Establishing and Sustaining a Technical ProgramtoAchieve Zero Fuel Failures

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Abstract

In 2006, Chief Nuclear Officers (CNOs) of electric utilities operating 103 commercial reactors in the United States (U.S.) formally endorsed an initiative to achieve failure-free fuel performance by the end of 2010. This became known as the *Zero-by-Ten Fuel Failure Initiative*. Support of the *Initiative*manifested during a meeting at the Institute of Nuclear Power Operations (INPO) while reviewing poor nuclear fuel performance trends. This paper provides a brief review of some of the drivers that caused those trends, the *Initiative* elements designed to address them, and a review of the technical program that helped achieve, and thus far sustain, improved fuel performance.

Key Words

Nuclear Fuel, Fuel, Fuel Failures, Fuel Failure Initiative, Zero by Ten Initiative

Introduction

In 2006, nearly 30 percent of the commercial nuclear reactors in the U.S. were operatingwith fuel failures. Each failure represented the loss of one of the barriers of a fission product release to the environment. Between 2002 and 2006, fuel failures had led to 8 unanticipated BWR mid-cycle outages which required replacing the affected fuel assemblies. The average outage duration was 10 days, representing 80 days that power wasn't being delivered to the electric grid. Over the same 5 year period, 84 BWR and PWR units in the U.S. reported fuel failures in *at least* one cycle [1]. **Figure 1** depicts this fuel failure history.

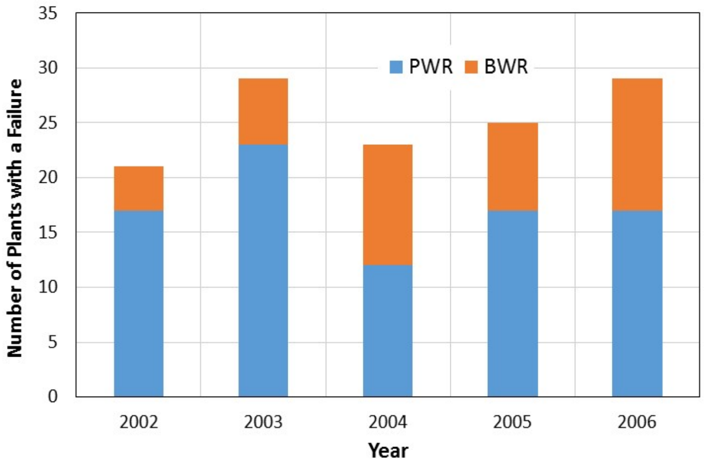

Figure 1: Number of U.S. Plants Reporting aFuel Failure: 2002 – 2006 [1]

Contributing Causes

To meet an increasing demand for energy in the U.S., as well as improve plant and core design efficiencies to remain competitive with other energy sources, nuclear utilities took measures to meet these needs. Power uprates became common place. **Figure 2** shows that for the period 1990 – 2006, 99 power uprates of varying sizes by 78 BWRs and PWRs were approved for implementation by the U.S. Nuclear Regulatory Commission [2].

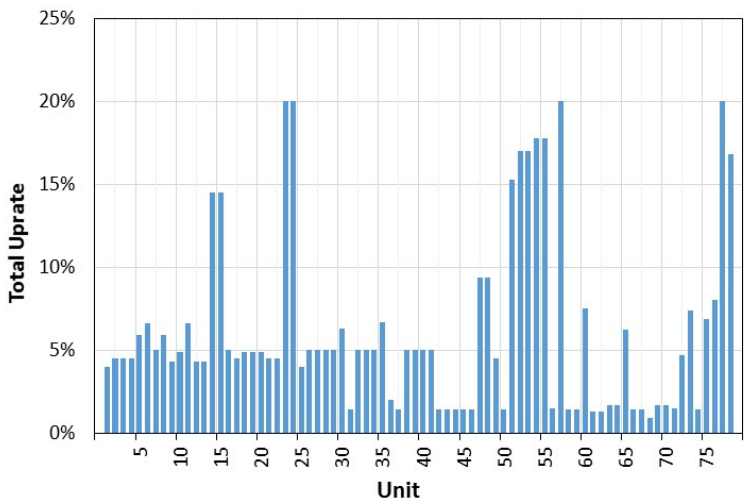

Figure 2: U.S. Nuclear Plant Power Uprate History: 1990 – 2006 [2]

Another measure included increasing the time between refueling outages. By 2000, virtually all plants had transitioned from nominal 12 month operating cycles to either 18 or 24 months [1]. **Figure 3** shows this trend.

