ABB MEETS THE FUEL CHALLENGES OF THE 21ST CENTURY

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ABSTRACT

Excellent fuel performance contributes directly to excellent nuclear plant operation. Many utilities estimate that a single failed fuel rod can increase a plant's operating costs by up to $1 million, while also raising as low as reasonably achievable (ALARA) dosage issues. As a result, zero defect fuel is an important objective for World Association of Nuclear Operators (WANO) and Institute of Nuclear Power Operations (INPO). ABB Combustion Engineering Nuclear Operation's (ABB CENO) fuel performance continues for the third straight year to be significantly better than the United States' pressurized water reactor (PWR) industry average. Ninety per cent of ABB CENO fueled plants operate with zero defects (as defined by INPO/WANO), compared to 79% for other U.S. PWR fuel vendors.

This paper describes the reasons behind this excellent fuel performance. First, it reviews the ABB CENO fuel performance in the context of current industry fuel problems such as: axial power offset anomalies, clad oxidation failures, extensive grid-to-rod fretting failures, slow insertion of control rods, and end cap weld failures. ABB CENO fuel has operated essentially free of these industry problems. Then, it reviews the reasons behind this performance, including:

1) a high strength rugged mechanical design that is better able to survive the long operating cycles and high burnup of modern fuel managements;

2) a variety of unique manufacturing processes that provide extra as-built margin to design limits; and

3) a formal program that carefully manages design change implementation including equipment to test new fuel assembly designs at reactor operating flow, temperature and pressure conditions.

1.0 INTRODUCTION

ABB CENO understands that the single most important attribute of nuclear fuel is excellent reliability, and ABB CENO has been very successful in meeting its goal of delivering fuel with "zero defects". Figure 1 contains the average and mean values of reactor coolant iodine levels for the plants fueled by ABB CENO, during the last ten years. The significant reduction in these values during the early part of this period is the result on many changes made by ABB CENO to improve its fuel's performance. As can be seen, these efforts have resulted in near zero iodine values for the last two years.

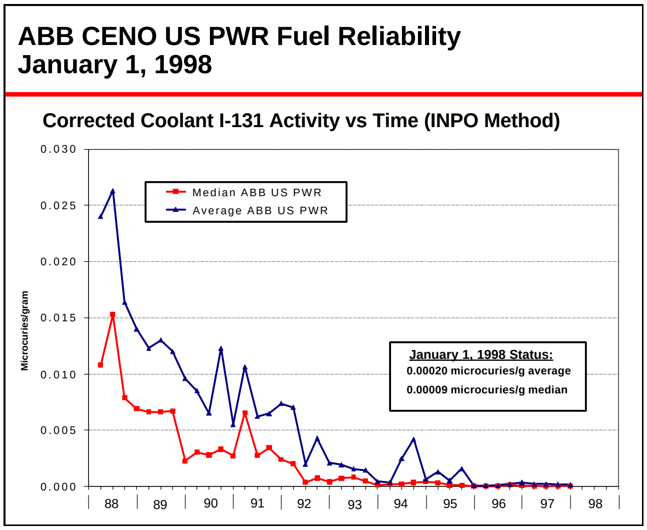

Figure 1

Figure 2 illustrates the same excellent fuel performance by presenting the fraction of ABB CENO fueled plants whose fuel performance meets the INPO and WANO criteria for zero failures. INPO and WANO would like 85% or more of all PWRs to meet this criteria. PWRs in the U.S.A. as a group have never achieved this goal, but as Figure 2 demonstrates, ABB CENO fueled plants have exceeded the INPO and WANO goal in 23 of the 24 months in 1996 and 1997.

