GE Nuclear Energy

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Office of Nuclear Reactor Regulation
Mail Station P1-137
Washington, DC 20555

Attention: R. C. Jones, Jr.
Chief
Reactor Systems Branch

Subject: **EXPERIENCE WITH BWR FUEL THROUGH DECEMBER 1988**

Gentlemen:

Enclosed is a copy of the GE report providing an update of GE's experience with BWR fuel through December 1988. It is being sent to you at your request for use in the preparation of your annual fuel performance report.

Please contact me if you have any questions.

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Enclosure

rmw

cc L. S. Gifford
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EXPERIENCE WITH BWR FUEL

THROUGH DECEMBER 1988

I. Introduction

This information report provides an updated review of General Electric experience with production and developmental BWR Zircaloy-clad UO_2 fuel rods through December 1988. This experience includes successful commercial reactor operation of fuel bundles to greater than 45,000 MWd/MTU bundle average exposure (approximately 60,000 MWd/MTU peak pellet exposure).

The performance of General Electric 8X8 fuel types continues to be highly successful as demonstrated by a 1988 fuel rod reliability rate of greater than 99.97%.

II. General Electric BWR Fuel Experience Base

As of December 31, 1988, over 3.5 million General Electric 8X8 fuel type production Zircaloy-clad UO_2 fuel rods were in, or had completed, operation in commercial BWRs. Figure 1 shows cumulative 8X8 fuel rods loaded as a function of calendar year. As of December 31, 1988, over 1.48 million General Electric fuel rods were in operation. Figure 2 illustrates General Electric's core loadings by fuel type as a function of calendar year. As of December 31, 1988, General Electric had loaded approximately 900,000 pellet-cladding interaction (PCI) resistant barrier fuel rods in commercial BWR's. The General Electric fuel manufacturing facility in Wilmington, North Carolina, is producing 100% of its 1989 load as barrier fuel, demonstrating the overall customer acceptance of this fuel design.

In 1988, sixteen domestic and ten overseas GE BWR plants had refueling outages with over 3300 new GE 8X8 fuel bundles loaded. Over 50% (or 11 reloads) of this new fuel loaded was GE's latest production fuel design (GE8X8EB).

III. In-Reactor Surveillance Programs and Summary of Surveillance Results

One of the most important aspects of the General Electric fuel design process is the in-reactor performance monitoring of a design before and after its introduction. In keeping with the General Electric philosophy of test-before-use, lead test assemblies (LTA's) containing selected key design features are used to demonstrate the satisfactory performance of these features and to provide lead experience for future production fuel. The fuel surveillance program adopted by General Electric and accepted by the NRC is described in References 1 through 4.

A summary of General Electric's lead test assembly surveillance program is contained in Table 1. Examination results are provided below:

A. Barrier Fuel Program

The goal of this program was the demonstration of a Pellet-Cladding Interaction (PCI) resistant fuel under conditions which would provide statistically significant results. The PCI-resistant fuel features the barrier concept to protect the fuel cladding from failure caused by PCI. The barrier fuel program consisted of four lead test assemblies, loaded into Quad Cities-1 in 1979 at the beginning of cycle 5, and a demonstration reload of 144 bundles with Zr-lined cladding placed into the core at Quad Cities-2 in 1981 at the beginning of cycle 6.

The barrier LTA's at Quad Cities-1 operated for 4 or 5 cycles and underwent four poolside examinations consisting of visual inspections and non-destructive testing of selected fuel rods. These examinations revealed that the bundles and individual fuel rods exhibited characteristics typical of normal operation.

The Quad Cities-2 barrier fuel program was designed to subject the barrier cladding fuel to significant power increases in order to demonstrate the PCI resistance of barrier fuel. Two power increase demonstrations were performed; the first in 1983 at the end of Cycle 6 and the second in 1985 at the end of Cycle 7. Sixteen barrier bundles were involved in each demonstration. During the following plant outage, all demonstration barrier bundles were evaluated by vacuum offgas sipping and determined to be sound. Subsequent to the power increase demonstrations, all PCIOMR operating restrictions were removed from the barrier fuel bundles in the core. Plant offgas surveillance indicates that all fuel bundles in the core continue to operate reliably. Of the 144 bundles in the reload, 32 operated for 3 cycles, 84 operated for 4 cycles, and the remaining 28 bundles are operating in their 5th cycle.

