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March 1, 2000

U. S. Nuclear Regulatory Commission
ATTN: Document Control Desk
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Subject: River Bend Station - Unit 1
Docket No. 50-458
License No. NPF-47
Licensee Event Report 50-458/99-016-00

File Nos. G9.5, G9.25.1.3

RBG-45275
RBF1-00-0030

Ladies and Gentlemen:

Enclosed is the subject Licensee Event Report. The report is being filed voluntarily, due to the potential generic applicability of this condition. No commitments are identified in this report.

Sincerely,

Rick J. King

RJK/dhw
Attachment
Enclosure

IE22

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NRC FORM 366 U.S. NUCLEAR REGULATORY COMMISSION (6-1998) **LICENSEE EVENT REPORT (LER)** (See reverse for required number of digits/characters for each block)	**APPROVED BY OMB NO. 3150-0104 EXPIRES 06/30/2001** Estimated burden per response to comply with this mandatory information collection request: 50 hrs. Reported lessons learned are incorporated into the licensing process and fed back to industry. Forward comments regarding burden estimate to the Records Management Branch (T-6 F33), U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001, and to the Paperwork Reduction Project (3150-0104), Office of Management and Budget, Washington, DC 20503. If an information collection does not display a currently valid OMB control number, the NRC may not conduct or sponsor, and a person is not required to respond to, the information collection.

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TITLE (4)
Thermally-Induced Accelerated Corrosion of BWR Fuel

EVENT DATE (5)			LER NUMBER (6)			REPORT DATE (7)			OTHER FACILITIES INVOLVED (8)	
MONTH	DAY	YEAR	YEAR	SEQUENTIA NUMBER	REVISION NUMBER	MONTH	DAY	YEAR	FACILITY NAME	DOCKET NUMBER 05000
04	20	1999	1999	--016--	00	03	01	2000	FACILITY NAME	DOCKET NUMBER 05000

OPERATING MODE (9)	5	THIS REPORT IS SUBMITTED PURSUANT TO THE REQUIREMENTS OF 10 CFR §: (Check one or more) (11)							
			20.2201(b)		20.2203(a)(2)(v)		50.73(a)(2)(i)(B)		50.73(a)(2)(viii)
POWER LEVEL (10)	0		20.2203(a)(1)		20.2203(a)(3)(i)		50.73(a)(2)(ii)		50.73(a)(2)(x)
			20.2203(a)(2)(i)		20.2203(a)(3)(ii)		50.73(a)(2)(iii)		73.71
			20.2203(a)(2)(ii)		20.2203(a)(4)		50.73(a)(2)(iv)	X	OTHER
			20.2203(a)(2)(iii)		50.36(c)(1)		50.73(a)(2)(v)		Specify in Abstract below or in NRC Form 366A
			20.2203(a)(2)(iv)		50.36(c)(2)		50.73(a)(2)(vii)		

LICENSEE CONTACT FOR THIS LER (12)	
NAME	TELEPHONE NUMBER (Include Area Code)
D. N. Lorfing, Supervisor – Licensing	225-381-4157

COMPLETE ONE LINE FOR EACH COMPONENT FAILURE DESCRIBED IN THIS REPORT (13)									
CAUSE	SYSTEM	COMPONENT	MANUFACTURER	REPORTABLE TO EPIX	CAUSE	SYSTEM	COMPONENT	MANUFACTURER	REPORTABLE TO EPIX

SUPPLEMENTAL REPORT EXPECTED (14)				EXPECTED	MONTH	DAY	YEAR
	YES (If yes, complete EXPECTED SUBMISSION DATE).	X	NO				

ABSTRACT (Limit to 1400 spaces, i.e., approximately 15 single-spaced typewritten lines) (16)

On April 20, 1999, with the plant in Mode 5 for a refueling outage, plant personnel documented an unusually heavy deposition of crud on fuel bundles (*AC*) removed following the preceding operating cycle (Cycle 8). A root cause investigation was performed. The information gathered and conclusions reached during the root cause process are of such relevance to the industry and the NRC that a voluntary report was deemed appropriate.

