Chemistry & Crud Risk Assessment Tools

AREVA has developed tools and methods for performing EPRI-defined Level III and Level IV crud risk evaluations. These tools and methods have been successfully applied to support utilities, with W, CE and/or B&W plants with AREVA fuel, in their efforts to manage the risks for crud-related issues. The techniques have allowed plants to move from situations of high crud risk, where significant crud deposition was measured, to lower, more manageable crud risk conditions, by using the following elements:

- Localized subchannel and fuel rod resolution in determining the "clean" rod thermal-hydraulic conditions along the full length of each fuel rod.
- A thermal-hydraulic subchannel code (COBRA-FLX™) benchmarked to evidence of observed in-plant rod surface steaming.
- A fuel deposit interactive chemistry tool (FDIC) for predicting crud thickness, crud ΔT, crud composition/species, etc., based on actual plant chemistry data and case studies for the most likely chemistry for the upcoming cycle.
- FDIC is benchmarked to fuel surveillance and crud samples collected (using a sampling method designed to recover intact crud flakes).

A crud-induced power shift (CIPS) occurs when boron/boron species precipitate in the fuel crud to a sufficient concentration for a sufficient period of time to impact localized power levels. The boron accumulation phenomenon is caused by the presence of crud deposits and is enhanced by increasing localized steaming within the crud structure, "clean" rod surface temperature, and other factors. AREVA's CIPS risk assessment thus includes a core-wide evaluation and a limiting locations evaluation for the specific core design.

Crud-induced localized corrosion (CILC) is an accelerated corrosion of the zirconium cladding caused by a number of factors including crud-induced cladding temperature increases, crud thickness, and enhanced corrosion from elevated detrimental levels of species (e.g. lithium in crud that results in increased uptake in the zirconium oxide layer increases the corrosion rate). Therefore, AREVA's CILC risk assessment is based on, but not limited to, the chemical species at the localized limiting regions and increased temperatures at the cladding surface.

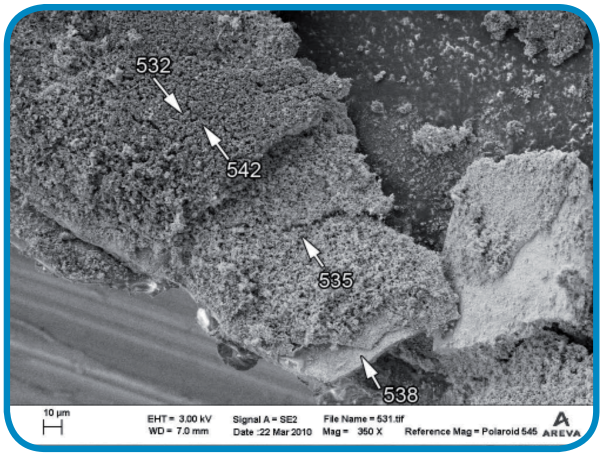

Figure 1. A Crud Flake Example
The image shows various layers of crud deposition including the zirconium slab seen at the bottom of the image on which the deposits have accumulated. The analysis at AREVA's Chemistry and Materials Center in Lynchburg allows identification of species accumulated in crud at their precise location in the deposit, thereby allowing a profound understanding of the deposition processes and leading to robust benchmarking of AREVA's chemistry deposition tool (FDIC).

The evaluation process for both Level III and Level IV crud risk analyses relies upon predicting the local thermal-hydraulic environment along "clean" fuel rods based upon the core radial and axial power distributions throughout the multiple cycles of interest. These predicted thermal-hydraulic conditions serve as input to the chemistry calculations for crud deposition that can potentially result at the plant in the upcoming cycle (Cycle N). The crud calculations are provided via AREVA's chemistry deposition tool called FDIC. The various parameters predicted by FDIC include fuel rod lifetime histories (for Cycles N, N-1 and N-2) for the crud thickness, cladding surface temperature under the crud deposit, evolution of the CILC and CIPS "affecting" chemical species. The resolution of the local thermal-hydraulic conditions is dependent on the level of the crud risk assessment evaluation method.

