Observation of hidden archaeologic relics using neutron radiography

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Neutron imaging division

1. Introduction

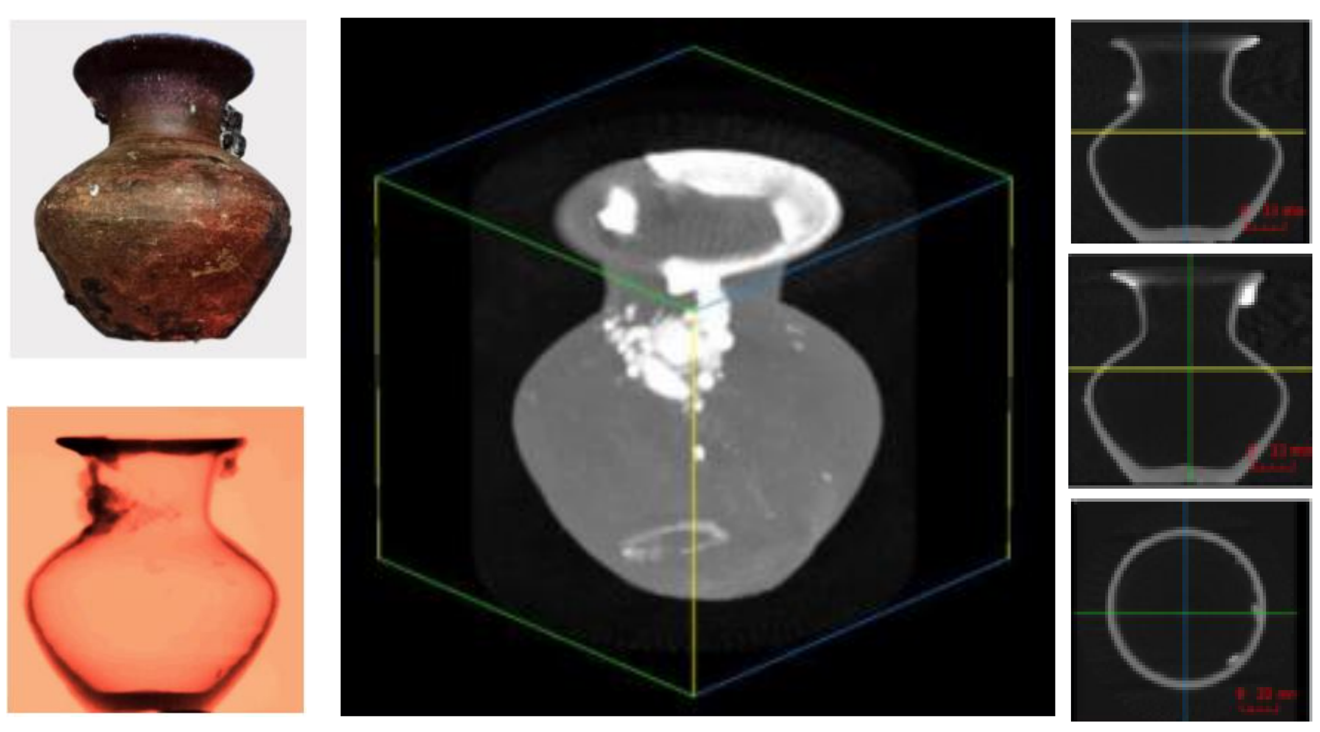
Cultural heritage is a valuable treasure and should be handed down to descendants. They contain a unique and irreplaceable historical record for understanding the history. Interestingly, some heritages include hidden relics inside them. Many researchers have tried to analyze information about the hidden relics to complete a preserved historical puzzle without any damage to the relics, which may occur during observation. In this respect, non-destructive analysis method is very important for the inspection of archaeological objects. Of the many available methods, X-ray radiography has been widely used for research and conservation of most archaeological objects.

Although neutron radiography is also non-destructive analysis method, it is much less used in this area. Until recently, the main reason for this was the very small availability of moderately easily accessible neutron sources and the lack of efficient modern neutron imaging equipment. However, Rant and Kardjilov [1] explored the advantages of the neutron which can penetrate metals. Also, Schillinger [2] reported that neutron non-destructive technique, i.e., tomographic scanning, enables to disclose hidden characteristics for relics.