An exact root cause was not identified, but the investigation indicates that multiple factors contributed to an accelerated corrosion of the fuel cladding in the highest-powered fuel bundles during Cycle 8. The heaviest deposition was discovered on the first-cycle fuel. Corrective actions were developed through River Bend's root cause analysis process, and these will aid in preventing recurrence of the crud deposition which induced the corrosion by thermally insulating the fuel rods.

Safety significance was evaluated for the increased crud level and for the clad perforations. The significance of the perforations was low, since they are considered in the licensing basis. Significance of the elevated crud level was determined to be acceptable through a process which included engineering judgement, combined with analyses of various plant conditions.

REPORTED CONDITION

On April 20, 1999, with the plant in Mode 5 for a refueling outage, plant personnel documented an unusually heavy deposition of crud on fuel bundles (*AC*) removed following the preceding operating cycle (Cycle 8). (Crud is a colloquial term for corrosion and wear products, e.g., rust particles, that become activated when exposed to radiation.) A root cause investigation did not reveal that the higher-than-normal crud levels existing at River Bend Station (RBS) warranted a report pursuant to 10 CFR 50.72 or 10 CFR 50.73. The information gathered and conclusions reached during the root cause process, however, are of sufficient relevance to the industry and the NRC that a voluntary report was deemed appropriate. Therefore, Entergy Operations, Inc. (EOI), is submitting a voluntary event report to document the thermally induced accelerated corrosion phenomenon discovered at RBS.

BACKGROUND

On September 18, 1998, a fuel element cladding defect was indicated by offgas (*WF*) chemistry sample data. Operations personnel requested the sample after noting an offgas pretreatment alarm (*RA*) during control rod drive (*AA*) operability testing. Immediate actions included re-sampling to verify results, informing plant management, and increasing the sampling frequency to once per day. Actions were taken in accordance with procedure ADM-0084, "Fuel Integrity Monitoring Program and Failed Fuel Action Plan." Operations personnel also verified that the thermal limits remained within the plant Technical Specifications 3.2.1, 3.2.2, and 3.3.3. A report was issued, pursuant to 10 CFR 50.72(b)(2)(vi), when the State of Louisiana was notified of the indication.

Additional fuel element cladding defects were indicated during the remainder of the operating cycle. These additional fuel element cladding defects were indicated by increases in the offgas activity and the guidance of ADM-0084 was followed. Reports were issued, pursuant to 10 CFR 50.72(b)(2)(vi), when the State of Louisiana was notified of the indications. Reactor power in the vicinity of the indicated defects was suppressed through control rod (*AC*) insertion, and this successfully mitigated the activity release consequences of the defects. Power operation continued until April 3, 1999, when RBS shutdown for refueling outage no. 8 (RF-8).

The bundles suspected to have experienced fuel clad perforations were those first-cycle bundles loaded into the reactor core for the previous Cycle 8 operation. These first cycle bundles were manufactured with a serial number which included the designation HGE. Visual inspection and telescopic sipping of the bundles during the refueling outage confirmed that all of the perforations did occur in a total of seven HGE fuel bundles.

Upon initial visual examination of selected fuel bundles with potential fuel cladding defects, the fuel inspectors noticed an unusually heavy deposition of crud on the fuel pins. Following the identification of the crud buildup, a multidiscipline team was instituted to determine the relationship of this material to the fuel element cladding defects. Additional fuel bundles were selected for examination, and other actions were initiated to address the issues.

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INVESTIGATION

Fuel inspection was conducted at RBS during RF-8 to determine the cause and extent of the fuel cladding defects, and to determine the population of fuel bundles acceptable for use in the next cycle. Inspections included not only HGE fuel (i.e., first-burned fuel), but also GGE (twice burned) and YJ8 (thrice burned) fuel in the reactor (*RCT*) during Cycle 8. Bundles that were not operated in the core during this cycle were inspected to establish a baseline for the observations. Bundles from Cycle 6 and Cycle 7 at RBS were inspected. Inspection data were also obtained for bundles that operated in similar plants that have operated with high feedwater iron concentrations.

