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INSPECTION OF THE ROMAN TREASURE FIND BY GAMMA AND NEUTRON RADIOGRAPHY AND I-NAA

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ABSTRACT

By the end of 2003 during the archaeological excavations near the village Drnovo on the construction site of future European highway Ljubljana-Zagreb (Croatia) an intact Roman ceramic pot assumingly containing a treasure find was unearthed The ceramic pot was dated into the 2nd half of the 3rd century A.D. In order to get some preliminary information for the archaeologists and to properly conduct the opening and salvaging the suspected precious contents of the find non-destructive radiographic examinations by both conventional radiographic techniques (X-ray and Ir-192 gamma ray radiography), by thermal neutron radiography (NR) and non-invasive instrumental neutron activation analysis (I-NAA) were performed. The pot was completely filled with earth, with total weight of over 9 kg and quiet large - out. dia 20 cm, height 24 cm) and hence presented a demanding task for radiographic examination. The radiographic techniques provided clear evidence on the presence of a hoard of coins and jewelry and confirmed the assumptions about the treasure contents. The I-NAA gave a clue about the elemental composition of the hoard. The NR complemented the conventional radiography since it revealed that the coins were hoarded in the 3 separate purses made of organic materials, probably leather.

Keywords: Archaeology, Neutron radiography, Ir-192 radiography, Instrumental neutron activation analysis, Ljubljana TRIGA reserach reactor

1. Introduction

In autumn 2003 during the routine excavations on the construction site of the future European highway Ljubljana-Zagreb (Croatia) near the village Drnovo the archaeologists unearthed an intact and excellently preserved Roman ceramic pot. The village Drnovo was once a Roman port Municipium Flavium Latobicorum Neviodunum on the river Sava. The river Sava was an important commercial route connecting Northern Italy with the Danube, the Balkans and Black Sea ("hyperborean" route) The intact find, most likely containing a precious treasure, is an extremely rare event of world-wide importance. An opportunity to inspect an intact, for almost 1800 years hidden Roman treasure is therefore a most exciting and very rare event for a NDT specialist.

To obtain some preliminary knowledge of the contents of the find before their removal and conservation, as are the type and number of artefacts, their internal position and their material composition, is of importance for the archeologist in order to elucidate the circumstances of the find, the historical time of the burial and for the characterization of each item. For the conservation specialist the information obtained by non-destructive methods is important to properly empty the pot, to remove the artefacts and prepare for appropriate conservation procedure.
Due to the rather extended dimensions of the pot (out. dia ~20 cm) filled completely with soil it was a demanding task to radiographically examine the pot with X-rays, in particular with the 200 kV machine available at he National Museum of Slovenia. Therefore the radiogarphic examination was carried out with thermal neutron radiography (NR) at the IJS TRIGA Mark II research reactor in Ljubljana and with the Ir-192 gamma rays of a private NDT company. In the paper following the description of the treasure find the radiographuc examinations are described and the results of the examination are reviewed. The examination confirmed the assumptions of the treasure since they revealed the presence of hoard of coins and jewelry.

2. The Drnovo Treasure Find

The Drnovo treasure find was a ceramic pot completely filled with compact soil and earth. The photography of the treasure find in the ceramic pot still unopened and positioned near neutron imaging camera of the Ljubljana TRIGA Mark II research reactor is presented in Fig. 1.
The total weight of the pot was 9.120 kg. The outer dimesions of the pot were:

- the height: 23.8 cm
- diameter of the orifice: 13.3 cm
- diameter of the bulge: 19.9 cm
- diameter of the bottom: 9.0 cm

Fig. 1: The photography of the treasure find in a ceramic pot positioned for NR examination in the NR channel of rthe Ljubljana TRIGA Mark II reserach reactor.

Almost at the same time another treasure find was unearthed nearby, however in this case the ceramic pot was destroyed by a farmers plug well back in the history and the contents, mostly silver coins, were found dispersed in the field. This led to the assumption that also the intact found pot could possibly contain a treasure. The pot was dated into the 2nd half of the 3rd century A.D., later confirmed by the coins found in the pot and coins in the field.. Since the pot was a rather thick object for investigation with the available 200kV X-rays the Ir-192 gamma-ray radiography and thermal neutron radiography (NR) were selected for examination of the pot

internals. The use of NR was also indicated in order to visualize possible remnants of any of organic materials, as for instance textile or leather bags, normally used to carry around money anciernt time.

