August 11, 2004

MEMORANDUM TO: Suzanne C. Black, Director
Division of Systems Safety and Analysis
Office of Nuclear Reactor Regulation

FROM: Farouk Eltawila, Director ***/RA/***
Division of Systems Analysis and Regulatory Effectiveness
Office of Nuclear Regulatory Research

SUBJECT: ASSESSMENT OF SHUTDOWN EVENTS FROM RECENT OPERATING EXPERIENCE

This memorandum transmits our assessment of operating experience as it relates to shutdown risk. Staff Requirements Memorandum (SRM) 97-168 dated, December 11, 1997, indicated that the Commission expected the staff to monitor shutdown risk to ensure that changes have not occurred that would otherwise warrant reconsideration of a shutdown rule. A prior Office of Nuclear Regulatory Research (RES) memorandum which forwarded NUREG/CR-6832, "Regulatory Effectiveness of Unresolved Safety Issue (USI) A-45, 'Shutdown Decay Heat Removal Requirements'" noted that USI A-45 did not address risk during shutdown operations; however, that memorandum also noted that the decay heat removal (DHR) function during shutdown can be an important component of risk. Therefore, as a follow-on to the USI A-45 effectiveness study, RES staff performed a review of shutdown operating experience to help address the question raised in the SRM.

The approach used in this assessment integrates together views expressed by the Office of Nuclear Reactor Regulation (NRR) staff in the Reactor Systems Branch, Probabilistic Safety Assessment Branch, and RES staff in the Advanced Reactors and Regulatory Effectiveness Branch. The formulated basis for this work includes a subset of shutdown events - specifically events involving inadvertent draindowns leading to reduced inventory and loss of shutdown cooling. The events were used to assess the effectiveness of measures to address the reduced inventory condition as an indicator of overall licensee performance during shutdown.

Based on the attached study, we conclude that actions taken by the Nuclear Regulatory Commission (NRC) and industry to address shutdown risk remain effective. A search for events, including Licensee Event Reports (LERs) and inspection reports, did not identify any additional events in the past 5 years which resulted in loss of DHR as a result of reduced inventory operations. To assure future effectiveness, programs currently in place which address DHR during shutdown operation will need to be continued.

Attachment: As stated

Contact: G. Lanik, RES
(301) 415-7490

August 11, 2004

MEMORANDUM TO: Suzanne C. Black, Director
Division of Systems Safety and Analysis
Office of Nuclear Reactor Regulation

FROM: Farouk Eltawila, Director ***/RA/***
Division of Systems Analysis and Regulatory Effectiveness
Office of Nuclear Regulatory Research

SUBJECT: ASSESSMENT OF SHUTDOWN EVENTS FROM RECENT OPERATING EXPERIENCE

This memorandum transmits our assessment of operating experience as it relates to shutdown risk. Staff Requirements Memorandum (SRM) 97-168 dated, December 11, 1997, indicated that the Commission expected the staff to monitor shutdown risk to ensure that changes have not occurred that would otherwise warrant reconsideration of a shutdown rule. A prior Office of Nuclear Regulatory Research (RES) memorandum which forwarded NUREG/CR-6832, "Regulatory Effectiveness of Unresolved Safety Issue (USI) A-45, 'Shutdown Decay Heat Removal Requirements'" noted that USI A-45 did not address risk during shutdown operations; however, that memorandum also noted that the decay heat removal (DHR) function during shutdown can be an important component of risk. Therefore, as a follow-on to the USI A-45 effectiveness study, RES staff performed a review of shutdown operating experience to help address the question raised in the SRM.

The approach used in this assessment integrates together views expressed by the Office of Nuclear Reactor Regulation (NRR) staff in the Reactor Systems Branch, Probabilistic Safety Assessment Branch, and RES staff in the Advanced Reactors and Regulatory Effectiveness Branch. The formulated basis for this work includes a subset of shutdown events - specifically events involving inadvertent draindowns leading to reduced inventory and loss of shutdown cooling. The events were used to assess the effectiveness of measures to address the reduced inventory condition as an indicator of overall licensee performance during shutdown.

