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Proposed Peach Bottom Atomic Power Station Unit 3 Alternate Absorber Control Blade Test Program

Approved: R. O. Brugge

R. O. Brugge, Manager
Services Licensing

BOILING WATER REACTOR PROJECTS DEPARTMENT • GENERAL ELECTRIC COMPANY
SAN JOSE, CALIFORNIA 95125
GENERAL ELECTRIC

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1018 222

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

1018 224

1. INTRODUCTION

It is proposed that an Alternate Absorber Control Blade Test Program be conducted at the Peach Bottom Atomic Power Station Unit 3 during fuel Cycle 4, (Reload 3), and Cycle 5 (Reload 4). The purpose of this test program is to obtain data on the performance of hafnium in a Boiling Water Reactor (BWR) environment. The primary parameters of interest are: (1) the corrosion rate, and (2) radiation growth. This series of tests is part of an improvement program to extend the useful operating life of BWR control blades.

1018 225

2. TEST PROGRAM DESCRIPTION

The Alternate Absorber Control Blade Test Program consists of the following major activities.

One standard control rod in the reactor core will be replaced with the test control rod. The test control rod contains five solid hafnium rods in each wing (Figure 3-1), which replace five standard boron carbide (B_4C) absorber rods. The control blade mechanical design has been modified to allow the removal of the edge rod in each wing. The mechanical design of the test control rod is described in Section 3.0.

The test control rod will be operated as a normal control rod during reactor operation.

After one fuel cycle, four irradiated hafnium edge rods will be removed and replaced with four fresh hafnium rods. The test control rod will be removed after two fuel cycles.

The irradiated hafnium rods which are removed from the test control rod will be shipped to General Electric's Vallecitos nuclear facility for examination and data collection.

The performance of this test program at Peach Bottom 3 is desirable because of the high power density in the core, and the control cell core mode of operation. This mode of operation allows the maximum control rod burnup in the shortest period of time. Also, the control blade would almost continually be in a high radiation field. This will maximize the radiation growth of the hafnium absorber rods.

The particular core locations in the Peach Bottom 3 reactor core which would be most desirable for the test control blade are: 22-31, 38-31, 30-23, or 30-39. These are expected to be the locations of highest control blade exposure in the core. However, other high control blade exposure locations in the core are also acceptable.

3. TEST CONTROL ROD

The test control rod is a standard control rod which has been modified as described below.

The test control rod contains twenty (20) solid hafnium rods (five per wing), and sixty-four (64) stainless steel tubes containing boron carbide (B_4C), as shown in Figure 3-1. The solid hafnium rods are the test material. The hafnium rods are spaced in the wings to obtain maximum data on irradiation growth due to fast neutron fluence.

The control blade mechanical design has been modified to allow the removal of the rod at the outer edge. The handle at the top of the test control rod is cut back as shown in Figure 3-2. A "U" shaped clip (Figures 3-2 and 3-3), made from the same material as the sheath, is welded to the handle. The sheath is cut out to allow the "U" shaped clip to be installed on the handle. The edge rod is slightly longer than the other hafnium and B_4C rods in the sheath (which are all of the same standard length). The tab, which is an integral part of the clip, extends above and over the edge rod, forming an "L" shaped stop at the top of the rod.

When removal of the edge rod is desired, the tab is removed, and the rod is grasped and pulled out of the blade. A new rod (slightly shorter in length) is inserted in the edge rod position and the clip structure below the tab is crimped to hold the new rod in place.

The test control rod modifications, including the clip and its integral "L" shaped tab have been evaluated for the worst case loading, which results from a cold control rod drive failed buffer scram. The results indicate that the tab will restrain the edge rod during both normal and abnormal operating conditions.

