

Radiography Using Fission Neutrons

Thomas Bücherl

*Institut für Radiochemie, Technische Universität München
Wlather-Meissner-Str. 3, 85748 Garching, Germany
E-mail: Thomas.buecherl@radiochemie.de*

Christoph Lierse von Gostomski

*Institut für Radiochemie, Technische Universität München
Wlather-Meissner-Str. 3, 85748 Garching, Germany
E-mail: Christoph.Lierse@radiochemie.de*

At the Forschungsneutronenquelle Heinz Maier-Leibnitz (FRM II) at the Technische Universität München, Germany, fission neutrons can be generated in the converter facility consisting of two plates of highly enriched uranium. An evacuated beam tube placed close to this secondary neutron source guides the fission neutrons to the NECTAR (Neutron Computerized Tomography And Radiography) facility, which is specially designed for radiography and tomography measurements.

Two different detector systems are actually available for the non-destructive inspection of various types of objects. The basic field of application of the NECTAR facility is where other radiograph methods using X-rays, gamma-rays, cold and thermal neutrons etc. fail, e. g. in the non-destructive inspection of thick and/or dense materials and material compositions like turbine blades, hydraulic motors etc.

*International Workshop on Fast Neutron Detectors
University of Cape Town, South Africa
April 3 – 6, 2006*

1. Introduction

The Forschungsneutronenquelle Heinz Maier-Leibnitz (FRM-II) at the Technische Universität München, Germany, is equipped with an additional fission neutron source. This thermal-to-fast neutron converter consists of two plates of highly enriched uranium mounted in a distance of about 1 m from the reactor core [1]. Its neutron source strength is about $5.7E+15 \text{ s}^{-1}$ operating at a thermal power of about 83 kW. The fission neutrons are guided to the converter facility by an evacuated beam tube (SR10) which is mounted close to the uranium plates to minimize moderation effects in the D_2O moderator (Figure 1). The converter facility consists of three rooms placed in a bunker made of heavy concrete with wall thicknesses of 1 m. The “Beckenwandnische” houses filters and collimators for manipulating the neutron spectrum and to reduce the gamma-ray background. The next room will be used for medical applications (MEDAPP facility) followed by the room for radiography and tomography (NECTAR facility). Both facilities will have to share the available beam time of 52 days permanent run per reactor cycle.

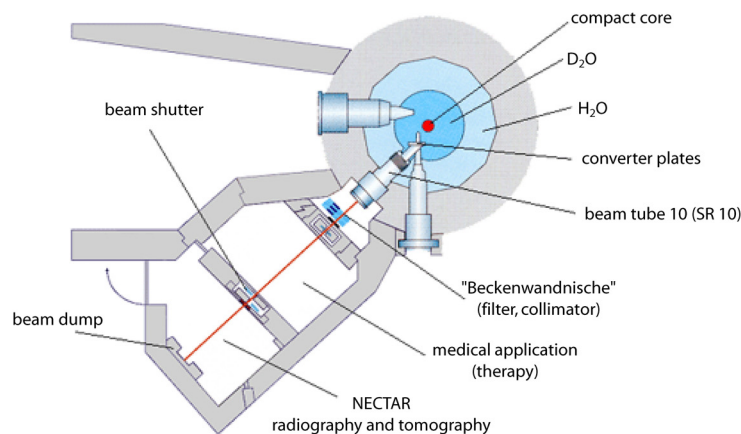


Figure 1: Sketch of the layout of the converter facility.

2. The NECTAR facility

2.1 General

The NECTAR (Neutron Computerized Tomography And Radiography) facility consists of collimators, a manipulator system to handle the sample and appropriate detector systems. To adjust the beam geometry two collimators are actually available. They are located in the “Beckenwandnische” and can be moved in the direct beam by means of hydropneumatics. The layout of the main collimator is based on extensive MCNP calculations and the requirements of optimized beam geometry (i.e. high L/D value, large FWHH of beam area at measurement position, minimized contribution of scattered neutrons at detector position), maximized neutron flux and reduced gamma-ray background. The final layout was a sandwich structure made out of cad-

mium, iron, lead and borated polyethylene. The second collimator is completely made out of iron and used in combination with the main collimator. Details are presented in [2,3]. All components are controlled by computers placed in a measurement cabin outside the rear wall of the bunker.