Based on the attached study, we conclude that actions taken by the Nuclear Regulatory Commission (NRC) and industry to address shutdown risk remain effective. A search for events, including Licensee Event Reports (LERs) and inspection reports, did not identify any additional events in the past 5 years which resulted in loss of DHR as a result of reduced inventory operations. To assure future effectiveness, programs currently in place which address DHR during shutdown operation will need to be continued.

Attachment: As stated

Contact: G. Lanik, RES
(301) 415-7490

Distribution w/ att.
DSARE R/F ARREB R/F JStarefos

C:\ORPCheckout\FileNET\ML042230307.wpd
*See Previous Concurrence
OAR in ADAMS? (Y or N) Y ADAMS ACCESSION NO.: ML042230307 TEMPLATE NO. RES-006
Publicly Available? (Y or N) Y DATE OF RELEASE TO PUBLIC 08/24/04 SENSITIVE? N
To receive a copy of this document, indicate in the box: "C" = Copy without enclosures **"E"** = Copy with enclosures **"N"** = No copy

OFFICE	ARREB		ARREB		C:ARREB		D:DSARE	
NAME	GLanik:dfw		JIbarra		MGamberoni		FEltawila	
DATE	08/05/04*		08/05/04*		8/06/04*		8/11/04*	

ASSESSMENT OF SHUTDOWN EVENTS
FROM RECENT OPERATING EXPERIENCE

The following assessment of licensee shutdown performance is based on a subset of shutdown events - specifically events involving inadvertent draindowns leading to reduced inventory and loss of decay heat removal (DHR). The events were used to assess the effectiveness of measures to address the reduced inventory and loss of DHR condition as an indicator of overall licensee performance during shutdown.

Reduced inventory exists when reactor vessel water level is lower than three feet below the reactor vessel flange. Midloop operation exists when reactor vessel water level is lower than the top of the flow area in the hot leg at the reactor vessel nozzle. Both definitions are actual conditions and allowance for instrument error must be included when using these definitions in plant operations.

SECY 97-168, "Issuance For Public Comment of Proposed Rulemaking Package For Shutdown And Fuel Storage Pool Operation," issued July 30, 1997, reported to the Commission that annual Pressurized Water Reactor (PWR) industry shutdown core damage frequency (CDF) can range from the high 10^{-6} to mid mid 10^{-5} per year depending on the robustness of a licensee's mitigation capability. Electric Power Research Institute (EPRI) also performed a generic PWR risk assessment looking at peak risk periods during a PWR outage and found the CDF to be around $2x10^{-5}$ per year.

Reasons that draindown events leading to reduced inventory and loss of DHR were chosen include: 1) the events have high safety significance, 2) there is a good expectation that these types of events would be reported, 3) there are many aspects of configuration management, operations, planning, and system characteristics that contribute to the occurrence of these events, and 4) there is a long history of NRC and industry efforts to address draindown and loss of shutdown cooling, as described below.

Generic Communications Addressing Shutdown and Reduced Inventory

Generic Letter 87-12: "Loss of Residual Heat Removal Systems While the Reactor Coolant System (RCS) is Partially Filled," dated, July 9, 1987, includes a list of potential problems which impact loss of DHR when at reduced inventory. The list includes: unexpected RCS pressurization can occur; RCS water level instrumentation may provide inaccurate information; vortexing and air ingestion from the RCS into the DHR suction line may impact DHR pump operation; operators have limited instrumentation; containment integrity may be compromised; and test and maintenance operations can perturb the system.

Based on Nuclear Regulatory Commission (NRC) reviews of the responses to Generic Letter 87-12, the NRC issued Generic Letter 88-17 ,"Loss of Decay Heat Removal," to address shutdown risk. Since 1990 approximately a dozen NRC Information Notices have been issued which address problems with DHR and mid-loop operation. Those provide a collection of the different types of events which can challenge DHR during shutdown operations or reduced inventory.

Based on the findings in NUREG-1269: “Loss of Residual Heat Removal System, Diablo Canyon Unit 2, April 10, 1987,” and review of the licensee responses to Generic Letter 87-12, the NRC determined that many deficiencies remained and needed to be corrected. NUREG-1269 had identified several previously unrecognized phenomena which impact DHR and showed that a complete and systematic study of all potential difficulties with DHR system operation was needed. To accomplish this, the NRC worked closely with the pressurized water reactor (PWR) owner’s groups to develop an understanding of the problems with level measurement, temperature measurement, flow paths, containment, etc., that occurred during outages.