1018 227

1018 229

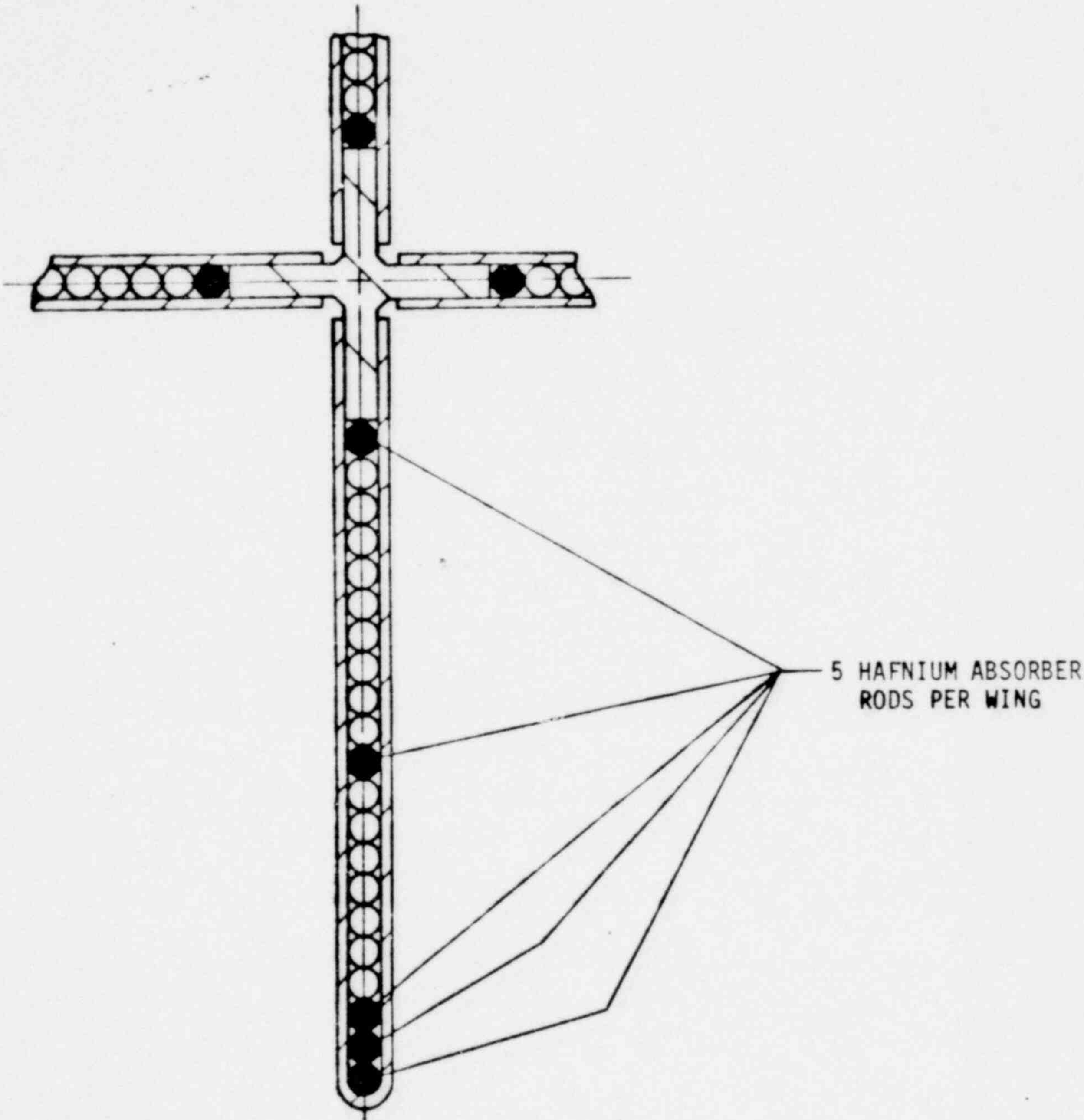


Figure 3-1. Location of Hafnium Absorber Rods

1018 228

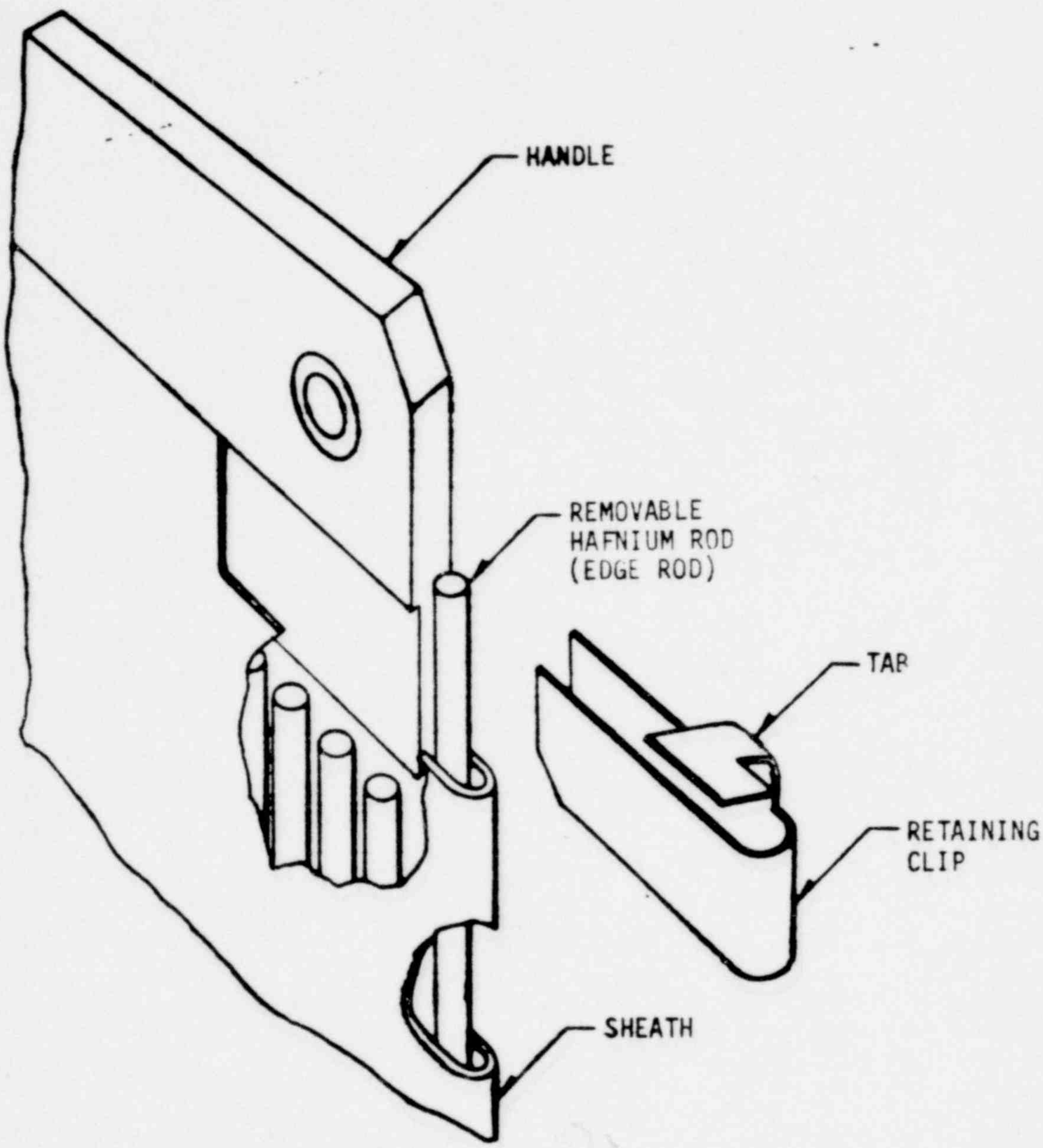


Figure 3-2. Edge Rod Retaining Clip Prior to Installation

1018 229

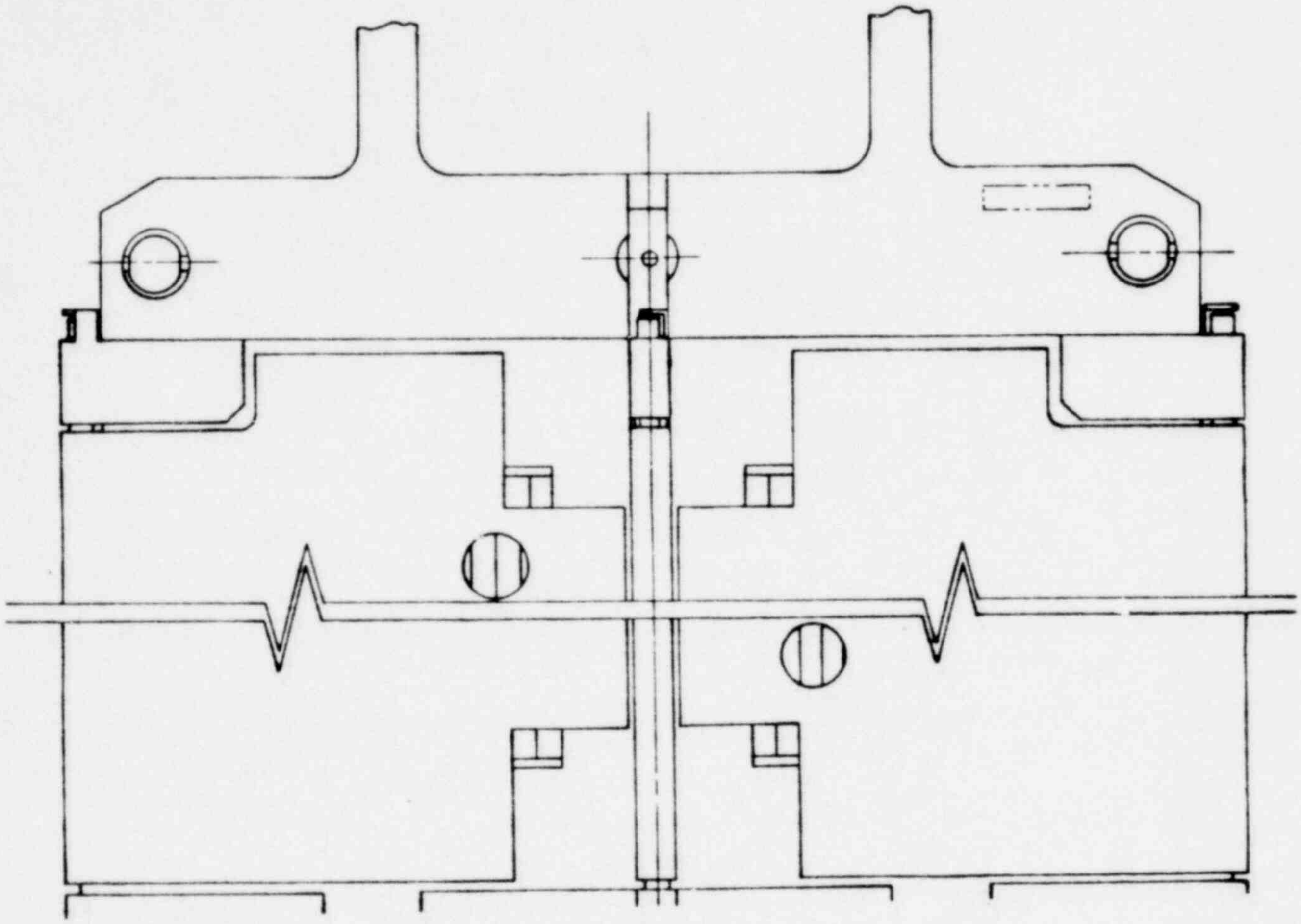


Figure 3-3. Edge Rod Retaining Clip Installed

1018 230

4. HAFNIUM ABSORBER RODS

Hafnium is a well known neutron absorbing material which has a long nuclear lifetime due to its ability to decay into other high cross-section hafnium absorber isotopes. Most of the reactor experience with hafnium is in naval pressurized water reactors, where hafnium has been used extensively as the control blade material. It has also been used in the Shippingport Atomic Power Station pressurized water reactor.

4.1 Corrosion Resistance

Almost all data available on hafnium corrosion in a reactor environment is under pressurized water conditions. Bare hafnium control blades were used in the Experimental Boiling Water Reactor (EBWR), but no quantitative data on corrosion is readily available for these control blades.

Data on the corrosion of hafnium are presented in References 1 through 4. Tables 4-1 and 4-2 present data from Reference 1 on the corrosion of hafnium of various chemical compositions. Figure 4-1 provides a graphical representation of the data in Table 4-2. The data in Figure 4-1 show that hafnium has very good corrosion resistance. The minimal corrosion which occurs under such conditions has made detailed measurements difficult. The data show that the oxide layer formed is only 1×10^{-6} inch thick after 200 days in water at 540°F. In addition, after approximately 30 days at 540°F, the rate of oxide layer growth becomes small, and remains relatively constant with time.

