Applied Radiation and Isotopes 85 (2014) 54–59

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

Application of Neutron Tomography in Culture Heritage Research

T. Mongy *

Atomic Energy Authority (AEA) of Egypt, Egypt Second Research Reactor (ETRR-2), P.O. Box 13759, Abo Zaabal, Cairo, Egypt

HIGHLIGHTS

- Neutron Tomography is an efficient tool in the field of Cultural Heritage research.
- The full description of the ETRR-2 and state-of-the-art Neutron Tomography system.
- Implementation of using computer software package in image reconstruction and imaging processing.
- Precise measurements that was impossible by traditional methods.
- The manuscript opens the door to investigate ancient Egyptian treasures.

ARTICLE INFO

Article history:
Received 31 July 2013
Received in revised form
2 October 2013
Accepted 12 November 2013
Available online 11 December 2013

Keywords:
Neutron imaging
Neutron Tomography
Neutron Radiography
Culture Heritage

ABSTRACT

Neutron Tomography (NT) investigation of Culture Heritages (CH) is an efficient tool for understanding the culture of ancient civilizations. Neutron imaging (NI) is a-state-of-the-art non-destructive tool in the area of CH and plays an important role in the modern archeology. The NI technology can be widely utilized in the field of elemental analysis.

At Egypt Second Research Reactor (ETRR-2), a collimated Neutron Radiography (NR) beam is employed for neutron imaging purposes. A digital CCD camera is utilized for recording the beam attenuation in the sample. This helps for the detection of hidden objects and characterization of material properties. Research activity can be extended to use computer software for quantitative neutron measurement. Development of image processing algorithms can be used to obtain high quality images.

In this work, full description of ETRR-2 was introduced with up to date neutron imaging system as well. Tomographic investigation of a clay forged artifact represents CH object was studied by neutron imaging methods in order to obtain some hidden information and highlight some attractive quantitative measurements. Computer software was used for imaging processing and enhancement. Also the Astra Image 3.0 Pro software was employed for high precise measurements and imaging enhancement using advanced algorithms.

This work increased the effective utilization of the ETRR-2 Neutron Radiography/Tomography (NR/T) technique in Culture Heritages activities.

1. Introduction

ERRR-2 Neutron Radiography (NR) facility was commissioned in 1999. The first experiments carried out were determination of characterization parameters, such as, flux map, n/γ ratio, Cd ratio and spatial resolution. The results were compared with MCNP calculations. Internal details were detected for different samples using a nitrocellulose film. The photographic film was replaced by a nitrocellulose film to get high quality image formation. A lot of experiments were performed toward scientific research and quality assurance as well. Welding inspection, measuring water permeability in building materials and imaging enhancement by scattered neutron deblurring were the major experiments achieved in the past.

Fast Neutron Resonance Radiography (FNRR) was also introduced using a portable neutron source. The characterization parameters were determined for the neutron source. Detection of hydrogenous components was implemented to study water permeability in building materials using quantitative FNRR (Mongy and Gaheen, 2011). Capabilities of underground water migration in soil were also investigated and implemented to preserve Cultural Heritage monuments.

The gamma ray radiography (γR) technique was used to inspect welding materials. The NR technique was compared with γR in 2011. Dynamic System Neutron Radiography (DSNR) was precommissioned using a DELCam camera. High definitions, high

* Tel.: +20 111 2247943; Fax: 002 02 44621838.
E-mail address: tmongy@gmail.com

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http://dx.doi.org/10.1016/j.apradiso.2013.11.028

resolution and high quality images were obtained using the imaging processing technique.

2. Description of ETRR-2

ETRR-2 is an open pool-type research reactor with variable core arrangement (Esposto, 1999). The core power is 22 MWth cooled by light water, moderated by water and with beryllium reflectors. The design concept is based on versatile utilizations. It has been mainly designed for:

1. basic and applied research in reactor physics and nuclear engineering,
2. Neutron Radiography for research and industrial purpose,
3. radioisotope production for medical and industrial purposes,
4. beam holes experimentation for neutron scattering experiments and Neutron Radiography,
5. material testing,
6. material irradiation,
7. activation analysis, and
8. training of scientific and technical personnel.

ETRR-2 has four neutron beams and a thermal column as the main experimental devices allow neutron sources outside the reactor core. The four neutron beams tubes are:

1. the Neutron Radiography Facility,
2. the Radial Beam Tube,
3. the Tangential Beam Tube, and
4. the Underwater Neutron Radiography Facility.