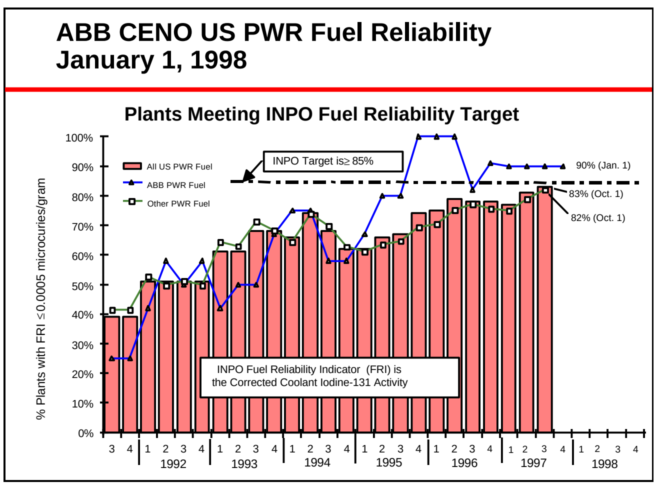

Figure 2

2.0 ONGOING INDUSTRY PROBLEMS

While ABB CENO fuel performance has been essentially perfect over the last three years, it is helpful to review some of the problems that others have experienced during this time. By reviewing the background of these problems, it is easier to understand why the steps ABB CENO has taken to prevent fuel performance problems have been so successful.

2.1 Advanced Clad Corrosion

Most recently occurred at: TMI (Zr-4), Seabrook (ZIRLO)

This type of corrosion typically involves accelerated crud and corrosion related to sub-cooled boiling. It normally occurs in fairly fresh fuel, operating early in the cycle, and usually occurs at plants with aggressive fuel management programs that are pushing the fuel's peak linear heat rate (Fq) design limits. *This problem has not occurred in modern fuel at ABB CENO fueled plants.*

2.2 Axial Offset Anomaly

Most recently occurred at: Callaway, Millstone-3, Vogtle 1&2, Catawba-1, Comanche Peak-1, Seabrook, Wolf Creek, Shearon Harris, TMI-1

An offset anomaly occurs when the power in the core undergoes an unexpected axial shift, generally to the bottom of the core. The recent events have been due to boron absorption in crud that builds up in the upper spans of high power fuel assemblies. Plants have experienced changes in Axial Offset (AO), of between -3 to -15% from this effect. As a result, some plants have had to operate at significantly reduced power levels, including Callaway, which operated at only 70% power during the Summer and Fall of 1997. *This problem has not occurred in modern fuel at ABB CENO fueled plants.*

2.3 Slow Control Rod Insertion

Most recently occurred at: South Texas, Wolf Creek, Ringhals (Sweden), Almaraz (Spain), North Anna.

This problem occurs when the control rod either inserts too slowly, and/or does not fully seat, due to guide tube distortions. The problem has resulted in extended outages, restrictions on placing partially burned fuel assemblies under control rods, and some plants had NRC-imposed mid-cycle shutdowns to investigate the cause. *This problem has not occurred in modern fuel at ABB CENO fueled plants.*

2.4 Extensive Grid to Rod Fretting Wear

Occurred most recently at: TMI-1, Ft. Calhoun, Maine Yankee, Wolf Creek, Beaver Valley-1, Salem-2, D.C. Cook-1, Angra (Brazil).

Grid-to-rod fretting wear occurs when the fuel rod becomes loose in the grid cell, which causes the rod to vibrate and eventually wear a hole in the cladding. Such damage has been extensive at some plants. The general conclusion has been that the grids were not sufficiently strong/stiff. This problem has not been observed at ABB CENO's fuel with laser welded grids. There are a few ABB CENO failed fuel rods in operation. These are probably fret failures in older, TIG welded grids, or debris failures in non-Guardian™ fuel. Until the assemblies can be inspected, the exact cause of failure is not know.

2.5 Fuel Handling Damage

Occurred most recently at: Alvaraz (Spain), ANO-1, Byron-1, Oconee.

Fuel handling damage occurs when fuel is being moved and grids or nozzles from adjacent assemblies hangup, thereby tearing or loosening the grids. While all fuel is designed with anti-hangup features, excessive fuel assembly bow can result in sufficient forces to cause fuel handling damage, frequently due to excessive contact with the bottom nozzle. Due to the ABB CENO high strength rugged assembly design, there is less bow. ABB CENO's exclusive skirted bottom grid and LEF design further reduces the opportunity for this sort of damage. As a result, *this problem has not occurred in modern fuel at ABB CENO fueled plants.*

2.6 Failed End Cap Welds

PWRs with TIG-welded end caps annually experience a low level of failure from poor clad-to-endcap welds. The failures are believed to result from small pieces of the tungsten weld probe falling into the weld and causing a local imperfection. ABB CENO uses a magnetic force clad-to-end cap weld that has no weld probe. It is a robust process, one in which welds can be made quickly and with an extremely high degree of consistency and quality. *With over 25 years experience, ABB CENO has never experienced a single in-core rod failure as a result of a defective end cap weld.*

2.7 Debris Failures

In the USA, six debris failures were reported in 1995, and three more in 1996.

