# RADIOLOGICAL EXAMINATION OF WOOD WITH NEUTRONS, DIFFERENT PERSPECTIVES

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## Introduction

While plain wood might be well studied by X-ray inspection, certain features remain less apparent in the resulting images so it appears obvious to consider alternative imaging technologies to obtain complementary information. Two different situations have been identified where such different perspectives could contribute to a better understanding of the internal status of a wooden specimen, i.e. the distribution of artificially inserted materials such as glue or the shielding effects of metal plates firmly attached or built into a wooden specimen. Both problems may be encountered when studying wooden construction elements that are made of glulam and joint together with metal plates, bolts and nuts. The glued layers of a glulam are only visible in an X-ray radiograph if it was hit exactly parallel to the beam direction but remains invisible otherwise due to low contrast. Since neutron radiation is sensitive to hydrogen, its use for radiological inspection has the potential to visualise the distribution of the glue in certain areas. This will be shown here by neutron radiography and tomography. The utilisation of the other property of neutrons to penetrating thick metal layers while giving contrast to light materials consisting of elements with a low order number, particularly hydrogen, will be demonstrated with a constructed sample made of a rotten piece of timber and three attached sheets of lead. This should symbolise metallically encased specimens as they may be encountered in the cultural and archaeological field. Particularly under such circumstances, radiological examination with neutrons may offer an opportunity to study the content of such objects without the need of disassembling. More in a forensic context, construction elements with a combination of light materials and metal components represent a challenge for radiological interrogation when the structural features of the light elements are of interest, particularly if oriented perpendicularly to the shielding metallic parts. It will be shown how neutron tomography has the capability to resolve such kind of problems.

However, wood itself represents a moderating matrix for the neutrons due to its hydrogen content; in other words, it slows down the neutrons in the beam. As a consequence, thermal neutrons well known for producing appreciable radiographic images are not suitable for penetrating wooden specimens of a larger volume, i.e. layers of several centimetres. Only fast neutrons in the energy range of above 1 MeV are capable for radiological examination of voluminous wooden objects, with the disadvantage of producing rather low quality images [1]. This problem cannot easily being resolved because it is of intrinsic nature. Any fast neutron capable to penetrate thick layers of any material has to be captured by a suitable imaging detector that is limited in its thickness to avoid blurring. So a compromise has to be found between the detector efficiency and the image quality, a problem certainly not finally resolved yet. The subject of this presentation is to highlight features in wooden specimens preferably detectable by neutron radiology. The majority of the images shown here are resulting from tomographic reconstructions that require the elimination of certain flaws that may spoil any reconstruction by an adding up effect rather than an overall level of image quality determinable by statistic means. Therefore, this study is limited to qualitative aspects. It should demonstrate the potential of radiological examinations with neutrons.

**Results**

The studies presented here were performed in the NECTAR facility of the FRM II research reactor of the Technische Universität München providing a flux of neutrons of $4{,}9 \times 10^{6}$ $cm^{-2}$ $s^{-1}$ with an energy spectrum of ca. 1.5 to 2 MeV. Further experimental details are given in [2]. The tomographic reconstruction was achieved by filtered back projection assuming parallel beam geometry based on a L/D ratio of 230.

