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An Analysis of Loss of Decay Heat Removal and Loss of Inventory Event Trends (1990–2009)

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EPRI Project Manager

D. Hance

This document does **NOT** meet the requirements of 10CFR50 Appendix B, 10CFR Part 21, ANSI N45.2-1977 and/or the intent of ISO-9001 (1994)

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PRODUCT DESCRIPTION

In recent years, there has been an observed increase in plant events during shutdown conditions. This has increased interest among the industry and the United States Nuclear Regulatory Commission to obtain a better understanding of the data and the trends. This report documents a long-term study of loss of decay heat removal and loss of inventory events during shutdown conditions in the nuclear industry, spanning a 20-year period from 1990 through 2009. The EPRI reports *An Analysis of Loss of Decay Heat Removal Trends and Initialing Event Frequencies (1989–1998): Outage Risk Assessment and Management (ORAM) Technology* (TR-113051) and *An Analysis of Loss of Decay Heat Removal Trends and Initiating Event Frequencies (1989–2000): Outage Risk Assessment and Management (ORAM) Technology* (1003113) documented the trends through 2000. This report provides information from the last decade and a review of previous data to present a current and comprehensive understanding of the trends of events during shutdown conditions.

Results and Findings

Highlights of the findings of this report include the following:

- The number of annual loss of decay heat removal events dropped sharply after 1995.
- Since 2000, the data indicate that about two-thirds of the United States fleet had no loss of decay heat removal events. These results are a significant improvement over previous years, when about half the units had two or more events and some had more than 10.
- The number of annual loss of decay heat removal events has not exceeded nine events over the past five years; however, there has been an increase in the trend of the three-year rolling average after 2004.
- The number of loss of inventory events was higher in 2007–2009 than in the prior three years, 2004–2006.
- One type of loss of inventory event is an over-draining event, in which water level is being reduced, but the reduction target is missed and too much water is drained. Fifteen over-draining events were recorded in the past 20 years, two since 2000.

This report provides detailed analyses of the dominant contributors to the causes of particular types of events. The benefit of this analysis is to provide a basis to understand the types of shutdown events that are being observed, their dominant causes, and how to effectively focus resources on improving outage safety.

Challenges and Objectives

This report is part of an ongoing research effort. Among the challenges of this effort is to search for and consolidate the data required. The objectives of this effort are to develop a credible, long-term trend analysis of shutdown events and to generate discussion and comments. It is envisioned that this will improve the overall knowledge base within the nuclear plant outage management and risk assessment communities concerning events during shutdown conditions. A follow-up final report is planned to incorporate comments and develop initiating event frequencies.

Application, Value, and Use

This report provides valuable insights for senior managers in need of facts concerning shutdown events, outage managers seeking to improve outage safety, and risk professionals in need of data.

EPRI Perspective

This report is a unique resource to understand the trends and causes of shutdown events. It documents the first research effort that provides a 20-year trend analysis of shutdown events, drawing from both public and private data sources. Earlier reports spanned shorter timeframes, and the data primarily reflected the early years of the implementation of defense-in-depth programs based on NUMARC 91-06, "NUMARC Guidelines for Industry Actions to Assess Shutdown Management." This report extends the earlier timeframes examined to 2009 and represents a more current view of event trends. It is envisioned that this report will be the basis for a better understanding of shutdown events and their causes and how to effectively focus resources on improving outage safety.

Approach

Data in support of this report were obtained from the INPO Plant Events Database through the INPO members' website, www.inpo.org. The data were analyzed for event type and event severity and classified by initiating event type for further analysis.

Keywords

Decay heat removal (DHR)
Inventory control
Key safety function
Low power and shutdown (LPSD)
Outage risk assessment and management (ORAM)
Risk assessment

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1
INTRODUCTION AND SUMMARY

This report reviews and evaluates the Loss of Decay Heat Removal (DHR) and Loss of Inventory events at U.S. nuclear power plants in the last twenty years (1990 to 2009). Previous analyses have reviewed and evaluated events from 1989 to 2000 [2,3]. This report includes trends since 1990, although more focus is provided on the last ten years (2000 to 2009), since these events have not been evaluated previously. The purpose of this analysis is to:

- Review the loss of Decay Heat Removal (DHR) and Loss of [Reactor Coolant] Inventory events at shutdown to provide a trend of these events over time.
- Evaluate the events to provide insights on the types, severity, and cause.