2.2 The detector systems

2.2.1 The CCD detector system

Two-dimensional position sensitive detector systems are state-of-the-art in neutron radiography and tomography. The NECTAR facility is equipped with a CCD detector system that comprises of a SITe 502AB grade 1 CCD (512 x 512 pixels) installed in a sideways looking high-performance liquid nitrogen dewar. Its quantum efficiency for light is 84.3 % at 400 nm and 81.7 % at 700 nm. The CCD detector system is connected with a lens (Noct-Nikkor 58 mm f/1.2) and is partly included in a light tight housing (Figure 2). The inner sides of this housing are coated by a special black cardboard to suppress light reflections by the walls and structures. The incoming neutrons are converted into visible light by a pp-converter (Polypropylene mixed with 50 wt.% ZnS(Ag), size 15 cm x 30 cm, [4]) which then is reflected to the lens by an aluminum coated mirror.

In the near future, the CCD-system will be replaced by Andor's DV434 CCD, having a 1024 x 1024 array and electro cooling at similar characteristics.

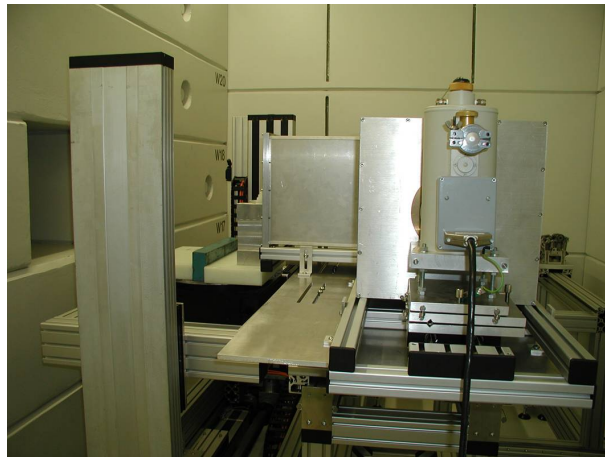


Figure 2: View in the measuring room of NECTAR with the manipulator for the samples (left) and the CCD detector system (right).

2.2.2 Set of collimated single beam detectors

At FRM-I radiography and tomography with fission neutrons were successfully performed in single beam geometry using a NE-213 scintillator in combination with a photomultiplier [5]. The attached electronics performed an excellent gamma-to-neutron discrimination, thus giving the basis for correction of beam hardening effects.

At the NECTAR facility a set of four of these single beam detectors was installed. For single slit collimation an iron block of 50 cm depth with four rectangular slits of 4 mm x 1 mm (height x width), one on top of the other, is used. The electronics were extended to discriminate two gamma and two neutron energy ranges, respectively. The detection efficiency should be about 30 %. The final adjustment and first measurements are actually performed.

3. Experimental results

3.1 Basic parameters

One of the main tasks in setting into operation of a radiography/tomography facility is the determination of all relevant parameters as there are neutron fluxes and spectra, gamma dose rates, L/D values etc. Some first results using the main collimator are reported next.

The fission neutron flux available at the measuring position was estimated to about $4.9\text{E}+06 \text{ cm}^{-2}\text{s}^{-1}$ taking into account the results of MCNP calculations and measured dose rates. The mean neutron energy is 1.6 MeV. Both data have to be verified by means of additional activation measurements.

One important parameter of a radiography system is the L/D value, where L is the distance between collimator and sample position and D the diameter of the circular collimator outlet window. It is a measure of the best available resolution. This value was determined experimentally for the main collimator by using an iron cylinder (diameter 5 cm, height 2.56 cm) fixed at the sample manipulator and varying the distance between the cylinder and the detector system [6]. A first estimation resulted in $L/D = 233 \pm 16$. The relatively large standard deviation may be caused by the contribution of scattered neutrons in the cylindrical object. This will be investigated in more detail in one of the next reactor periods.