Table 4-3 (from Reference 2) shows the superior corrosion resistance of hafnium compared to Zircaloy 2 at various temperatures in water and in steam. Figure 4-2, from the same reference, shows the effect of the nitrogen content in hafnium on its corrosion resistance in 680°F water and 750°F steam. The average nitrogen content of the hafnium to be used for the absorber rods in the test program at Peach Bottom 3 is 26 ppm (Table 4-4), which is equal to the lowest value of nitrogen shown in the curves.

Figure 4-3 (from Reference 3) shows data reported by the Bettis Atomic Power Laboratory on the corrosion of hafnium at different temperatures in water and in steam. Table 4-5 (from Reference 4) gives irradiated corrosion data from the Shippingport Reactor.

While almost no quantitative data is available on hafnium under boiling water reactor conditions, it is expected that corrosion in a boiling water environment, even if significantly greater than under pressurized water reactor conditions, will be minimal, and fully acceptable. Corrosion of the hafnium rods to be used in the test program is expected to be low, particularly in view of the low average nitrogen content (26 ppm). However, one of the objectives of the test program is to quantitatively determine the actual corrosion rate under boiling water reactor operating conditions.

4.2 Radiation Growth

Detailed radiation growth data for hafnium is not available except in nuclear naval reactor programs. The radiation growth of hafnium is expected to be less than that of Zircaloy. The retaining clip and its integral "L" shaped tab are designed to account for the radiation growth of the hafnium edge rod. One of the objectives of the test program is to quantitatively determine the radiation growth of the hafnium absorber rods under boiling water reactor operating conditions.

4.3 Nuclear Characteristics

Data on the nuclear characteristics of hafnium are available, including cross-section data. Hafnium cross-section data will be available in the ENDF/B-V library system maintained by the Brookhaven National

