Entergy Operations

Entergy Operations, Inc.
P.O. Box B
Killona, LA 70066
Tel 504-464-3120

D. R. Keuter
General Manager
Plant Operations
Waterford 3

W3F1-95-0180
A4.05
PR

November 8, 1995

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, D.C. 20555

Subject: Waterford 3 SES
Docket No. 50-382
License No. NPF-38
Reporting of Special Report

Gentlemen:

Attached is Special Report Number SR-95-003-00 for Waterford Steam Electric Station Unit 3. This report outlines the results of the investigation into the Emergency Diesel Generator "A" crankcase overpressurization event that occurred on October 10, 1995. The root cause of the overpressurization event was determined to be tin transfer from the 5L piston to the cylinder liner. This Special Report is submitted in accordance with Technical Specifications 4.8.1.1.3 and 6.9.2 and USNRC Regulatory Guide 1.108.

Very truly yours,

D.R. Keuter
General Manager
Plant Operations

DRK/RTK/tjs
Attachment

IE22
1/1

cc: L.J. Callan, NRC Region IV, C.P. Patel, NRC-NRR,
G.L. Florreich, J.T. Wheelock - INPO Records Center,
R.B. McGehee, N.S. Reynolds, NRC Resident Inspectors
Office (WMSB4300), Administrator - LRPD

SPECIAL REPORT
SR-95-003-00

REPORTABLE OCCURRENCE

On October 10, 1995, Waterford Steam Electric Station Unit 3 was shutdown for the Refuel 7 outage when Emergency Diesel Generator (EDG) "A" experienced a crankcase overpressurization. The EDG was being run in accordance with Surveillance Procedure OP-903-115 "Train A Integrated Emergency Diesel Generator/Engineering Safety Features Test" when the overpressurization event occurred. This event is classified as a valid failure in accordance with Regulatory Guide 1.108 and is being reported in accordance with Technical Specifications (TS) 4.8.1.1.3 and 6.9.2. This failure is the first failure in the last 20 valid tests and the fourth failure in the last 100 valid tests. In accordance with the Waterford 3 Technical Specifications, the currently required surveillance test interval for EDG "A" is at least once per 31 days.

EVENT DESCRIPTION

The Refuel 7 outage at Waterford 3 began on September 22, 1995. On September 25, 1995, EDG "A" was removed from service for a routine maintenance outage that included the 18 month inspection required by Inspection Procedure MM-003-015. An exhaust manifold replacement, a fuel pump upgrade, and the removal and reinstallation of three cylinder heads (4R, 5R, 5L) were to be performed. The selection of these three heads for removal was based upon the need for maintenance or inspections that required these heads to be removed.

During the period of September 25, 1995, to October 1, 1995, Entergy Operations maintenance personnel from Waterford 3, the River Bend Station, and the Grand Gulf Nuclear Station performed the scheduled maintenance and inspections on EDG "A". Engineering, maintenance, and vendor personnel (Cooper-Bessemer) utilized the "Inspection Manual for Cooper-Bessemer Model KSV Diesel Engines" to conduct an underside inspection of all 16 cylinder liners. A boroscopic inspection through the removed fuel injector holes of the area of the cylinders above the pistons for those pistons which did not have the heads removed was also performed. The areas of the cylinder liners above the pistons for the 4R, 5R, and 5L cylinders were also inspected.

Planned maintenance activities were completed on October 1, 1995, and the taggout was cleared in preparation for post maintenance testing. Several post maintenance starts of EDG "A" were performed for adjustments prior to

releasing the EDG to Operations for retesting. On October 8, 1995, EDG "A" was released to Operations for performance of the required Surveillance Testing necessary to demonstrate the operability of the EDG. On October 9, 1995, Surveillance Testing was commenced in accordance with Surveillance Procedure OP-903-115 "Train A Integrated Emergency Diesel Generator/Engineering Safety Features Test". At 0316 hours on October 9, 1995, a successful start of the EDG was recorded during the performance of Surveillance Procedure OP-903-115, Section 7.4, "Train A Safety Injection Actuation Test With Offsite Power". However, the EDG was not loaded at this time.