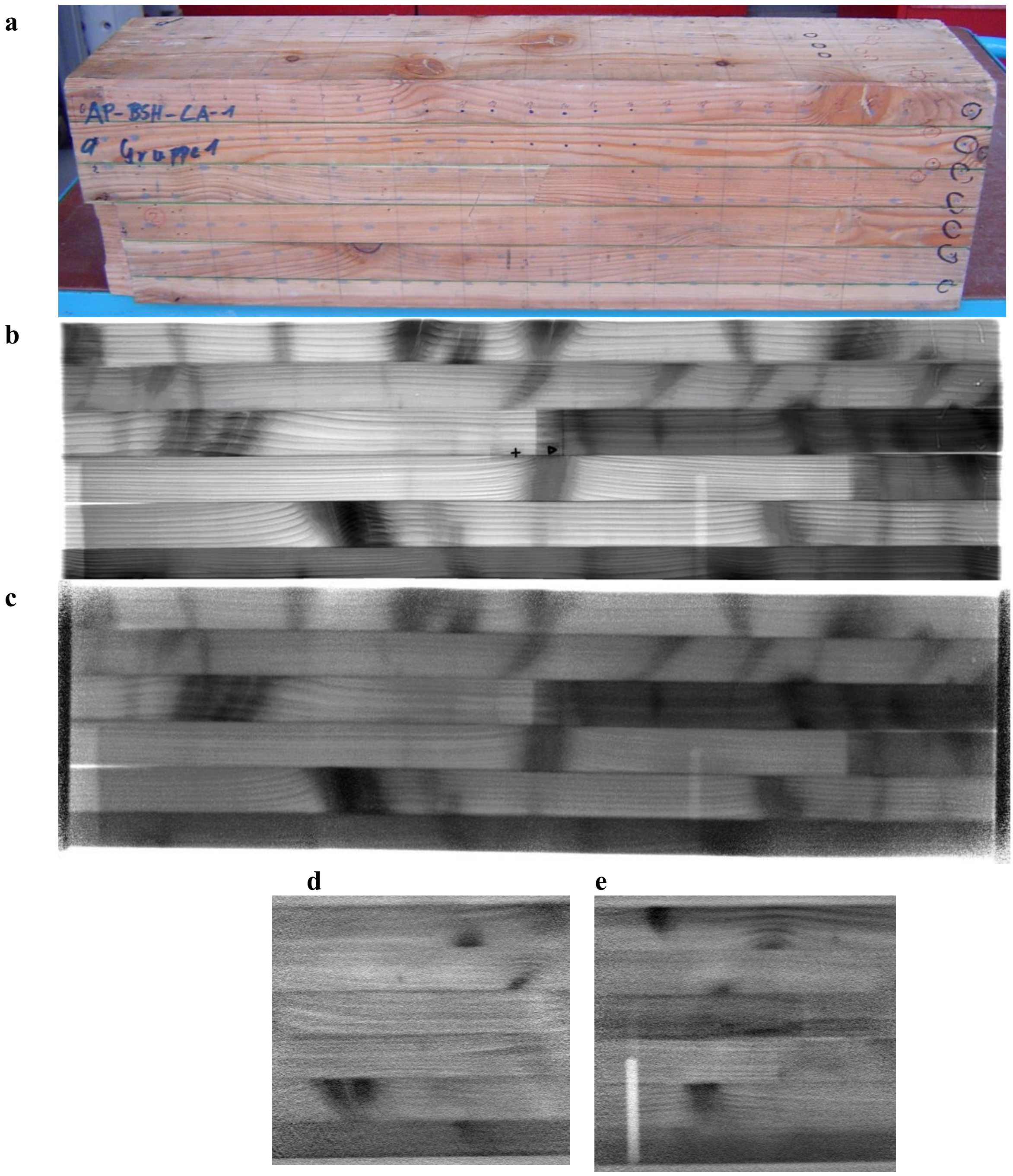


**Figure 1:** glulam girder with radiological results, **a)** specimen, **b)** X-ray image, 160 kV, **c)** neutron radiography, **d, e)** neutron tomography, sum of 30 layers in a selected section.