Fig. 1 represents the reactor tank with its internals. The figure shows: ① passing mechanism, ② pool cooling pipe, ③ thermal column, ④ beryllium block, ⑤ tangential tube, ⑥ guide box, ⑦ control rods, ⑧ chimney, ⑨ core cooling system pipe, ⑩ pool cooling system diffuser, ⑪ fuel elements, ⑫ reflectors, ⑬ irradiation grid, ⑭ irradiation chamber shield, ⑮ suction box, ⑯ radial tube and ⑰ Underwater Neutron Radiography (UWNR) tube.

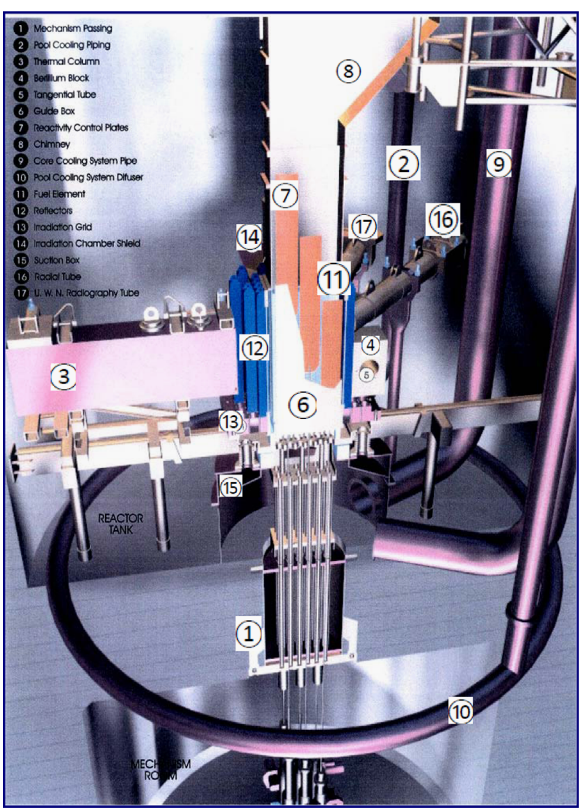

Fig. 1. ETRR-2 tank with its internals.

3. State of the art neutron imaging facility at ETRR-2

The commissioning of the state of the art new neutron imaging (NI) system started at the end of March 2012 under the framework of TC communication between AEA and IAEA. The layout of the system is shown in Fig. 2. The NI system was installed to replace static based film neutron radiography.

For NI, the neutrons are attenuated and a sufficient amount of light is produced by a scintillation screen that detected with a CCD camera. The scintillation screen used had a composition of LiF:ZnS: Cu (Bennett et al., 2001). The neutrons interact with lithium due its large cross section to produce an alpha particle ($^{4}He^{++}$) and tritium (^{3}H) daughter products. The energy from alpha particle is deposited into zinc sulfide (ZnS) and efficient phosphor producing

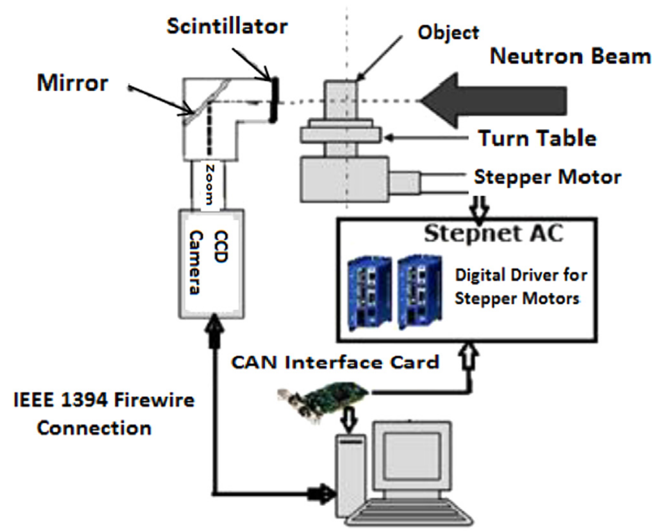

Fig. 2. Layout for neutron radioscopy system with a scintillation screen and cooled CCD camera as used in ETRR-2.

Table 1
Equipment used for NT in ETRR-2 with specifications.

Equipment	Technical specifications
PCO2000 CCD thermo-electrical cooling camera system compact with power supply 	High resolution (2048 × 2048 pixel) 14 bit dynamic range Image rate of 14.7 fps @ full resolution Low noise Low dark current Pixel size (hor. × ver.) is 7.4 × 7.4 μm^2 4 GB camera memory
Lenses	Nikon, 50 mm focal length
Mirror	45° High reflectivity polished silicon
Scintillator	6LiF+ZnS
Light tight box	Aluminum