ISSUE STATEMENT

Foreign material intrusion can lead to fuel cladding failures. A 2012 Fuel Reliability Program self-assessment concluded “Debris fretting is projected to become the leading cause of nuclear fuel failures.” Recent failure trends fully support this prediction. Since 2008, debris failures have caused more than 90% of the fuel failures observed in U.S. BWRs and are the dominant mechanism in non-U.S. BWRs. For PWRs, the situation is similar in that foreign material failures account for roughly half of fuel rod failures now that most plants have eliminated grid to rod fretting failures by adopting robust designs. Debris failures are the dominant mechanism of failure for our international members. As such, international member’s participation in resolving this issue has grown, and the implementation strategy and project plan described below have been adapted to better reach the international audience.

DRIVERS

• **Nuclear Safety:** Fuel cladding is the first barrier to a fission product release to the general public and all reasonable actions to maintain the integrity of this barrier should be taken.

• **Personnel Radiological Factors:** Even small breaches of the fuel cladding can cause increased plant radiation fields and increase worker contamination events. Keeping worker integrated doses As Low As Reasonably Achievable (ALARA) is the cornerstone of a good radiological health program.

• **Operational Drivers:** Fuel failures drive up operating costs and can lead to unplanned outages, particularly in BWRs. These effects can impact public confidence and increase regulatory scrutiny.

• **Industry Commitment:** In 2006, utility chief nuclear officers pledged to support an initiative to drive industry to zero fuel failures (referred to as the “Zero by 2010” initiative). This commitment remains in effect and is now referred to as “Driving to Zero”.

IMPLEMENTATION STRATEGY

Upon completion of this work, it is expected that:

- Alternate products that have been developed will be used where appropriate in lieu of wire brushes for most applications. Strands of small wire from wire wheels and brushes used during maintenance activities are one of the most common foreign materials causing fuel cladding failure.

- Utilities will incorporate FME techniques and culture into their business practices. Utilities will ensure material and service providers institute standards that preclude the introduction of foreign material into components and systems.

- Utilities will implement a program that systematically searches for and removes existing debris from plant systems and components. Areas of high risk and potential for debris accumulation need to be identified and resources committed to search and removal.

- Fuel suppliers will continue development of and improve debris filters and debris fretting resistance designs for their fuel products. Controlled testing will be conducted prior to introducing these products into commercial reactors. Once introduced commercially, a period of performance monitoring will be required to assess improvement gains.

PROJECT PLAN

A defense-in-depth approach is required to eliminate fuel failure caused by foreign material. Four strategies are needed to eliminate debris-related fuel cladding failures.

*Eliminating the Introduction of Foreign Material*

- Plant personnel must improve their implementation of FME programs, processes and practices. Twenty percent of all Maintenance Areas for Improvement are related to FME. Essential industry guidance is in place, as described below:
  - In 2010, EPRI developed the video *Foreign Material Exclusion: Changing Site Behaviors* (1021397) to address desired site culture changes.
  - In February 2011, INPO released Revision 1 of 07-008, *Guidelines for Achieving Excellence in Foreign Material Exclusion* (FME). Utility gap analyses that benchmarked existing programs against the new Guidelines were analyzed and follow-up actions have been developed and implemented by utilities. This gap execution plan will be complete in 2014.
• EPRI has revised prior guidance by issuing Foreign Material Exclusion Process and Methods, Product ID 3002003060 in 2014 to improve industry alignment following the utility gap analysis of INPO 07-008, Rev. 1.

• Utilities and vendors who provide refueling or other outage services, or who supply fuel, should provide training to newly assigned FME program Coordinators; collaborate to implement new best FME practices and products; and enhance training where needed for applicable personnel. Industry support for training and collaboration is provided as described below:
  – The FME Industry Working Group meets domestically twice a year, with EPRI, INPO, and IAEA participation as warranted.
  – EPRI co-sponsors an international FME workshop (As demand exists, usually annually) with support from the FME Industry Working Group, IAEA, and WANO as warranted.
  – EPRI provides FME Coordinator Training domestically and, since 2015, internationally, (as demand exists) in the U.S. and in conjunction with the international FME workshop. Recent international participation in these two venues indicates strong demand exists in the Pacific Rim and Europe.
  – FME Coordinator training is available to EPRI NMAC members and vendors who provide refueling or other outage services or supply fuel.

• EPRI has researched and developed a high performance High Filament Retention (HFR) wire wheel for use where alternatives cannot be used. Utility implementation is in progress.

• EPRI has developed new video-format training on wire brush fundamentals and use. EPRI has reviewed and accepted for continued training use the timeless principles expressed in Foreign Material Exclusion – Striving for Industry Excellence, Product ID 1014962.

• EPRI has developed standardized FME procurement requirements for material and service purchases. Utilities will incorporate these standardized FME procurement requirements into the appropriate material and service purchases. Material and service providers will incorporate FME techniques and culture into their business practices.

• EPRI has issued Foreign Material Exclusion Practices in the Field: What Good Looks Like, Product ID 3002003061.

• Utilities should use whenever possible gaskets (and other sealing devices) which have features which would prevent the release of any harmful debris that could be generated should the gasket structural integrity be lost. This could include use of gaskets with outer rings, use of non-metallic valve seals, etc.

