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Design of cold neutron imaging facility at china advanced research reactor

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Abstract

The radiography imaging with cold neutrons is being planned at China Advanced Research Reactor (CARR). The 60MW CARR at China Institute of Atomic Energy (CIAE) has got full power in March, 2012. It is a tank-in-pool type reactor using a D_2O reflector for inverse neutron trap, and the expected optimal undisturbed thermal neutron flux is 8×10^{14} n/cm^2•s. Cold neutron imaging facility will be built at the guide hall. At present, its conceptional and physical designs have been finished. The cold neutron imaging facilities will provide an efficient and versatile tool for basic scientific and industrial non-destructive investigation.

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1. Introduction

Non-destructive testing (NDT) methods are quite often mandatory to guarantee the safe operation of a system or to check highly expensive or unique samples. Neutrons are the ideal probes to study the structure and the behaviour of the sample material due to the fact that neutrons enabling deeper penetration and much sensitivity to light elements as hydrogen, lithium, boron and so on [1-8].

For neutron imaging, strong neutron sources are required in order to guarantee high quality
radiography pictures. The 60MW China Advanced Research Reactor (CARR) at China Institute of Atomic Energy (CIAE) has got full power in March, 2012[9, 10]. It is a tank-in-pool type reactor using a D2O reflector for inverse neutron trap, and the expected optimal undisturbed thermal neutron flux is \(8 \times 10^{14} \text{n/cm}^2\cdot\text{s}\). The reactor experiment hall houses a set of instruments connecting to 7 horizontal thermal neutron beam tubes, two of which are dual beam ports. Additionally, cold neutrons produced by a liquid D2 cold source are transported via 4 guide systems to the \(30 \times 60 \text{m}^2\) guide hall. One of its main purposes is the development and application of cold neutron radiography technique. Upon the financial support from the Chinese government, a cold neutron imaging facility is under construction at the guide hall (Fig1). At present, its conceptional and physical designs have been finished. The cold neutron imaging facilities will provide an efficient and versatile tool for basic scientific and industrial non-destructive investigation. Our plan is to design a multipurpose facility allowing for the development of advanced image techniques like phase-contrast imaging and energy-selective radiography. To realize such functions the facility should be flexible to change easily the beam geometry by positioning various neutron optical components in the beam to adjust its energy, flux and spatial resolution in an appropriate way.

### 2. Collimation system

The available beam position for the cold neutron imaging facility at CARR is at the end of a neutron guide with the length of 48m. This guide system is made of supper mirror of \(m=2\), enabling a broad cold neutron spectrum possessing a negligible high-energy fraction. Such spectral beam characteristics are very suitable for advanced imaging.

The available distance behind the neutron guide is about 20 meters. The front 16meters will be used for collimating the neutron beam, and the remainder of 4 meters for samples, sample manipulators, and neutron imaging detectors as shown in figure 1. There are two measuring positions of 16 m and 8 m at the end of the guide. The L/D ratio was designed to be optional from 200 to 1600 and the size of fully illuminated area was calculated by Monte Carlo simulation (Vitess [11]) and analytical formula [12], as illustrated in Table.1.

![Fig.1 Geometry design of the cold neutron imaging facility](image)

1Neutron guide; 2Rotation aperture; 3Neutron fast shutter; 4Flight tube/velocity selector; 5Flight tube; 6Beam limiter; 7Sample table; 8Detection system; 9Shielding; 10Entrance

Fig.1 Geometry design of the cold neutron imaging facility
Table 1. Geometry Parameters of the cold neutron imaging facility

<table>
<thead>
<tr>
<th>D(cm)</th>
<th>L(cm)</th>
<th>L/D</th>
<th>Fully illuminated area (cm²)</th>
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<th>Analytical calculation</th>
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</table>

2.1 Aperture and fast neutron shutter

Size, location and shape of the aperture define the spatial resolution of the neutron imaging facility and the size of the fully illuminated area at the detector position. The aperture is designed as a rotating disk type (Fig. 2 left) at the end of the guide. The disk is filled with B₄C and its shell is made of aluminum. There are 5 circular cores made of several layers of neutron absorbing materials are embedded inside the disk. Four of them are drilled with cone-shaped holes for the beam to come out when it opens, with the maximum diameters of 5cm 4cm, 2cm and 1cm, respectively. The fifth is designed as solid at present and can be modified in the future. In some cases it is desirable to shut the neutron beam for a very short time. This is especially the case during tomography measurements. The rotation of the specimen to the next angular position and data read out from the detector usually needs a few seconds. In order to eliminate the avoidable activation, a fast neutron shutter (Fig. 3 right) made of a layer of boron carbide is amounted behind the aperture to attenuate the neutron beam quickly.

Fig. 2 Diagrammatic sketch of the rotating aperture (left) and the fast shutter (right).
2.2 Flight Tube and beam limiter

The distance between the shutter and entrance of the experimental chamber is 16 m. Within this distance neutron scattering and absorption in air will reduce the total neutron flux, worsen the signal to noise ratio significantly and deliver an unwanted, prohibitive contribution to activated gases in the reactor hall. A flight tube made of aluminum with the vacuum enclosed inside is amounted between the shutter and the experimental chamber. The tube can be divided into 3 parts for different sample positions.

At the end of the flight tube (in beam direction) a beam limiter will be installed. It consists of four boron carbide plates that can be driven independently into the neutron beam. As a result, the beam size at the position of the sample can be adjusted to the desired area. Background radiation neutrons and activation in the experimental chamber can be reduced by this device.

3. Sample positioning system and detection system

The sample positioning system (Fig.5 left) is designed to position the sample accurately at the desired location and orientation and to collect images for tomographic reconstruction. This sample positioning system has four degrees of freedom, three of them being linear along ‘x’, ‘y’ and ‘z’ axis and one rotational with axis along ‘z’ direction. The linear motion is controlled by two stepper motors and the rotational motion is controlled by the servo motor. The rotational stages are mounted on the linear platform. The motors are controlled by the controllers which are signaled by a personal computer.
The diagrammatic sketch of the detection system is shown in the right of Fig.5. The scintillator was chosen to have 40cm×40cm dimensions and $^6\text{LiF-ZnS (Ag)}$ type with the peak of the light emission at 450 nm. The aluminized mirror has 40cm×56cm dimensions and was obtained by a aluminum plate with thickness of 5mm. The aluminum layer (100nm) is covered by a SiO$_2$ (3-4nm) protective layer. The lens of 50mm F 1.2 or 85mm F1.4 and the CCD of PIXIS2048 are selected.

Fig.5 Diagrammatic sketch of the detection system.

4. Shielding for the imaging facility

The shielding for the facility is mainly made up of heavy concrete ($\rho=3.7\text{t/m}^3$). The shield thickness is about 50cm in all sides except the beam stop. Its outer appearance is depicted in Fig.6. The beam stop is made up of one huge piece of heavy concrete block 100cm thick with layer of iron and B$_4$C mixed inside.

Fig.6 Diagrammatic sketch of the shielding.

5. Conclusion

The radiography imaging with cold neutrons is being planned at CARR. It is a multipurpose facility allowing for the development of advanced image techniques like phase-contrast imaging and energy-selective radiography. The cold neutron imaging facilities will provide an efficient and versatile tool for basic scientific and industrial non-destructive investigation in China.
Acknowledgements

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References