On October 10, 1995, Surveillance Procedure OP-903-115 testing was recommenced at Section 7.5, "Train A Safety Injection Actuation Test With Concurrent Loss of Offsite Power". The EDG was started at 1652 hours and immediately loaded to approximately 2.6 MW. For approximately the next hour, EDG "A" continued to run partially loaded in support of the Surveillance Procedure requirements until 1805 hours when the EDG was fully loaded to 4.4 MW. At 1806 hours on October 10, 1995, a full load rejection test was successfully performed per the procedure with the diesel returning to standby operation. At 1821 hours, EDG "A" was paralleled with offsite power and electrical loading of the EDG was once again commenced. By 1840 hours on October 10, 1995, the EDG was loaded to 110% (approximately 4.7 MW) and the 24 hour run required by Surveillance Procedure OP-903-115, Section 7.6, "24 Hour EDG A Run and Subsequent Loss of Offsite Power Test" was begun.

At approximately 2012 hours on October 10, 1995, Operations and Maintenance personnel in the EDG "A" room heard a muffled "thud" like transient. These personnel observed an immediate issuance of lubricating oil and smoke from the EDG "A" crankcase relief ports. However, no visible flames were observed. The control room was subsequently contacted, EDG "A" was immediately unloaded and secured, and the Fire Brigade was dispatched. During an inspection of the EDG performed later that evening, it was determined that the 5L piston had failed.

On October 11, 1995, the 5L piston, liner, and articulating rod were removed from EDG "A" and inspected by maintenance, engineering, and EDG vendor (Cooper-Bessemer) personnel. Extensive damage to both the piston and the liner was observed. An underside inspection was conducted and the 8R liner was observed to exhibit light, vertical scoring on the non-thrust side. As a result of this observation, the 8R piston was pulled and the piston rings were determined to be excessively worn. The cylinder liner was removed and light scoring was visible over the cylinder area traversed by the 6th and 7th piston rings. As a result of the excessively worn piston rings on the 8R piston, it was decided to pull one other piston for inspection. The 6L piston was selected because the piston rings on this

piston had been replaced at the same time as the 8R piston rings. The 6L piston was observed to be in good condition, exhibiting normal wear.

CAUSAL FACTORS

Entergy Operations, Inc. believes that the root cause of this event was that poor lubricating conditions during startup and rapid loading led to tin transfer from the piston to the cylinder liner. Tin transfer refers to wear or removal of tin plate material from the non-thrust side of the cast iron piston skirt and originates primarily at the skirt upper ridge. The tin is transferred to the chromium-plated cylinder liner surface. The tin deposited on the cylinder liner becomes embedded in the porous surface of the cylinder liner. The embedded tin, often combined with iron wear particles, reduces the porosity of the liner from the Cooper-Bessemer specified 15-25% to some smaller value. The desired porosity is engineered to retain lubricating oil to support lubrication of the piston skirt/cylinder liner interface. With the porosity reduced, the lubricating oil film is reduced or eliminated. This results in increased friction and heat generation, and potentially, piston seizure or a crankcase overpressurization.

Tin transfer is caused by a combination of the following conditions:

- Poor lubrication conditions during startup and rapid loading due to draindown of the oil from the cylinder liner walls during standby is exacerbated by the lower oil control ring which acts to remove lubricating oil from the region of high contact stresses discussed below;
- The sharp edge located at the top of the piston skirt combined with the concave piston skirt shape at low (standby) temperatures presents a relatively small contact area or line contact between the piston skirt and the cylinder liner and results in high stresses in this region; and
- Large lateral forces towards the non-thrust side of the piston which occur during both starting and loading caused by high compression pressures due to leaking or floating of the start air valves during starting and rapid increases in inlet air manifold pressure during rapid loading.