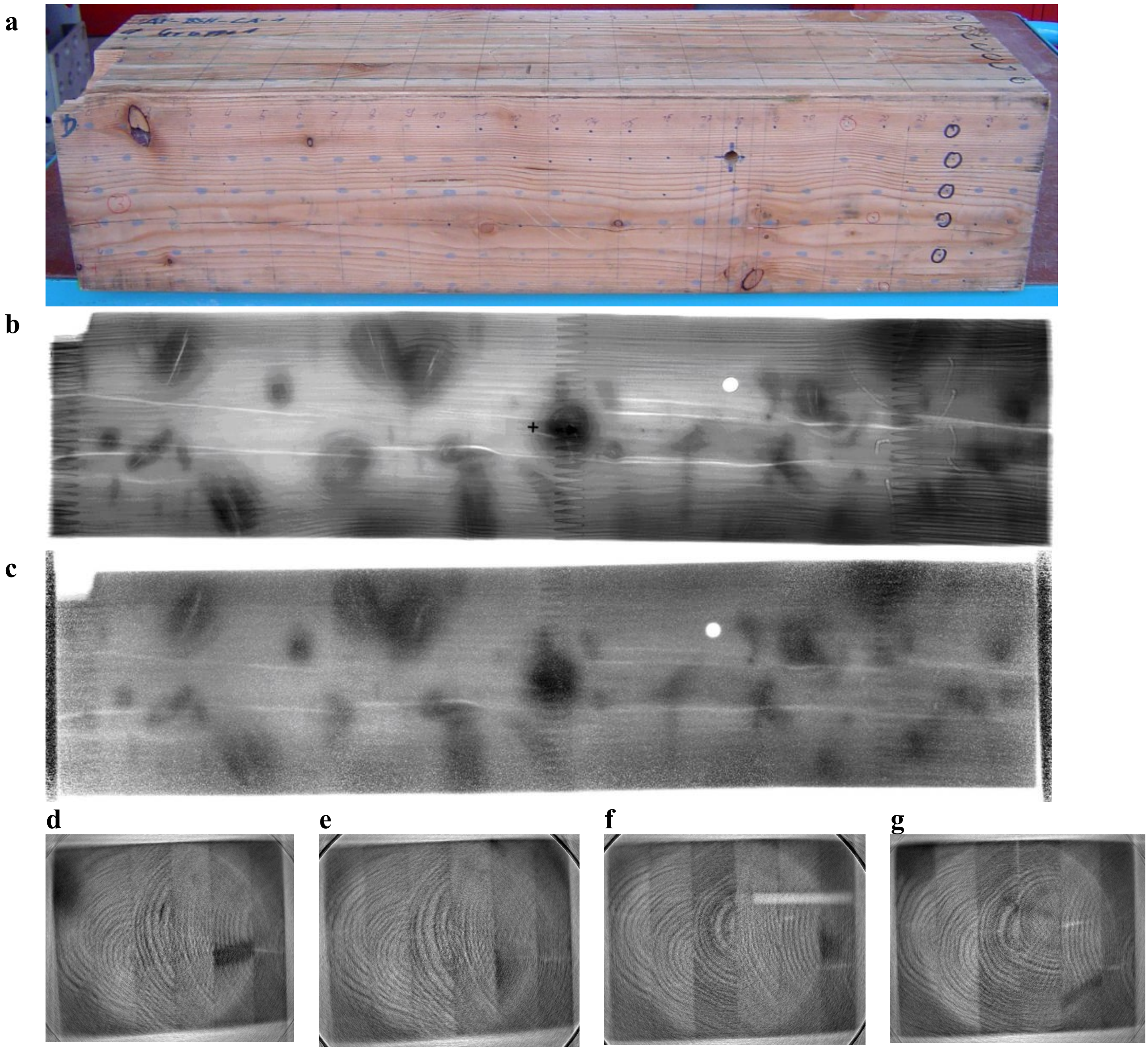

Figure 2: glulam girder with radiological result, **a)** specimen in a rotated position, **b)** X-ray image 160 kV, **c)** neutron radiograph, **d – g)** neutron tomography, cross sections, sum of 40 layers from selected positions

The first object to be studied was a glulam as shown in **Figures 1 and 2** with the aim to assess the condition of the interior, particularly of the glued layers. The comparison with an X-ray image shows a density difference of the glued layers particularly in the centre part (**Figure 1**), though the overall image quality is inferior to that one achievable with other technologies (**Figure 2**). The tomographic reconstruction allows viewing of selected layers, e.g. that one in the position of the drilled hole, undisturbed by overlaying features. A detailed assessment of the glued layers may require a tomography as shown in the panels **d – g** of **Figure 2**. The glue appears to be unevenly distributed, in some spots soaked by the annual ring structure (**d, e**). Some work on the overall image quality and that of the tomographic reconstruction is still in progress. In particular, the precise image geometry including scattering effects should be considered in the future. Pertaining to the tomography technique, the nature and the origin of certain image impurities will be further investigated either to avoid them as far as possible or to correct them with an appropriate image processing algorithm.