B. Improved Design Feature Lead Test Assemblies

Several Lead Test Assemblies have been designed and placed in operation for the purpose of obtaining experience and performance data on new product design features. These LTAs have undergone extensive pre-irradiation characterization, with plans for interim poolside examinations. These Improved Design Feature LTAs include:

1. 1981 Lead Test Assemblies

Eight LTAs were loaded into Browns Ferry-3 in 1982 at the beginning of Cycle 5. Design features tested include fuel rod helium prepressurization, cladding surface treatment, axial zoning of gadolinia, cladding thickness, and pellet density. A poolside examination of these bundles was completed in June 1984, after the first cycle of operation, and showed characteristics typical of normal operation. Browns Ferry-3 operated briefly in Cycle 6 before administrative shut down and has not operated since that time (March 1984).

2. 1983 Lead Test Assemblies

Four LTAs were loaded into Peach Bottom-3 in 1983 at the beginning of Cycle 6. Design features tested include improved spacer and upper tie plate, axial zoning of gadolinia, cladding thickness, pellet dimensions, and fuel rod helium prepressurization. The first poolside examination of these bundles was completed in August 1985, after one cycle of operation, and showed characteristics typical of normal operation. The second poolside examination was completed in November 1987, after two cycles of operation, and showed characteristics typical of two cycles of normal operation. Peach Bottom-3 has not returned to service since its refueling outage at the end of Cycle 7 in April 1987.

3. 1984 Lead Test Assemblies

Five LTAs were loaded into Duane Arnold in 1985 at the beginning of Cycle 8. Features tested include water rod configuration, improved spacer and upper tie plate, cladding surface treatment, axial zoning of gadolinia, fuel rod helium prepressurization, pellet dimensions, and pellet density. The first poolside examination of these bundles was completed in April 1987, after one cycle of operation, and showed characteristics typical of normal operation. The second poolside examination was completed in October 1988, after two cycles of operation, and showed characteristics typical of two cycles of normal operation. The next poolside examination is scheduled in 1990 after the third cycle of operation.

4. 1987 Lead Test Assemblies

Four LTAs were loaded into Hatch-1 in 1987 at the beginning of Cycle 11. These fuel assemblies represent lead use GE8X8NB production fuel. The first poolside examination of these bundles was completed in October 1988, after one cycle of operation, and showed characteristics typical of normal operation with no evidence of Crud-Induced Localized Corrosion (CILC). The next poolside examination of these bundles is scheduled in 1989 after the second cycle of operation.

5. Cladding Corrosion Performance LTAs

Six LTAs were loaded into Hatch-2 in 1988 at the beginning of Cycle 8. Features tested include cladding material, heat treatment, and surface conditioning. The first poolside examination of these bundles is scheduled in 1989 after the first cycle of operation.

6. 1988 Lead Test Assemblies

Four LTAs were loaded into Cooper in 1988 at the beginning of Cycle 12. These LTAs represent lead use of GE8X8NB-1 production fuel bundle design features. The first poolside examination of these bundles is scheduled in 1989 after the first cycle of operation.

IV. Generic Fuel Performance Mechanisms

Pellet-cladding interaction (PCI) and crud-induced localized corrosion (CILC) are the only cladding perforation mechanisms that have affected fuel performance in recent periods. As described below, product improvements have been developed that will essentially eliminate these two fuel rod failure mechanisms.