Tin transfer has not been previously observed to progress from non-existent to the advanced stage in the brief period observed at Waterford 3. The rate at which tin transfer progresses, once initiated, has not been determined. Prior to this event, it was believed to occur over many hours of operation. This is because tin transfer has been detected in several stages of progression following long periods of engine operation. If it were to progress very rapidly, it is unlikely that tin transfer would be identified in the intermediate stages of development.

EDG "A" was operated for approximately 7.5 hours cumulatively following the initial maintenance inspection and prior to the crankcase overpressurization event. However, over this 10 day period, the EDG was started 16 times. It is plausible to conclude that the number of starts can account for the rapid initiation of the tin transfer observed and that the rapid loading sequences that followed on October 10, 1995, as part of the Technical Specification required Surveillance Testing, could have further propagated the tin transfer to the point of failure. It is also noted that both crankcase overpressurizations that occurred at Susquehanna Steam Electric Station in 1989 and 1990 which were attributed to tin transfer occurred under the same circumstances as this event (that is, during the 110% load run).

There have been no indications to date as to why the 5L cylinder was the source of the crankcase overpressurization in lieu of other cylinders. The leakage rate of the start air valves, the magnitude of the concavity of the piston skirt, and quantity of residual lubricating oil are somewhat random. These effects are directly related to the root cause of the overpressurization event, therefore, the formation of tin transfer is expected to be random as well.

CORRECTIVE MEASURES

Condition Report (CR) 95-0962 was generated in accordance with Waterford 3 Administrative Procedure UNT-006-011, "Condition Report," to provide a means to implement the Waterford 3 Corrective Action Program. The crankcase overpressurization event described in this CR was classified as a significant adverse condition. Events classified as significant adverse conditions require the preparation of a root cause analysis. The root cause analysis was subsequently prepared by Waterford 3 personnel.

The available start evaluation data sheets and running logs were reviewed concurrently with the control room logs and a chronology of events prepared by the Waterford 3 System Engineer for the period October 1, 1995, to October 10, 1995. All recorded parameters and trends were in specification and appeared normal. This includes the log readings that were taken at 2008 hours on October 10, 1995, four minutes prior to the crankcase overpressurization.

On October 11, 1995, a sample of the Delvac 1340 lubricating oil was drawn from the EDG "A" crankcase sump. Portions of this sample were sent to three different laboratories for analysis. No abnormalities were identified in any of the analyses.

The 5L fuel injector was tested by Waterford 3 personnel on October 14, 1995. This injector was found to be operating within specifications.

The left bank starting air distributor operation was checked by Waterford 3 personnel. This air distributor was found to be operating properly with the exception that the distributor did not appear to be shutting off air completely to the pilot valve supply lines. The 5L air start valve was also checked and was found to be operating properly. The routing of the 5L pilot valve supply tubing was checked for kinks. No kinks were found in this tubing.

Waterford 3 recently purchased and began to employ the BETA Recip-trap hand held engine analyzer. This engine analyzer system measures cylinder pressures, crank angle, and vibration. Due to the newness of this equipment and a need to gain experience in its use, limited data was available regarding EDG "A". With the assistance of BETA field personnel, previously unanalyzed data collected from a September 12, 1995, EDG "A" run was recovered. Analysis of the data from this run was inconclusive.

The 5L piston and cylinder liner were sent to the vendor (Cooper-Bessemer) for inspection. An interim report on the inspection was received by Waterford 3. The interim report provides specific details on the condition of the piston and liner. On October 12, 1995, Waterford 3 obtained the services of MPR Associates to act as a third party with regard to the root cause of the crankcase overpressurization event. The MPR Associates observations with regard to the 5L piston and liner were essentially the same as the Cooper-Bessemer observations with a few exceptions noted. MPR Associates also inspected the underside of EDG "A" and the 8R piston and cylinder liner at Waterford 3. It was noted that there were no indications of tin transfer or wear on the lower half of the visible portions of the 14 liners still installed. With regard to the 8R piston and cylinder liner, MPR Associates identified a darkened vertical mark on the non-thrust side of the liner. The mark was diagnosed to be an early phase of tin transfer.