For the purposes of this report, a Loss of DHR is defined as: *A momentary or sustained loss of forced cooling and/or flow through the reactor core, that requires manual or automatic actions to re-establish the cooling and/or flow.* The approach for the analysis of the data is presented in Section 2 of this report. Trends for the number and severity of Loss of DHR events are presented in Section 3. Similar results for Loss of Inventory events are in Section 4. Analyses of other event trends, such as event causes, are presented in Section 5. A follow-up report is expected to publish the results of the initiating event and recovery analyses, for use in shutdown Probabilistic Risk Assessments (PRA).

Number and Severity of Events

The number of events per year is trended and reviewed, as well as the severity of events. Key conclusions from Sections 3 and 4 of this report include the following:

- The long-term trend (1990-2009) of the number of Loss of DHR events indicates general improvement. A large drop in Loss of DHR events was seen from about 1995, prior to which the frequency of events varied from 20 to 30 per year. Since 1995, the average for Loss of DHR events is about 8 per year. There were several years in the early 2000s with few events; there were 3 events in 2002, and 5 in 2004 and 2006. The recent trend appears to be steady or slightly increasing, with 3 of the last 5 years having 9 events each.
- BWR and PWR units have averaged about the same number of Loss of DHR events per year since 2000. However, BWRs only constitute about one-third of the U.S. commercial reactors in operation. Therefore, the BWRs have about twice as many events per year, on average, than PWRs.
- Since 2000, almost two-thirds of the U.S. nuclear units have had no Loss of DHR events. Approximately one-quarter of the units only had one event. The most events per unit in the last ten years are 4. These results are a significant improvement over previous years, when about half of the units had 2 or more events, some having more than 10.

- RHR isolation is the most prevalent event type, accounting for about one-third of the Loss of DHR events from 2000 to 2009. This event is primarily associated with BWRs. 20% of the events are due to momentary or sustained loss of power to one electrical bus and 13% are from draindown events. The remainder of the event types each account for 10% or less of the total.
- The long-term trend (1990 to 2009) of the severity of events shows improvement. Since 2000, the average severity is less than 0.1; for this report, severity is a measure of the amount of margin used during the event. There were many events involving Loss of DHR where coolant temperature rise was negligible prior to restoring shutdown cooling (SDC).
- "Significant" events are defined consistent with previous reports [2,3]; a "significant" event is one in which the margin used is greater than 20% (i.e., a severity of greater than 0.2). The trend of "significant" events has shown good improvement, with 6 events since 2000 as compared to 23 events from 1990 to 1999. The most severe event since 2000 has a severity of approximately 0.4, but there were several events with higher severities in the 1990s, including one with a severity = 1.0.
- Events where SDC could not be established (i.e., loss of SDC/RHR while in cooling down in Hot Shutdown) are reported separately. Although there were a large number of events in the early 2000s (12 events in 4 years), there have only been 4 such events since 2004.
- This report is the first time Loss of Inventory events and trends have been analyzed separately from Loss of DHR, although Loss of Inventory events resulting in a Loss of DHR are included in that analysis also. For the purposes of this study, Loss of Inventory events are counted whether or not a Loss of DHR ensues; about 20% of all Loss of Inventory events lead to a Loss of DHR. The Loss of Inventory event trend has varied considerably since 1990, with relatively low periods from 1996 to 1998 and 2004 to 2006, and a fairly large spike from 1999 to 2001. Although the current three-year average is about 6 events per year, there have only been 3 Loss of DHR events due to losses of inventory since 2002.
- A majority of the Loss of Inventory events (about 75%) are due to inadvertent inventory losses (e.g., stuck open relief valves, incorrect valve lineups). There have been 15 events due to over-draining or draining past the intended target level. Two events of this type have occurred since 2000.
- More than half of the units have had a Loss of Inventory event since 1990, although nearly two-thirds of units have had no Loss of Inventory events since 2000. Approximately 75% of the Loss of Inventory events occur at PWRs, slightly higher than the relative population of PWRs in the U.S.

- The trend of event severity has shown good improvement for Loss of Inventory events since 1990. There has been only one Loss of Inventory event since 2000 that would be considered "significant." It should be noted that only about 75% of the Loss of Inventory events had adequate information available to calculate the severity.
- Since 1990, approximately 60% of Loss of Inventory events resulted in inventory losses between 1,000 and 10,000 gallons. Less than 1,000 gallons was lost in about 30% of the events, and only 6 events involve the loss of more than 10,000 gallons. Similar to the severity information, only two-thirds of the events had the inventory data needed for analysis.