The following are observations specific to the HGE bundles, which were the only bundles that experienced cladding perforations.

- The perforations were due to cladding corrosion, which appears to be related to the thermal effects of high crud loading. Limited spalling patterns were observed on the highest power rods.
- The rods with perforations had heavy crud with clumpy formations.
- The perforations were at about the 50" elevation on the rods.
- The perforations were in HGE (first-burned) fuel.
- The affected HGE bundles had Linear Heat Generation Rates (LHGR) at the 50" level that were in the top 3% of the entire core power levels during the first control rod sequence of Cycle 8 operation.
- All but one of the affected bundles had a shallow control blade adjacent to the bundle during the first control rod sequence.
- The bundles with perforations were in the high-powered core ring.

In determining causal factors for the observations noted above, various facets were investigated. The investigation is divided into two sections: an investigation of the crud itself; and an investigation of the differences in operational parameters between Cycle 7, which had no clad defects, and Cycle 8, which had multiple clad defects.

<u>Crud</u>

The amount of crud observed during the fuel inspections was higher than normal. The observed iron deposits are the result of the input from the feedwater stream combined with a chemistry excursion which occurred during startup from RF-7. The chemistry excursion manifested itself as a conductivity excursion that began at the point of heater drain (*SM*) pumped-forward operation and persisted for approximately three weeks (10/23/97 to 11/15/97). The conductivity excursion, which qualitatively accounts for the balance of the iron noted on the fuel, beyond that accounted for in the feedwater stream, is believed to have contributed to the onset of the cladding corrosion condition. At the time of the excursion, there was no reason to suspect it would affect crud deposition on the fuel.

In response to this condition, the investigation included an examination of locations that might contain an inventory of iron oxides available for future release. These areas included the main condenser (*SG*) and the condensate storage tank (*KA*) by direct visual and sampling, and the reactor vessel by running the reactor water cleanup (RWCU) (*CE*) loop aligned to the bottom head, where no flow restriction was noted. Only the condenser exhibited any significant inventory of iron oxides and copper, which was removed during RF-8. Flow accelerated corrosion (FAC) program results did not indicate unusual wear that could account for the level of iron found in the vessel.

Chemistry analysis history was reviewed for any significant anomalies that could have caused either the crud deposition, or the accelerated corrosion. The one extended period of a conductivity spike, with a gradual return to normal over a three-week period early in the cycle, was unusual. The review indicates that plant parameters were within the EPRI guidelines for operation of the plant.

The potential for a chemical intrusion (as a direct corrosive agent) was also considered. Data for plant chemistry during RF-7, including the residual heat removal (RHR) (*BO*) chemical cleaning conducted for the first time during the outage, and the forced outage in April 1998 were reviewed. No evidence of a significant chemical intrusion thought to be capable of affecting the core was identified.

Cycle Differences

A synergy among various parameters related to plant chemistry and core operation is required, in conjunction with the iron deposits, to adequately explain the corrosion phenomenon. A review of parameters that changed in any significant way between Cycle 7 and Cycle 8 was performed.

- The amount of iron input to the reactor vessel increased by ~70% in Cycle 8, versus Cycle 7, due in part to the removal of low cross-linked resins from service in the condensate demineralizers (*SF*). This removal was done because of sulfate bleed-through associated with this particular resin type. An iron oxide crud layer on the fuel provides a means to concentrate soluble elements such as copper.
- The amount of copper input to the reactor vessel increased by ~30% in Cycle 8 versus Cycle 7, again due to the removal of low cross-linked resins from service in the condensate demineralizers. An additional source of increasing copper is the “blinding” effect of higher iron on the demineralizers copper removal efficiency. Copper has been previously implicated as an agent of local cladding corrosion in the BWR fleet. Analysis of the crud layers indicated that copper had concentrated in the crud layer adjacent to the cladding.
- Zinc was injected into the feedwater system in significant quantities for the first time in Cycle 8. However, the amount of zinc injected and ultimately deposited on the fuel was unremarkable, as compared to the BWR fleet experience. There is no known corrosion or corrosive agent concentration mechanism associated with zinc injection. This is not believed to be a factor in the crud formation.
- The plant operated in the Maximum Extended Load Line Limit Analysis (MELLLA) domain for the first time following RF-7. While this allowed plant operation at lower overall core flows, the locations of the fuel failures were not the locations of lowest flow. The failure locations show a strong correlation to peak nodal powers (as expected for a duty-related failure mechanism such as corrosion), but do not show such a correlation to low bundle flow. The lower flows due to MELLLA would only be a minor aggravating factor for crud deposition. Bundle inspections at other BWRs with high feedwater iron concentrations and MELLLA operation do not indicate any significant increases in crud levels due to MELLLA operation.