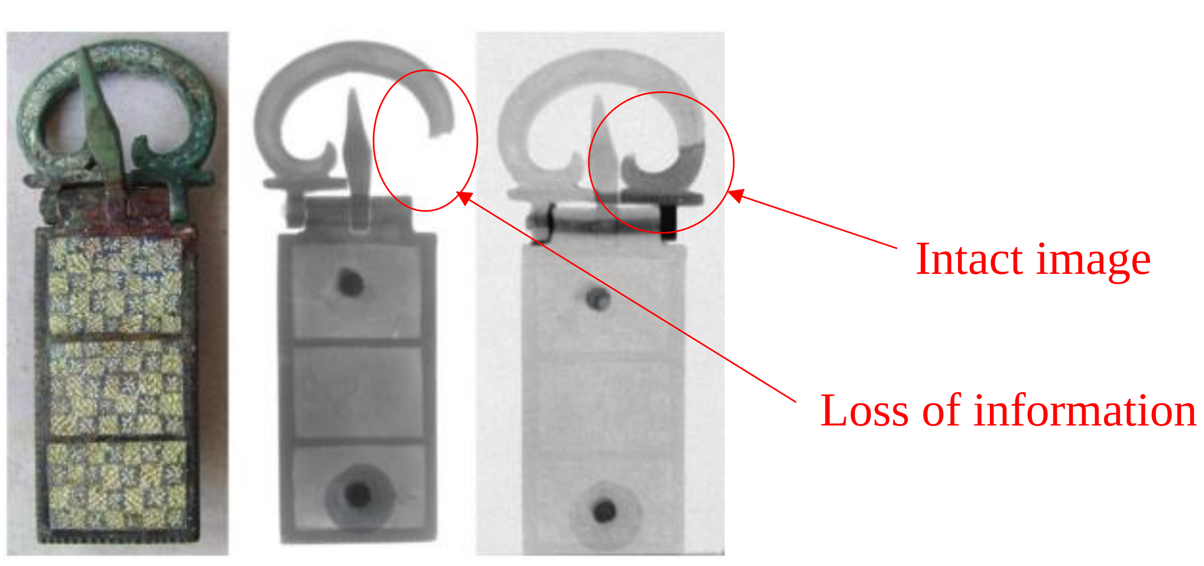
Neutron radiography improves the knowledge and understanding about the past cultures. In specific, tomographic scanning is a powerful method for studying of archaeological objects. Therefore, the various characteristics of the object can be examined by neutron radiography.

2. Background

Understanding of relics is an important process that enables us to understand the past and it as a basis for the development of technology. Even if X-ray radiography/tomography is one of the non-invasive and non-destructive inspection methods, it has limitations such as detailed analysis, e.g., observation of the internal structure of relics. However, because neutron has different attenuation characteristics depending on the material, it provides a way to observe the interior and other properties of relics.



S. Khaweerat et al. [3] used 3D neutron imaging to observe 15^{th}-16^{th} century earthenware jar. When the authors captured 2D NR image, its repaired part and debris were unclear. In this regard, they tried to get a 3D NR image; it visualized repaired part showing the different material. Even if 2D and 3D NR image give us information about the ancient jar, 3D NR image provides more information.