The 5L and 8R pistons and cylinder liners have been replaced on EDG "A". As previously mentioned a vendor inspection of the failed 5L piston, articulating rod, and cylinder liner was performed.

The sequence of testing described in section 7.5 of OP-903-115 was reviewed. The actual loading sequence that occurred was evaluated to ensure proper precautions are exercised to avoid unnecessary rapid loading during performance of this surveillance. Also, a Technical Specification (TS) change has been submitted which will allow the two hour 110% load test to be performed anytime during the 24 hour test run which is performed every 18 months. Waterford 3 TS currently require this 110% load test to be performed during the first two hours of the 24 test run.

The lower oil control rings and piston pin end caps have been removed from all EDG "A" and EDG "B" pistons. This should assist in maintaining a lubricating film on the piston skirt/cylinder liner interface and thus reduce the possibility of scuffing and overheating.

Procedure OP-903-068 was revised to specify the performance of the Cooper-Bessemer recommended four hour monthly surveillance runs. The loading sequence for the EDGs was also revised.

During the post maintenance testing of EDG "A" and EDG "B" during Refuel 7, a vibration, crank angle, and firing pressure engine analysis was performed using the BETA engine analysis equipment. The results of this analysis have been evaluated and no significant anomalies were noted.

An evaluation of a proposed modification to replace the existing EDG governor with a dual program slow start governor will be performed. In addition, an evaluation of a proposed piston modification will be performed. The modification would alter the profile of the piston skirt to a barrel shape during all modes of operation by chamfering the top piston skirt radius and provide a gradual taper transition to the full piston skirt radius.

Periodic underside inspections of the EDGs to check for the presence of tin transfer will be performed during planned component outages of sufficient duration. The condition of Cooper-Bessemer EDGs throughout the nuclear industry will be monitored through the Cooper-Bessemer Owners Group. This effort will focus on EDGs that have the lower oil control rings and piston pin end caps removed.

SAFETY SIGNIFICANCE

Waterford 3 was shutdown for the Refuel 7 outage at the time of this event. Technical Specifications require that one EDG be operable when the plant is shutdown. The "B" train EDG remained operable throughout the time that EDG "A" was out of service. In addition, the crankcase relief ports on EDG "A" functioned as designed. Therefore, this event did not compromise the health and safety of the public or plant personnel.

SIMILAR EVENTS

On March 18, 1991, Waterford 3 was in the Refuel 4 outage when EDG "A" experienced a crankcase overpressurization event while being run in accordance with the prerequisites of the 18 month EDG Inspection Procedure MM-003-015. This crankcase overpressurization event was also initiated in the 5L cylinder. The root cause of this Refuel 4 event was the gross

cylinder to cylinder load imbalance that existed on EDG "A" prior to the Refuel 2 outage. It is believed that this condition caused an excessive buildup of carbon deposits behind the upper compression rings of piston 5L. Normal deposit accumulation during correct operation of the engine added additional small amounts of carbon deposits that also built up behind the piston rings. This situation led to the piston rings becoming stuck. Eventually additional deposits forced the compression rings against the cylinder liner and significantly reduced lubrication. The lack of lubrication resulted in increasing the surface temperatures of the piston and liner. As the temperatures increased, the chrome plating on the liner cracked and began spalling off. A piece of chrome plating debris lodged between the piston and the liner. The resulting friction caused the piston area around the debris to become incandescent. This incandescent area ignited the crankcase oil vapor causing the crankcase overpressurization.

The root cause of the Refuel 4 outage crankcase overpressurization is not the same as the root cause of the Refuel 7 crankcase overpressurization. On-site inspection of the piston rings in the 5L cylinder on October 11, 1995, and a subsequent vendor laboratory inspection on October 13, 1995, confirmed that the piston compression rings were not stuck prior to the crankcase overpressurization. These rings were free to move and there was little or no carbon buildup found. The applicability of the corrective actions for the Refuel 4 outage event to preventing the Refuel 7 outage event were reviewed and were found to be not applicable.