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SUBJECT: **GE EXPERIENCE WITH BWR FUEL THROUGH DECEMBER 1990**

Attached is the subject report you requested. This report provides an update of the in-reactor surveillance programs as well as overall GE BWR fuel experience. Please call Gary Jones of my staff on (4[illegible]) 925-1417 if you have any questions relative to this report.

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GE EXPERIENCE WITH BWR FUEL THROUGH DECEMBER 1990

I. Introduction

This information report provides an updated review of GE experience with production and developmental BWR Zircaloy–clad UO_2 fuel rods through December 1990. 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 GE 8X8 fuel types continues to be highly successful as demonstrated by an overall fuel rod reliability rate from 1974 to the end of 1990 of greater than 99.98%.

II. GE BWR Fuel Experience Base

As of December 31, 1990, over 4.0 million GE 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, 1990, over 1.5 million GE fuel rods were in operation. Figure 2 illustrates GE's core loadings at the end of 1990 by fuel type. As of December 31, 1990, GE had loaded approximately 1.37 million pellet–clad interaction (PCI) resistant barrier fuel rods in commercial BWR's. The GE fuel manufacturing facility in Wilmington, North Carolina, is producing 100% of its 1991 load as barrier fuel.

In 1990, sixteen domestic and six overseas GE BWR plants containing GE fuel had refueling outages with over 3300 new GE 8X8 fuel bundles loaded. Nearly 80% of this new fuel loaded was GE's latest production fuel desi... GE8X8EB and GE8X8NB.

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

One of the most important aspects of the GE fuel design process is the in–reactor performance monitoring of a design before and after its introduction. In keeping with the GE philosophy of test–before–use, lead use assemblies (LUA'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 GE and accepted by the NRC is described in References 1 through 4.

A summary of GE's lead use 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 use 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 of Quad Cities–2 in 1981 at the beginning of cycle 6.

The barrier LUA's at Quad Cities–1 operated for up to 5 cycles and underwent five 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.

Six rods were removed from one of the discharged LUA's (at 43000 MWd/MTU) and were then exchanged with 6 rods from a bundle that had completed two cycles of operation. The reload bundle containing the 6 barrier LUA rods was reinserted in Quad Cities 1 for Cycle 11. In November 1990, at the end of Cycle 11, examination of these six rods showed that they continued to exhibit normal performance. They were re–inserted in Cycle 12 for an additional cycle of irradiation.

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, 80 operated for 4 cycles, 32 for 5 cycles and 16 bundles are operating in their 6th cycle.

B. <u>Improved Design Feature Lead Use Assemblies</u>

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

1. <u>1983 Lead Use Assemblies</u>

Four LUAs were loaded into a BWR 4 in 1983. 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. The LUAs returned to service in December 1989. The third poolside examination is planned for October 1991.

2. 1984 Lead Use Assemblies

Five LUAs were loaded into a BWR 4 in 1985. Four of the LUAs were loaded in central core locations and one LUA was loaded at the edge of the core. 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 third cycle of operation ended in July 1990. The four central LUAs achieved bundle exposures of about 40000 MWd/MTU. The edge LUA achieved about 25000 MWd/MTU and was re-inserted for continued operation.

3. 1987 Lead Use Assemblies

Four LUAs were loaded into a BWR 4 in 1987. These fuel assemblies represent lead use GE8X8NB 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. The second poolside examination of these bundles was completed in March 1990, after two cycles of operation, and showed characteristics typical of normal operation. The next poolside examination is scheduled in 1991 after the third cycle of operation.

A second group of four LUAs were loaded into another BWR 4 in 1989 at the beginning of cycle 8. The first poolside examination of these bundles is scheduled in 1991 after the first cycle of operation.