3. Experimental

3.1 Neutron radiography

The principles of NR, the experimental techniques and equipment have ben desribed previously and can be found elswhere (1).

The NR facility in the thermal column of the Ljubljana TRIGA Mark II reactor has already been used successfully for the NR examination of archaeological objects in the past. Applications of NR to archaeology and to the examinations of objects of cultural heritage have ben reviewed recently by Rant et. et al. (2). Some of its updated basic data are quoted in Table 1.

Table 1: Characteristics of the Ljubljana TRIGA RR (250 kW) thermal column NR facility.

Neutron beam collimation (L/D ratio)	65, range up to 80
Useful beam diameter at detector	12 cm
Beam shutter opening/closing time:	~ 1 sec
$_{th}$-thermal neutron fluence rate (Au foil)	3.8 (range 3.4 - 4.6) 10^5 n cm^{-2} s^{-1} (*)
R_{Cd} (Au) – Cd ratio	9.6 (range 9.1 – 14.9) (*)
I_γ - Gamma –ray intensity	1.4 10^{-2} mSv s^{-1}

(*) Data depend on the reactor core configuration

The rather slow film/Gd screen based direct neutron high imaging technique was efficiently substituted by fast direct neutron imaging using Gd doped imaging plate neutron detectors (IP-NDs) produced by FUJI Photo Film Co.. The IP-NDs are read out by a FUJI BAS 1500 reader with 0.1mm pixel size and 10 bit digitalisation. The use of FUJI IP-NDs reduced the exposure time from 1.5 h with the Gd screen/radiographic film method to only 20-100 seconds (factor 100), greatly increasing the speed of the NR non-destructive examinations and reducing the activation of the object. In our case of investigating a rather with soil the exposure time was increased to 2 – 3 min.

The effective neutron beam diameter (~12 cm) does not cover the whole object and a complete imaging of the pot was obtained by a series of exposure. In two series of exposures the n beam was centerd once for the upper part and neck of the pot and separately to image the lower part with the bottom of pot. In both seroes the imaging of the central part of the pot (belly) was overlapping. In each of the series three irradiation positins were chosen by translating the pot for 4 cm from left rim to the right rim and in each position the pot was examined ijn two positions rotated by 90 degrees. Alltogether 12 neutron exposures were performed in a total duration of about 32 min. By this way an almost complete information on the pot contents was obtained. More accurate and of better image quality information could by obtained by computed neutron tomography using far more intensive and better collimated neutron beams of the NR facilities at the Paul Scherrer Institute in Villigen (Switzerland) or at Hahn-Meitner Institute in Berlin. Unfortunately the problems with the safe transportation and costly insurance of the very precious treasure prevented such a thorough examination.

Due to the low neutron beam fluence rate (~3.5 10^5 n cm^{-2} s^{-1}) the activation of the find was almost negligibile. Total $\beta+\gamma$ dosis rate on the surface of the pot and 5 min after the irreadiation was 3-5 μSv/h and after 1 h approached the background value of 1.5 μSv/h. The precious find coul hence be released back to the museum in the same day.

3.2 Instrumental neutron activation analysis

After the last neutron irradiation the pot was placed on the surface of HPGe gamma spectrometer, removing the Pb/Cu top shield. The counting time was ½ hour.The analysis was purely qualitative, since the detector efficiency could not be estimated due to the complicated counting geometry and of the object.