Laboratory. Formal documentation of the ENDF/B-V data, which update the previous ENDF/B-IV data (Reference 5), will not be released until work on all of the libraries is completed. However, General Electric has the incomplete ENDF/B-V libraries, which include the completed cross-section data on the hafnium isotopes.

Using the hafnium data from the ENDF/B-V library, the worth of the test control rod is 0.0035 ΔK less than a standard B_4C control rod. This is equivalent to a 2% reduction in the relative control rod worth at the beginning-of-life. The end-of-life of a control rod is defined as a 10% reduction in the relative worth of the control rod. Therefore, the 2% reduction in the relative worth of the test control rod at the beginning-of-life is only one-fifth of the reduction in relative worth which defines the end-of-life of a control rod.

Since the control rod that the test control rod will be replacing has been in service for several years, its reduction in relative worth will be greater than or equal to 2%. Therefore, the worth of the test control rod will be equal to, or slightly greater than, the worth of the control rod being replaced. This means that the previously calculated shutdown margin for the Reload 3 core (Reference 6) will not be reduced with the test control rod in the Reload 3 core.

Also, because the worth of the test control rod is equal to, or slightly greater than, the worth of the control rod being replaced, the control rod drop accident and the rod withdrawal error event results previously reported for the Reload 3 core (Reference 6) are unchanged with the test control rod in the Reload 3 core.

Because the test control rod is designed to the same end-of-life criteria as the standard B_4C control rod, and because the worth of the test control rod is equal to, or greater than, the worth of the control rod being replaced, the scram reactivity functions reported for the Reload 3 core (Reference 6) are unchanged with the test control rod in the Reload 3 core.

