Characterization of film dryout on silicon carbide cladding with and without crud

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ABSTRACT:

The deposition of corrosion products (crud) on nuclear fuel cladding can degrade fuel performance, result in high maintenance costs, and lead to fuel failures. Crud forms when the concentration of a given impurity in the coolant rises above its precipitation limit. Localized crud was recently found in the annular flow region of a boiling water reactor, which is atypical for these systems. This crud was particularly problematic because it was accompanied with cladding oxidation and a fuel failure in one location, which may indicate local dryout. The goal of this project is to collect experimental data and extend mechanistic two-phase flow models to better understand and predict crud deposition and dryout in annular two-phase flow.

This project will be split into two major efforts – experimental characterization and model development. The experimental effort will measure the properties of annular liquid films that drive crud deposition and intermittent dryout. Specifically, we will measure disturbance wave velocities, frequencies, shapes, and statistical distributions of these values over a range of heat fluxes, mass fluxes, and fluid properties. All experiments will be done on both smooth surfaces and surfaces with simulated crud that mimic the structures seen on nuclear fuel cladding. The experiments will yield correlations for fundamental annular film properties that can be used to predict the performance of high-pressure steam. Additionally, we will quantify how these properties change in the presence of crud. The modeling effort will develop a stand-alone annular two-phase flow model capable of predicting crud deposition and intermittent dryout. This model will build on the four-field approach for annular flow and will use correlations developed in this project for closure relations. The code will be open source to benefit other research groups, enhance collaboration, and further progress on the modeling of annular two-phase flows. The results from this work will help predict conditions where crud deposition will occur and will determine if crud changes the intermittent dryout and CHF characteristics of annular two-phase flow.

The major deliverables that will come out of this project are:

1. A database of annular two-phase flow hydrodynamic and heat transfer data including disturbance wave properties and intermittent dryout characteristics over smooth surfaces and surfaces with localized crud. Experiments will be performed over a range of conditions relevant to boiling water reactors and will be published in two journal articles.
2. Correlations for key annular two-phase flow properties that impact dryout. These correlations will include the impact of fluid properties, surface properties, and operating conditions on each parameter. The resulting relations will be published with the experimental data in journal articles.
3. A four-field annular two-phase flow model that utilizes the developed correlations as closure relations. This mechanistic model will give a more detailed look at the conditions that lead to crud deposition and dryout. The resulting code will be open source and available to the broader research community.