4. Cladding Corrosion Performance LUAs

Six LUAs were loaded into a BWR 4 in early 1988 and six LUAs were loaded into another BWR 4 in late 1988. Features tested include cladding material, heat treatment, and surface conditioning and the most recent corrosion improvement processes. These two reactors have historically exhibited highly variable cladding corrosion performance, even for cladding material taken from the same tubing lot but irradiated in the two different reactors. Three LUAs were examined in the first BWR 4 reactor in late 1989, after one cycle of operation. Another three LUAs were examined in the second BWR 4 reactor in early 1990, also after one cycle of operation. These LUAs reflected bundle average exposures up to 13,000 MWd/MTU. Visual inspection revealed excellent corrosion resistance along the full length of the fuel rods. The second poolside examination of the LUAs is scheduled in March 1991 and in October 1991.

5. GE8X8NB-1 Channel Lead Use Assemblies

Four LUAs were loaded into a BWR 4 in 1988. These LUAs represent lead use of GE8X8NB-1 design features. The first poolside examination of these bundles was completed in April 1989, after one cycle of operation, and showed characteristics

typical of normal operation. The second poolside examination of these bundles was completed in March 1990, after two cycles of operation, and showed characteristics typical of normal operation.

6. GE11 Lead Use Assemblies

In 1990 four GE11 LUAs were loaded in each of three reactors (Two BWR 4s and one BWR 5). Poolside examinations of these bundles are scheduled to begin in 1991.

IV. Generic Fuel Performance Mechanisms

Pellet–cladding interaction (PCI) and crud–induced localized corrosion (CILC) are the primary 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 GE 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 GE in 1983. With the succesful completion of the Quad Cities–2 barrier demonstration program, GE recommended the removal of all PCIOMR operating restrictions on GE barrier fuel. Over 50 reactor cycles of operation have been succesfully completed by GE barrier fuel without restrictive PCIOMR controls. The effectiveness of the GE barrier cladding design feature has been confirmed by the extensive commercial reactor experience where not a single barrier fuel rod failure due to PCI has been observed in over 920,000 GE barrier fuel rods completing at least one cycle of operation. PCI failures are expected to be eliminated within the next few years as the population of non–barrier fuel (29% of all GE fuel currently in operation is non–barrier) is discharged.

B. Crud–Induced Localized Corrosion

In 1979, an unexpected 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 GE 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.

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 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 GE fuel to provide a high degree of assurance that adequate corrosion resistant properties are achieved.

V. Conclusions

GE 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 GE production and developmental fuel continues to demonstrate the high reliability of the GE 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 Surveillance 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 Use Assembly Surveillance Programs

Program	Reactor Class	Number of Bundles	Number of Completed Cycles of Operation[1]	Bundle Average Exposure At Last Outage (GWd/MTU)	Objectives
Barrier LUA's	BWR 3	2	5*	43	Barrier Cladding
1983 LUA's	BWR 4	4	2	24	Improved design features
1984 LUA's	BWR 4	1	3	25	Improved design features
1987 LUA's	BWR 4	4	1	12	Lead Use GE8X8NB
Corrosion Performance	BWR 4	6	1	13	Clad Mat'l Process Variables
GE8X8NB-1 Channel LUA's	BWR 4	4	2	15	Lead Use GE8X8NB-1 Features
Corrosion Performance	BWR 4	6	1	12	Clad Mat'l Process Variables

(1) As of December 1990
* Six fuel rods have been reirradiated for a 6th cycle to average exposures of 50 GWd/MTU

Table 1. Continued
Summary of Ongoing Lead Use Assembly Surveillance Programs

Program	Reactor Class	Number of Bundles	Number of Completed Cycles of Operation	Bundle Average Exposure At Last Outage (GWd/MTU)	Objectives
1987 LUA's	BWR 4	4	–	–	Lead Use GE8X8NB
GE11 LUA's	BWR 4	4	–	–	Lead Use GE11
	BWR 4	4	–	–	
	BWR 5	4	–	–	