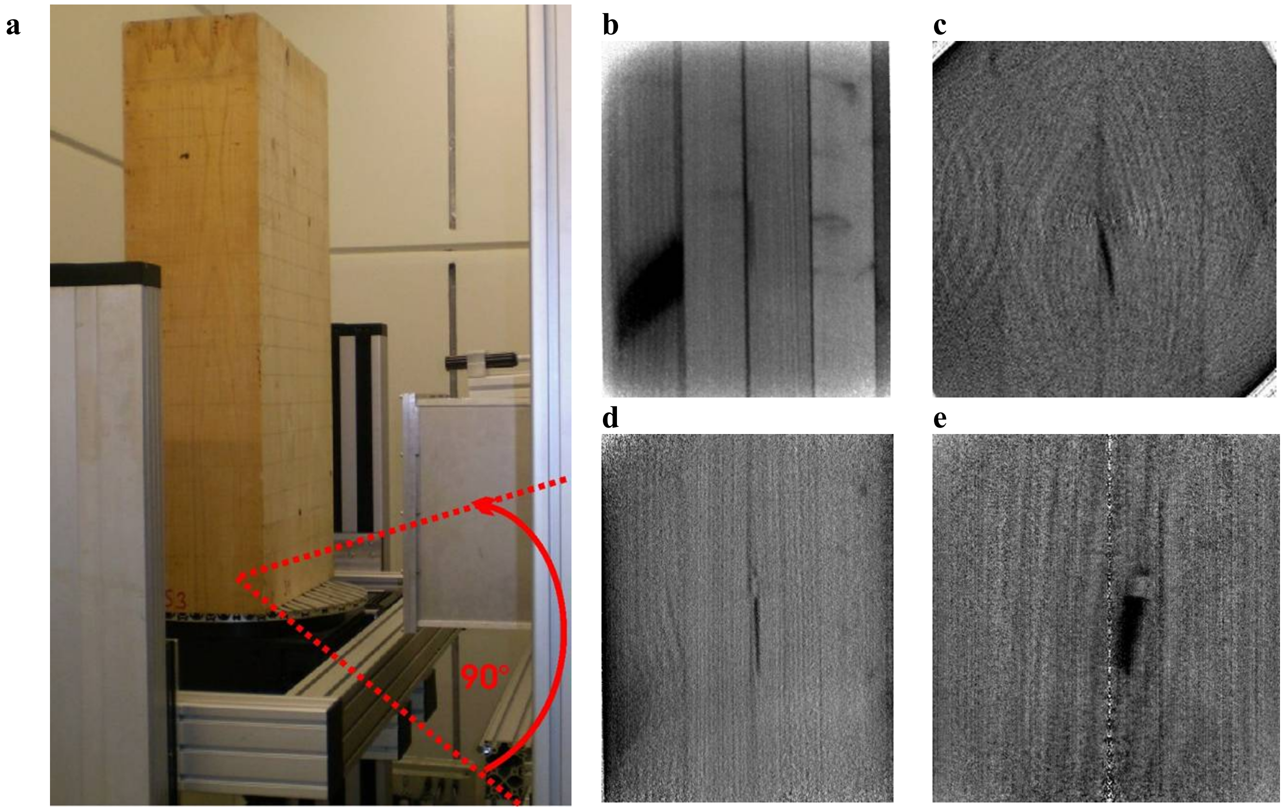


**Figure 3:** partial tomography of a large piece of glulam (width 50 cm), **a)** specimen in beam position, **b)** neutron radiograph with glued layers, **c-e)** partial tomography (90°), **c)** cross section with inclusion, **d)** longitudinal section with inclusion and knot, **e)** section parallel to the central glued layer with the adjacent inclusion.

One achievement of the reconstruction algorithm used in this study was that it allowed compiling an image with an incomplete set of projections. This was necessary in cases when the size of a specimen exceeds the dimensions of the neutron beam and those of the detector window. An example for such a situation is shown in **Figure 3**. This large piece of glulam obviously did not fit into the beam volume. It was the aim of the experiment at least to obtain an access to the structural features parallel to the beam direction that included the glued layers in the area shown by the plain radiograph shown in the panel **b**. In the very centre, an inclusion was detectable that might have consisted of a resin, at least of some material giving contrast to neutrons, i.e. rich in hydrogen. This central feature was visualised in detail by partial tomography with a set of projections restricted to an angle of 90° only. The cross section (**c**) and the longitudinal sections (**d** and **e**) showed this feature in its whole appearance.

The other perspective of radiology with neutrons was to visualise structural features of light materials hidden behind metallic shielding that usually could raise problems when using X-rays or gamma radiation. For the sake of demonstration, three lead sheets of 1 mm thickness each were attached to a wooden specimen with a detailed internal structure as shown in **Figure 4**. The whole sample was interrogated by tomography. The block diagrams shown in the panels **c** and **d** provide an overview of the internal features such as rotten areas, knots and nails. All the structures appear with a contrast similar to that associated with the lead shielding that would be impossible to achieve with X-rays (as to be demonstrated in a further example).