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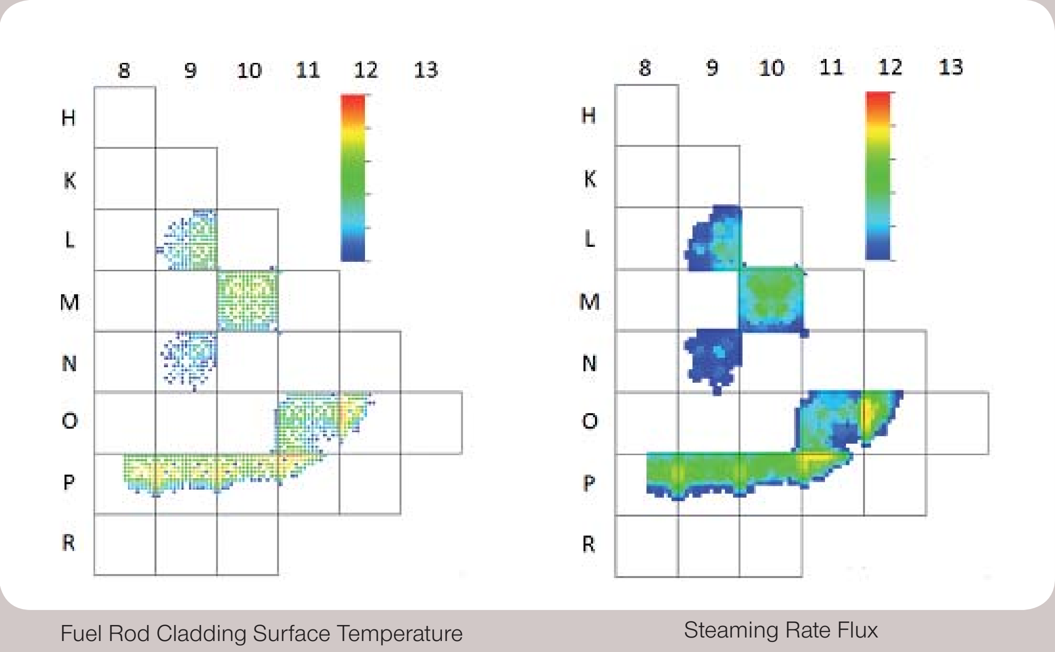

Figure 2. 1/8 Core cross-sectional views of the Level III COBRA-FLX™ predicted "clean" fuel rod cladding surface temperature (above Tsat) and steaming rate flux at a fixed axial location and time during the cycle.

- For a Level III evaluation, AREVA's COBRA-FLX™ thermal-hydraulic subchannel code is used to provide local rod surface and subchannel conditions corresponding to the typical axial node size used in conventional DNB analysis simulations.
- For a Level IV evaluation, first, AREVA isolates the limiting rod/subchannel locations determined using the Level III COBRA-FLX™ predictions. Next, a computational fluid dynamics (CFD) code is used to more closely examine the limiting rod/ subchannel regions using higher resolutions of 10^3 or more. This greater resolution allows more precise detection of the limiting surface region and conditions for input to the FDIC calculation.

Figure 2 provides examples of the Level III COBRA-FLX™ predicted cladding surface temperature and steaming rate flux (at a limiting axial location and time in the fuel rod life) for a "clean" fuel rod for input to the FDIC analysis.

This figure indicates the most limiting conditions for this elevation and time occur at the interface between fuel assembly locations O11 and O12, which is a fresh fuel-to-fresh fuel interface. These types of figures can provide a "first look" at the core for identifying regions that would be experiencing the more severe "clean" rod local thermal-hydraulic conditions. However, for assessing crud-related risks, it is necessary to rely upon the complex and integrating nature of the chemistry calculations.