The NRC worked with the PWR owners’ groups to develop specific approaches to improving performance during shutdown, which were the basis for Generic Letter 88-17. Also, subsequent to Generic Letter 88-17, the NRC continued to focus considerable attention on industry improving overall outage planning. To that end, the NRC worked closely with the nuclear industry to develop guidelines such as Nuclear Management and Resources Council (NUMARC) NUMARC 91-06, “Guidelines for Industry Actions to Assess Shutdown Management,” dated December 1991.

The following generic communications were issued following the Commission’s SRM 97-168 that directed the staff to monitor shutdown risk to ensure changes had not occurred that might warrant reconsideration of a shutdown rule.

1. NRC Information Notice 2000-13: “Review of Refueling Outage Risk,” September 27, 2000

2. NRC Information Notice 99-14: “Unanticipated Reactor Water Draindown at Quad Cities Unit 2, Arkansas Nuclear One Unit 2, and Fitzpatrick,” May 5, 1999.

3. NRC Information Notice 97-83: “Recent Events Involving Reactor Coolant System Inventory Control During Shutdown,” December 5, 1997.

Information Notice 2000-13 addresses the potential risk significance of reduced inventory operations. The Information Notice includes an estimate that 22 hours of mid-loop operation account for approximately 10 percent of the cumulative annual risk for pressurized water reactors. Also reported here are estimates of the time to boiling in the core during mid-loop operations - several are less than 20 minutes. Analyses of risk during shutdown operations have identified mid-loop operations as high risk, despite the short time spent in those conditions. The message conveyed is that licensees need to be especially attentive regarding mid-loop operations.

Modifications to Design and Operation to Address Shutdown and Reduced Inventory

NRC Generic Letter 88-17, “Loss of Decay Heat Removal,” issued October 17, 1988, contained specific suggestions for equipment design and operations; they can be summarized as follows.

Design modifications:

The most general design modifications were twofold - level and temperature instrumentation was improved, with redundancy and diversity; and DHR suction valve interlocks were changed to reduce the frequency of spurious closing.

Originally, level instrumentation to monitor operation at reduced inventory was usually comprised of transparent tygon tubing used as a sight glass. Problems with loop seals and other blockages or conditions which led to pressure anomalies were the cause of many level reading errors and some actual events of loss of DHR. The improved designs were permanently routed sensing lines for more robust instrumentation. In addition, some licensees installed ultrasonic sensors to detect water level in the hot leg as a redundant and diverse capability.

Operational changes:

Many operational changes were made. The most prominent included: address containment integrity during reduced inventory conditions; provide redundant and diverse heat removal capability employing steam generators and coolant injection pumps; limit blocking of hot leg nozzles; improve procedures; improve training; improve outage planning; and implement extensive administrative controls.

Operating Experience Related to Shutdown and Reduced Inventory

A search of Licensee Event Reports (LERs) for the 6 year period 1997-2003 found no loss of DHR events as a result of mid-loop operations or reduced inventory operations. Review of inspection reports also found no loss of DHR events as a result of mid-loop operations or reduced inventory operations.

Several events involving draindown were terminated prior to reaching the elevation of the hot leg or loss of DHR capability. As might be expected, errors occur during transitions from one operating state to another, or during an activity which affects the flow paths or instruments used for inventory control.

The last event which involved an actual loss of DHR during reduced inventory conditions is described in NRC Information Notice 92-16, Supplement 1: “Loss of Flow from the Residual Heat Removal Pump During Refueling Cavity Draindown,” issued February 20, 1992, which describes an event at the Prairie Island Nuclear Generating Plant, Unit 2.

Another event relevant to this discussion is described in NRC Information Notice 95-03: “Loss of Reactor Coolant Inventory and Potential Loss of Emergency Mitigation Functions While in a Shutdown Condition,” issued January 18, 1995, which describes an event which occurred at the Wolf Creek Station on September 17, 1994. That event was similar to inadvertent draindown events in that lack of coordination of valve manipulations led to loss of inventory. However, the event occurred while the system was partially hot and pressurized, resulting in a rapid inventory loss. The potential consequences were more serious because the discharge of superheated liquid into the suction piping of the Safety Injection +pumps could have led to gas binding of those pumps and disabled mitigative systems.