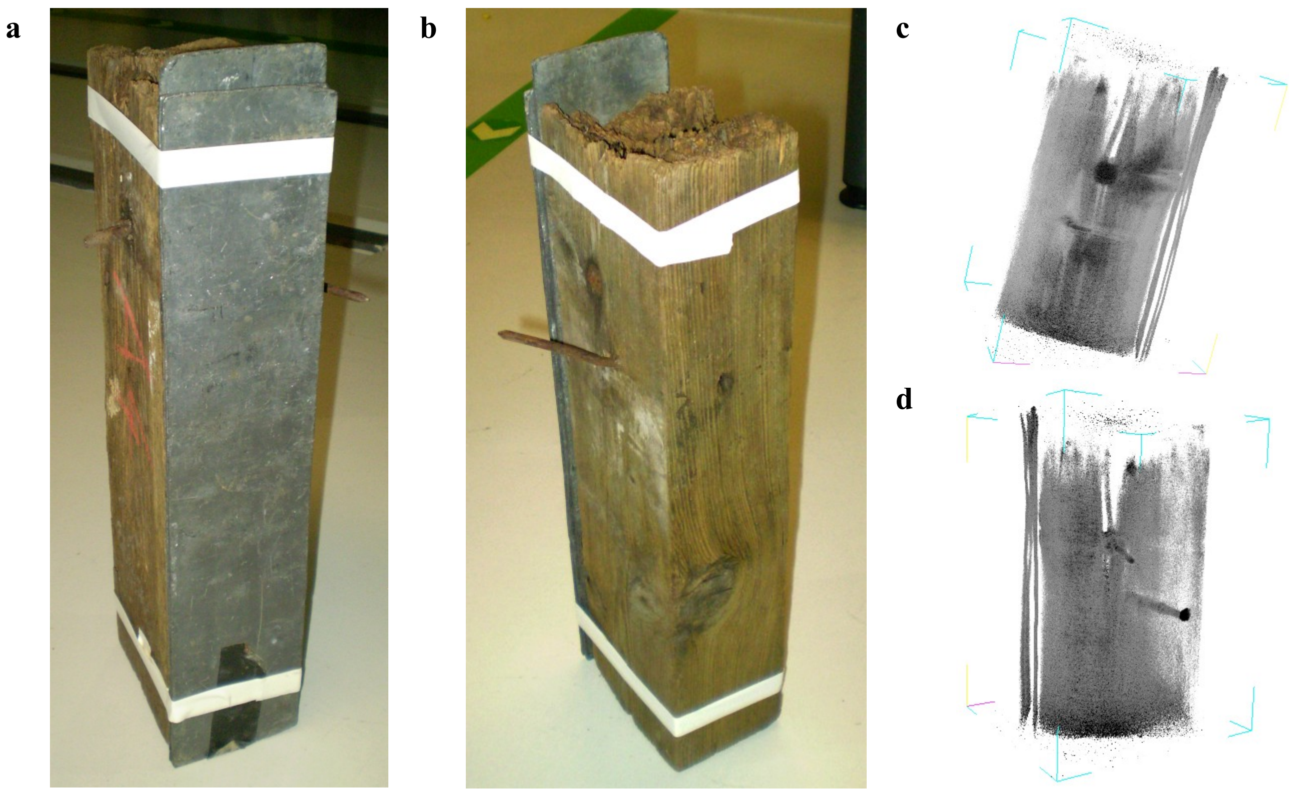


**Figure 4:** wooden beam with lead shielding, **a)** lead sheets (3) attached with adhesive tape, **b)** front view with the protruding nail, **c)** block diagram of tomographic reconstruction showing some internal features with more contrast than the lead sheets, **d)** block diagram from the other side indicating a second nail through the knot in central position.

All these features were studies more in detail as shown in the cross sections of **Figure 5**. The positions of all those sections are indicated by the cartoons in the panels **a**, **e** and **g**. The cross section shown in panel **b** exhibits not only the rotten area but also the tape used to affix the lead sheets. Further down, many details are resolved including the annual rings running perpendicularly to the lead shielding. The section running diagonally through the wooden girder shows both nails, one of them running right through the knot, and the metal sheets to the left. The last two sections located more laterally to the front and to the rear were showing these two features separately. The first one showed impressively the details of a knot in direct vicinity to the lead shielding (**h**). The other one featured both nails, the one running straight through the central knot and the protruding one which was hit outside the wooden body.