TABLE 4-1

CHEMICAL ANALYSIS OF HAFNIUM

%		PPM							
Hf	Zr	W	Fe	Si	Cu	Ti	Al	N_2	U
Bal.	1.1	100	190 83*	35	10	8	25	-	-
(95.3) min	(4.5) max	(150) max	(500) max	-	(100) max	(100) max	(100) max	(100) max	(200) max

* Wet chemical analysis

() Values in parentheses represent the military specifications for reactor grade hafnium

TABLE 4-2

CORROSION OF HAFNIUM (REFERENCE 1)

DAYS -- Mg/Dm^2

	No.	7	14	28	42	46	70	84	98	112	140	163	168	191	196
540°F Water	1	1.4	2.0	1.7	1.7	2.0	2.6	-	2.3	2.8	2.3	2.0		2.8	
	5	1.1	1.7	2.3	2.3	1.7	2.3	-	2.6	2.3	2.3	2.3		2.8	
	9	0.9	1.4	1.7	1.4	1.7	1.1	-	2.3	2.0	2.3	1.7		2.8	
	11	0.6	1.4	1.4	1.1	1.2	0.9	-	1.7	0.9	1.1	1.1		2.0	
	Avg.	1.0	1.6	1.8	1.6	1.6	1.7	-	2.2	2.0	2.0	1.8		2.6	
680°F Water	2	2.8	4.0	4.8	4.8	5.1	5.7	-	6.8	7.7	6.5		6.8		8.3
	6	2.3	3.7	4.6	4.9	4.6	5.4	-	5.7	6.8	6.0		6.8		8.0
	7	2.8	3.[illegible]	4.3	4.9	4.8	5.4	-	6.3	7.4	6.3		6.8		8.0
	12	2.0	3.4	4.3	4.0	4.3	4.6	-	5.4	6.8	6.0		6.0		7.4
	Avg.	2.5	3.6	4.5	4.7	4.7	5.3	-	6.1	7.2	6.2		6.6		7.9
750°F Steam	3	4.5	7.7	13.1	14.5	17.4	20.8	26.5	30.8						
	4	4.8	8.5	12.8	14.2	16.4	19.8	25.5	29.8						
	8	3.7	7.7	12.8	13.9	16.7	20.1	26.1	30.9						
	10	3.1	7.1	11.4	11.9	14.5	17.9	24.7	29.0						
	Avg.	4.0	7.8	12.5	13.6	16.3	19.7	25.7	30.1						

1018 235

TABLE 4-3

CORROSION OF HAFNIUM* (REFERENCE 2)

(Weight Increase in Mg/Dm^2)

TIME (DAYS)	600°F WATER		680°F WATER		750°F STEAM	
	HF	ZR-2	HF	ZR-2	HF	ZR-2
44	5	14	6-9	27	4-7	48
195	6	21	7-9	65	7	210
234	-	23	-	100	9	300

* Crystal Bar

TABLE 4-4

HAFNIUM ABSORBER ROD CHEMICAL ANALYSIS

DESCRIPTION: Hafnium Rod - Annealed

DIMENSIONS: 0.188" dia. x 147" L

The test report follows:

NUCLEAR GRADE

INGOT ANALYSIS IN PPM

	Spec.	Top	Middle	Bottom
Al	100	<35	NA	<35
C	150	<30	NA	<30
Nb	100	<50	NA	<50
Cr	200	<20	NA	<20
H	25	<5	NA	<5
Fe	500	140	NA	151
Mo	20	<5	NA	<5
Ni	50	<25	NA	<25
N	100	28	NA	24
O	400	230	NA	210
Si	60	39	NA	46
Ta	200	<100	NA	<100
Ti	100	<25	NA	<25
Sn	30	<10	NA	<10
W	150	<10	NA	<10
U	10	1.5	NA	2.2
U-235	.07	0.0166	--	--
V	50	<10	NA	<10
Zr	4.5% max.	1.8%	NA	1.9%

TABLE 4-5

OXIDE FILM THICKNESS ON IRRADIATED HAFNIUM

Thermal Neutron (<0.625 eV) Exposure n/cm^2	Measured		Measured Thickness μ	Calculated Value of Oxidation Weight Gain mg/dm^2
	% Ta	% Lu		
4.17×10^{20}	0.34	0.02	0.62	4.4
5.15×10^{20}	0.40	0.02	0.45	3.2
6.16×10^{20}	0.57	0.03	0.71	5.0
7.61×10^{20}	0.65	0.04	0.55	3.9
11.60×10^{20}	1.02	0.05	0.32	2.3
0			0.65	4.7 (measured)

