IN USE: MITIGATION OF BWR FUEL FAILURES CAUSED BY CORROSION AND CRUD

ISSUE STATEMENT

Corrosion- and crud-related fuel failures have been documented since the 1970s and have persisted through the last decade. During 2002 – 2004, three units experienced corrosion failures causing two mid-cycle shutdowns to off-load the damaged fuel; one of these discharged an entire reload prematurely. These events were linked to cladding manufacturing, as well as synergistic effects between fuel duty and water chemistry. While improvements have been made in fuel cladding manufacturing processes and water chemistry quality, new chemistry additives are being introduced or contemplated that are designed to mitigate structural material problems or to reduce radiation fields. The potential interactions of these additives with fuel cladding must be evaluated in the context of demanding operating environments (high fuel duty) brought on by longer fuel cycles and power up-rates.

DRIVERS

Nuclear Safety

Fuel cladding is the first barrier ensuring fission product containment and all reasonable actions to maintain the integrity of this barrier should be taken.

Radiological Factors

Crud deposited on the fuel cladding becomes activated and may move to non-fuel surfaces where it becomes responsible for plant shutdown radiation fields. Fission product releases from small breaches of the fuel cladding contribute to radiation fields and increase worker contamination events. Keeping worker dose and contamination events as low as reasonably achievable (ALARA) is the cornerstone of a good radiological health program.

Operational Impact

Fuel failures increase operating costs, reduce capacity factors through flux suppression testing and ramp rate restrictions and can lead to unplanned outages to replace damaged fuel.

Industry Commitment

In 2006, utility Chief Nuclear Officers committed to support the goal of zero fuel failures (referred to as the "Zero by 2010" goal). This commitment remains in effect.

RESULTS IMPLEMENTATION

- Updated guidance will provide utilities a clear path to implementing existing and future chemistry regimes so that they will not adversely impact fuel integrity. This will entail periodic updates to the BWR Fuel Cladding Corrosion and Crud Guidelines and relevant sections of the BWR Water Chemistry Guidelines. The chemistry regimes under current and possible future application that will be addressed are:
  - Zinc addition,
  - Hydrogen water chemistry,
  - Online noble metal chemical addition and early application of online noble metal chemical addition,
  - Early hydrogen water chemistry (first application happened in 2011),
  - Titanium dioxide (possible future application),
  - Methanol (possible future application).
- The BWR Fuel Cladding Corrosion and Crud Guidelines Revision 1 is being updated with results from ongoing and future R&D activities that assesses the potential impact of parameters such as manufacturing processes and chemical impurities on fuel failure susceptibility. Publication is being coordinated with the next revision of the BWR Water Chemistry Guidelines (BWRVIP-190Rev.1), as well as FRP's Fuel Surveillance and Inspection Guidelines Rev.2. Future revisions of these guidelines will be coordiated too.
- Crud Deposition Modeling: EPRI has been developing a software product that incorporates thermal hydraulic conditions and metal mass balances to predict crud deposition within a BWR fuel bundle. The model currently serves as an R&D tool, but with further development it is envisioned the code can be used as a predictive tool to assess susceptibility of fuel rods to excessive crud deposition under anticipated chemistry and operating conditions.

PROJECT PLAN

1. New BWR water chemistry technologies are typically developed to improve plant material conditions unrelated to nuclear fuel. As each is introduced or consiredered, it is necessary to assess the potential adverse impacts to fuel.

The first application of **Early Hydrogen Water Chemistry (EWHC)** occured in a U.S. BWR in 2011. Other BWRs are expected to follow. Fuel inspections are planned to assess:

- Potential increase in hydrogen pickup by the fuel cladding and structural materials,
- The release and redistribution of crud onto first cycle high-powered fuel assemblies.

On-Line Noblechem Chemistry (OLNC) is being applied at a number of BWRs with no apparent adverse effect to fuel cladding corrosion or crud. To complete the assessment of OLNC, the following activities are being carried out or are under consideration:

- A fuel surveillance at a high duty plant where a complete fuel cycle (initial load to discharge) has been exposed to compare crud loadings with the experience base and to compare crud platinum concentrations to those with the earlier noble metal chemical application (NMCA) process,
- Assessment of whether platinum can act as a window for hydrogen uptake,
- Additional qualification efforts if earlier application of OLNC is pursued (currently, the fuel vendors restrict OLNC to be applied only after the first 90 days of the operating cycle).