The Wolf Creek event, when analyzed by the Accident Sequence Precursor (ASP) Program, resulted in the highest conditional core damage probability (CCDP) for an event since the TMI accident. NRC Generic Letter 98-02: "Loss of Reactor Coolant Inventory and Associated Potential for Loss of Emergency Mitigation Functions While in a Shutdown Condition," was issued May 28, 1998, to address the concerns raised by the Wolf Creek event.

Other selected but more recent events include:

1. Sequoyah Unit 1, March 13, 2000, Inspection Report 50-255/99-12.

A loss of reactor coolant system inventory occurred while the plant was in Mode 5 making preparations to transition to Mode 4 at the conclusion of the refueling outage. During this time operators initiated an operating procedure to vent the DHR discharge piping with a DHR pump running. This evolution resulted in the actuation of a relief valve in the DHR pump discharge flow path. The relief valve subsequently failed to reseat which resulted in an estimated 10,000 gallons of reactor coolant being discharged to the pressurizer relief tank.

2. Palisades Nuclear Generating Plant, November 10, 1999, Inspection Report 50-255/99-12.

The inadvertent loss of six gallons of primary coolant system inventory due to an inadequate tagging order, did not result in significant adverse safety consequences. However, the incident occurred when the primary coolant system was in a reduced inventory condition and if the leak had not been terminated, it could have interrupted decay heat removal. The leak occurred when maintenance workers removed a valve bonnet on a valve which should have been tagged.

3. Several plants, several inspection reports.

Several instances of problems with level instrumentation used during reduced inventory operations were noted in inspection reports. Generally, these involved operators not responding correctly to situations where redundant instruments were indicating differences in level. Other conditions have occurred which had the potential to interrupt DHR, but didn't evolve to the point of actually having done so. These have resulted in green findings by the NRC significance determination process.

NRC Inspection of Shutdown and Reduced Inventory Operations

Perhaps as important as the licensee actions in response to potential events is the NRC focus on the risk during shutdown with reduced inventory. Current inspection activities during shutdown focus on the most risk significant parts of the shutdown which are the periods of reduced inventory. Inspection reports which address plant shutdown activities typically include a statement such as the following:

> "The inspectors provided continuous observations of operator actions to reduce reactor coolant system inventory, establish conditions at the centerline of the hot leg, install nozzle dams and increase reactor coolant system inventory. The inspection included control room observations, vital support system alignments (i. e., reactor vessel level monitoring instrumentation, containment closure process, and nozzle dam monitoring instrumentation), and observations of steam generator manway removal and nozzle

dam installation. The inspectors also verified implementation of Con Edison commitments to NRC Generic Letter 88- 17, “Loss of Decay Heat Removal.”

Or another example:

> “The inspectors reviewed diverse operational, maintenance and scheduling activities prior to and during the eighth refueling outage to evaluate the licensee’s activities to assess and manage the outage risk. Specific activities reviewed included Reactor Coolant System (RCS) evacuation and fill (mid-loop operations) and control and coordination of activities to minimize risk while in a reduced RCS inventory condition.”

Assessment of Licensee Performance During Shutdown and Reduced Inventory

Actions taken to prevent recurrence of loss of shutdown cooling include: better understanding of the risk involved in reduced inventory operations; NRC generic letters to ensure that licensees have adequate systems and administrative controls to manage the plant in those conditions; NRC inspection activities which focus attention on the reduced inventory activities; and a consensus industry document to facilitate better overall outage management. As long as those processes and activities remain in place, the likelihood of recurrence of these types of events is greatly reduced.

The last two risk significant events as determined by the ASP program - Prairie Island and Wolf Creek - occurred more than 9 years ago. A search for events, including LERs and inspection reports, did not identify any additional events in the past 5 years which resulted in loss of DHR as a result of reduced inventory operations.

Based on the operating experience over the past 5 years, it appears that the actions taken by the NRC and the industry to address this issue remain effective in preventing loss of DHR while operating at reduced inventory. To assure future effectiveness, programs currently in place which address DHR during shutdown operation will need to be continued.