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MEMORANDUM TO: Raj M. Iyengar, Chief
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SUBJECT: SUMMARY OF THE JUNE 3, 2020, RES CATEGORY 3 PUBLIC MEETING WITH EPRI AND STAKEHOLDERS TO DISCUSS MODELS IN THE XLPR PROBABILISTIC FRACTURE MECHANICS CODE

The U.S. Nuclear Regulatory Commission (NRC) staff from the Office of Nuclear Regulatory Research (RES) held a meeting on June 3, 2020, with representatives of the Electric Power Research Institute (EPRI) to provide an overview of the models in the Extremely Low Probability of Rupture (xLPR) Version 2 probabilistic fracture mechanics code.

The agenda and slide presentations for the meeting are available in the NRC's Agencywide Documents Access and Management System (ADAMS) under Accession Numbers ML20142A429 and ML20157A113, respectively. Enclosed is a list of the meeting participants. Additionally, a video recording of the meeting is available at www.youtube.com. A summary of the meeting's discussions follows by agenda topic.

1. Introduction and Opening Remarks

   The NRC staff welcomed the participants and covered administrative items for the meeting. It provided a recap of a related meeting on April 23, 2020, where the planned public release of the xLPR Version 2.1 (V2.1) code was announced. The NRC staff indicated that a summary of that meeting and a video recording had recently been made available to the public. The NRC staff also provided an overview of the xLPR V2.1 code request process using the NRC and EPRI websites. It stated that the request process was expected to become active within days of the meeting and that a formal announcement would be issued at that time. The NRC staff covered the contents of the xLPR V2.1 release package and highlighted some of the training resources contained therein. An updated schedule for a planned series of webinars for new xLPR code users was also provided. It was indicated that the actual schedule would be announced when there are enough new users to support the webinars.

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2. xLPR Code Overview

For orientation purposes, an EPRI contractor provided a basic overview of the code. He described the basic components of the software and their functions. He also described the underlying physical piping model and the two included crack orientations: circumferential and axial. In addition, he described the time evolution of a simulation while highlighting some the features included for modeling changing plant conditions and different chemical and mechanical mitigation techniques. For additional details, several references were provided, which include materials that would be available in the xLPR V2.1 release package.

3. Deterministic Models Overview

When executing a probabilistic simulation, the code samples input values from uncertainty distributions and propagates them through its set of deterministic models. An EPRI contractor provided an overview of these deterministic models. The primary areas that they model are:

- loads and stresses
- stress intensity factors
- fatigue and stress-corrosion cracking initiation
- crack growth and coalescence
- crack transition
- crack opening displacement (COD)
- leak rates
- crack stability
- inservice inspection (ISI)

It was explained that the load and stress models cover normal plant operating conditions, such as pressure and deadweight, and several types of transients. It was also explained how welding residual stresses (WRS) are modeled within the code. Numerous WRS profiles are supplied with the xLPR V2.1 release package for typical large-bore dissimilar metal welds, and users can also enter their own WRS profiles.

The stress intensity factor models were covered next. These models are used in the crack growth calculations. The models are based on the universal weight function method, which allows for greater accuracy when considering more complex WRS profiles. Additional considerations for calculating stress intensity factors for transients were also covered.

The fatigue and stress-corrosion cracking initiation models were then explained. These models determine an initiation time for a discrete volume of weld material. All the models are semi-empirical and contain functional dependencies for conditions that are known to have strong impacts on crack initiation. Three different primary water stress-corrosion cracking (PWSCC) initiation models are available: (1) a material index model, (2) a cold work-based model, and (3) a Weibull model. Fatigue initiation models are also available for carbon and low-alloy steels, austenitic stainless steels, and nickel-based alloys.

Subsequently, the crack growth and coalescence models were described. Three idealized flaw shapes are used: (1) semi-elliptical surface cracks, (2) transitioning cracks, and (3) idealized through-wall cracks. PWSCC growth models are available for Alloy 600 and Alloys 82/182/132, and stress-corrosion cracking in other materials can be modeled using custom model parameters for the same model forms. Material-specific fatigue crack growth models are included for nickel-based alloys, austenitic stainless steels, and ferritic steels. All the initiation models are semi-empirical and include theoretical dependencies with laboratory data used to develop the fatigue model parameters, and both laboratory and field data used to calibrate the PWSCC model parameters. The coalescence model uses a set of rule-based conventions for simulating the combination of circumferential cracks based on their sizes, shapes, and locations.

Next, the crack transition model was described. This model accommodates a gradual evolution from a near-through-wall surface crack to an idealized through-wall crack by calculating adjustments for the stress intensity factor and COD solutions for both axial and circumferential transitioning through-wall cracks. The adjustments are applied to the corresponding stress intensity factor and COD solutions for idealized through-wall cracks. The applied correction factors are based on finite element models. The corrections result in more accurate leak-rate predictions.

The COD model was covered next. This model is used in the leak rate calculations. The model is an extension of prior methods developed by EPRI and General Electric, where elastic and plastic influence functions are fit to finite element results. The total COD is the sum of the elastic and plastic contributions.

Then, the leak rate model was covered. The leak rates for tight cracks are calculated by solving for equations developed to represent fluid flow through a long pipe in which steam generation occurs resulting in two-phase, choked flow. To more accurately adapt these equations to fluid flow through a crack, modifications to the equations are implemented to account for pressure losses due to several effects, including those from the crack morphology. An orifice flow model using single-phase properties is used for wider cracks. A transition model serves as a bridge to calculate leak rates between the choked-flow and orifice flow models.

Afterwards, an overview of the crack stability models was given. These models primarily determine whether rupture occurs due to the presence of cracks. Both net-section-collapse and elastic-plastic fracture mechanics models are employed.

Finally, the ISI models were explained. The inspection model uses a probability of detection curve as a function of crack depth to determine if a crack is detected during a given inspection. The evaluation model is then used to size the detected crack and determine if the measured size of that crack is greater than the threshold size for a repair. The ISI model parameters were developed based on data from the EPRI Performance Demonstration Initiative program.

4. Questions and Answers

As an NRC Category 3 public meeting, stakeholders had the opportunity to participate by providing comments and asking questions throughout the meeting. This participation was facilitated through the electronic submission of questions and comments using the question and answer feature of the virtual platform used to host the meeting. All questions were answered over the course of the meeting.

5. Closing Remarks

   The NRC staff concluded the meeting by providing a recap of the presentations. Participants were thanked for their time and encouraged to submit any future questions or comments to the NRC staff at xlpr@nrc.gov and to EPRI at xlpr@epri.com. The NRC staff also reminded stakeholders to look for the upcoming announcements for the new user webinars.

The NRC staff provided EPRI with an opportunity to review a draft of this meeting summary. EPRI comments were incorporated as appropriate.

Enclosure:
As stated

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