A Quadrennial Review of Safety-Related Physics Studies at HFIR

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INTRODUCTION

The High Flux Isotope Reactor (HFIR) first achieved full power in September 1966. Since that time, there has been only one structural change to the fuel elements and two changes to the central target region of the reactor. The ^{235}U loading and geometric configuration of the fuel plates are unchanged from 1966. Design basis reactivity accidents are the same as those identified during the construction of the reactor. For decades, nuclear safety (defined here as meaning the reactor physics component of nuclear safety) at HFIR has consisted of compliance-related analyses and review of experiments proposed for irradiation in the reactor. While support for these two areas still yields interesting issues to be investigated, during the past four years, control element, fuel element and central target changes (either real or proposed) have spurred the application of modern analysis techniques to a reactor that was largely designed from experimental measurements. This paper will provide a summary of those studies conducted during the past four years which the author found of particular interest and a preview of studies expected to be completed in the near future.

COMPLIANCE-RELATED ANALYSES

Before startup of the reactor, the estimated symmetric critical control element position must be predicted and reported to the reactor operators. If the actual, critical configuration of the control elements differs from the predicted value by more than 1.27 cm (about $1.50 in reactivity), startup operations are paused pending a review of the prediction. The prediction method is prescribed by procedure and during the past four years, symmetric critical control element positions have been correctly predicted for 22 of 23 cycles.

The incorrect prediction (cycle 403b) was for restart with a partially burned core that was reloaded to the reactor after having cooled (decayed) for 130 days. Several changes had been made to the central target loading during the 130 days that the cycle 403 element was idled. The restart position was under-predicted by about $1.85. Following review it was determined that ^{182}Ta decay (half-life is 114 days) had been doubly compensated (effect included in both the procedure and in the diffusion theory/depletion calculations to estimate impact of fission product decay). The configuration of the HFIR is such that at the level of exposure at which cycle 403 was being restarted, most of the reactivity "hold-down" was from the tantalum portion of the control elements. Hence an error in computing ^{182}Ta decay was significant. Restart was delayed two days due to the review. Had the cooling time been less or the core burnup been different (hence a different position of the control elements), the predicted startup position might have been acceptable and the "double counting", i.e. inaccurate modeling of ^{182}Ta decay, would likely not have been found.

EXPERIMENT-RELATED ANALYSES

The change in experiment loading from one cycle to the next, in terms of reactivity, is usually very small, i.e. a few cents. Procedures at HFIR require that these changes be quantified (or at least bounded) in a defensible manner. For low absorbing samples, either "hand calculations" or reference to previous, bounding irradiations is sufficient. For stronger absorbers, studies are conducted with baseline and modified Monte Carlo (MCNP) models. Diffusion theory and/or discrete ordinates calculations are also used to verify that the flux tilt in the reactor core due to an experiment does not perturb the nominal power distribution by more than 9% (a requirement due to incipient boiling limits for the reactor core).

While the impact of small-worth experiments on reactor startup configuration is almost impossible to observe experimentally (and therefore, generally not worth the effort to calculate accurately), a recent modification to the central target region revealed the significance and need for accurate analyses. The HFIR contains a "rabbit tube" in the central target region in which samples can be hydraulically loaded to and unloaded from the reactor while it is in operation. Experiments performed in the 1960s showed the transient performance of the reactor under insertion or removal of Cd specimens. Recently, these configurations were modeled and the calculated worths were shown to agree very well with measured values. [2]

At the request of and support from a private company, the HFIR central target region was modified to include three hydraulic tubes instead of one. Testing was initiated. Upon insertion of aluminum rabbits into the hydraulic tubes, an alarm indicating a power excursion of at least 2 MW (but less than 5 MW, a reactor SCRAM point) had occurred when the reactor was at full power. Though both experiment and calculation had shown the worth of the aluminum targets to be insignificant, the new, three-tube configuration had a much more rapid flow rate than the single tube configuration. Small worth but short time yielded an undesirable (and probably unacceptable had the targets been more strongly absorbing) excursion.

RETHINK, REDESIGN, REANALYZE

Reduction in tantalum loading in control elements

Due to an instance of control element failure (before irradiation), the content of HFIR control elements was modified, The tantalum content of the "grey" portion of the rod was reduced from 38 vol % to 30 vol %. Certification that this change did not create an unreviewed safety question required analyses documented in [3] and [4]. The reduced-tantalum control elements are currently being fabricated.