Methanol addition has been proposed by a fuel vendor as an alternative to hydrogen injection to lower the electrochemical potential (ECP) of the reactor internals. Similarly, titanium dioxide has been applied at one BWR in Japan as an alternative to noble metals. Should these chemistry technologies gain broader interest; plans will be developed to assess their impact on fuel. Also, EPRI's Radiation Management Program has introduced a medium-term project to assess what optimized fuel crud looks like and what R&D would be required to alter the chemical and/or physical properties of crud to make it more benign from a radiation management standpoint, and ostensibly, from a fuel performance standpoint.

2. BWROG is evaluating full system decons as a means of reducing plant dose rates. Should a plant show interest in implementing a decon of this scale, plans will be developed to assess the impact on fuel.

3. **High Efficiency Ultrasonic Fuel Cleaning (HE-UFC)** is being considered as a new method to reduce radiation source term in BWRs. Radiation Management program plans to perform a feasibility study to understand the potential impacts to plant radiation fields and radwaste handling, storage, and disposal. Then Fuel Reliability Program in collaboration with the Radiation Management Program will perform a qualification and demonstration of this technology.

4. **Enhanced Spacer Shadow Corrosion (ESSC)** – Accelerated corrosion of Zircaloy cladding when in close proximity to Inconel spacer grids is being investigated. In response to recent corrosion failures in Europe, spacer shadow corrosion performance of new fuel designs with Inconel spacers in different water chemistry environments will be evaluated. New technologies to mitigate spacer shadow corrosion are being developed by fuel vendors and these technologies will be demonstrated when they become available.

5. FRP is also investigating the possible impact of impurities that may be present in the reactor water or intruded into the reactor water unintentionally on fuel cladding and fuel component corrosion, and hydrogen pickup. This program includes laboratory tests, fuel surveillances and hot cell examinations, as well as an assessment of plant system configurations to develop a plant challenge factor as they apply to condensate filtration and feedwater chemistry control.

6. FRP is developing a software tool called **CORAL** to model crud deposition within a fuel bundle over the course of the cycle. This code is currently in the development phase, but could be adapted to a commercial product to use in core design. To make the code more robust and user friendly, benchmarking, addition of more physical models and further development of the graphical user interface (GUI) will be required. In order to support CORAL models, laboratory crud deposition tests and fuel surveillance programs are also planned. CORAL will also support activity transport modeling in collaboration with EPRI's Radiation Management Program.

7. New fuel cladding or structural component alloys that are introduced will be assessed and appropriate fuel surveillances performed to verify material integrity and performance.

RISKS

- Laboratory testing of new materials or water chemistry cannot fully simulate the reactor environment. Test reactors have limited capability to perform long term tests or address water chemistry variability. While new products are developed based on the best science available, demonstration programs which phase in an application are necessary to manage the risk to the fleet. From the time a new technology is introduced into a commercial reactor, there can be a long lag time to assess its potential impact on fuel. Most BWRs are operating on 24 month cycles and the "incubation period" of a problem could take six or more years (until the fuel is discharged). If the assessment requires fuel shipment and hotcell examination, analytical results could take an additional two years. Therefore, adverse effects of a new technology on fuel may not be revealed until after the technology had been applied several times in the same reactor or at multiple reactors.

RECORD OF REVISION

This record of revision will provide a high level summary of the major changes in the document and identify the Roadmap Owner.

REVISION	DESCRIPTION OF CHANGE
0	Original Issue: August 2011 Roadmap Owner: Aylin Kucuk
1	Revision Issued: December 2011 Roadmap Owner: Aylin Kucuk Changes: Minor edits and updates
2	Revision Issued: August 2012 Roadmap Owner: Aylin Kucuk Changes: Additional projects and milestones were added to flowchart. Other minor edits.
3	Revision Issued: December 2012 Roadmap Owner: Aylin Kucuk Changes: Minor edits and updates to the flowchart
4	Revision Issued: August 2013 Roadmap Owner: Aylin Kucuk Changes: Additional projects and milestones were added to flowchart. Other minor edits.
5	Revision Issued: December 2013 Roadmap Owner: Aylin Kucuk Changes: Additional projects and milestones were added to flowchart. Some of the unfunded projects are deleted. Completed projects are also deleted from the project plan.