• Some BWRs have installed strainers in feedwater and other similar systems to filter out debris that would otherwise reach the reactor vessel. These installations warrant monitoring for effectiveness and broader application.

Process and Methods for Unrecovered Foreign Material

• Utilities will implement a program that systematically searches for and removes debris from plant systems and components. This program should include boroscope, robotic camera, velocity flushes, tank inspections and periodic inspection of other locations where debris might settle or accumulate.

• EPRI has developed guidance that includes a decision tree process for utilities to address when below-the-reactor-vessel-core-plate inspections for foreign material should be performed in BWRs (Product ID 1024917) and in PWRs (Product ID 1026776). These inspections are high risk but potentially high reward activities.

• EPRI plans to issue a best practices and lessons-learned fuel-specific FME document for BWRs and PWRs in 2018 that includes descriptions of the types of debris that can cause failures for the purpose of assessing retrieval risk.

Debris Resistant Fuel

• Fuel vendors continually upgrade their fuel products to improve performance. Bottom nozzle debris filters have evolved over time and the latest generation products filter very small debris. The new generation debris filters are currently being placed in service and require monitoring for effectiveness. Other design considerations have been feature which could minimize the risk of debris dropping into the bundles or becoming captured within the spacer grids. In the longer term, hard clad coatings may be developed which would make the fuel much more resistant to fretting.

• Fuel suppliers have and continue to improve manufacturing processes for foreign material exclusion during fabrication as well as designing improved debris filter features in their assembly designs as the result of the Zero-by-2010 initiative. These improvements will be monitored to ensure their effectiveness.

• EPRI is working with the industry to assess standardized practices for testing debris-filtering capabilities of fuel assembly designs, including all types of variable-sized debris and hydraulic conditions. These results may be used to recommend an industry standard test protocol for consistent performance evaluations of existing and new assembly debris filter designs. Testing is complete, and EPRI has published the results in June 2015 (Product ID 3002005520). An assessment will be made with industry partners in follow on years to determine if an industry standard testing protocol for fuel assembly filtration can be recommended.
Debris Resistant Plant Features

• Plants with chronic debris failures will assess whether additional plant system enhancements are necessary to address the failures. EPRI studies have shown that pump-forward BWRs can be at particular risk for this failure mechanism as heater drains are not returned back to the condenser for filtration by condensate polishing. Pump-forward BWRs represent 25% of the U.S. fleet but account for ~50% of BWR failures. World-wide, the situation is similar. For EPRI member BWRs with cascading heater drain designs active in the last 5 years, only 5 of 34 plants reporting data in FRED have had debris failures even though debris is still the dominant failure mechanism. In the same 5 year period, 7 of the 13 active pump-forward BWRs reporting data experienced a debris failure. One system enhancement that has been implemented by BWRs is reducing the mesh size of feedwater pump suction strainers. Some BWR utilities are also considering the installation of advanced straining devices in the feedwater system.

RISKS

There can be a long lag time between in-cycle identification of a fuel failure and determining the cause of failure. This, coupled with the fact that more than two or more cycles of defect-free fuel performance is needed to assess the effectiveness of actions taken to prevent failures; it may take several fuel cycles (up to 6 years) to determine if other measures are needed to address this Roadmap issue. Therefore, implementing parallel and multiple activities is necessary if results are desired in a shortest time frame possible.

Implementing a program that systematically searches for and removes debris from plant systems and components has moderate risks. The costs associated with developing and staging contingency activities and resources can be high. Planned on-line and outage activity durations, as well as worker dose, also might be increased if foreign material is discovered in a system or plant component.

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.

<table>
<thead>
<tr>
<th>REVISION</th>
<th>DESCRIPTION OF CHANGE</th>
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<tbody>
<tr>
<td>0 Original Issue: August 2011 Roadmap Owner: Lee Rogers and Jeff Deshon</td>
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<tr>
<td>1 Revision Issued: December 2011 Roadmap Owner: Lee Rogers and Jeff Deshon</td>
<td>Changes: Minor edits and updates</td>
</tr>
<tr>
<td>2 Revision Issued: August 2012 Roadmap Owner: David Ziebell and Jeff Deshon</td>
<td>Changes: Updated issue statement/flowchart [project plan] to 2012 FRP self-assessment and progress to date.</td>
</tr>
<tr>
<td>3 Revision Issued: December 2012 Roadmap Owner: David Ziebell and Jeff Deshon</td>
<td>Changes: Updated Issue Statement, minor edit to last paragraph of Project Plan, small updates to flow chart, including completed task.</td>
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<tr>
<td>4 Revision Issued: August 2013 Roadmap Owner: David Ziebell and Jeff Deshon</td>
<td>Changes: Updated Issue Statement and Project Plan. Expanded the three strategies in the Project Plan to four. Flow chart adjusted accordingly.</td>
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<tr>
<td>7 Revision Issued: August 2016 Roadmap Owner: David Ziebell and John Beale</td>
<td>Changes: Updated the Issue Statement and Project Plan.</td>
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<tr>
<td>8 Revision Issued: December 2016 Roadmap Owner: David Ziebell and John Beale</td>
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