The outputs from COBRA-FLC™/FDIC are subsequently utilized for the CIPS and CILC risk assessments for the planned core design (Cycle N). Actual chemistry data from previous cycles are used to model/compare risk for previous Cycles N-1 and N-2. Based on that chemistry, the most reasonable expected operating chemistry conditions are selected for the upcoming Cycle N risk assessment, labeled by AREVA as the "Risk Case." AREVA also performs a few other operating chemistry conditions/chemistry sensitivity studies, and subsequently selects the most likely worst-case chemistry conditions for the risk assessments and labels that as the "Margin Cases." The Margin Case(s) is considered a credible, but likely bounding operating chemistry for Cycle N.

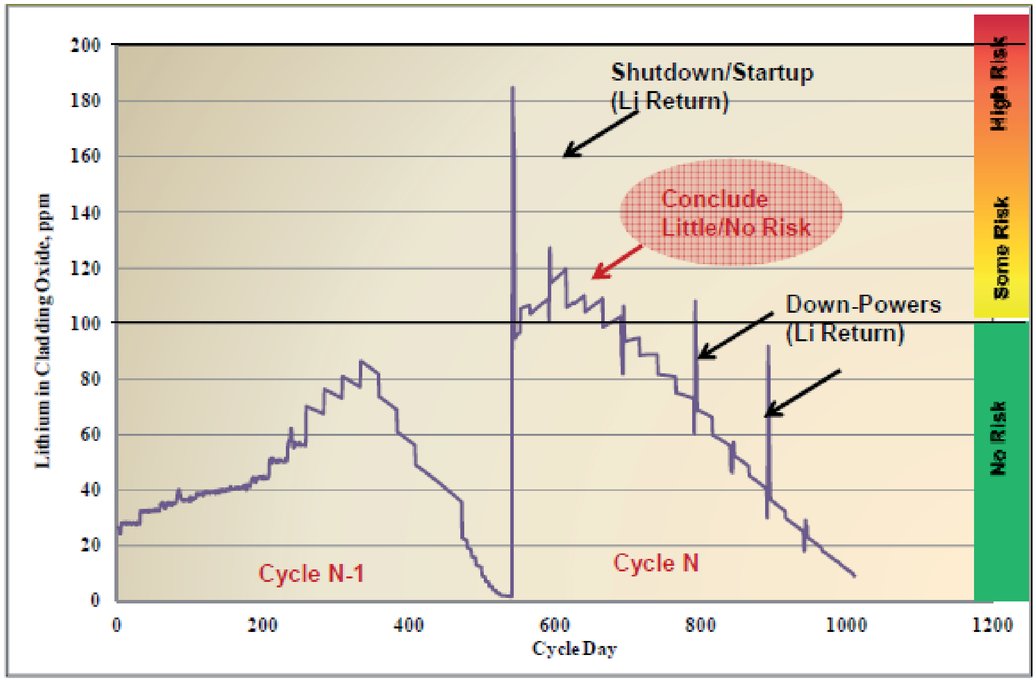

Figure 3. Corrosion Assessment (CILC) for Species of Interest — Lithium Corrosion/Uptake for M5™

The CILC analysis involves evaluating the risk with predicted crud deposition for Cycle N compared to Cycles N-1 and N-2. For example, in Figure 3, the lithium (Li) uptake/potential of increased cladding corrosion was assessed (the absorption of lithium from crud into the fuel pin zirconium oxide layer), considering the quantity of Li in fuel crud and the related boron-lithium curve to evaluate the Li-corrosion risk for Cycle N. As shown the corrosion from Li is predicted to be low.

The CIPS risk is limited by the boron/boron species that occur with crud deposition. Like the CILC evaluation process, results of COBRA-FLX™/FDIC predictions and chemistry data are used to evaluate the most likely risk of CIPS. The evaluation considers both the limiting locations in the core as well as the overall core-wide risk associated with the cycle's core design.