Other Event Data and Trends

Key conclusions from Section 5 of this report include the following:

- For Loss of DHR events, operations-related activities were involved in about 40% of the events, and Maintenance activities accounted for 45%. This shows a relative decrease in the contribution from operations, compared to previous years [2,3], and a relative increase in the contribution from maintenance activities. System alignment changes were being performed during nearly half of the operations-related Loss of DHR events. Pump starts represent nearly 25% of the event. For maintenance-related activities, testing (which includes testing by both operators and technicians) accounted for more than half of the events. Loss of DHR events during preventive and corrective maintenance contributed about 40%.
- Loss of Inventory events is a new category for evaluation in this report; it includes all inventory loss events, whether or not DHR was lost. Operations-related activities were involved in nearly 75% of all Loss of Inventory events, with maintenance having a relatively smaller contribution at only 17%. A large percentage of the events associated with Loss of Inventory were during system alignment changes (e.g., swapping trains) and tagging activities (e.g., clearing tags with drains or vents still open). Testing and calibration were the primary maintenance-related activities.
- Work practices were the most prevalent cause for both Loss of DHR and Loss of Inventory events. Work practices include operator or technician errors, failure to follow plant processes or procedures, and general human performance failures (e.g., lack of conservative decision-making). Work practices contributed to approximately 35% of both types of events.
- Other event causes of note are (1) inadequate or incorrect procedures (accounting for nearly 30% of all Loss of inventory events, and 20% of Loss of DHR events) and (2) Planning and Scheduling.

2
APPROACH

The approach for data collection and analysis is described:

- U.S. nuclear plant operating experience from 1990 through 2009 was obtained from the Institute of Nuclear Power Operations (INPO) plant events database, accessed using the INPO website. The Operating Experience (OE) Search feature was used with key word searches; some of the document types included in these searches are NRC documents (Licensee Event Reports (LER), Information Notices, and Plant Notifications) as well as INPO documents (operating experience (OE) and Significant Event Reports (SER)). Additionally, a review of each OE for all U.S. Nuclear plants from 1999 to 2009 was performed as part of the data collection.
- Spreadsheets were created containing each loss of reactor coolant system inventory or DHR event. Loss of spent fuel pool (SFP) inventory and events that can be considered near-misses or precursors to a loss of inventory or DHR are currently not evaluated. Although the data has been collected, it has not been categorized nor entered into the spreadsheets. Loss of Inventory or DHR events reported by international plants are also not included. A total of 122 loss of reactor coolant system and inventory events and 255 loss of DHR events at U.S. nuclear plants from 1990-2009 are included in this analysis. Note that 24 Loss of Inventory events are counted twice, since they also resulted in a Loss of DHR.
- To the extent discernible by the data, event severity was assessed for each event identified. For loss of DHR, the event severity was determined by the amount of thermal margin used (prior to boiling) during the event. For Loss of Inventory, the event severity was determined by the amount of inventory margin used prior to a loss of DHR. In some cases where inadequate data was available to calculate the severity, it was estimated or qualitatively categorized (e.g., “Low”). If data was unavailable and could not be accurately estimated, the severity was designated “Unknown.” Events that resulted in losing more than 20% of the thermal or inventory margin were arbitrarily classified as “significant” events for the purpose of trending these types of events over time. This definition of “significant” is used to be consistent with the previous analyses [2,3].
- The initiating event (e.g., Isolation of RHR) for each event was determined for further categorization and trending. The breakdown of initiating events and examples of each are provided in Section 3.
- The cumulative number of events and individual event severity for each year was determined and graphed.
- The spreadsheet contains several other fields for performing trend analysis, such as the event description, the type of activity involved during the event, and the cause(s) of the event.