A. Pellet-Cladding Interaction

Light Water Reactor (LWR) nuclear fuel is susceptible to fuel rod cladding perforation, commonly called pellet-cladding interaction (PCI) failure, when subjected to fast power increases at moderate to high exposures. Operational procedures (PCIOMRs), which involve slow approaches to power, have essentially, but not completely, eliminated PCI failures in LWRs, but at the cost of reactor capacity factor losses. Zirconium barrier fuel was invented by General Electric as a material solution to the PCI failure problem. Extensive test reactor and laboratory tests along with successful in-core power ramp

demonstrations in the Quad Cities Unit 2 power reactor have shown that Zr-barrier fuel is convincingly failure resistant. Barrier fuel was commercially introduced by General Electric in 1983. The Zr-barrier fuel commercial experience further confirms the effectiveness of this fuel des:gn concept, with not a single PCI-induced Zr-barrier fuel rod failure in greater than 470,000 barrier fuel rods completing at least one reactor cycle of operation. PCI failures are expected to be eliminated within the next few years as the population of non-barrier fuel (45% of all GE fuel currently in operation is non-barrier) is discharged.

B. Crud-Induced Localized Corrosion

In 1979, an unexpected low-level failure mechanism of localized fuel rod cladding corrosion was revealed in some BWRs. Poolside examination of the failed fuel rods revealed plant corrosion product (crud) scale deposits with high copper concentrations. The nature of the failures led to identification of special conditions of environment, operational history, and material-susceptibility that must occur simultaneously to cause failure. These crud-induced localized corrosion (CILC) failures have been limited to plants with copper alloy condenser tubes and filter demineralizer condensate cleanup systems.

Fuel examinations, surveillance, and extensive research have led to a practical understanding of this mechanism. A reproducible out-of-reactor test for measuring the susceptibility of Zircaloy to in-reactor nodular corrosion was developed by General Electric and correlated to in-reactor performance (Reference 5). This test confirmed a previously undetected variability in the susceptibility of Zircaloy to in-reactor nodular corrosion. This test has been patented and made available to the industry on a non-profit basis through the ASTM.

Improved manufacturing processes have been developed that both improve the corrosion resistance of the incoming material produced by the Zircaloy vendors and further ensure that improved corrosion resistance is maintained throughout the remaining fabrication processing to yield final size fuel rod cladding that is more resistant to in-reactor nodular corrosion. These processes have been implemented in the production of all General Electric fuel to provide a high degree of assurance that adequate corrosion resistant properties are achieved.

V. Conclusions

General Electric has developed a substantial fuel experience base that, coupled with an aggressive fuel surveillance program, has provided significant feedback on statistically significant numbers of fuel rods with regard to the performance effectiveness of design, operational and manufacturing changes. It is concluded that the experience gained with General Electric production and developmental fuel continues to demonstrate the high reliability of the General Electric designed BWR fuel.

VI. References

1. J. S. Charnley (GE) to C. H. Berlinger (NRC), "Post Irradiation Fuel Surveillance Program", November 23, 1983.

2. J. S. Charnley (GE) to L. S. Rubenstein (NRC), "Fuel Sruveillance Program", February 29, 1985.

3. J. S. Charnley (GE) to L. S. Rubenstein (NRC), "Additional Details Regarding Fuel Surveillance Program", May 25, 1984.

4. L. S. Rubenstein (NRC) to R. L. Gridley (GE), "Acceptance of GE Proposed Fuel Surveillance Program", June 27, 1984.

5. B. Cheng, H. A. Levin, R. B. Adamson, M. O. Marlowe, V. L. Monroe, "Development of a Sensitive and Reproducible Steam Test for Zircaloy Nodular Corrosion", ASTM 7th International Conference on Zirconium in the Nuclear Industry, Strasbourg, France, June 24-27, 1985.

Table 1

Summary of Ongoing Lead Test Assembly Surveillance Programs

Program	Reactor	Number of Bundles	Number of Completed Cycles of Operation	Bundle Average Exposure At Last Outage (GWd/MTU)	Objectives
Barrier LTA's	Quad Cities-1	2	5	43	Barrier Cladding
1981 LTA's	Browns Ferry-3	8	1	12	Improved design features
1983 LTA's	Peach Bottom-3	4	2	24	Improved design features
1984 LTA's	Duane Arnold	5	2	28	Improved design features
1987 LTA's	Hatch-1	4	1	12	Lead Use GE8X8NB
Corrosion Performance	Hatch-2	6	-	--	Clad Mat'l Process Variables
1988 LTA's	Cooper	4	-	--	Lead Use GE8X8NB-1 Features