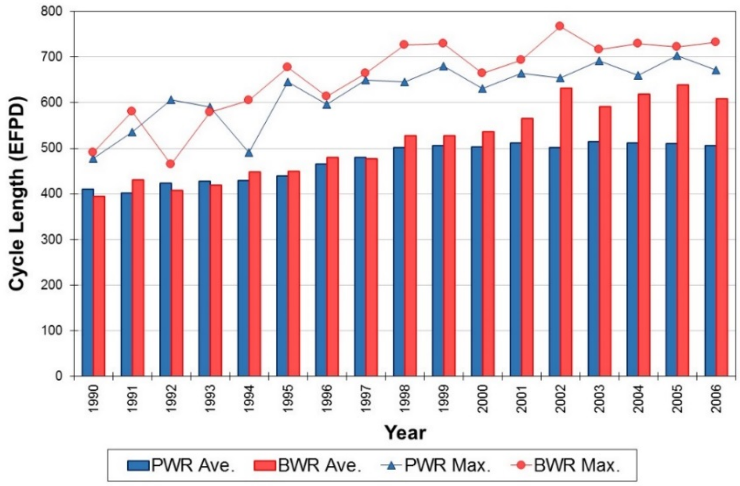

Figure 3: U.S. Nuclear Plant Cycle Length History in Effective Full Power Days (EFPD) [1]

The combination of power uprates, longer fuel cycles and actions to improve core design efficienciesled to higher U^{235} enrichments, loading pattern changes, smaller feed batch sizes and higher peaking factors. The cumulative effect meant cores were generally operating under more demanding environments, thus potentially reducing margins to failure. In some cases, fuel designs and manufacturing issues also contributed to the number of fuel failures rising during this period. The primary failure mechanisms included pellet-clad interaction (PCI), PWR grid-to-rod fretting (GTRF), crud and corrosion, and debris fretting.

Industry Action Plan

The 2006 meeting of U.S. utility CNOs at INPO resulted in a commitment to improved fuel performance. An action plan was initiated to establish and meet a goal of zero fuel failures by 2010. The initiative, coined "Zero-by-Ten", was supported by utility executives, EPRI, INPO and the three vendors supplying fuel in the U.S.

<u>Guidance Development</u>

The objective of the *Zero-by-Ten Initiative* was for industry to take high impact actions to significantly improve fuel reliability. Clearly defined roles were establishedfor all stakeholders. A substantial focus of the effort was the development of fuel reliability guidance documents. This effort was performed in two phases:

Phase 1

As a short term measure and within the first several months of the *Initiative* being established, INPO would develop fuel integrity improvement guidance that would rely on existing knowledge and include industry best practices. These guidance documents would be utilized as benchmark standards for evaluation teams to assess current utility practices.

Following the guidance development, INPO wrote an *Excellence Guideline* [3] to focus nuclear plant leadership on improving fuel reliability. The seven attributes of the document urged support of fuel reliability activities from the executive down to individual contributor levels. This support was deemed necessary to make fuel reliability a priority in the stations' culture – from work scheduling to funding of needed improvements. It advised senior leaders to establish a goal of zero fuel failures and to create a strategic plan to achieve that goal that included establishing operating margins and determining fuel failure causes. It advocated understanding each of the fuel failure mechanisms, consideration of fuel reliability in any plant changes, and establishing an environment in which individuals throughout the organization were aware of the potential impact of their actions on fuel performance. For example, specific guidance was provided for creating foreign material exclusion zones to prevent debris from entering systems. The *ExcellenceGuideline* also addressed other issues such as maintaining appropriate ramps rates to prevent PCI failures and chemistry control programs to prevent crud and corrosion failures. Oversight of fuel fabrication activities and fuel inspections were also provided.

