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Neutron Radiography and Computed Tomography at Oak Ridge National Laboratory

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Abstract

The capability to perform neutron radiography and computed tomography is being developed at Oak Ridge National Laboratory. The facility will be located at the High Flux Isotope Reactor (HFIR), which has the highest steady state neutron flux of any reactor in the world. The Monte Carlo N-Particle transport code (MCNP), versions 4A and 4B, has been used extensively in the design phase of the facility to predict and optimize the operating characteristics, and to ensure the safety of personnel working in and around the blockhouse. Neutrons are quite penetrating in most engineering materials and can be useful to detect internal flaws and features. Hydrogen atoms, such as in a hydrocarbon fuel, lubricant or a metal hydride, are relatively opaque to neutron transmission. Thus, neutron based tomography or radiography is ideal to image their presence. The source flux also provides unparalleled flexibility for future upgrades, including real-time radiography where dynamic processes can be observed. A novel tomography detector has been designed using optical fibers and digital technology to provide a large dynamic range for reconstructions. Film radiography is also available for high resolution imaging applications. This paper summarizes the results of the design phase of this facility and the potential benefits to science and industry.

Design Goals

The key issues in the design of the beam for the Neutron Computed Tomography and Radiography Facility (NCTRF) were the neutron flux, the L/D ratio, the cadmium ratio, the thermal neutron-to-gamma ratio, the flux uniformity, and the imaging method. Optimization of all these parameters is usually constrained by the source type, as well as by the means available to bring the neutrons from the source to the desired location. The goal of this work was to optimize the beam for the NCTRF and provide the maximum possible flux to permit high resolution imaging with exceptional dynamic range. The beam will have an L/D ratio greater than 100, a thermal neutron-to-gamma ratio greater than 1×10^6 n/cm^2-mR, and

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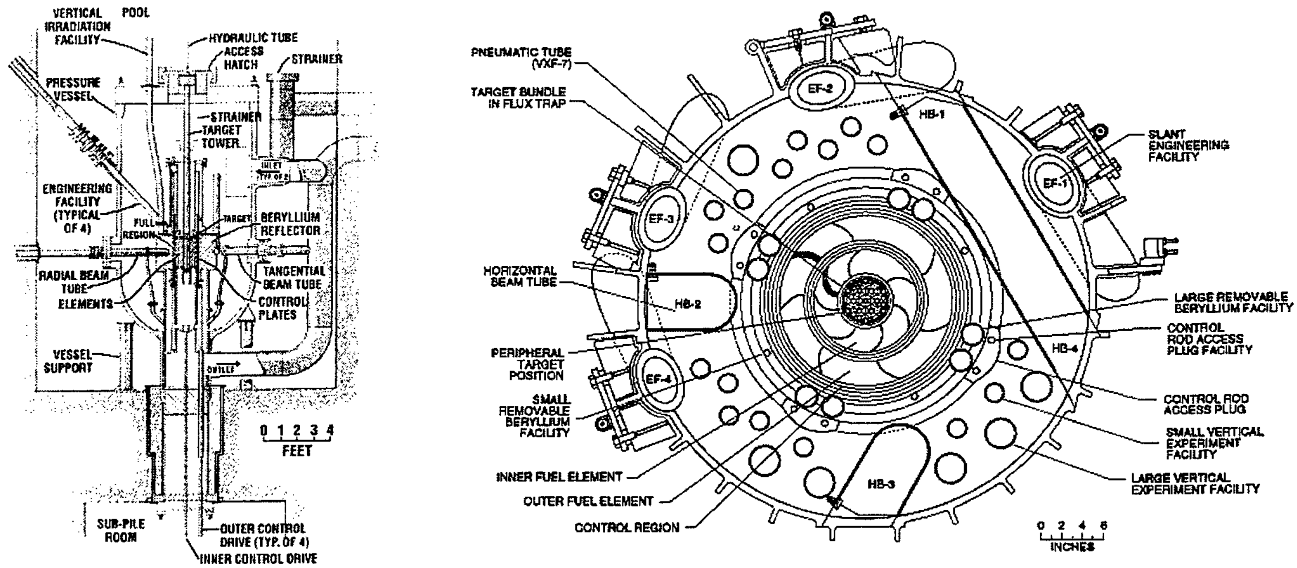

Figure 1 Drawings showing the layout of the HFIR core and the four HB and EF facilities, plan view (left), vertical section (right).

provide a flat flux profile. The prototype facility will use film radiography for high resolution applications, and a new digital detector has been designed for tomographic applications.