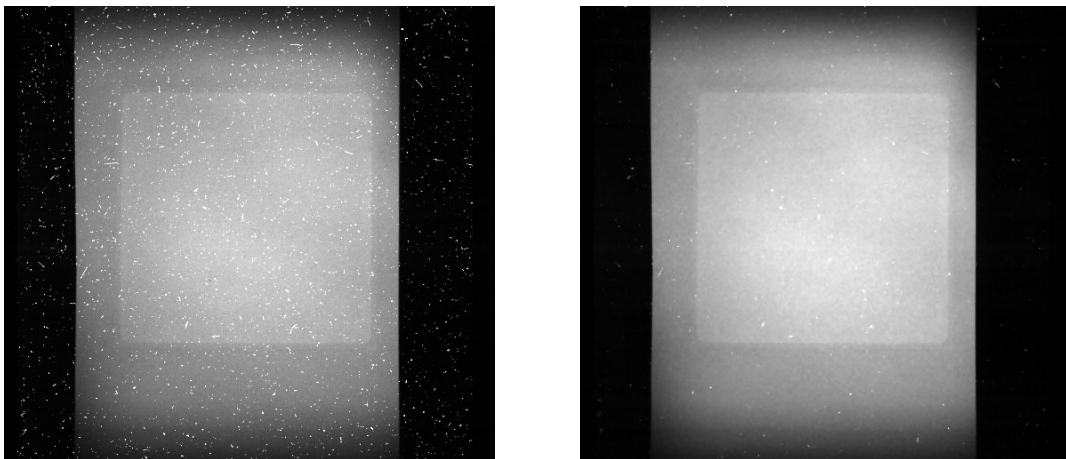


Figure 3: Open beam (flat field) image. The rectangular structures visible are caused by the preliminary fixing of the pp-converter on the detector housing. Left: Original image (1 minute measuring time). Right: Resulting image after median filtering and summing of 10 "original" images.

3.2 Radiographs

All radiographs shown were measured using the nitrogen cooled CCD camera system in combination with the pp-converter. During the measurements a relatively large number of scattered gamma rays hits the CCD chip causing randomly distributed signals in individual pixels (Figure 3 left). Thus for each radiography a set of typically 10 frames in total was measured (measurement time per frame 1 minute). Then a median filter (3 x 3) was applied on each frame and the resulting images were summed up (Figure 3 right). After dark image subtraction and normalization the final radiograph of the object is achieved.

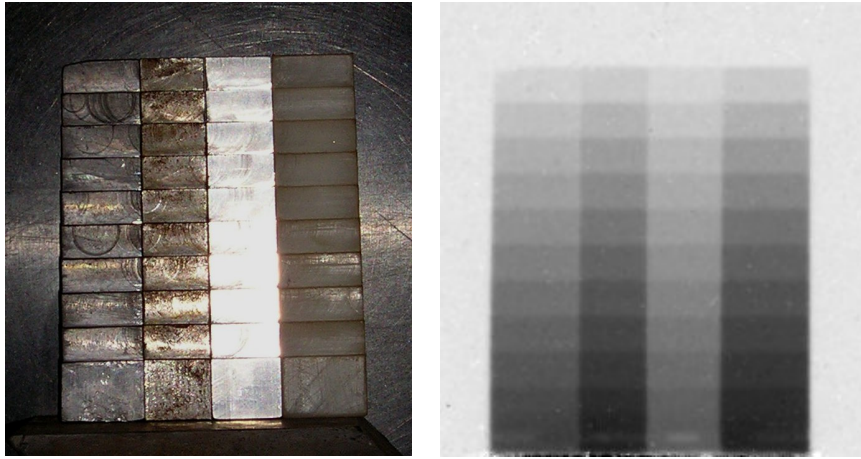


Figure 4: Photo (left) and radiograph (right) of a step wedge made of lead, iron, aluminum and polyethylene (from left to right). The depth of the each step increases by 5 mm, i.e. the maximum depth is 50 mm.

