Neutronics Analyses for Beam Line Upgrades to the High Flux Isotope Reactor

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Introduction

The High Flux Isotope Reactor (HFIR) located at Oak Ridge National Laboratory is one of the world's most powerful research reactors.[1] Since its initial operation in 1966, the HFIR has served three primary missions: (1) the production of isotopes such as californium-252 and other transuranium isotopes for research, industrial, and medical applications, (2) material irradiation experiments to study radiation damage effects in materials, and (3) neutron scattering experiments to study the basic structure and dynamics of materials that are of interest to solid-state physicists, chemists, biologists, polymer scientists, and metallurgists. While the first two missions utilize several irradiation facilities located within the reactor pressure vessel, the third mission utilizes the four horizontal beam lines.

In 1996, one year after the demise of the Advanced Neutron Source Project, the U.S. Department of Energy embarked on an aggressive program to upgrade the neutron scattering facilities at HFIR. These upgrades, which are now in progress, include the installation of larger beam tubes, a high-performance hydrogen cold source, and additional neutron guides and neutron scattering instruments. An extensive analysis effort was performed over the past four years to support the design of the modified beam lines and new user facilities, and to assess the impact of the upgrades on the integrity of the existing reactor system. The results of three of these analyses are summarized here. Specifically, results are presented for analyses related to: (1) the design of the new cold neutron source, (2) the assessment of beam tube changes on the anticipated pressure vessel lifetime, and (3) the effectiveness of a new shield design for the tangential beam lines.

Cold Neutron Source Design

The HFIR has four horizontal beam lines, designated HB-1 through HB-4. Probably the most exciting aspect of the HFIR upgrade project is the addition of a cold neutron source (CNS) to be placed in the existing HB-4 beam line.[2] Extensive analyses were performed initially to assess the feasibility and performance of the CNS, and later to optimize the CNS design.[3] The MCNP Monte Carlo code[4] was used to perform the analyses, which included a highly accurate model of the CNS, the liquid hydrogen feed lines, the HB-4 beam line, and the surrounding reactor components.

Of primary importance was the effective "brightness" of the CNS, i.e. the neutron flux per unit angle per unit wavelength produced by the CNS within the desired range of neutron wavelengths (7.5 to 16 angstroms). Within this range, the HFIR CNS appears to be comparable to the horizontal cold source at the Institute Laue-Langevin (ILL) in France.[5] Another important operational consideration is the heating load generated in the CNS since this impacts the refrigeration system that must maintain the 20 K temperature of the liquid hydrogen contained within the CNS. A thorough analysis of neutron and gamma-ray heating from primary and secondary radiations yielded an estimated heat load of 2.2 kW for the final CNS design.

An important part of the validation of the design analyses was the comparison of various HFIR CNS performance characteristics to existing cold neutron sources at other reactors such as at ILL and at the National Institute of Science and Technology (NIST). In general, the comparisons of brightness, relative gain, and heat loads compared well with existing experience. One aspect that did not was the sensitivity of the CNS spectrum to the relative portions of ortho- and para-hydrogen in the cold source. Unlike NIST's CNS, which showed considerable sensitivity to ortho-hydrogen content, the HFIR design showed only modest sensitivity. A separate physics study was performed in which the HFIR CNS was gradually "morphed" into the NIST design.[3] This study showed clearly how the physics of neutron scattering within the CNS changes dramatically as the design changes in a way that supports both the NIST and the HFIR assessments.

Pressure Vessel Integrity

In order to increase the brightness of the beam lines and add additional neutron guides, the diameter of two of the beam lines (HB-2 and HB-4) are being increased during the upgrade process. Since these changes reduce the amount of shielding between the beam lines and the reactor pressure vessel (RPV), it was important to estimate the potential impact of a higher vessel fluence on the lifetime of the RPV. This was especially true because of the RPV dosimetry problem that had occurred earlier in HFIR.[6]

A series of calculations were performed[7] using multidimensional discrete ordinates codes from the DOORS code system[8] and an available multigroup cross-section library. A 2-dimensional (2-D) calculation was made of the reactor core and reflector in order to generate neutron and gamma-ray source distributions. Using auxiliary codes from DOORS, boundary fluxes were generated for each of the beam lines and detailed beam-line calculations were then performed using either the DORT 2-D code for the case of HB-2 or the TORT 3-dimensional code for the case of HB-4. The 2-D analysis of HB-2 was appropriate because of the symmetry associated with the radial orientation of HB-2. Finally, calculated neutron and gamma-ray fluxes at various points in the RPV nozzle areas were converted to "displacements per atom" (dpa) using appropriate metallurgical data.

Results of the analyses indicated that the dpa rates will be nearly a factor of 10 higher for the enlarged HB-2 and approximately a factor of 2.6 higher for HB-4. Despite these higher damage rates, it is estimated that the HFIR RPV will continue to operate within its allowed criteria until at least the year 2035.[9] A thorough dosimetry program will be implemented to ensure that the RPV retains sufficient integrity for the remaining years of operation.

Tangential Beam Line Shielding

A relatively minor change during the HFIR upgrade will be a new beam-line baffle design to accommodate flooding the beam lines, which is done when maintenance of the neutron scattering instruments is needed during full power operation. To adequately reduce dose rates at the exit of the beam lines, the beam shutter must be closed and the beam line must be flooded with water. The new approach, motivated by the desire to increase the inside diameter of the beam line, results in a lesser amount of water shielding "upstream" of the shutter.

A very intricate MCNP model was produced for the entire HB-3 beam line in order to assess the impact of this change on the maintenance doses at the science instruments.[10] The long flight paths and narrow gaps created significant challenges for the analysis. The final results, which are in good agreement with measured dose rates, indicate that the revised flooding strategy provides adequate shielding, and in fact, the maintenance dose is dominated by the activation of the closed shutter and is relatively insensitive to the flooded portion of the beam line.

Conclusions

Extensive neutronics analyses have been performed over the past four years to support a major upgrade to the neutron scattering facilities at the HFIR. The resulting design changes will significantly increase the brightness of the neutron beam lines, add a new cold neutron source facility, and provide for several new scientific instruments. The upgrades are currently being installed at HFIR and should become fully available in 2002.

References

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