- Although precursor events were collected, they have not been analyzed and are not reported herein. Only actual losses of reactor coolant system inventory and DHR occurrences are included. Utilities more consistently report actual events; precursor events are not reported consistently.
- It is recognized that perhaps not all losses of inventory and DHR events are included in the database due to differences in reporting criteria used by utilities. However, these differences should not impact the overall trend results. There are some events which were considered "significant" by INPO or the NRC, but which may not have met the significance criteria described in this report. The principle reason for this difference is that significance in this report is based on what occurred, as opposed to the potential for significance, which is more commonly used by INPO and the NRC. Additionally, some precursor or near-miss events may be considered significant by the NRC, but they are not reported in this analysis.
- Although the data includes Loss of DHR events in Hot Shutdown (PWR Mode 4, BWR Condition 3), the severity for these events is not calculated, unless due to a Loss of Inventory. This is because time-to-boil (TTB, which is used for severity calculations) is not a valid end state for the plant conditions (temperature and pressure) in Hot Shutdown.
- The results only include events that occurred after the unit had achieved initial criticality. Events prior to initial criticality have no actual outage safety impact because there is no decay heat. This only applies to the older data (1990 - 1999), since there have been no new U.S. reactors during 2000 - 2009.
- Unlike the previous analysis [2], data was kept for units that have subsequently been shutdown and are no longer operating. These events are still indicative of the trend and severity of loss of DHR.
- Events occurring when the entire core is offloaded to the SFP (so-called Mode 0) are not reported herein. Although obtained during the data collection phase, they were not reviewed in detail nor analyzed.
- Some loss of RHR shutdown cooling (SDC) events occurred while transitioning to RHR SDC (e.g., in Mode 4 in a PWR, going from Steam Generator (SG) to RHR cooling). Although these are not necessarily losses of DHR, the data was maintained and some analysis was performed. This data is reported at the end of Section 3.

The event trend results (number and severity) for U.S. Loss of DHR events from 1990 through 2009 are presented in Section 3. Similar results for Loss of Inventory events are in Section 4. Other event trends and insights (e.g., the cause of events) are presented in Section 5.

3
LOSS OF DECAY HEAT REMOVAL DATA AND TRENDS

The database contains 255 events from 1990 through 2009 that resulted in a Loss of DHR capability. None of these events resulted in fuel damage. For the purposes of this report, a Loss of DHR is defined as: *A momentary or sustained loss of forced cooling and/or flow through the reactor core, that requires manual or automatic actions to re-establish the cooling and/or flow.* A large majority of these events had negligible reactor safety impact, resulting in small inventory losses and/or little to no heat-up of the reactor coolant system. A few events were more significant, resulting in larger inventory losses or greater reactor coolant system temperature increases. The data from 1990 through 2000 differs slightly from the previous report [2], due to a re-review of the data and a change to the criteria for plotting the data. Additional events were identified in the data review compared to previous reports. This is likely due to the many events which were added to the INPO plant events database; previous data analysis required searches through multiple data sources. In this report, only Loss of Inventory events that result in a Loss of DHR are included in the totals discussed here. Further analysis of Loss of Inventory events, regardless of their impact, is presented and discussed separately in Section 4.

The number, trends, type, and severity of events results are presented in Figures 3-1 through 3-9 and Tables 3-1 through 3-3, and are discussed below.