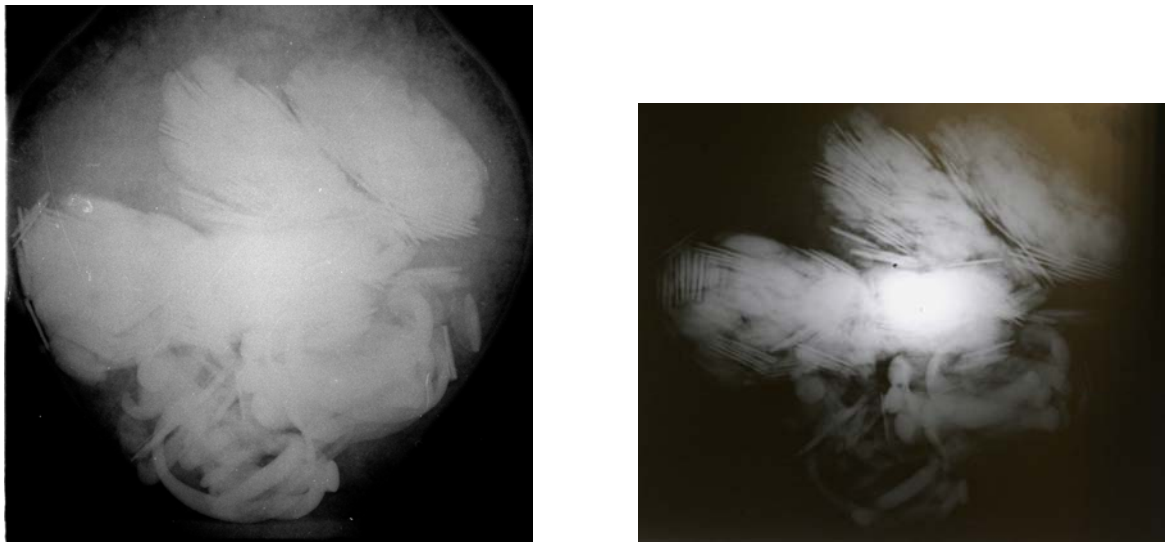
3.3 Ir-192 gamma ray radiography

For Ir-192 gamma ray radiography a standard Ir-192 source of 7 10^{11} Bq (19 Ci) activity and 1.9 mm by 2.1 mm dimensions. The AGFA Structurix D7 radiographic films with standard lead cover were used. The FOD was 800mm and film exposure times were 30 min. The image of the whole object was recorded. Again the object was rotated for 90 degrees.

4. Results

4.1 Neutron radiography

Oner of NR images of the pot is presented in Fig 2a. Neutron radiography revealed the position of 4 different groupings of coins, possibly contained in bags or sacks made of textile or leather. The coins could clearly be resolved only if they were located near the rim of the pot, where the the exposure was sufficient to obtain a good contrast. The presence of the jewelry was reveled in the lower part of the pot and on the bootom. The presence of fibulae and bracelets was revealed.



(a) (b)

Fig. 2: Neutron radiography (a) and Ir-192 gamma radiography (b) of the central and lower part of the treasure pot. The coins are hoarded in 4 distinct purses. Most of the silver jewelry (3 fibulae and 11 bracelets) is located on the bottom of the pot. The very central and thickest part of the pot is underexposed in both NR and gamma-ray radiography.

4.2 Instrumental neutron activation analysis

The I-NAA revealed the presence of copper (from annihilation radiation and 1345 keV line of 12.8h Cu^{64}) and gold (412 keV). In addition activated common constituents of soil as Fe, Mn, Na, Ca and natural soil radioactivity (K^{40}, U and Th decay products) were detected. It was not possible to detect silver due to the short decay times of activated Ag isotopes, short irradiation time and after ~30 min of waiting time. Suprisingly no golden artefacts were subsequently found in the pot and later analysis should reveal whether the gold is present as constituing

element of an alloy in the silver jewelry. Since the presence of copper was confirmed one could conclude that the hoard contains copper coins (*denarius*), possibly covered by silver (suberates).

4.3 Ir-192 gamma-ray radiography

The gamma-ray radiography clearly revealed that the money bags (purses) are filled with coins. and that the coins are mostly of the denarius type. The presence of fibulae and bracelets was also clearly confirmed. However, again the object was too thick in the middle of the pot to allow visualizing and resolving of the contents in the middle section.

5. Conclusions

The NR and Ir-192 gamma-ray radiography usefuly complemented each other in the visualizing and characterization of the internals of the Drnovo Roman treasure find. The 4 groups of hoarding the coins into the money bags made possibhly of textile or leather were more clearly seen by NR, while individual coins were more clearly detected by gamma-ray radiography. The positions of the bags and their contents were determined. Both methods were able to visualize several pieces of jewelry, consisting of 3 fibulae and several bracelets (11 pcs). The object was too thick to allow the examination of the pot in the midddle section.

The I-NAA provided rough information about the material constitution of the pot internals, confirming the presence of the copper and gold. From this information and from the size of the coins it was concluded that the coins could be copper denariusi. The presence of golden artefacts was not established leading to the conclusion that the gold might be present in an alloy together with silver in the silver jewelry.

6. References

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