Creation of internal beryllium reflector in central target region

The HFIR was designed to create ^{252}Cf from ^{242}Pu targets. With the advent of Cm supplied from Savannah River reactors, not all of the positions in the HFIR central target were needed for Cf production. Studies have shown that the HFIR cycle length can be increased by approximately 5% without significantly affecting Cf production by filling unneeded central target positions with Be rods. [5], [6]. Design drawings for Be rods have been created. Additional safety-related calculations (showing magnitude of flux tile) and documentation are underway.

Increase in uranium loading in the current, highly enriched uranium core

Shortly after the startup of the HFIR, studies were conducted to consider fuel element changes to extend the cycle length. [7] However, the high availability factor during the 1970s and 1980s mitigated the interest in modifying the HFIR element. Recent studies have shown that the cycle length could be extended considerably with only a modest increase in fuel loading. [8] Thermal hydraulic studies of the proposed fuel element design are the next step in the analysis of this proposal.

Low enriched uranium fuel?

At the request of the Department of Energy, ORNL has begun to study the feasibility of using low enriched uranium/molybdenum fuel in the HFIR [9]. Should the concept prove feasible, planning for an extensive experimental engineering program, likely similar in scope to that performed in the early 1960s, will be conducted during fiscal years 2007 and 2008.

CONCLUSIONS

The somewhat unusual condition that HFIR control elements increase in worth during irradiation (due to ^{182}Ta building) and decrease in worth during reactor shutdown (^{182}Ta decay) led to the one mis-prediction of critical configuration during the past four years. Development of transient analysis models and methods for HFIR-specific applications is an identified need. Several modifications to the HFIR physical plant are being considered, all with the goal of increasing cycle length. The availability of computational methods and nuclear data not present at the construction of HFIR has led to the use of these methods for safety assessment of the proposed modifications. To date, these methods were validated with HFIR operating experience. However, the development of a low enriched uranium fuel for HFIR would lead to the requirement of a series of engineering experiments to demonstrate acceptable operating margins for the fuel.

REFERENCES

1. R. T. Primm, III, *Reactor Physics Input to the Safety Analysis Report for the High Flux Isotope Reactor,* ORNL/TM-11956, March 1992.
2. C. O. Slater and R. T. Primm, III, *Calculation of Rabbit and Simulator Worth in the HFIR Hydraulic Tube and Comparison with Measured Values,* ORNL/TM-2005/94, September 2005.
3. R. T. Primm, III, *Reactor Physics Studies of Reduced-Tantalum-Content Control and Safety Elements for the High Flux Isotope Reactor,* ORNL/TM-2003/65, December 2003.
4. R. T. Primm, III, *Reactor Physics Studies of Reduced-Tantalum-Content Control and Safety Elements for the High Flux Isotope Reactor,* Proc. PHYSOR 2004, April, 2004.
5. N. Xoubi and R. T. Primm, III, *Investigation of Beryllium Internal Reflector Installation on the Fuel Cycle Length of the High Flux Isotope Reactor,* ORNL/TM-2004/252, August 2005.
6. Ned Xoubi, R. T. Primm, III, and G. I. Maldonado, *Fuel Cycle Extension of the High Flux Isotope Reactor Using a Beryllium Internal Reflector*, Trans. Am. Nuc. Soc., vol 92, June 2005.

7. R. D. Cheverton and T. M. Sims, *HFIR Core Nuclear Design,* ORNL-4621, July 1971.
8. Ned Xoubi, G. I. Maldonado, and R. T. Primm, III, *Investigation of Increased HEU Loading on the Fuel Cycle of the High Flux Isotope Reactor*, Trans. Am. Nuc. Soc., vol 92, June 2005.
9. R. T. Primm, III, R. J. Ellis, J. C. Gehin, D. L. Moses, J. L. Binder, and N. Xoubi, *Assumptions and Criteria for Performing a Feasibility Study of the Conversion of the High Flux Isotope Reactor Core to Use Low-Enriched Uranium Fuel*, ORNL/TM-2005/269, February 2006.