Figure 1
GE 8X8 BWR Fuel Rod Experience

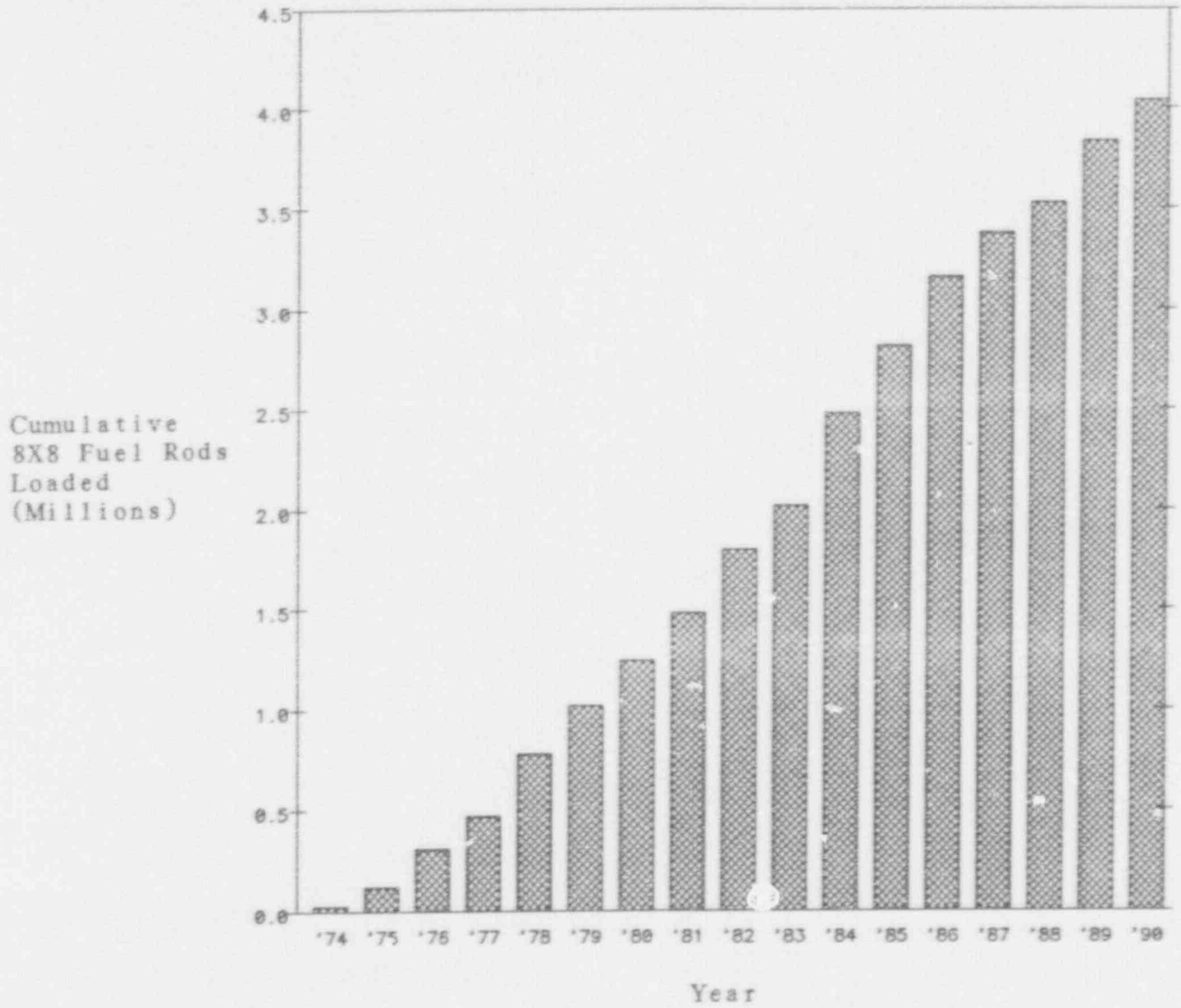

Figure 2
GE BWR Fuel Rods in Operation on 12/31/90