1018 238

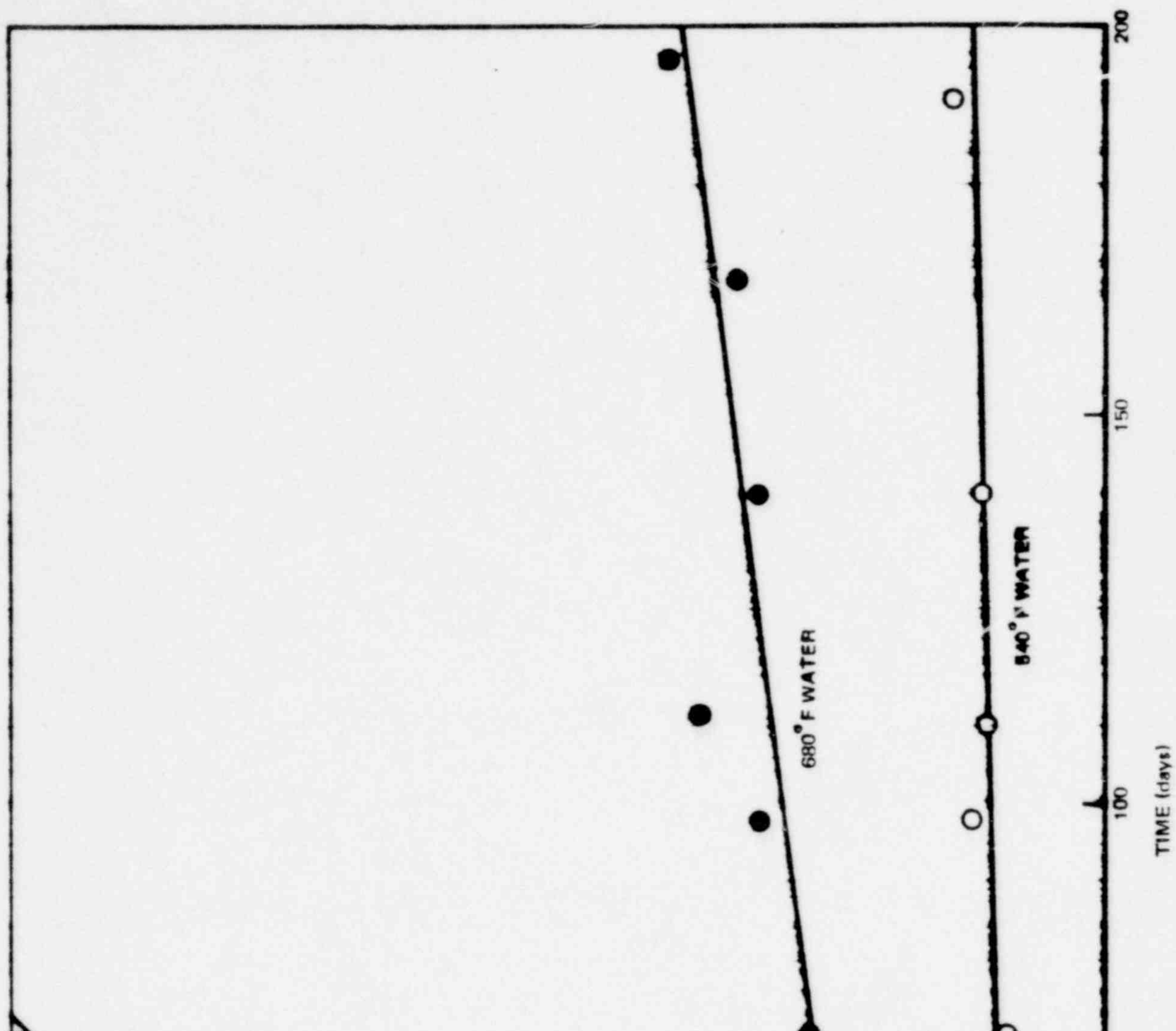
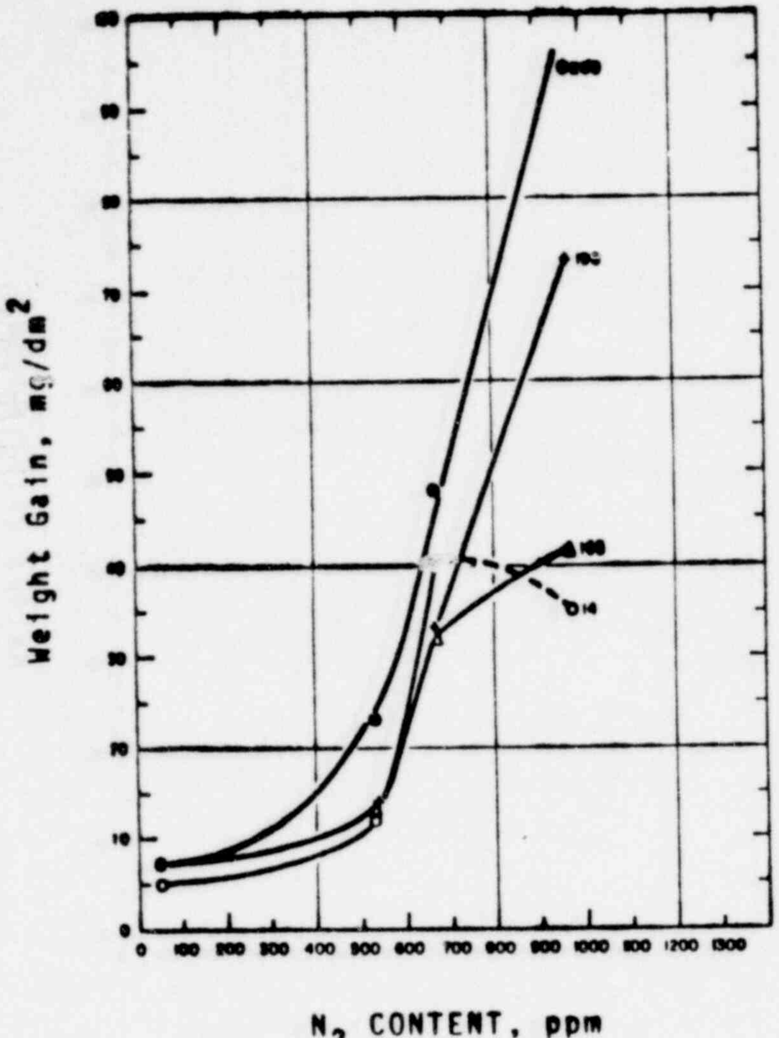
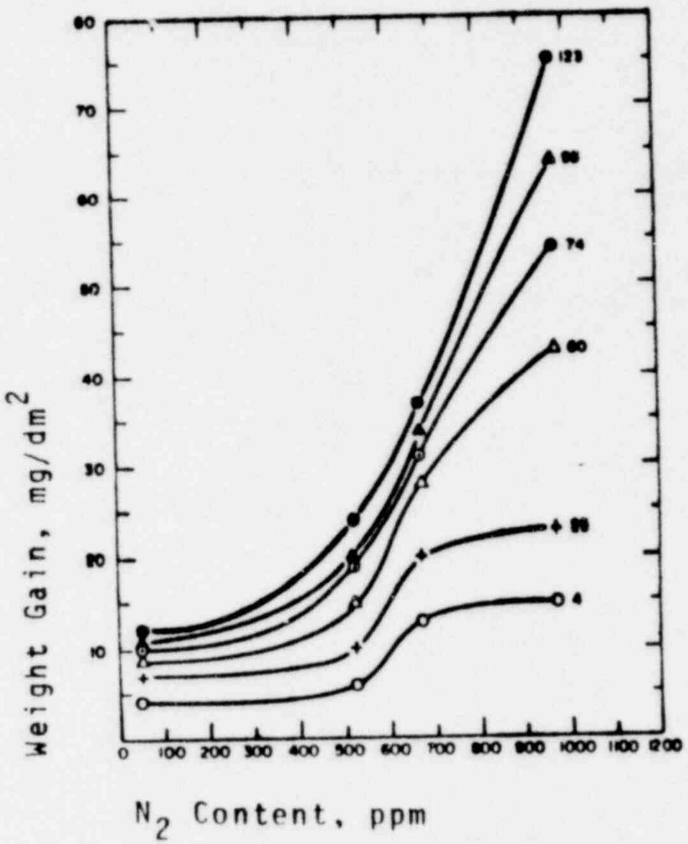