The High Flux Isotope Reactor has numerous beam facilities available for research. There are four horizontal beam (HB) tubes, primarily used for neutron scattering experiments, and four engineering facility (EF) tubes, which are slant tubes passing by the core at the periphery of the beryllium reflector (Figure 1). These EF tubes are inclined at a forty-nine degree angle from the horizontal plane and enter rooms one floor above the reactor and HB experiment rooms. Due to the angle of the EF tubes, their use has been limited to certain specialized experiments and activation analysis work. In October, 1995, a Laboratory Directed Research and Development proposal was submitted with one part devoted to installing a neutron computed tomography and radiography facility at HFIR. Since all of the HB tubes were already in use, the decision was made to use one of the open EF slant tubes. The choice provided the maximum flexibility for optimizing the key features listed above without interfering with the operation of any of the established facilities.

Monte Carlo Models

Optimization of the parameters important to the NCTRF required Monte Carlo models to be developed. An existing model of the High Flux Isotope Reactor was modified to include transport through the EF tube that was selected for the NCTRF. Initial K-code (criticality) runs were performed with MCNP to benchmark the measured flux levels recorded in the EF tube against various other known values in other regions of the core. These results were also compared with prior models and experimental data to verify their accuracy. The K-code runs were then used to generate surface source files which could be used in subsequent calculations. This greatly reduced the time required to generate adequate statistics for the tallies at the end of the beam tube. Initial simulations showed the beam flux at the exit plane of the collimator to be approximately $4x10^9$ n/cm^2-s with a neutron-to-gamma ratio of $2x10^6$ n/cm^2-mR. With a bismuth "lens" to shape and filter the beam, it was shown that the collimator design could produce a beam with a flux around $2x10^9$ n/cm^2-s with less than five percent variance from center to edge, and a neutron-to-gamma ratio

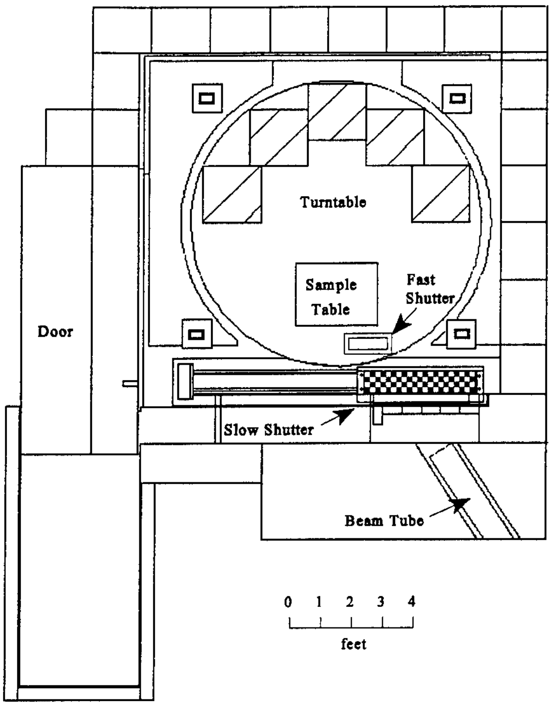

Figure 2 The layout of the Neutron Computed Tomography and Radiography Facility.

of 4×10^6 n/cm^2-mR. However, further simulations indicated that the shielding requirements for such a beam were greater than the safety analysis for the floor loading would permit.

Modifications were made to the collimator design based on the allowable floor loading and the reduced shielding available. The thickness of the bismuth filter was increased until the flux at the exit of the collimator was approximately 1×10^7 n/cm^2-s. The beam was shaped by placing a small hemisphere of bismuth at the top of the filter to provide a uniform flux. This also increased the neutron-to-gamma ratio to 1×10^7 n/cm^2-mR.

Prototype Facility

Two different imaging methods will be available for research applications in the prototype facility. Film radiography will be performed for high resolution applications using a gadolinium conversion screen and aluminum film cassette. The tomography detector is nearing completion and will have 96 pixel elements, each a one by one millimeter square Li^6F/ZnS scintillator cube coupled to optic fibers, which will carry the signal from the detection array to a diode array detector outside the blockhouse. Each element will have its own 32-bit counter to provide superior dynamic range.

The design of the facility provides for a fast shutter for accurate exposure control, as well as a slow shutter and shielded turntable to permit personnel access without the necessity of filling the collimator with water (Figure 2). The sample positioning device is a large 4-axis unit designed to hold and maneuver an object weighing up to 100 kg at the required 49 degree tilt of the beam.

Conclusions

A new Neutron Computed Tomography and Radiography Facility is under construction at the High Flux Isotope Reactor at Oak Ridge National Laboratory. The facility will provide routine film radiography for high resolution applications and will utilize a novel fiber-based detector system for neutron computed tomography. Future upgrades are possible with continued support from the user community, including the installation of real-time capabilities. The design of the collimator also provides a straightforward avenue for increasing the beam flux once shielding issues are resolved.

The Monte Carlo N-Particle transport code (MCNP) has been an invaluable tool in the analysis of the beam characteristics and the resulting performance issues associated with the installation of this facility. It is anticipated that this experience will provide significant insights for the design and construction of future facilities and instruments.

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