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Computational analysis supporting the design of a new beamline for the mines neutron radiography facility

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Abstract

The Colorado School of Mines installed a neutron radiography system at the United States Geological Survey TRIGA reactor in 2012. An upgraded beamline could dramatically improve the imaging capabilities of this system. This project performed computational analyses to support the design of a new beamline, with the major goals of minimizing beam divergence and maximizing beam intensity. The new beamline will consist of a square aluminum tube with an 11.43 cm (4.5 in) inner side length and 0.635 cm (0.25 in) thick walls. It is the same length as the original beam tube (8.53 m) and is composed of 1.22 m (4 ft) and 1.52 m (5 ft) flanged sections which bolt together. The bottom 1.22 m of the beamline is a cylindrical aluminum pre-collimator which is 0.635 cm (0.25 in) thick, with an inner diameter of 5.08 cm (2 in). Based on Monte Carlo model results, when a pre-collimator is present, the use of a neutron absorbing liner on the inside surface of the beam tube has almost no effect on the angular distribution of the neutron current at the collimator exit. The use of a pre-collimator may result in a non-uniform flux profile at the image plane; however, as long as the collimator is at least three times longer than the pre-collimator, the flux distortion is acceptably low.

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Keywords: Neutron radiography; Neutron beamline; TRIGA reactor

1. Introduction

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In 2012 the Colorado School of Mines (CSM) completed construction of a neutron radiography system, called the MInes NEutron Radiography (MINER) facility. Several potential improvements to the MINER facility have been identified, particularly with respect to the neutron beamline. Limitations of the current beamline include a lack of beam tube “straightness” (which leads to excessive scattering of the neutron beam), a small imaging area, and an inability to adjust the properties of the beam through the addition of filters or apertures. This paper describes the computational analyses conducted to support the design of a new beamline to overcome these limitations. Section 2 describes the relevant facilities and equipment, and Section 3 describes the models used in these analyses. Section 4 covers the results of the computational analyses. The analyses were performed using the Monte Carlo N-Particle (MCNP) transport code (Goorley, 2012), and consist of two steps. First, the optimal collimator shape is investigated along with the potential advantages of lining the collimator with a neutron absorbing material to remove scattered neutrons and improve beam quality. Then, based on the chosen collimator geometry, the uniformity of the neutron beam intensity at the imaging plane is evaluated.

2. Facilities and Equipment

The MINER facility is a first generation neutron radiography system attached to a nuclear research reactor owned by the United States Geological Survey (USGS) (Craft and King, 2014). The USGS research reactor, located in Lakewood, CO, is a Mark-I Training Research and Isotopes—General Atomics (TRIGA) reactor, and acts as the neutron source for the MINER facility. The USGS TRIGA Reactor (GSTR) is a typical Mark-I TRIGA design, consisting of a graphite reflected TRIGA core at the bottom of a below-ground aluminum tank filled with demineralized water (Fouquet, Razvi, and Whittemore, 2003). The GSTR is licensed to operate at a steady-state power of 1 MW_{th} and is capable of pulsing up to 1600 MW_{th} (United States Geological Survey, 2009).

The MINER facility sits at the top of the reactor tank and includes a neutron beamline and beamstop, an optical table on a support stand, an experiment enclosure, and a computer control system to run the associated electronics. Fig. 1 presents a cut-away view of the MINER facility as it is installed at the GSTR. The source-end of the beamline is located near the top of the core, and is held in place by an aluminum stand. When the reactor is running and the beamline is open, neutrons stream up the beam tube and are collimated into a beam. The neutron beam can then be used to perform imaging inside the experiment enclosure, before being attenuated to safe levels by the beamstop.

The design of the reactor requires that any beamline must be quite long (>7 m). The current beamline consists of two main 3.66 m (12 ft) sections and a 1.22 m (4 ft) top section that are joined by 5.08 cm (2 in) Swagelok connectors. The beamline is made of 0.635 cm (¼ in) thick 6061 aluminum alloy tubing with an inner diameter of 3.81 cm (1.5 in). The beamline is secured at the top of the reactor tank by a Teflon-lined clamp, allowing the beam tube to slide vertically to accommodate thermal expansion. The beamline is open at the bottom so that when it is not in operation it is filled with water from the reactor. Near the top, the beamline is connected to a pressurized

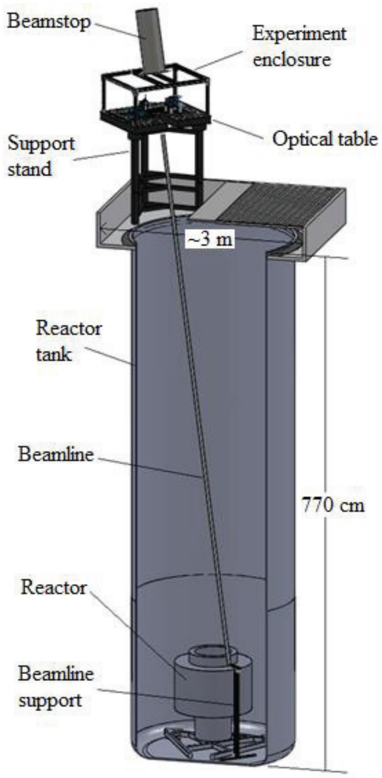

Fig. 1. Cut-away rendering of the MINER facility

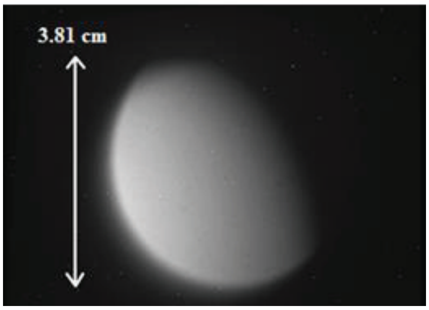

Fig. 2. Bright field image with visible flux distortion produced by the current beamline.