Figure 4-1. Corrosion of Hafnium (Reference 1)



Weight Gain vs. Nitrogen Content for Hafnium in 680°F Water at Saturation Pressure. Numbers on Curves Refer to Exposure Time in Days.



Weight Gain vs. Nitrogen Content for Hafnium in 750°F Steam at 1,500 psi. Numbers on Curves Refer to Exposure Time in Days.

Figure 4-2. Effect of Nitrogen Content on Corrosion of Hafnium

1018 240

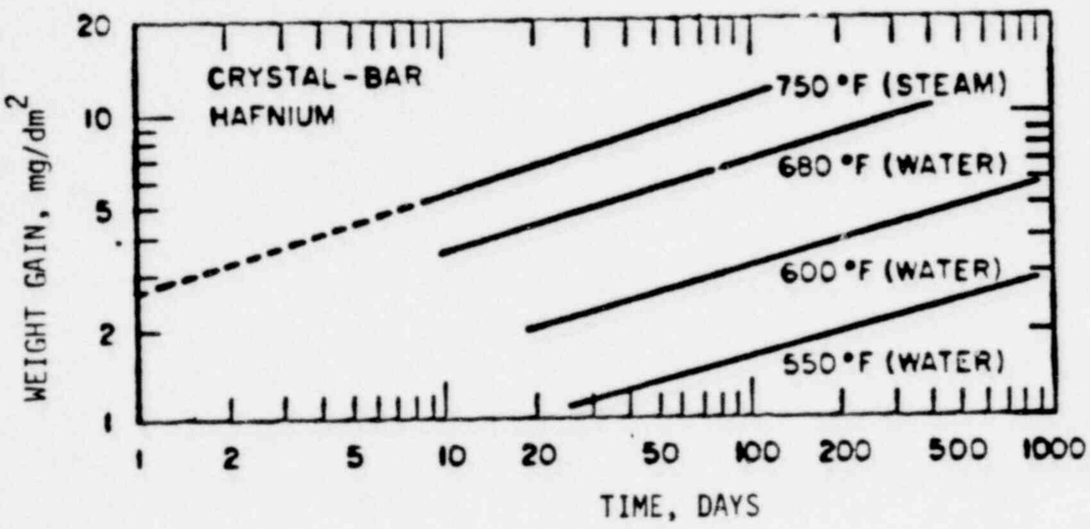


Figure 4-3. Corrosion of Hafnium (Reference 3)

1018 241

5. SAFETY EVALUATION

The results of the safety analysis presented in the Peach Bottom 3, Reload 3, licensing amendment submittal (Reference 6) are not affected by the use of the test control rod in the Reload 3 core during Cycle 4 operation.