Phase 2

Inparallel with the INPO effort but on a longer delivery time basis, EPRI would develop technical guidelines for fuel reliability in each fuel failure causal area. These would address gaps in knowledge and become the industry standards for fuel reliability. Once the EPRI Guidelines were released, the INPO companion guidance documents would be removed from circulation. **Figure 4** outlines this strategy and the areas of guidance development.

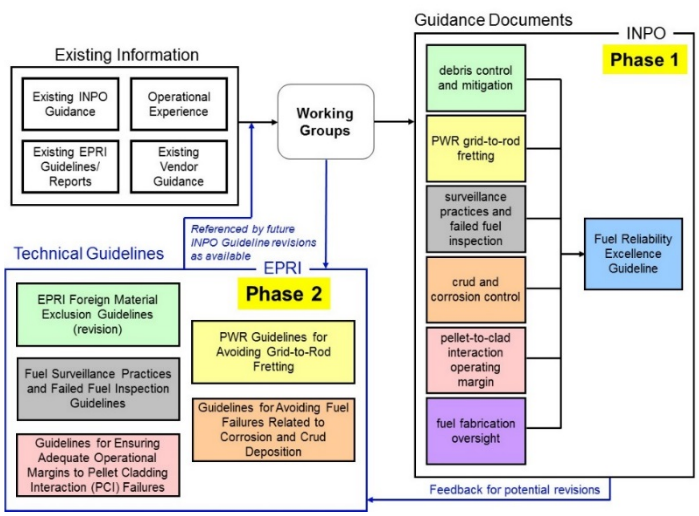

Figure 4: Two Phase Approach to Establishing Fuel Reliability Guidelines [4]

As reflected in **Figure 4**, EPRI developed new *Fuel Reliability Guidelines*to prevent four of the known fuel failure mechanisms:

- *BWR Fuel Cladding Corrosion & Crud*
- *PWR Fuel Cladding Corrosion & Crud*
- *PWR Grid-to-Rod Fretting*
- *Pellet - Cladding Interaction*

Two common objectives for eachguideline are described below:

- To present sufficient background and causal information that allows the reader to grasp the actual and potential contributors that can lead to cladding failure by each mechanism.

- To provide a technical basis and list preventive / correctivemeasures that can be taken to minimize the potential for cladding failures by each mechanism.

In addition to the above guidelines, EPRI developed a *Fuel Surveillance and Inspection Guideline*to "…provide guidance to nuclear plant operators for developing proactive fuel assessment, inspection and surveillance programs" [5]. The main thrust behind this guideline is to ensure utilities understand what their margins are to cladding failure through baseline inspections and to ensure margins are understoodfollowing any significant change in operating practices, such as a change in fuel design or material manufacturing process, or adoption of a new reactor coolant chemistry regime.

All U.S. utilities were [and continue to be] required to adhere to the guidance in each guideline. Recommendations are delineated in hierarchical format, based on the established need for that guidance to be followed. There are three levels of adherence and these are summarized as follows:

Mandatory	to be implemented at all plants where applicable
Needed	to be implemented wherever possible, but alternative approaches are acceptable
Good Practice	implementation is expected to provide significant operational and reliability benefits, but the extent of use is at the discretion of the individual utility

Each of the guidelines are reviewed every 3 – 4 years and are updated as necessary with recent operating experience or improvements in preventive guidance or technologies.

Additionally, an existing EPRI guideline, *Foreign Material Exclusion*, was updated to reflect the *Zero-by-Ten Initiative*with the most recent advances in maintenance practices and alternative materials development to apply during maintenance on plant systems.

<u>Other Action Plan Activities</u>

Monthly Industry Operating Experience Conference Call

Another early action taken was to establish a monthly industry conference call to share operating experience.The call become known as the "Zero-by-Ten Call" and it continues today as the "Driving-to-Zero Call". Itis sponsored by the EPRI Fuel Reliability Program and is led by utility personnel. Attendees include all U.S. utilitiesand several non-U.S. utilities, EPRI, INPO and fuel suppliers.