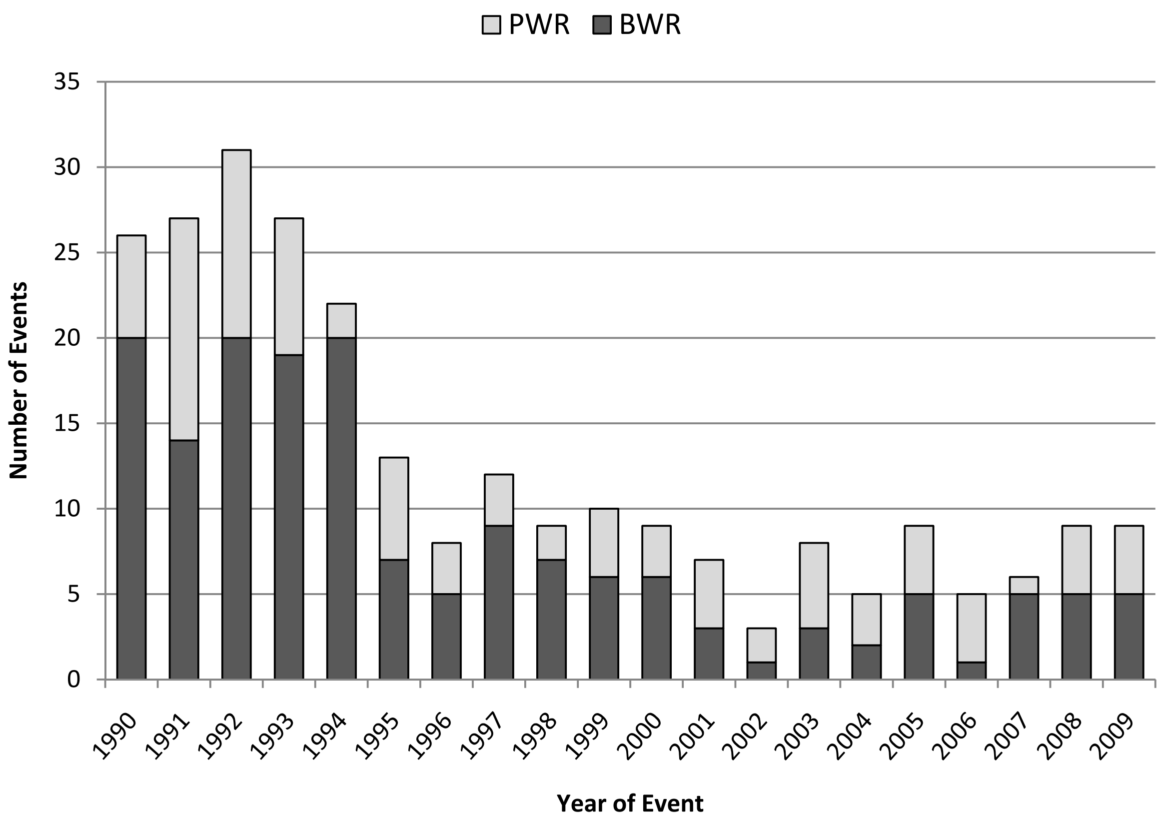

Figure 3-1
Number of Loss of DHR Events from 1990 to 2009

Number and Trend of Events

The number of events and their trend from 1990 through 2009 is presented in Figure 3-1. This figure shows that there is a substantial decrease in the number of events per year around 1995. This observation was also noted in the previous report [2]. A review of the trend indicates that in the time-period following this steep decrease, the number of events varies around 8 events per year, as compared to the years 1990 to 1994, in which the there were on the order of 20 - 30 events per year. Therefore, a better time-frame to examine trends up to current outages would be starting in 1995. Figure 3-2 shows the number of PWR and BWR events from 1995 - 2009, along with a 3-year rolling average trend line for the total number of events.

