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ABSTRACT

In-Vessel Retention Technology Development Use for Advanced PWR Designs in the USA and Republic of Korea

In-Vessel Retention Strategy for High-Power Reactors

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In-vessel retention (IVR) is a key severe accident management strategy adopted by some operating nuclear power plants and proposed for some advanced light water reactors (ALWRs) and next-generation (Gen IV) reactors. If there were inadequate cooling during a reactor accident, a significant amount of core material could become molten and relocate to the lower head of the reactor vessel, as happened in the TMI-2 accident. If it is possible to ensure that the vessel head remains intact so that relocated core materials are retained within the vessel, the enhanced safety associated with these plants can reduce concern about containment failure and associated risk. For example, the Westinghouse AP600's enhanced safety resulted in NRC approving the design without requiring certain conventional features common to existing LWRs. However, it is not clear that currently proposed external reactor vessel cooling (ERVC) without additional enhancements could provide sufficient cooling for high-power reactors (up to 1500 MWe). Application of the design recommendations obtained from this project will enhance the performance of ERVC and core catchers to ensure that IVR will be available for reactors up to 1500 MWe (encompassing all reactor designs incorporating these features).

IVR is a keystone of the severe accident management for Westinghouse's AP600 (advanced passive light water reactor) design. A successful IVR would terminate a severe accident, passively, with the core in a stable, coolable configuration (within the lower head), thus avoiding the largely uncertain accident evolution with the molten debris on the containment floor. The passive plant design concept is being upgraded by Westinghouse to the AP1000, a 1000 MWe plant that is very similar to the AP600. The severe accident management approach is very similar also, including IVR as the keystone feature, and initial evaluations indicate that this would be feasible at the higher power as well

Task I – In-Vessel Strategy for High-Power Reactors

In this Sub-Project (Task), specific recommendations will be developed to improve the margin for IVR in high-power reactors (up to 1500 MWe). The systematic approach applied to develop these recommendations combine state-of-the-art analytical tools and key U.S. and Korean experimental facilities. Recommendations will focus on modifications

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to enhance ex-vessel reactor cooling (improved data, vessel coatings to enhance heat removal, and an enhanced vessel/insulation configuration to facilitate steam venting) and modifications to enhance in-vessel debris coolability (enhanced in-vessel core catcher configuration, thickness, and material). Improved analytical tools and experimental data will be used to evaluate options that could increase the margin associated with these modifications. This increased margin has the potential to improve plant economics (owing to reduced regulatory requirements) and increase public acceptance (owing to reduced plant risk). Because the design information available for Gen IV designs is insufficient, these studies will initially focus on the Korean Advanced Power Reactor –1400 MWe (APR-1400) design. However, margins offered by each modification will be evaluated such that results can easily be applied to a wide range of existing reactors, advanced reactor designs, and Gen IV reactor designs.

This task is essential to make significant improvements to the safety and economics of existing, advanced, and next-generation nuclear reactors, world-wide.

Task II - Development of IVR for Advanced PWR Designs in the USA and Korea

The research in this task is intended to support the IVR aspect of the AP1000 design and to do so in a timely fashion for the certification submittal expected to be made by mid-2002 to the US Nuclear Regulatory Commission. IVR is now also being pursued in Korea (KEPRI being the leader of these efforts), for their evolutionary APR1400, as well as the Korean Standard Nuclear Power Plant (KSNPP), a 1,000 MWe PWR.

IVR is assured if the thermal loading from the melt is exceeded by the coolability limit (the critical heat flux—CHF) on the outside, everywhere on the lower head of the reactor pressure vessel. They both depend strongly on the angular position around the lower head, so the "everywhere" refers to all angular positions, from the very bottom (position 0º) to the very edge (position 90º). From experience with AP600, we know that this thermal-load-to-coolability margin is most comfortable in the lower portions, and that it reaches a minimum value at the position that corresponds to the top of the molten fuel pool (typically around 80º). Also, we know that this margin decreases as reactor power (decay heat) increases. It is quite comfortable at 1933 MWt (AP600), but at 3400 MWt (AP1000) it drops to under 10%, so on the basis of existing technology, it may be hard to justify an IVR -based severe accident management approach. The work proposed herein is aimed to remedy this situation, and present tangible evidence that this is indeed feasible.

This aim is to be principally pursued by means of a design improvement on the flow path between the lower head and the thermal insulation. Work with a preliminary such design implemented in the ULPU facility shows that we can expect CHF improvements by at least 25%, over current state-of-the-art values as defined by the ULPU results obtained in support of AP600. If this could be fully demonstrated, the 10% margin noted above would increase to almost 30%, a much more reasonable basis for the robust conclusion sought. As an auxiliary objective we propose to extend available natural convection data, again the state of the art being defined by ACOPO experiments conducted in support of AP600, to include the Rayleigh number range relevant to AP1000 (about an order higher than the AP600), and to refine our understanding (and quantification) of the heat flux peaking at the upper edge of the molten pool. Thus, the principal components of the effort will involve the large-scale experiments: ULPU at full scale, and ACOPO at 1/2 scale, but prototypical Rayleigh numbers. In addition, there will be fundamental components involving small experiments and numerical simulations.