ROOT CAUSE

Absent a single event or clear indication of a cause, it is concluded that an early cycle event, indicated by the prolonged early-in-cycle conductivity transient, combined with higher iron and copper levels, resulted in an unusual crud deposition that initiated the process which led to accelerated cladding localized corrosion-induced perforations. None of the individual factors, alone, have caused the corrosion phenomenon at plants in the past, as evidenced by a review of operating experience.

The higher input of iron and copper during the operating cycle, with a chemistry excursion early in the operating cycle, produced the unusual crud deposition and composition observed during the visual inspections. The concentration of copper in the crud layer provides an attack mechanism to foster the observed corrosion. It is significant to note that the crud deposition peaked at approximately the 50" level, which is where the primary clad perforations also occurred. The 50" level corresponds to the power peak for the first (A2) rod sequence in six of the seven perforation locations. The early-cycle conductivity increase occurred during the A2 rod sequence.

It is a well known relationship that Zircaloy corrosion increases with increasing clad temperature. It is not unexpected to find that the corrosion occurred in the highest-powered regions of the core. The formation of a Zircaloy oxide layer is dependent on temperature. As the crud loading on the fuel became heavier, it increased thermal resistance and raised clad temperature, which resulted in increased clad oxidation. The presence of high copper concentrations under these conditions tends to aggravate the situation. Soluble copper will concentrate in the oxide layers adjacent to the fuel rod. Differences in copper oxide growth and Zircaloy oxide growth can result in a higher insulating effect. The increased oxidation thickness results in increased thermal resistance. This becomes an autocatalytic process, which proceeds until the combination of higher temperature, crud, and copper result in clad perforation.

This process resulted in perforation only for the highest-powered bundles (the HGE batch). Measured Zircaloy oxide thickness on high power unfailed HGE bundles was up to 6-mils at the 50" level, where the cladding perforations occurred. By contrast, the lower power GGE bundles (initially inserted for Cycle 7) experienced fuel oxide layers of typically only 1 mil, which is in the normal range. This demonstrates that without power to drive the oxidation process, the crud deposition does not result in a higher thickness of Zircaloy oxide. The GGE bundles did not experience fuel perforations.

It is therefore concluded that the elevated crud and the corrosion were likely due to a combination of various plant chemistry and operating characteristics that changed substantially from Cycle 7 to Cycle 8. The corrosion mechanism is likely due to the presence of contributing agents (primarily copper) within the crud on the higher-powered bundles. Absent any of these factors, the corrosion would likely not have been experienced to the degree observed.

CORRECTIVE ACTIONS

The root cause analysis report for this condition identifies corrective actions being taken at River Bend Station to address the issues. These include immediate actions taken for the startup and operation of the reactor for Cycle 9, and long term actions to be completed throughout the operating cycle and the subsequent refueling outage. These actions are being tracked in the RBS corrective action program.