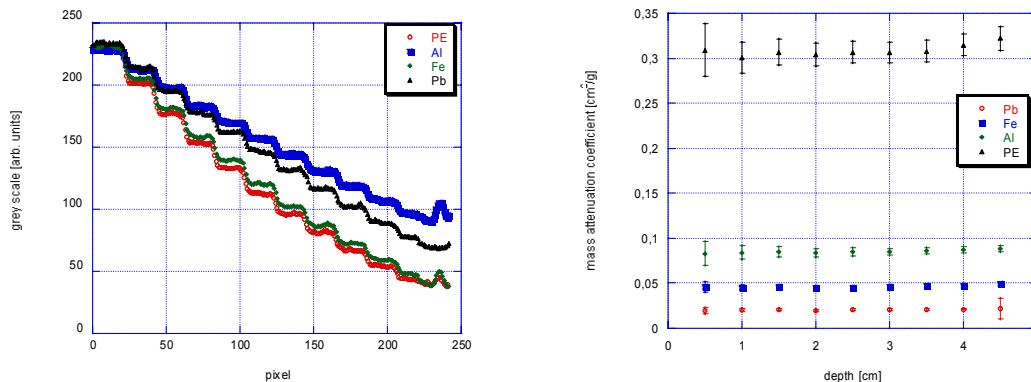


Figure 5: Left: Course of the intensity values for the individual materials as a function of position (distance). Right: Derived mass attenuation coefficients as a function of the thickness of the individual materials.

Figure 4 shows the photo and the corresponding radiograph of a step wedge made of lead, iron, aluminum and polyethylene (from left to right). The depth of each step increases by 5 mm, i.e. the maximum depth is 50 mm. The course of the intensity values for the individual materials derived from the radiograph is shown in Figure 5 left. Based on the known thickness of each

step the corresponding mass attenuation coefficients were calculated. The results are shown in Figure 5 right. Within the measurement uncertainty the coefficients are independent of the thickness of the steps except for polyethylene where a slight increase with thickness is observed. The values are $0.0195 \text{ cm}^2\text{g}^{-1}$ for lead, $0.0437 \text{ cm}^2\text{g}^{-1}$ for iron and $0.0819 \text{ cm}^2\text{g}^{-1}$ for aluminum, respectively. For polyethylene the mass attenuation coefficients range from $0.298 \text{ cm}^2\text{g}^{-1}$ for a thickness of 0 cm up to $0.322 \text{ cm}^2\text{g}^{-1}$ for a thickness of 5 cm.

Figures 6 and 7 show two further examples of radiographs of a three-phase A.C. motor and a cylinder head. Turbine blades up to 30 cm in height and a maximum thickness of 12 cm have been radiographed successfully, too.

