Severe Accident and Thermal-Hydraulic Analysis of Human Error in Fuel Loading for TRR-1/M1

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EXTENDED ABSTRACT

INTRODUCTION

The TRR-1/M1 research reactor is designed with a high level of protection against human errors, especially during fuel loading operations. These operations are carried out by certified operators under direct supervision, with clearly defined procedures and verification steps in place. Despite these safeguards, human error remains a credible initiating event; therefore, the safety analysis includes a conservative evaluation of the worst-case fuel loading error. This research addresses the consequences of such an error and assesses the impact on reactor safety margins.

FUEL LOADING ERROR SCENARIO

In this work, we examine a scenario based on the assumption that it occurs independently, without any coincidental initiating events. The postulated scenario involves the incorrect placement of fuel elements during core loading, specifically the substitution of a fresh 20/20 fuel element into a B-ring position (B3) and a fresh 8.5/20 fuel element into a D-ring position (D8). This misloading would result in a significant power peaking in the B-ring location, as the 20/20 element has a higher enrichment and would produce substantially more power when placed in a high-flux area near the core center. Although such an error is unlikely due to procedural controls and independent verification by multiple operators, this single-element misplacement represents the most severe credible scenario for analysis and is thus used to bound all other potential misloading.

NEUTRONIC ANALYSIS

Neutronic simulations were conducted using the MCNPX code to evaluate the effects of the misloading on core power distribution. The simulations showed that the rod power factor increased from 1.894 in the reference core to 2.396 in the error scenario. This corresponds to a maximum power generation of approximately 29.6 kilowatts in the affected fuel element at the reactor's nominal operating power of 1.3 megawatts. This elevated power density forms the basis for the thermal-hydraulic assessment.

THERMAL-HYDRAULIC ANALYSIS

The thermal performance of the reactor core under the misloading condition was analyzed using the COOLOD-N2 code. The analysis revealed that the fuel temperature in the hottest location increased due to the elevated power density. In the reference core, the peak fuel temperature is approximately 450°C at nominal power. In the misloaded core, this temperature increases to around 550°C at 1.3 megawatts and reaches approximately 620°C at 1.5 megawatts, which corresponds to 115% of nominal power. Despite this increase, the maximum fuel temperature remains well below the conservative safety limit of 930°C. The analysis also showed a decrease in the minimum DNBR, as expected due to the higher heat flux. However, the minimum DNBR under the worst-case scenario remains at 1.65 when operating at 1.5 megawatts, which is comfortably above the typical safety threshold of 1.3 used in pressurized water reactors. This indicates that the conditions necessary for film boiling and potential cladding burnout are not reached.

SAFETY IMPLICATIONS

The results of the analysis confirm that even under the most severe credible single-element misloading scenario, the TRR-1/M1 reactor maintains safe operating margins. The increased power peaking and higher local fuel temperatures do not result in safety limit violations. The DNBR remains within acceptable limits, providing further assurance that fuel integrity is preserved. These findings demonstrate the robustness of the reactor's safety design and operational protocols in mitigating the consequences of potential human errors during fuel loading.

CONCLUSION

This study has evaluated the safety impact of a postulated fuel loading error in the TRR-1/M1 reactor, involving the misplacement of one fresh 20/20 and one 8.5/20 fuel element. Through detailed neutronic and thermal-hydraulic analysis, it has been demonstrated that the reactor core remains within all safety margins, including fuel temperature and DNBR limits. Although such an error is improbable due to rigorous operational procedures and supervision, this analysis confirms that the reactor's safety systems are sufficiently robust to handle such an event without compromising fuel integrity or reactor safety. Further research could explore more detailed effects of misloading, including scenarios involving multiple misloaded elements. Conducting a hazard analysis would also be beneficial in enhancing the overall safety evaluation of the TRR-1/M1 reactor.

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