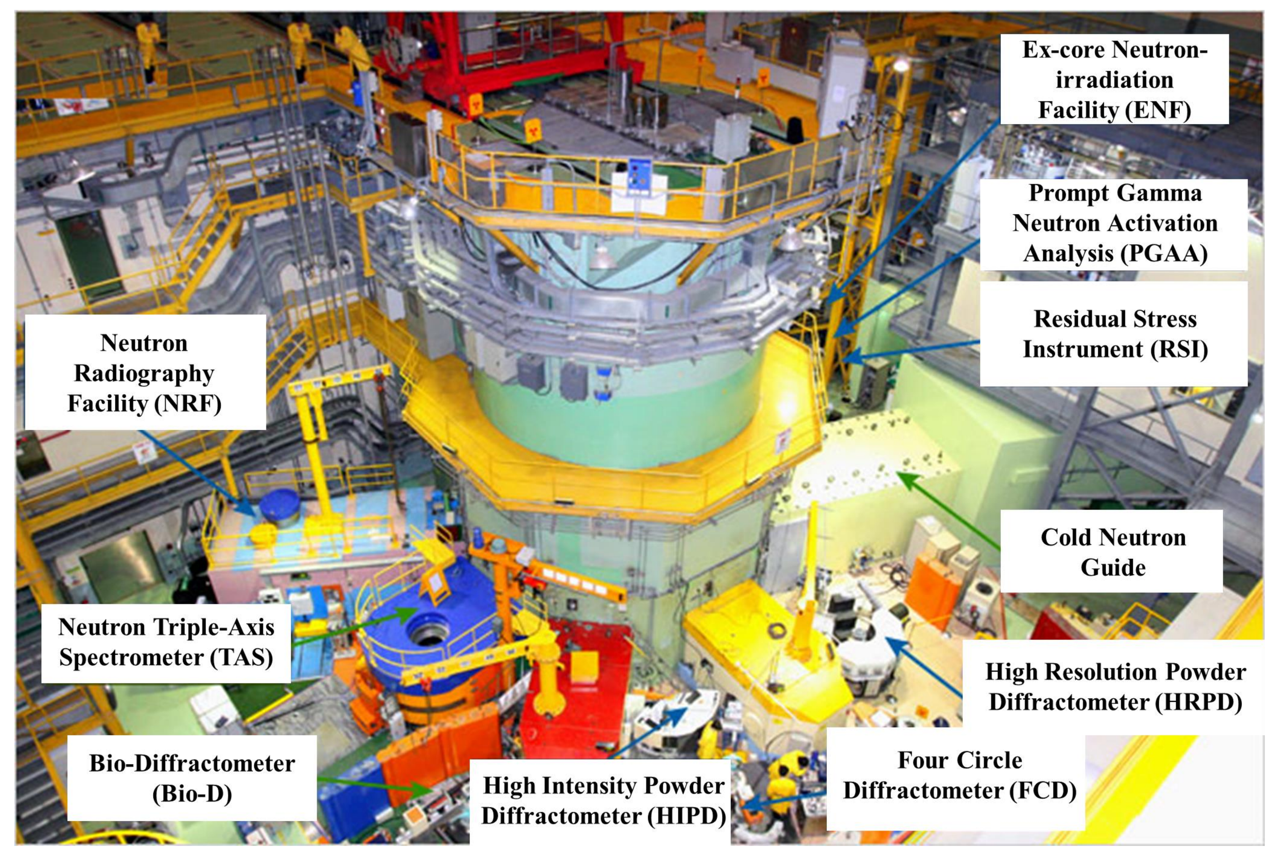
Piece of a middle-age belt buckle made using the Mileflori technique - left: photo; middle: X-ray image; right: neutron image [4]

D. Mannes et al. [4] investigated cultural heritages using neutron radiography. They compared observed the piece of a middle-age belt buckle using X-ray and neutron radiography. In the above figure, the photo image shows its overall shape for the belt buckle. When it was observed with a X-ray, the belt buckle was observed as if it were broken. On the other hand, neutron image shows the perfect shape of the belt buckle. The result suggests that neutron imaging is indispensable technique because it can observe things that can not be observed with X-rays.

3. Experimental facilities of HANARO

HANARO is a 30 MW high-performance research reactor built by the Korea Atomic Energy Research Institute. Designed and constructed with own technology from 1985 to 1995, the design output reached 30 MW in 2004. HANARO has played an important role in the national facilities of neutron science, radioisotope production, power reactor applications, neutron transmutation doping, neutron activation analysis, and neutron radiography (NR). After installing a cold neutron source in 2010, it has been a regional and international facility for neutron science.