Establishment of a Fuel Reliability Database (FRED)

In 2004, EPRI established a database, FRED, for utilities to enter fuel performanceinformation.The objective for the database was to "…*support event-free nuclear fuel performance through timely industry-wide sharing of ongoing and historical fuel performance data and events.*"[2]. FRED was updated to accommodate additional needs from the *Zero-by-Ten Initiative*, such as inclusion of summaries ofbaseline margin assessments. The database includes all relevant fuel design information as well as control rod / blade data, fuel burnup and failure information, cycle chemistry, and other performance issues information. All utilities that enter data into FRED (U.S. and non-U.S.) have access to the data contained in the database. By September 2015, 179 BWRs, PWRs and VVERs from 12 countries have entered 1200+ cycles of data into FRED.

Follow-up Assessments

Utility executives expected stations to implement the INPO guidance documents and the EPRI guidelines into their programs and procedures as they were released. As an important follow-up activity to ensure the guidance was being adopted, INPO integrated Fuel Integrity Review Visits (FIRVs) into its core business. FIRV teams, comprised of INPO evaluators and industry peers, visited every station, utility corporate office and fuel vendor in the U.S. between 2007 and 2009. The focus of the visits was to assess the state of utility programs and practices that supported fuel reliability. These included chemistry programs, foreign material control programs and practices, fuel operating practices and fuel inspection programs. Other items such as procedures for evaluating and predicting fuel behavior and vertical and horizontal communications of fuel strategies were reviewed.

Following each FIRV, reports were prepared by INPO for utility management that cited strengths that were identified during the visits as well as gaps between station programs and the guidelines.

A number of themes emerged among the plants. For instance, plants that experienced repeated debris failures were also observed to need more focus on maintenance practices and correcting personnel behaviors. In many cases, these plants needed to improve general foreign material exclusion (FME) programs to include looking for, removing and analyzing debris in the reactor coolant system (RCS) and systems in communication with the RCS.

Other opportunities commonly identified for improvement were in the area of communications and relationships between core design, reactor engineering, chemistry and operations groups. Also, a need to make station senior leaders more aware of fuel integrity plans and strategies was observed.

Fuel vendor assist visits were also an important component to achieving and sustaining zero fuel failures. Vendor organizations were found to need stronger corrective action programs and human performance practices.

Status of Fuel Failures in the U.S.

The pie charts depicted in **Figure 5**show the distribution of failure mechanisms by assembly count that occurred during two periods: the 4-year period afterthe start of the*Zero-by-Ten Initiative*; and the 4-year period after theconclusion of the*Initiative*.

For the 64 PWRs in operation, grid-to-rod fretting continues to dominate the number of failures that have occurred through 2014, though the numbers are down by 75%. PWR fuel vendors have addressed this failure mechanism through new designs and only a few plants remain to fully transition to grid fretting resistant assemblies. After these convert, it is expected that few failures, if any,will occur by this mechanism based on the performance of the new designs to date. Fabrication and debris related failures are down significantly as well, by 78% and 79% respectively. As a result, debris and fabrication failures are expected to become the most prominent failure mechanisms for PWRs

For BWRs, debris has been and continues to be the dominant fuel failure mechanism and has become a chronic issue for utilities. Fuel vendors have designed debris filters that allow only the smallest of foreign objects to pass through.Yet these objects, typically very small wire, either pass through the filters or access the assemblies from another pathway. While debris failures have been reduced by 45% between the two periods; at any given time, two to five of the 34operating BWRs have an active fuel failure and the statistics suggest they are most likely caused by debris.

BWRs come in two general plant configurations and one design appears more vulnerable to debris failures than the other:

- Cascade Plants where heater drains are directed back to the condenser so all water flowing to the reactor passes first through condensate polishers and filters.
- Pump Forward Drains Plants where heater drains are fed into the feedwater and flow directly to the reactor with limited filtration. Heater drains are a fairly large fraction of the total feedwater flow, hence foreign objects left in the heater drains system or systems connected to heater drains during a maintenance outage can be delivered directly to the reactor.

There are only nine pump forward drains BWRs in the U.S. (26% of total) but these units incur about 50% of the debris failures.

It is noted that no crud induced corrosion related failures have occurred since 2006 for PWRs and 2004 for BWRs, therefore this mechanism is not identified in the pie charts.