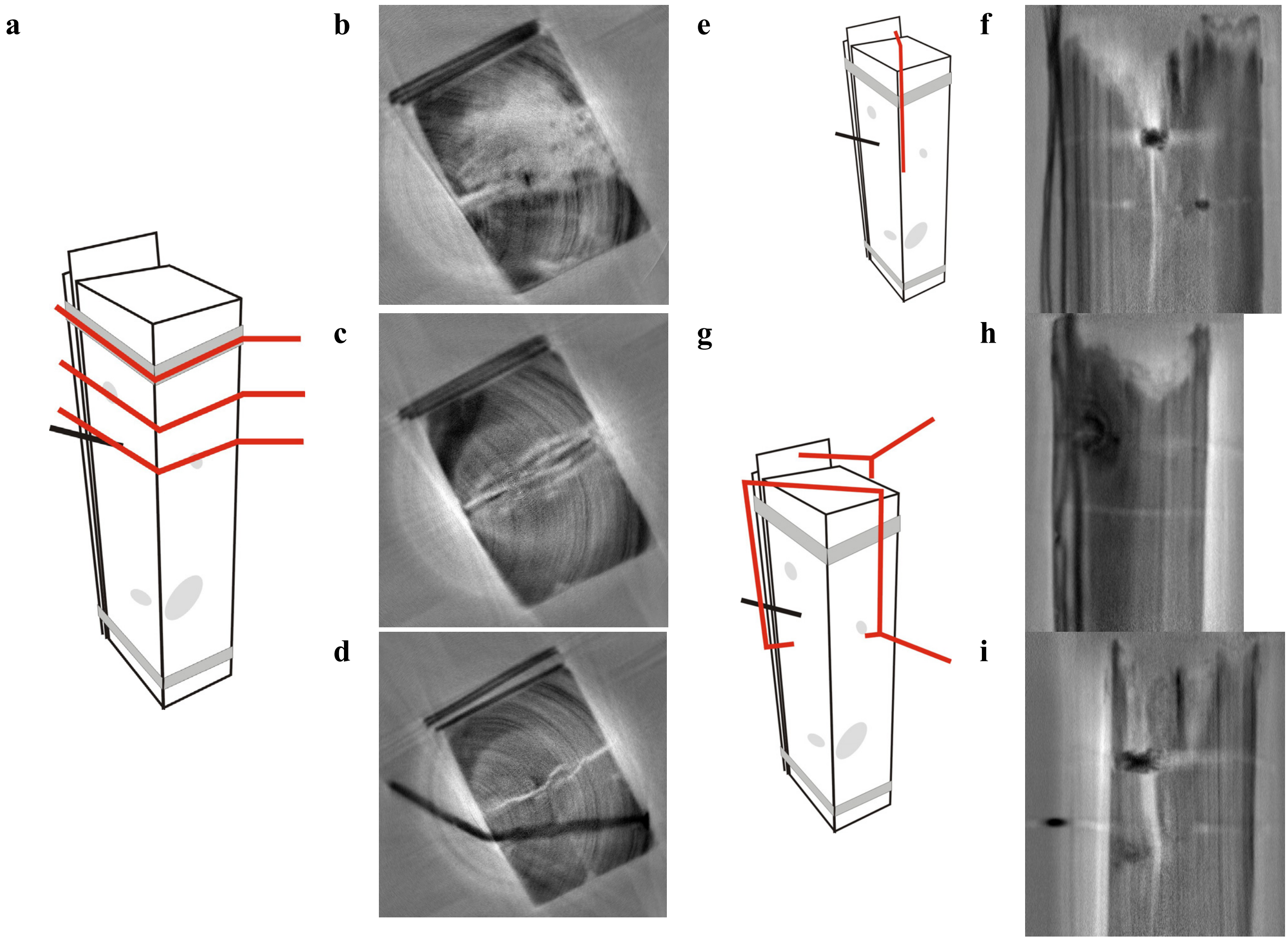


**Figure 5:** details of the specimen with lead shielding, **a)** position of the following cross sections, **b-d)** cross sections, **e)** position of diagonal section, **f)** diagonal section with lead sheets, **g)** positions of the following longitudinal sections, **h)** section with lead sheets, **i)** sagittal position with nail on the surface.

The last example of this presentation represents a more forensically oriented application, i.e. the interrogation of components removed from buildings. The origin of this part was an abandoned pedestrian bridge across the river Danube at Dietfurt (somewhere between Munich and Nuremberg) which was demolished because it was not safe anymore to cross (**Figure 6**). A wooden joint hat a steel plate inserted centrally which was obviously an obstacle to radiological interrogation with X-rays. An insight into the interior was only possible when the incident X-rays were oriented parallel to the metal plate, but was hard to inspect in perpendicular direction. This specimen was subjected to neutron tomography.