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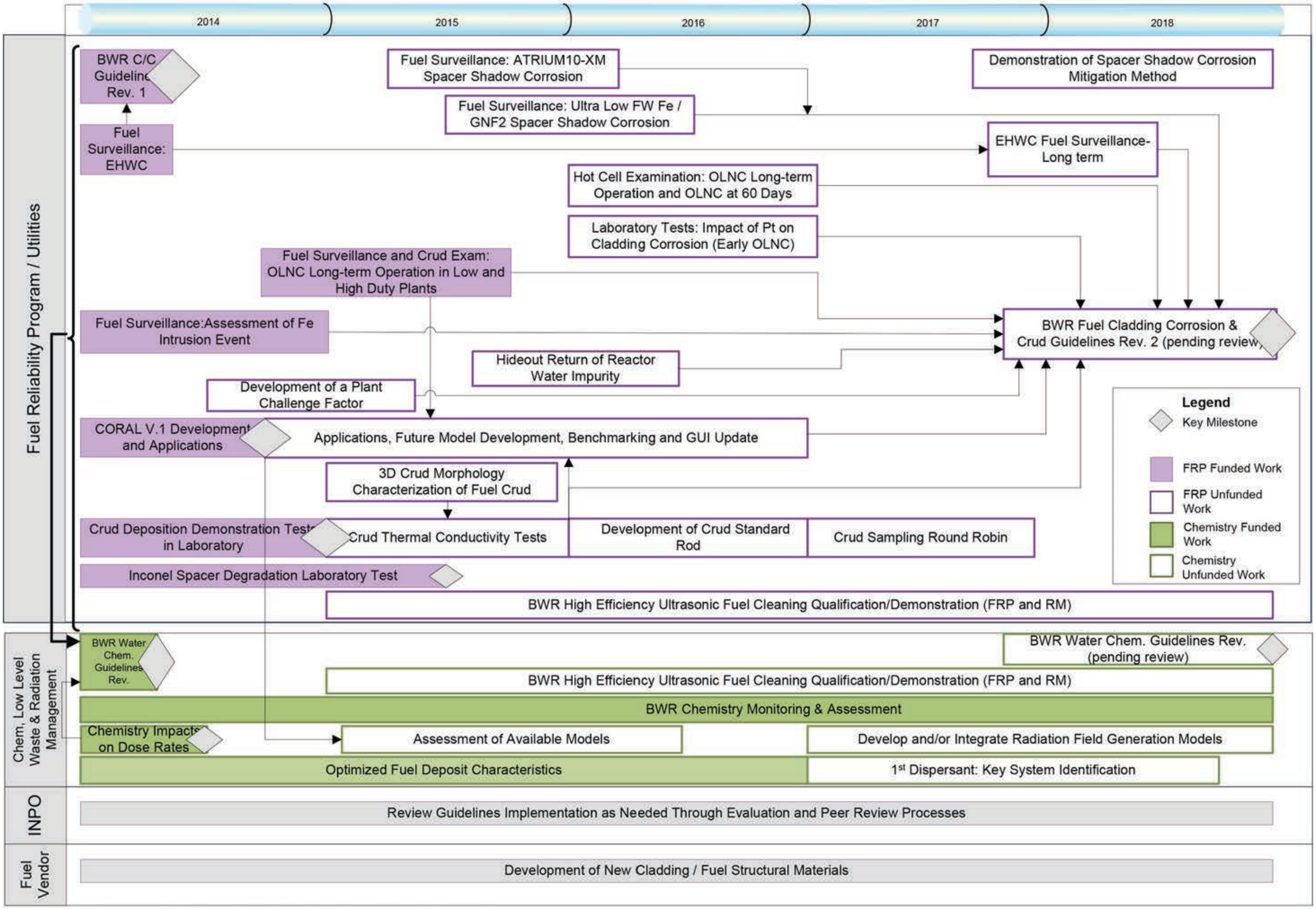

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