As previously mentioned in Section 4.3, the worth of test control rod is equal to, or slightly greater than, the worth of the control rod being replaced. Therefore, the control rod drop accident, and the rod withdrawal error event results previously reported for the Reload 3 core (Reference 6) are unchanged with the test control rod in the Reload 3 core.

Hafnium is heavier than B_4C. This results in a 26 lbm. increase in the total test control rod weight. The effect of this increased weight is a slight increase in scram time. The calculated increase in scram time of the test control rod for 5%, 20%, 50%, and 90% insertion is given in Table 5-1. The effect of the slight increase in the scram times for a single control rod (the test control rod) on the core average scram times employed in the Reload 3 licensing amendment submittal (Reference 6) is negligible, and the critical power ratio (ΔCPR) results for all of the abnormal operational transients reported in the Reload 3 licensing amendment submittal are unchanged.

The proposed test program could be implemented under the provisions of 10CFR50.59, except that a change to the Technical Specifications is required. This is discussed in Section 6. However, the other requirements of 10CFR50.59 are satisfied by the proposed test program, as discussed below.

The first requirement of 10CFR50.59 is that a proposed change in a facility, or the operating procedures, shall not increase the probability of occurrence or the consequences of an accident or malfunction of equipment important to safety. The proposed test program meets this requirement, since it has been shown above that the Reload 3 safety analysis (Reference 6) is not affected by operation with the test control rod.

The second requirement of 10CFR50.59 is that the possibility of an accident or a malfunction of a different type than any evaluated previously in the safety analysis report shall not be created. This requirement is also satisfied for the proposed test program. In Section 3 it was stated that the test control rod modifications have been evaluated for the worst case loading. The results indicate that the tab will restrain the edge absorber rods during both normal and abnormal operating conditions. Therefore, an accident or malfunction of a different type than any previously evaluated will not occur during operation with the test control rod.

The third requirement of 10CFR50.59 is that the margin of safety as defined in the basis for any technical specification is not reduced. This requirement is also satisfied. The operating limits defined in the Reload 3 licensing amendment submittal (Reference 6) are unaffected by the use of the test control rod. The shutdown margin is also unaffected. Therefore, the margins of safety as defined in the basis for the Technical Specifications are not reduced by the test control rod.

However, changes can only be implemented under 10CFR50.59 if, in addition to satisfying the above requirements, no changes to the Technical Specifications are required. The proposed test program does require a change to the Peach Bottom 3 Technical Specifications, as discussed in Section 6.

TABLE 5-1

TEST CONTROL ROD SCRAM TIME INCREASE

% INSERTION	SCRAM TIME INCREASE (SEC)
5	0.008
20	0.015
50	0.026
90	0.05

1018 244

6. PROPOSED TECHNICAL SPECIFICATION CHANGE

To conduct the proposed test program a temporary change must be made in Section 5.2 of the Peach Bottom 3 Technical Specifications.

Specification 5.2.C currently limits the control material to boron carbide powder. The specification reads as follows:

> The reactor core shall contain 185 cruciform-shaped control rods. The control material shall be boron carbide powder (B_4C) compacted to approximately 70% of the theoretical density.

It is proposed that this specification be changed to permit operation with one control rod (the test control rod) containing up to 20 solid hafnium absorber rods in place of a corresponding number of B_4C absorber rods. The test control rod will replace one standard control rod in the core.

1018 245

7. REFERENCES

1) B.E. Dearing and A.M. Andrako, "Corrosion Behavior of Hafnium in Aqueous Media as a Function of Temperature", KAPL-M-BED-3 August, 1961.

2) D.E. Thomas and E.T. Hayes, "The Metallurgy of Hafnium", Naval Reactors, Division of Reactor Development, AEC.

3) "A Compilation of the Properties of Hafnium", Bettis Atomic Power Laboratory, WAPD-TM-528.

4) G.J. Salvaggio, "Hafnium Control Rod Behavior in the Shippingport Pressurized Water Reactor", Nuclear Applications, Vol. 5, July, 1968.

5) "Data Formats and Procedures for the Evaluated Nuclear Data File, ENDF", BNL-NCS-50496 (ENDF 102), TID-4500, October 1974.

6) Supplemental Reload Licensing Submittal For Peach Bottom Atomic Power Station Unit 3 Reload No. 3, NEDO-24204A, July, 1979.

1018 246