Debris failures are the result of small pieces of metal or other foreign objects in the coolant being trapped between a grid and fuel rod, and then vibrating against a fuel rod. This process eventually wears a hole in the cladding. Although all fuel manufacturers are implementing debris-resistant designs, some of these designs rely on small holes in the bottom nozzle flow plate and continue to be susceptible to debris failures. *There has never been a debris failure in a fuel assembly protected by ABB CENO's Guardian™ debris filter lower end fitting design.*

2.8 Improper Introduction of New Features

There continue to be miscellaneous nuclear fuel problems due to new features being introduced or changes being made that lead to new, unexpected problems. Examples include: the loss of DNB margin when intermediate flow mixer grids were re-designed to reduce fretting failures; the need to return some fuel to the factory to have IFBA rods re-pressurized; new coolant chemistry controls that were expected to benefit steam generators but caused accelerated crud formation and clad corrosion; misplaced WABAs at Turkey Point; and the RCCA guide card change at Daya Bay that was intended to fix a wear problem, but caused the control rods to insert slowly. Such problems often resulted in extended unscheduled shutdowns, core power derating and in some cases fuel failures. *ABB CENO has never had a recall or fuel failure associated with a fuel design change or introduction of a new feature.*

3.0 EXPLANATION OF ABB CENO'S SUCCESS

ABB CENO's superior performance is the result of: 1) a robust mechanical design, 2) the world's newest, most modern fuel fabrication facilities, which assure that this excellent design is properly built; and 3) a comprehensive change control management system.

3.1 Robust Mechanical Design

ABB CENO fuel contains a number of features that make the fuel more robust others. These features contribute to ABB CENO's excellent fuel performance, and are particularly desirable as fuel cycles become longer and fuel is operated to higher discharge burnups.

3.1.1 Large Guide Tubes

All ABB CENO's fuel contains five, high strength, large diameter guide tubes. These large guide tubes, together with a shorter grid spacing, result in a compressive strength about 30 times that of the typical, small guide tube design. This significantly higher strength contributes to minimal fuel assembly bow, and to a generally more robust design.

3.1.2 Welded Grid-to-Guide Tube Connections

ABB CENO is the only fuel vendor in the U.S.A. to attach the spacer grid to the guide tube by welding. Again, this results in a stronger, more robust design.

3.1.3 Short Grid Spans

With a shorter distance between spacer grids, typically 40 cm (15.7 inches), ABB CENO fuel assemblies are sturdier and stiffer than others. This feature also provides improved thermal performance and reduced fuel rod bow.

3.1.4 GUARDIAN™ Debris Protection

During the late 1980s debris caused approximately two-thirds of the fuel failures in U.S. PWRs. The GUARDIAN™ lower end fitting debris filter design was developed to protect fuel from debris in the coolant. Presently, all fuel delivered by ABB CENO contains this design feature, and every assembly has operated with absolutely zero debris failures.

3.1.5 Large, Fission Gas Plenum Volume

The ABB CENO fuel rod has a particularly large plenum region. This results in an increased ability to accommodate fission gas release, and provides physical design margin to prevent rod internal pressure from becoming a performance or licensing limiting issue.

3.1.6. Erbium Burnable Absorber

ABB CENO is the only vendor to use erbium as a dilute, integral burnable absorber in commercial reactors. (Erbium is used as a burnable absorber in TRIGA reactors). No helium is generated in erbium burnable absorber rods, so the accommodation of fission gas is simplified relative to a core containing boron-based burnable absorbers.

The addition of erbium does not increase the tendency of the fuel pellets to pick up moisture, as is the case with some coated fuel pellet burnable absorbers. Thus special fabrication techniques are not needed, which reduces fuel manufacturing costs and decreases the potential for hydride failures due to moisture pickup in the fuel fabrication process. Finally, erbium rods do not experience the significant increase in local power associated with depletion in other burnable absorber designs. This reduces the problems of clad oxidation that other designs can experience.

3.2 Improved Manufacturing

With a goal of 100% zero defect performance, ABB CENO began in the late 1980s and early 1990s to create the world's finest fuel manufacturing facilities. As a result ABB has invested more than $50 million in the past ten years at its Hematite, Missouri, and Windsor, Connecticut, manufacturing facilities. Today those facilities are essentially rebuilt; over 80% of the manufacturing process is new.