Figure 1

GE 8X8 BWR Fuel Rod Experience

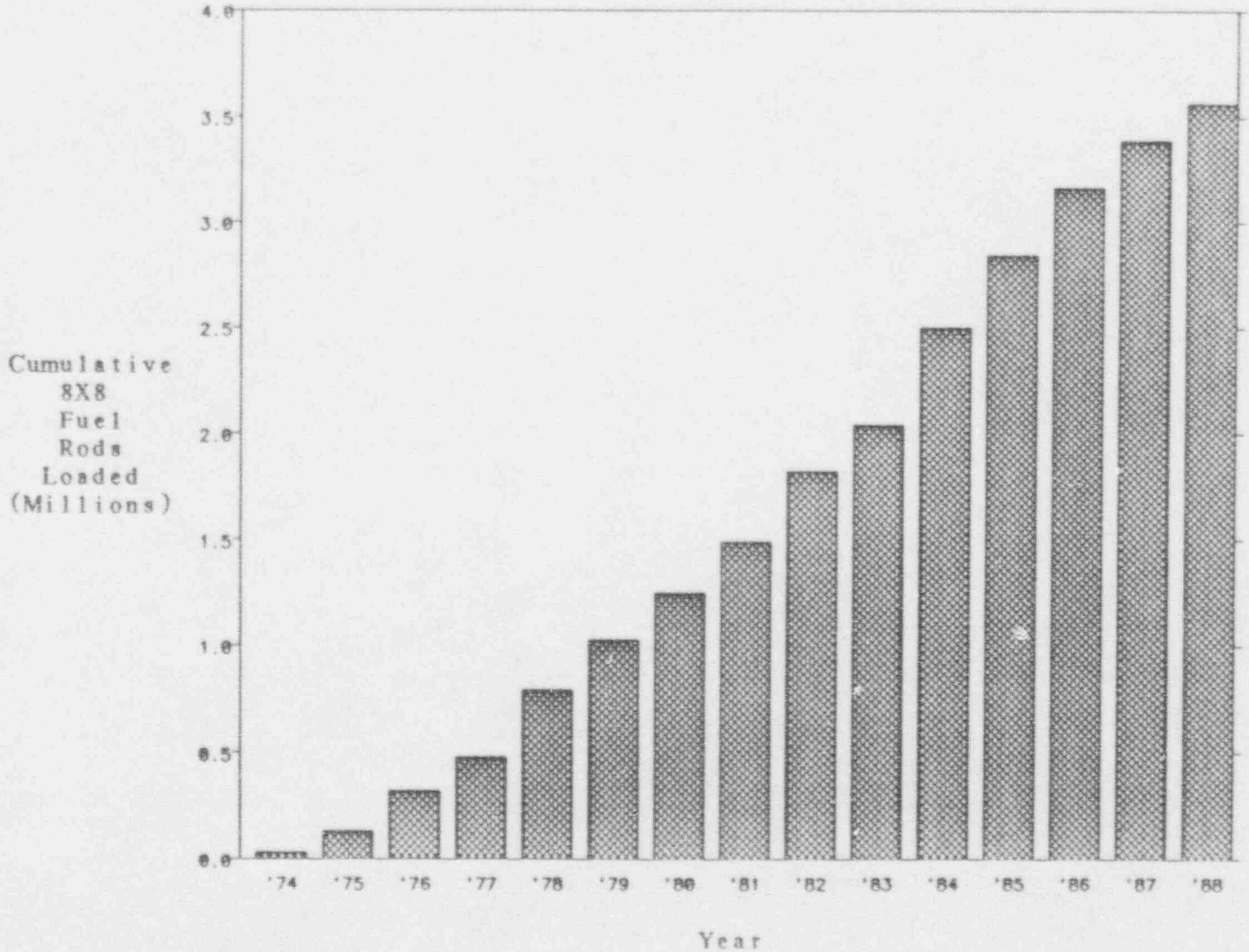

Figure 2

GE BWR Fuel Rods in Operation