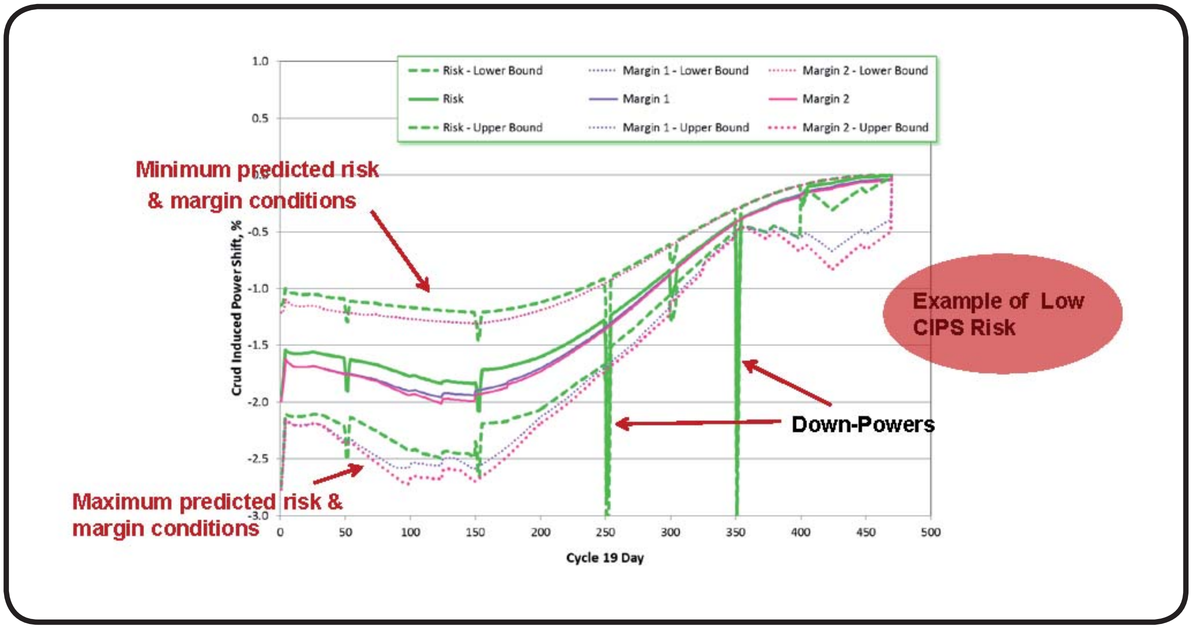

Figure 4. Example of Predicted CIPS for Limiting Core Conditions

Figure 4 is an example of CIPS risk assessment results that illustrate the likely CIPS "Risk" along with the likely bounding/"Margin" results. Note that similar assessment results are generated for core-wide predictions by the AREVA process.

AREVA's advancements in Level III and Level IV crud risk assessment tools and methods allow it to provide crud risk assessments that more accurately reflect the risk for CIPS and CILC. These advancements have not only guided utility customers to move away from cycles with high CIPS and CILC risk, but also has provided a means to manage crud risks as plants experience changes that influence crud risks.

Features and Benefits

- Industry-leading capability for predicting Level III and IV crud risks with the application of AREVA's FDIC Chemistry deposition tool.
- FDIC is benchmarked to fuel surveillance and to crud samples collected using a sampling method designed to recover intact crud flakes.
- A subchannel and fuel rod resolution is achieved for the core using COBRA-FLX™ to obtain the local thermal-hydraulic environment for Level III needs.
- Even higher resolutions (with >10^3 finer discretization) are achieved with a CFD code-predicted local thermal hydraulic environment for Level IV applications.
- The FDIC code, when using the applicable resolutions of thermal-hydraulic environment, provides a significant leap forward in the industry for predicting the complex nature of crud formation and evolution.
- AREVA's tools can provide the necessary means for an effective crud risk management capability.

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