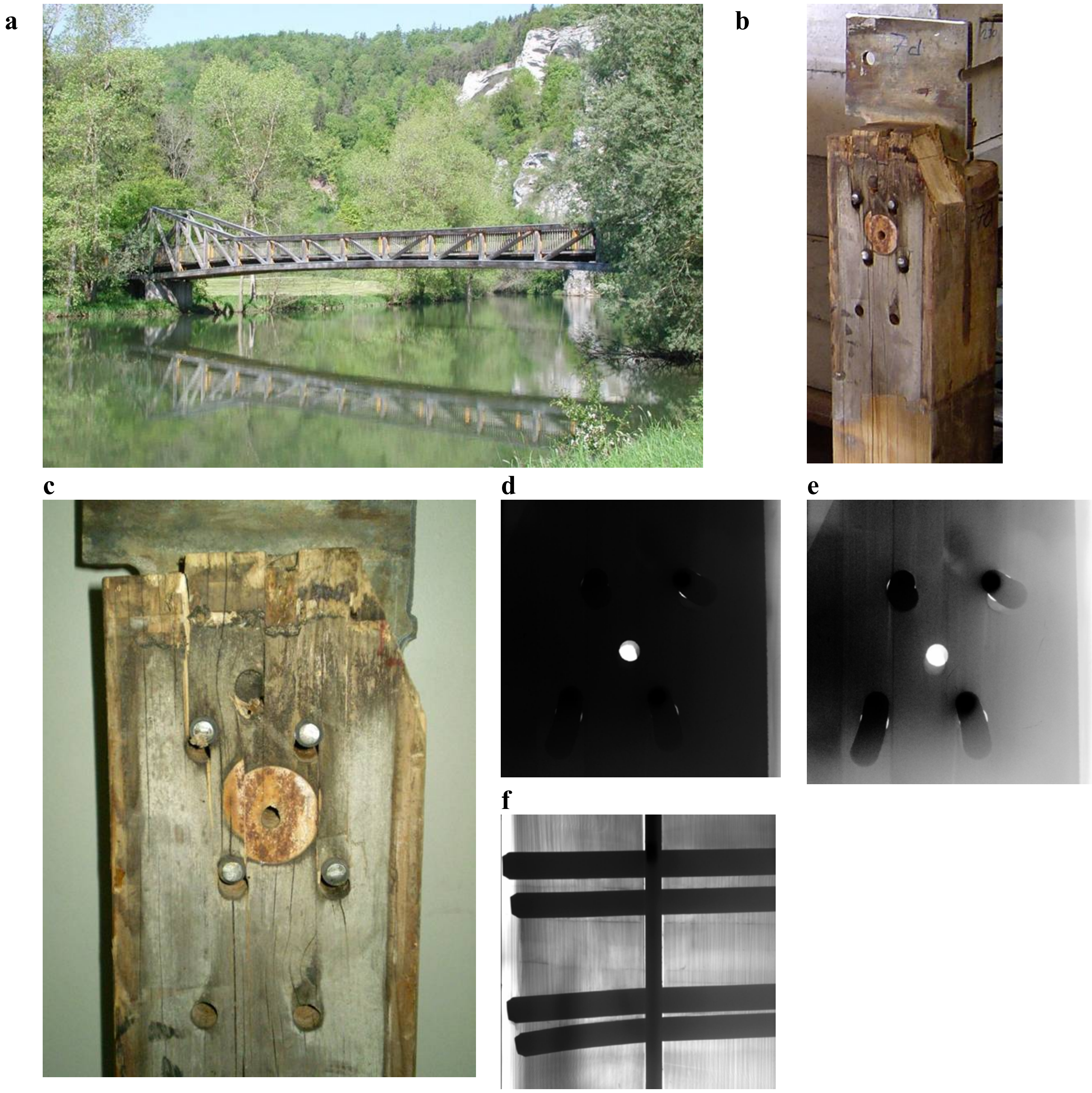


**Figure 6:** joint element of a wooden bridge with steel plate, **a)** original pedestrian bridge crossing the Danube river at Dietfurt, **b)** wooden joint element with steel plate and bolts, **c)** frontal view (as in the following radiological image), **d)** attempt to penetrate the specimen with X-rays (150 kV flash tube and phosphor imaging plate), **e)** further attempt with maximal sensitivity, **f)** lateral view (X-rays) allowing to visualise structural features parallel to the steel plate.

The results of the tomograpic reconstructions are shown in **Figure 7**. The cross sections revealed that it was a glulam that was not obvious at the first glance due to the lasting atmospheric influence and presumable neglect of care. For a better orientation, the positions of the sections are indicated in the cartoons **a** and **e**. The cross sections did show the structural features perpendicular to the steel plate such as the crack and the knot (**b**), the bolts together with the surrounding hollow space (**c**) and the central hole (**d**). The longitudinal sections behind (**f**) and in front of (**g**) the metal plate even showed some of the annual rings oriented perpendicularly to the metal plate.