*Neutron flux: ~ 2.1×10^{14} n/cm²/s (fast neutron)
~ 5.4×10^{14} n/cm²/s (thermal neutron)

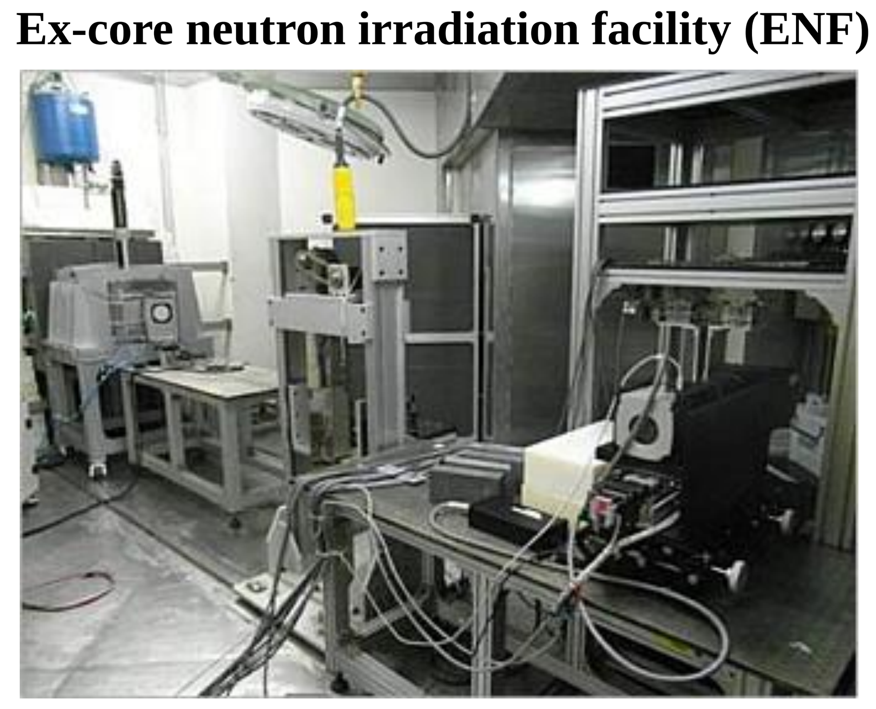


Reactor type	Open-type
Thermal power	30MWth
Fuel	19.75% U-235 uranium, U_3Si-Al core material, Al cladding material, 36 rods and 18 rods fuel assembly
Coolant	Light water (H_2O)
Moderator	Light water/Heavy water
Reflector	Heavy water (D_2O)
Core cooling	Upward forced circulation
Control rod	4 control rods for each, Hafnium

Neutron radiography facility (NRF)

Maximum neutron flux: 2×10^7 n/cm²/s
Maximum L/D: 290
Beam size: 350 × 450 mm²
Image size: 5 × 5 cm ~ 10 × 10 cm
Image resolution: 50 ~ 150 µm

Ex-core neutron irradiation facility (ENF)



Maximum neutron flux: 1.5×10^9 n/cm²/s
Maximum L/D: 800
Beam size: 2000 × 200 mm²
Image size: ~ 3 × 3 cm or 5 × 5 cm ~ 10 × 10 cm (two CCDs)
Image resolution: 30 ~ 50 µm or 50 ~ 150 µm

4. Future work

- Development of high-resolution image analysis technology for archaeological objects
- A new understanding of relics using neutron radiography
- Expansion of advanced neutron radiography technology into other fields
- Development of compact neutron source to observe relics on site

5. References

[1] J.J. Rant, in: The Eighth International Conference of the Slovenian Society for Non-Destructive Testing, Portorož, Slovenia, 1–3 September 2005, pp. 181–188.
[2] B. Schillinger, et al., in: Proceedings of Fifth World Conference on Neutron Radiography, Berlin, Germany, 17–20 June, 1996.
[3] S. Khaweerat, W. Ratanatongchai, S. Wonglee, B. Schillinger, The early stage of neutron tomography for cultural heritage study in Thailand, Phys. Procedia. 88 (2017) 123–127.
[4] D. Mannes, E. Lehmann, A. Masalles, K. Schmidt-Ott, K. Schaeppi, F. Schmid, S. Peetermans, K. Hunger, The study of cultural heritage relevant objects by means of neutron imaging techniques, Insight-Non-Destructive Test. Cond. Monit. 56 (2014) 137–141.