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Supporting the Industry Cost-Saving Initiative for Longer Operating Cycles: Accident Source Term Analysis of High-Burnup Operation

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Risk-Informed Systems Analysis Pathway

The amount of energy produced in a nuclear power plant depends on how much uranium is burned in the reactor, a measurement called "burnup" that is expressed in gigawatt-days per metric ton (GWd/MTU) of uranium. The burnup levels have changed throughout the history of nuclear fleet operation. It was around 35 GWd/MTU two decades ago and over 45 GWd/MTU today. The increased burnup means that utilities are now using fuel more efficiently and can extract more power from their fuel before replacing it.

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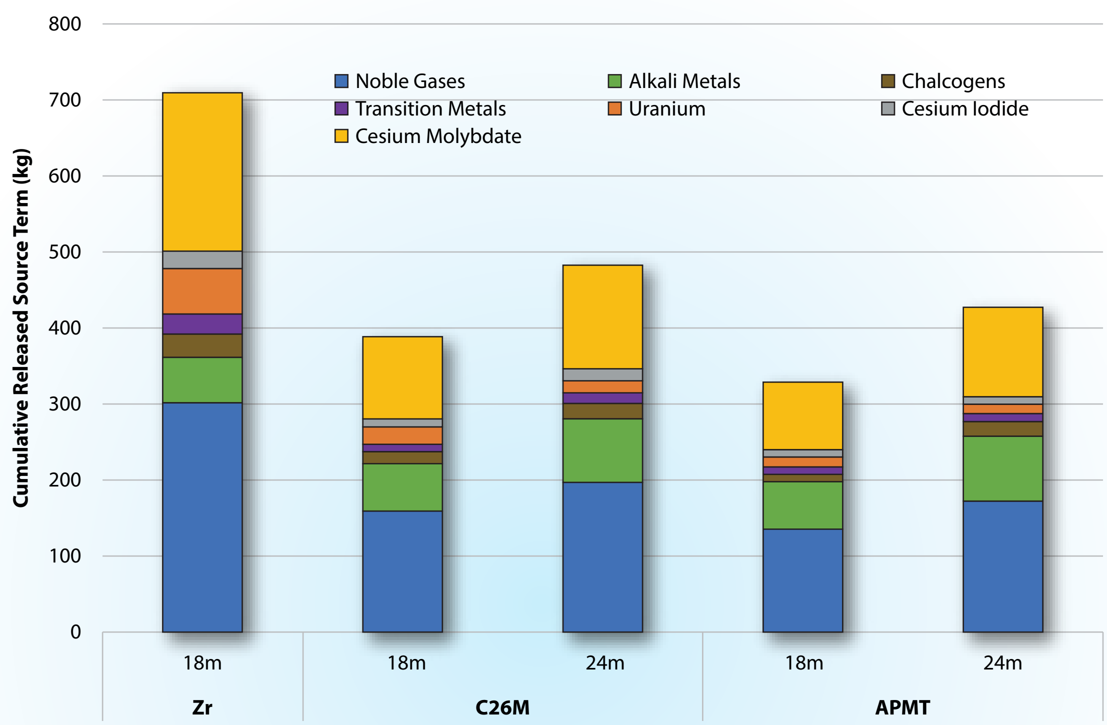

Figure 1. Cumulative released source term.

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Operating nuclear power reactors at higher burnup (HBU) levels can significantly reduce costs associated with refueling and licensing, leading to substantial economic benefits for plant owners. The cost savings are twofold—first, they are due to longer operating cycles where reactors can operate longer between refueling outages, and second, because fewer fuel assemblies are subsequently required at each refueling.

HBU operation requires higher enriched uranium fuel that is more achievable with accident tolerant fuel (ATF) (e.g., Chromium [Cr] coated clad fuel compared to the traditional Zirconium [Zr] clad fuel). This is due to the more robust cladding characteristics of ATF, which allow them to cope better with postulated accident conditions. The deployment of ATFs with normal burnup is already underway in the industry, but HBU ATFs are still being evaluated to ensure their safety—especially under accident conditions. In particular, it is necessary to accurately evaluate the "accident source term," or the amount of radioactive materials that could be released from a nuclear power plant during an accident.

In this context, the LWRS Program Risk-Informed Systems Analysis (RISA) team is conducting research on the safety assessments of HBU ATF during a recovered large break loss of coolant accident of a pressurized water reactor. This topic is an urgent near-term industry initiative offering safety enhancements, as well as economic gains. The result could serve as a roadmap for the safety analyses that nuclear power plants must submit in their license amendment request to the U.S. Nuclear Regulatory Commission (NRC) when switching to new fuels [1].

Following Three Mile Island the accident in 1979, the NRC developed an extensive methodology for analyzing the consequence of a nuclear accident. This methodology considers both the timing and the chemical composition of the source term from coolant and fuel gap release to in- and ex-vessel of the source term [2]. The accident source term analysis for traditional Zr-clad fuel with HBU has been completed for burnup levels up to 62 GWd/MTU with a duration in the core from 14 to 18 months [3]. However, there is no publicly available assessment of source terms from HBU ATFs.

In the LWRS Program study, two different iron-chromium-aluminum alloy FeCrAl-clad materials (e.g., Kanthal APMT, Ironclad C26M) were selected as ATF, which have a lower high-temperature oxidation and hydrogen generation rate compared with Zr-clad fuel. Reactor cores were designed for 24-month burnup operation and compared with the 18-month case. A large break loss of coolant accident scenario as a postulated accident, with intentionally delayed activation of the emergency core cooling system, allowed reactor core damage and source term release to the reactor containment. This scenario is just one of the standard severe accident case studies from the NRC's state-of-the-art reactor consequence analysis report [4]. A reactor core was designed with a total of 193 fuel assemblies with a 17 × 17 lattice configuration for both the Zr- and FeCrAl-clad fuels and applied to a model of the Zion Nuclear Power Plant in Illinois using MELCOR, a severe accident simulation software. The decay heat and fission product inventories were calculated for both the 18- and 24-month cycle cases.

The Figure 1 shows the total mass of the cumulative released major source term during the recovered large break loss of coolant accident scenario. For all cases, noble gases (Xe, Kr, Rn, etc.) were the largest amount released from the source term, followed by cesium molybdate and alkali metals (Cs, Rb, Li, etc.). For the Zr-clad case, a large amount of uranium was found in the source term as compared with the ATF clad fuel cases.

This LWRS Program study showed the released accident source term from the ATF clad fuels is significantly smaller than from the Zr-clad fuel even in HBU operation for the accident scenario under consideration. In other words, the use of ATF clad fuels will be acceptable to current licensing requirements in terms of accident source term evaluation. In this scenario, ATF clad fuels (C26M 18m, C26M 24m, APMT 18m, APMT 24m) generate less hydrogen than Zr-clad fuel which can support mitigating hydrogen explosion risk (Figure 2). Future work will include safety analysis of a pressurized water reactor loaded with higher enriched Cr-coated Zr ATF during a recovered large break loss of coolant accident considering fuel deposition and impacts from the radioactivity release. Future work could also extend this analysis to other transients to determine whether these benefits generalize to an overall reduction in source term over a range of postulated scenarios.

References:

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Figure 2. Hydrogen release over the transient.