neutronenradiographie zum Test des Eindringverhaltens von Harzen bei Massnahmen zur Holzfestigkeitserhöhung, Restauro, in preparation

[7] L. Berger, Ein Fingerring mit jüdischen Symbolen aus Kaiseraugst, Kanton Aargau, Germania 80, 2002, pp. 529-545

[8] P. Vontobel, E. Lehmann, G. Frei, Performance characteristics of the tomography setup at the PSI NEUTRA thermal neutron radiography facility, Proc. Int. Symp. on Computed Tomography and Image Processing for Industrial Radiology, Berlin, 2003

[9] http://www.volumegraphics.com/

[10] https://www.isnr.de/