Improvements at Hematite include a state-of-the-art pellet plant, incorporating a separate urania-erbia pellet line, and UO_2 pelletizing process. A new, environmentally-controlled fuel rod and bundle assembly building brings the facility to a total of 34,160 square metres (112,000 square feet). This building is equipped with highly sophisticated, computer integrated control and data information systems. The major features are:

3.2.1 Dry UF_6 Reconversion Process

ABB CENO uses a dry conversion powder which is unique in its low surface area (activity) compared to competitor powder processing. The virgin powder is jet milled to further improve its pressing and sintering behavior.

3.2.2 Green Pellets Pressed to High Density

The press feed is subjected to a higher than average tonnage to produce pellets with a high green density of approximately 70 percent of theoretical density for UO_2. This contributes to pellets with high integrity, low open porosity, and increased resistance to chipping. Low open porosity leads to reduced susceptibility to moisture pickup from the factory atmosphere and contributes to a consistently low hydrogen level in the pellets.

3.2.3 Separate Dewaxing and Sintering Furnaces

The two-stage sintering process allows for better control of the dewaxing and the sintering atmosphere during low and high temperature processing. This results in fewer complications in achieving proper sintering atmosphere that is free of hydrocarbons from the green pellets. The result is a more homogeneous pellet with low open porosity.

3.2.4 Heated Pellet Storage

Another unique feature is the storage of the pellets at a high temperature and in a very dry atmosphere. This patented system and apparatus assures that pellets do not pick up moisture from the air during their storage prior to rod loading.

The Windsor facility contains state-of-the-art manufacturing operations with the latest in laser welding technology, modern numerically controlled manufacturing equipment, automated inspection machines and manufacturing information systems. In particular, all ABB CENO supplied fuel contains 100% laser welded spacer grids. Because the location of the laser can be more precisely directed, laser welding applies less heat to the grid. This results in less heat related grid deformation during manufacture and permits manufacture of all grid cell locations to tighter dimensional tolerances. This is particularly important in preventing grid-to-rod fretting during operation.

3.3 Change Control Management

While a robust mechanical design and excellent manufacturing are important to zero defect fuel performance, it is also necessary to have a process that carefully controls changes in the design and manufacturing. Changes can range from introduction of a new design feature, to evolutionary improvements that are refinements to the design or manufacturing process. If proper care is not taken in implementing such changes, they can lead to unanticipated problems that reduce design or thermal margins or contribute to a fuel failure.

ABB CENO utilizes a comprehensive formal change control system. When a change is proposed, a report is prepared that evaluates the change from the perspective of: mechanical, nuclear, and thermal hydraulic design; manufacturability; Quality Assurance; Quality Control; manufacturing health and safety; licensing; and plant operations. This review searches for any unintended effects of the change. It is only after this review has been completed and independently reviewed that the change proceeds.

A design change review may involve qualification testing of a new fuel design. ABB CENO is unique in the U.S.A.; since the early 1970s it has had equipment to test full-scale fuel assembly prototypes at its TF-2 test facility. This stainless steel test loop is designed for flow rates up to 946 L/s (15,000 gpm), temperatures up to 343°C (650°F), and pressures up to 16.8 Pa (2,500 psig). The loop has two test sections. The main section can accommodate up to five full-size fuel assemblies and their control rod(s). The bypass section is sized for single bundle testing. Heat is provided by a single-stage pump that can be operated at two speeds. Qualification testing may include assembly pressure drop tests, assembly flow sweep vibration tests, and assembly endurance tests with vibration monitoring.

This comprehensive change control management system, including full-scale prototype qualification testing at full reactor flow, pressure and temperature conditions when appropriate, is a significant contributor to ABB CENO's record of never having had a fuel assembly recall or failure associated with the introduction of a fuel design change or a new fuel assembly feature.

4.0 SUMMARY

With deregulation of the electric utility industry, operators are placing an even greater focus on plant performance, which requires excellent fuel performance and reliability. ABB CENO has responded with a robust fuel assembly design, manufacturing process, and comprehensive change management systems. The combined effect is nuclear fuel performance that is significantly better than the INPO and WANO objectives, significantly better than the remainder of the U.S. industry, and free of the fuel operational problems others are experiencing. ABB CENO is proud of its fuel performance record, and the contribution it is making in helping its customers better meet the competitive requirements of deregulation.