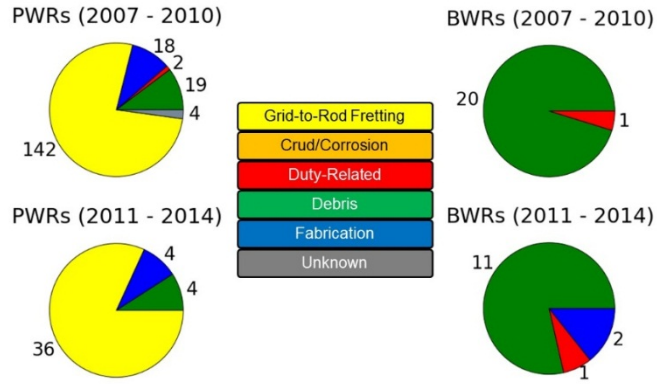

Figure 5: Distribution of Fuel Failure Mechanisms in the U.S. [1]

Figure 6 depicts fuel failure trends for the period January 2007 through April 2016. As can be seen from the line graph, for a brief time in 2013, 98% of the U.S. fleet was defect-free. While zero failures have yet to be achieved, a high level of fuel reliability has been sustained since 2010 when compared to 2007 and earlier.

More recently, there has been a slight increase in fuel failures. INPO Event Report, L4-16-5, Adverse Trend in Debris-Related Nuclear Fuel Failures, looks at recent performance in both PWRs and BWRs and noted that the increase in failures was the result of debris failures. Focus has waned on preventing the introduction of foreign material into systems directly connected to the flow path of coolant through fuel. In some cases, stations had evaluated sources that could introduce foreign material into the coolant system; however, the follow up was insufficient to eliminate the sources. These lapses are at the worker, supervisor and program levels of foreign material practices and prevention techniques.

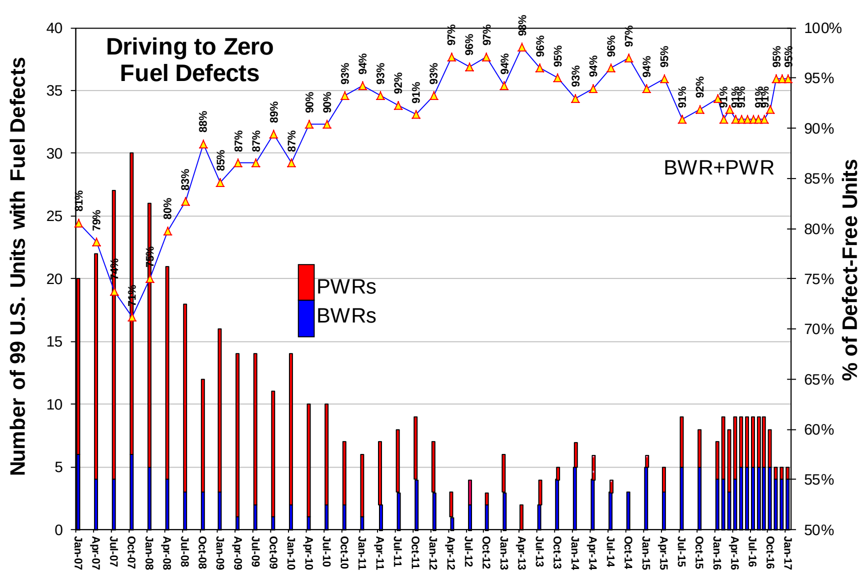

Figure 6: Status of U.S. Fuel Reliability: 2007 - 2016

Summary

The *Zero-by-Ten Fuel Failure Initiative*represented a unique level of cooperation among utilities, fuel vendors, INPO, and EPRI that effectively mitigated a chronic issue adversely affecting a primary fission product barrier. Dedicated teams developed complex technical documents in a relatively short time that provided specific actions to avoid fuel failures. These documents combined with utility and vendor leadership support resulted in the significant fuel reliability improvement achieved after 2007. The *Initiative* also provided the basis for a living program still functioning effectively today as demonstrated by the ongoing monthly Driving-to-Zero conference call and timely revision to guidelines as operating experience broadens. The strategy used in the development and execution of the *Initiative* could be applied to any group of utilities world-wide for any wide-ranging issues.

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