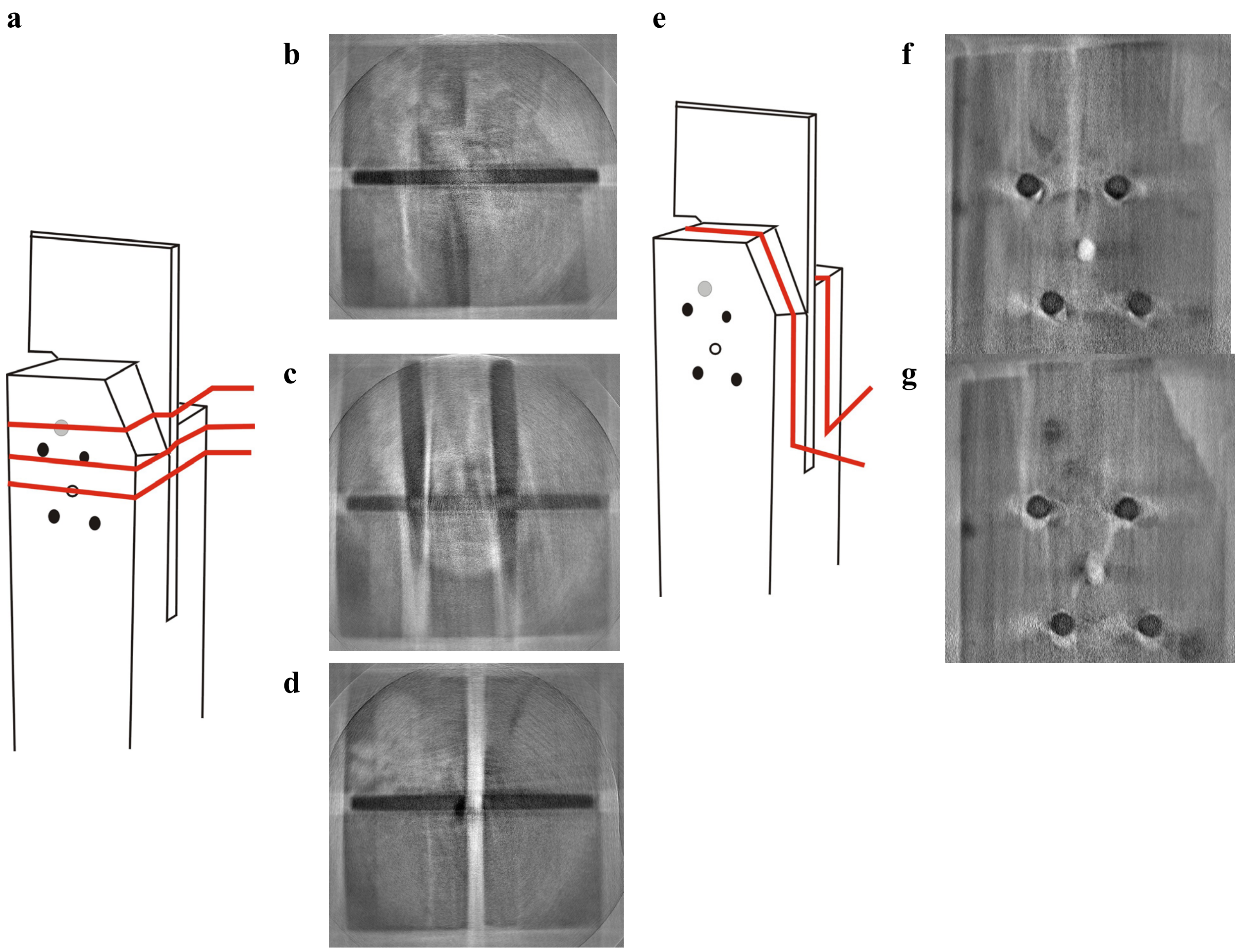


**Figure 7:** neutron tomography of wooden joint element showing structural features perpendicular to the inserted steel plate, **a)** positions of the cross sections, **b)** cross section with knot, **c)** same with bolts (bent and tilted position), **d)** same with central hole, **e)** positions of longitudinal sections, **f)** behind the steel plate, g) in front of the steel plate.

## Discussion

Though inferior in image quality as compared to X-ray radiology, the examination of large wooden specimens with fast neutron reveals different features on one hand, and may allow an access through metal shielding that would be largely impaired otherwise. The property of neutrons passing through heavy metals while being absorbed by hydrogen containing materials has been successfully utilised. Two situations have been identified where the application of neutron radiology has been successful to wooden samples. One was the visualisation of low differences in hydrogen content as it might occur in introducing artificial materials such as glue. The other was simply the view behind a metal shielding. This situation may be encountered particularly in the study of cultural or archaeological artefacts that may be encapsulated in a metal shell without the need of disassembling.

## References

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[2] Kurt Osterloh, Uwe Ewert, Christoph Rädel, Uwe Zscherpel , Andreas Hasenstab, Thomas Bücherl: Radiographie und Tomographie von Holz mit Neutronen, Proceeding/Tagungsband: DGZfP-Berichtsband BB 113 – CD, 2008, ISBN 978-3-940283-09-2