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The Advanced Test Reactor (ATR) is a light water reactor with aluminum-clad driver fuel. A primary mission of the ATR is to support the next generation of nuclear reactors. This support necessarily requires irradiation of advanced materials such as sodium, fuel salts, and metal eutectics. Irradiation of advanced materials in the ATR environment presents a challenge when completing accident analyses and demonstrating compliance to the Safety Analysis Report (SAR). Many advanced materials have the possibility to react with the ATR protective barriers such as the cladding or primary coolant system (PCS) boundary during postulated accident scenarios. Further, molten fuel experiments fall outside of the standard regulatory framework for dose consequence analyses. ATR is currently developing new safety analysis methods to support irradiation of advanced materials. The primary considerations for this development are 1) experiment containment design requirements, 2) primary coolant system response to an experiment containment failure, and 3) dose analyses for molten fuels.

ATR irradiation experiments typically consist of a fuel or material inside of a hermetic containment. This containment is typically a stainless-steel capsule, and it provides the first line of protection for the ATR safety systems and protective barriers. Historically, the experiment containment has been required to meet applicable provisions of Section III of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) code. ASME Section III is written to support the design and analysis of light water reactor pressure vessels and does not encompass the thermodynamic and material conditions needed to support advanced material irradiation. To overcome this challenge, provisions have been added to the ATR SAR to allow for deviations from ASME Section III so long as the containment design is based on industry standards and codes, and the design provides adequate pressure retention. An allowable deviation is to pivot from ASME Section III, a design-by-rule code, to a Load and Resistance Factor (LRF) design methodology. An LRF design methodology has the advantage of demonstrating adequate pressure retention as well as providing a probability of failure, which is greatly advantageous for completing experiment accident analyses. The LRF format is:

$$\sum_i \gamma_i Q_i \leq \phi R_n$$

In the above equation, Q_i are the loads, and γ_i represents primary load effects. The material resistance (allowable stress) is given by R_n, and ϕ is a material resistance factor. The LRF design methodology must also be coupled with predefined laboratory test, e.g. burst testing, to validate the usage of the equation factors. Burst testing is an effective method to test capsules because it can capture a prototypic pressure loading in a controlled environment. The internal pressure applied during testing will simulate the loading side of the equation. Specific flaws can be introduced into specimens that simulate the resistance side of the equation. Other testing, such as axial loading, can also be utilized in certain circumstances to validate equation factors.

While experiment containment is the first line of defense for the ATR safety systems, accident scenarios may exist that result in a failure of the containment. Experiment containment failure could cause a release of material into the PCS and affect the ATR driver fuel. Accident analyses must consider such an event and demonstrate that the ATR driver fuel cladding is not damaged. The ATR driver fuel is an aluminum clad fuel that is pre-filmed with a boehmite oxide layer to provide protection from the environment. This layer is credited in the safety basis, and it is maintained using tight PCS chemistry controls on pH, conductivity, and halide content. To support accident analyses, titrations of ATR coolant with advanced materials have been performed to quantify the PCS response during postulated failures. Titrations are done using coolant water extracted from the PCS during power operations. A response curve is developed, and in combination with failure probabilities, an acceptable material limit is determined. Advanced material analyzed for irradiation under this methodology include sodium, $NaCl$-UCl_3, and UF_4-NaF-KF.

Potential dose consequences must also be determined for postulated accident scenarios. The ATR SAR relies heavily on Nuclear Regulatory Commission (NRC) Regulatory Guide (RG) 1.183 when determining dose consequences. Molten fuels do not necessarily always fall under this guidance, especially when considering fuel handling accidents. Design basis fuel handling accident analyses have been updated to bound molten fuel experiments. These analyses include updated assumptions on accident release fractions, water decontamination factors, and radionuclide dispersion.