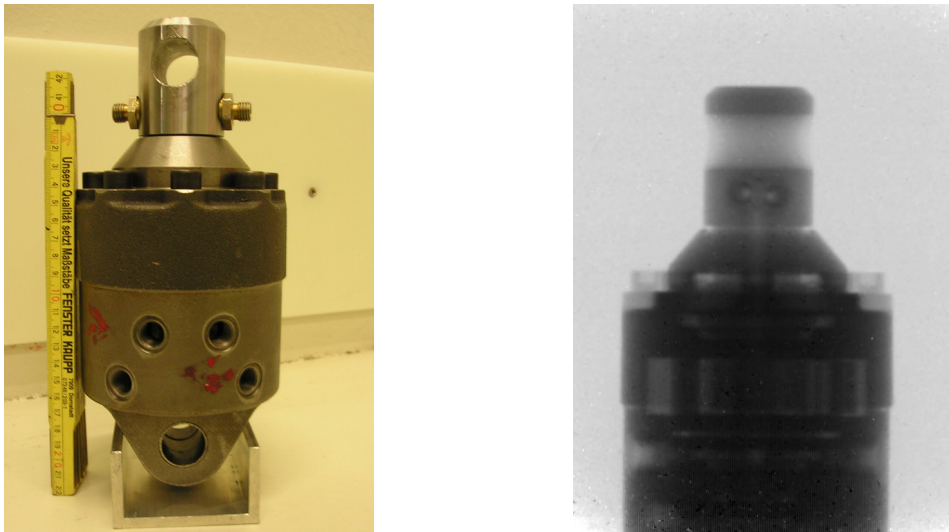


Figure 6: Photo (left) and radiograph (right) of a three-phase A.C. motor

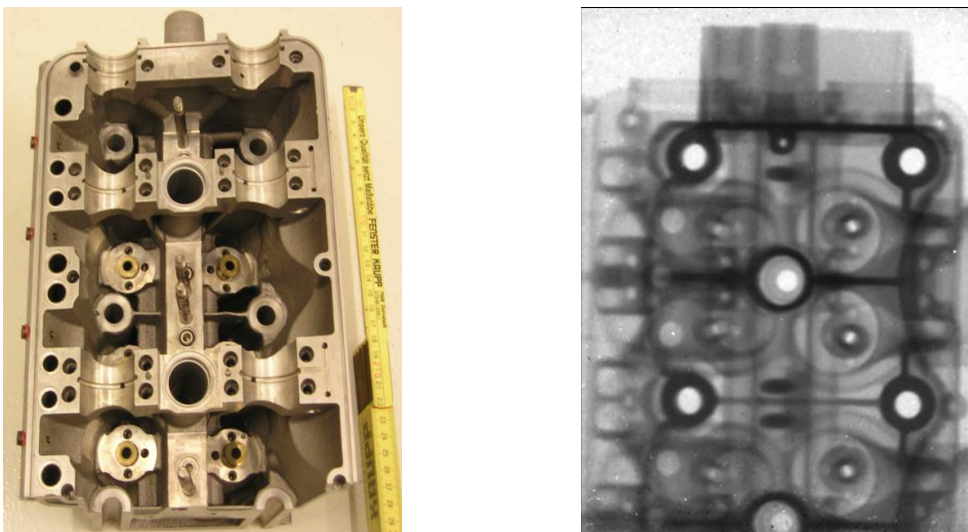


Figure 7: Photo (left) and radiograph (right) of a cylinder head.

4. Summary

The NECTAR facility provides a well collimated fission neutron beam on a large area for radiography and tomography applications as well as for testing of new detector systems. A detailed experimental determination of the most important parameters and the final implementation of the tomography mode in the next reactor periods will complete the phase of setting into operation and offer the capabilities of NECTAR to users from research and industry.

References

- [1] *Annual Report 2004 Forschungs-Neutronenquelle Heinz Maier-Leibnitz*, Technische Universität München, Neue Forschungsneutronenquelle ZWE-FRM-II, Lichtenbergstr. 1, 85747 Garching, Germany.
- [2] T. Bücherl et al, *Radiography and tomography with fast neutrons at the FRM-II – A status report*, Appl. Rad. Isot. 61 (2004) 537-540.
- [3] T. Bücherl et al, *The NECTAR facility at FRM-II: Status of the set-up of the radiography and tomography facility using fast neutrons*, Proceedings of the Seventh World Conference on Neutron Radiography, Rome, Italy, September 15-21, 2002, 401-409, ISBN 88-8286-199-6.
- [4] K. Yoshii, K. Miya, *A study of the mechanism model of luminescence in fast neutron television converter*, Nucl. Inst. Meth. A 346 (1994) 253-258.
- [5] A. Schatz et al, *Computer-Tomography with Fast and Thermal Neutrons*, Neutron Radiography (3), Osaka, Kluwer Academic Press, 1989.
- [6] K. Yoshii, H. Kobayashi, *Characterization of the YAYOI fast neutron radiography field*, Nucl. Instr. Meth. A 377 (1996) 68-71.