SAFETY EVALUATION

Effects of Fuel Cladding Defects

The safety significance of the fuel cladding defects that resulted in fuel failure is low. Continuous monitoring of the reactor coolant system offgas provides early indication of the problem, allowing time to take the appropriate actions to monitor and mitigate the activity release consequences of the perforations. The plant's licensing basis and safety analysis assumes that fuel cladding defects can occur during normal operation. Even with the fuel cladding defects experienced during Cycle 8, the plant continued to operate within the bounds of its Operating License, including the Technical Specifications, and its licensing basis, including the Updated Safety Analysis Report (USAR). Together, these documents contain NRC-approved limitations for operating parameters such as reactor coolant system activity, gaseous radioactive effluents, and occupational radiation exposure. These limitations provide defense-in-depth protection for the public health and safety. Fuel cladding failure is not an unanticipated condition, but rather is an integral part of the licensing basis of RBS. Fuel cladding defects are acceptable to the extent that they do not jeopardize radiation protection limits established in the plant Technical Specifications and other licensing basis documents.

Effects of Crud

The safety significance of the effect of the elevated crud on Cycle 8 operation was evaluated. The results, as summarized below, demonstrate, based on previously performed analyses and engineering judgment, that the safety significance of the elevated crud levels is acceptable.

- The Thermal-Mechanical evaluation is intended to provide protection to thermal mechanical limits, such as cladding strain. Increased crud on HGE would accelerate the cladding oxidation process. An assessment of the number of "failed" fuel rods (based on exceeding LHGR limits derived from the thermal mechanical limits) indicates that the dose consequences would represent only a small fraction of 10CFR100 limits, and therefore the River Bend Cycle 8 condition was of acceptable safety significance.
- Given the inherent conservatism in the Safety Limit Minimum Critical Power Ratio (SLMCPR) process and the fact that suppression rods were required during the Cycle 8 operation, it is concluded that the SLMCPR would remain valid for operation in Cycle 8 under the assumed elevated crud conditions.
- The evaluation of operational transients concluded that the Minimum Critical Power Ratio (MCPR) operating limits that were established for Cycle 8 operation would not ensure that at least 99.9% of the rods in the core would avoid boiling transition for an abnormal operational occurrence. However, an assessment of the number of "failed" fuel rods indicates that the dose consequences would represent only a small fraction of 10CFR100 limits. Therefore, the River Bend Cycle 8 condition was of acceptable safety significance.
- The peak clad temperature (PCT) for HGE fuel was calculated to have been 1700°F or less. This still demonstrates substantial margin to the 10CFR50.46 PCT limit of 2200°F. Note that excluding the oxide buildup during steady state operation, the peak local clad oxidation due to LOCA would remain well below the 17% requirement of 10 CFR 50.46, as there would have been no appreciable change in the percent of clad participating in the Metal-Water Reaction under LOCA conditions.

Other analyses such as nuclear reactivity, over-pressure protection, and stability remain unaffected by the elevated crud.

PREVIOUS OCCURRENCE EVALUATION

Previous Fuel Cladding Defects at RBS

Previous fuel clad defects and perforations at River Bend were reviewed. No previous occurrences were applicable to the RF-8 fuel conditions, since the previous occurrences did not exhibit the heavy crud and the thermally induced accelerated corrosion.

Related Defects (Caused by Corrosion) at Other Facilities

No previous occurrences were found at other facilities that were similar to th occurrence at RBS. In the NRC's Safety Evaluation Report (SER) (NUREG-0989) for RBS, external corrosion and crud buildup on the waterside of the fuel was discussed. The NRC notes that in the late 1970s and early 1980s, certain of these types of perforations were referred to as "crud-induced local corrosion (CILC) failures." A contributor to CILC was an unusual composition of metallic crud. The NRC further notes that the corrosion was reportedly associated with a variably high copper concentration in the core coolant water and a minor anomaly in the Zircaloy cladding metallurgy, although both the water chemistry and cladding metallurgy were within allowable specifications. Crud deposits, aside from the CILC phenomenon, were expected even with improvements in newer plants such as RBS. Unlike the classic CILC, and even though a crud layer existed with high copper concentration, corrosion levels were driven more by crud thickness rather than corrosion caused by local cladding conditions.

Note: The Energy Industry Identification System (EIIS) component/system number is indicated by a parenthesis after the affected component/system. (Example: (*XX*))