

## Investigation of a Simulated Chinese Jade Dagger by Multiple Imaging Techniques

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In ancient China during the Shang dynasty, ca. 1600-1046 BCE, jade and bronze dagger-axes (*ge*) were used by the elite as ritual symbols of power and prestige. These ceremonial weapons consist of a nephrite jade  $[\text{Ca}_2(\text{Mg}, \text{Fe})_5\text{Si}_8\text{O}_{22}(\text{OH})_2]$  blade mounted in a bronze haft. Several of these daggers are held by the Smithsonian Institution [1], and their conservators are interested in applying neutron radiography to image the jade tang concealed within the bronze haft and uncover early manufacturing techniques. As a preliminary test of feasibility, a simulated dagger was made using a modern replica blade carved from nephrite from Wyoming, USA, and copper alloy plates (Fig. 1). The simulated dagger was first imaged by X-ray and neutron radiography at the NIST Neutron Imaging Facility [2] with a fluence rate of  $6.36 \times 10^6 \text{ cm}^2/\text{sec}$  for 5 minutes. The details of the semi-circular tang within the copper alloy haft are not visible in the X-ray image (Fig. 2), but are clearly visible in the neutron image (Fig. 3). Subsequently, the nephrite blade and the copper alloy plates were analyzed by cold prompt gamma neutron activation (PGAA) [3] to evaluate the feasibility of this technique for identifying the nephrite source by characteristic elements such as Fe, Mn, Cr and Ni. This was done by irradiating three points along the blade with a 1 cm diameter beam having a fluence rate of  $3 \times 10^9 \text{ cm}^2\text{s}^{-1}$  for about 15 hours at each point.

The samples were measured for gamma-ray radioactivity three times: before any irradiation, after the neutron radiographic imaging and 110 days after the PGAA measurements. The pre-irradiation measurements revealed that the blade had a natural gamma radioactivity level of  $507.7 \text{ pCi} \pm 479.4 \text{ pCi}$  due to  $^{226}\text{Ra}$  and  $^{235}\text{U}$ . The post-imaging measurement found no induced radiation. Finally, the post-PGAA measurement gave a total gamma activity of  $78.47 \text{ nCi} \pm 3.17 \text{ nCi}$  at 110 days due to  $^{46}\text{Sc}$ ,  $^{59}\text{Fe}$  and  $^{60}\text{Co}$ . In addition, it was calculated that there would be 80 nCi of beta radiation from  $^{45}\text{Ca}$  which does not emit detectable gamma radiation. In order to confirm these results, the blade was imaged by autoradiography for alpha and beta particle activity using a storage phosphor image plate which is sensitive to both alpha and beta radioactivity. An imaging plate (BAS-IP MS 2025E) was exposed to the blade for roughly 164 hours, and then was scanned in a reader (Typhoon FLA 8000) to obtain a spatial map of the activities (Fig. 4) [4]. The anticipated overall shape of the blade defined by the alpha radiation from the natural sources  $^{226}\text{Ra}$  and  $^{235}\text{U}$  could not be detected above background, whereas the regions of induced beta radioactivity from the neutron beam used for PGAA were clearly shown. Further improvement is expected with better controlled environmental background. Image analysis software will be applied to provide quantitative estimates of the alpha and beta activity based on their characteristic patterns of pixels [5].

### References:

- [1] Lawton, T. *et al.*, "Asian Art in the Arthur M. Sackler Gallery" (Smithsonian Institution, Washington, D.C.)
- [2] LaManna, J. *et al.* Review of Scientific Instruments **88** (2017), p. 113702.

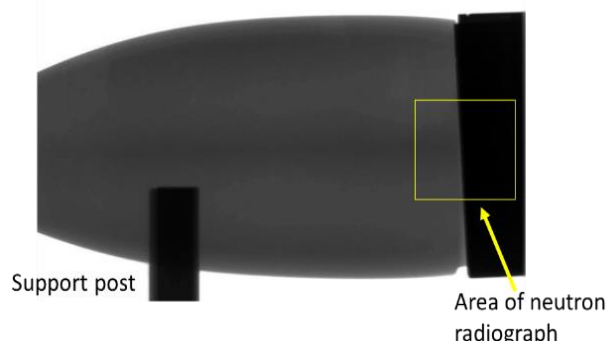
[3] Paul, R. *et al.* Journal of Radioanalytical and Nuclear Chemistry **278** (2008), p. 697

[4] Any mention of commercial products is for information only; it does not imply recommendation or endorsement by NIST.

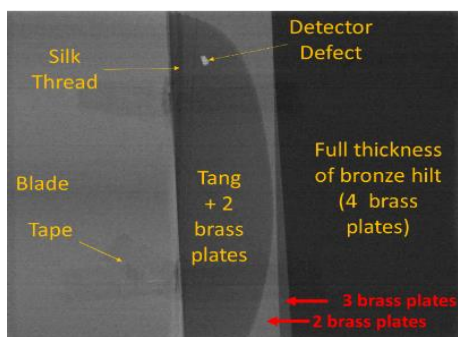
[5] Zeissler, C. and A. P. Lindstrom Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment **624** (2010), p.92



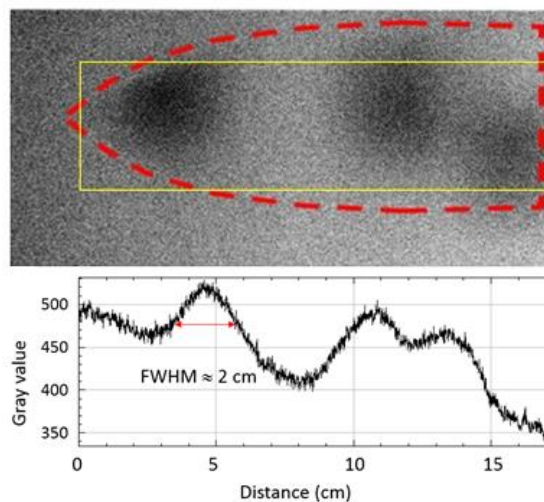
**Figure 1:** Simulated Shang Dynasty Dagger Axe. Overall length is 20 cm



**Figure 2:** X-ray radiograph



**Figure 3:** Neutron radiograph of tang area



**Figure 4:** Preliminary image of beta activity showing the three areas exposed to the neutron beam. The blade is outlined in red. The intensity profile is summed across the width of the yellow rectangle