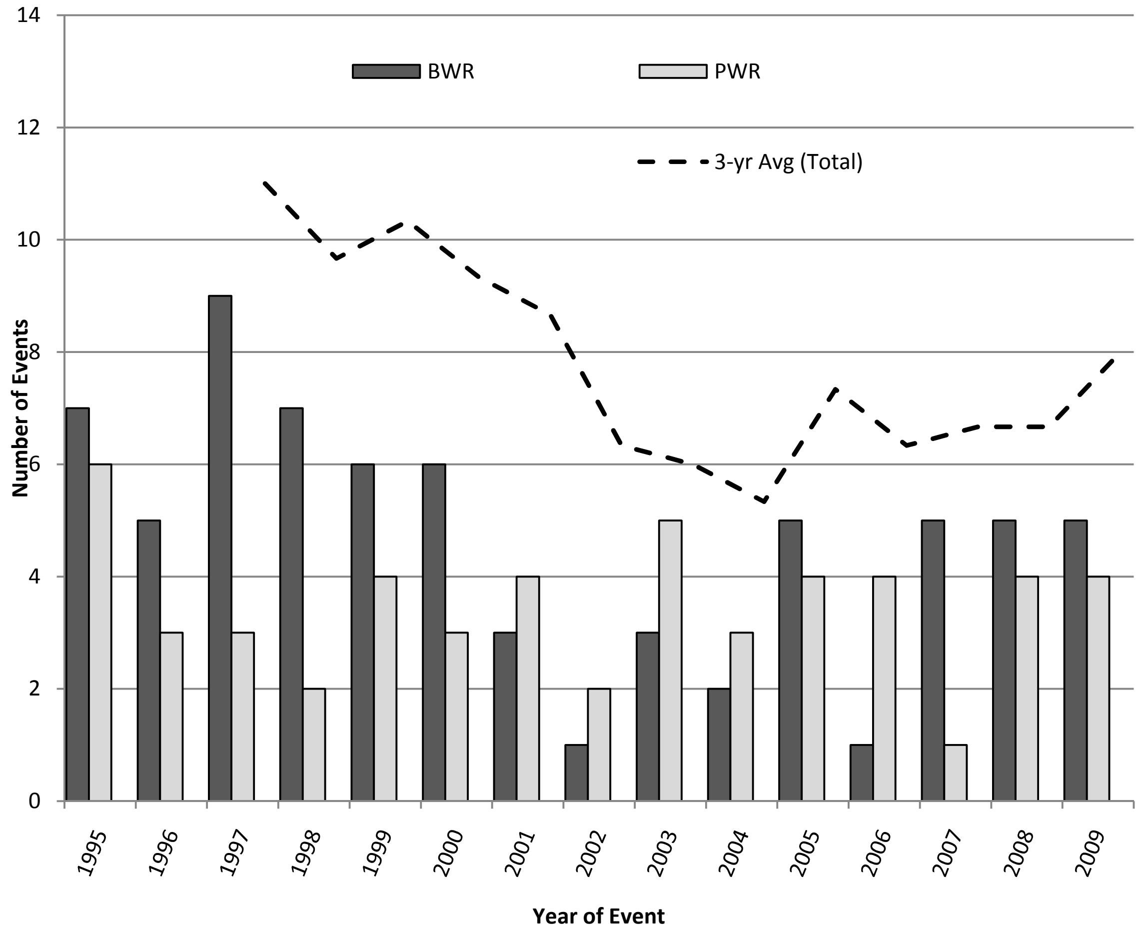

Figure 3-2
Number and Trend of Loss of DHR Events from 1995 to 2009

From the 1995 - 2009 data in Figure 3-2, the number of events per year continued the downward trend seen through the 1990's until the early 2000's. After 2004, there is an upward trend, based on a 3-year rolling average. However, the last 5 years shows an almost constant number of events per year. In 4 of the 5 years, there were 5 BWR or 4 PWR events. In 2006, there was only one BWR event, and in 2007 there was only 1 PWR event. Lastly, Figure 3-3 shows the Loss of DHR events for the last 10 years, from 2000 to 2009. Except for 2002, the total number of events has varied between 5 and 9 per year, with an average of 7 events per year. There is an average of 3.6 BWR and 3.4 PWR events during this period.

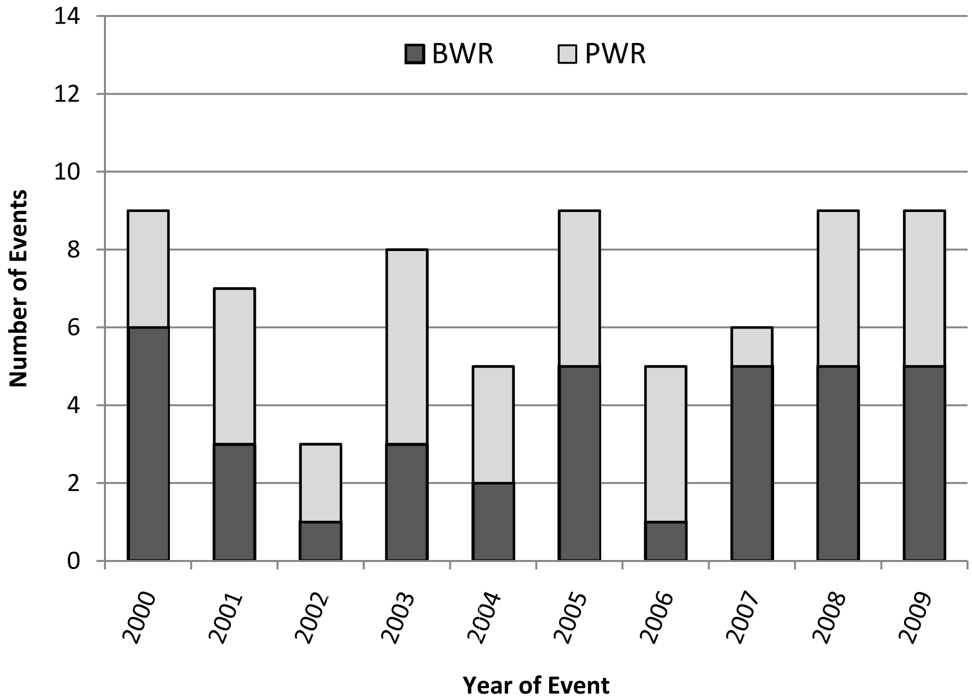

Figure 3-3
Number of Loss of DHR Events from 2000 to 2009

Types of Initiators

Table 3-1 lists the number of events per year and the initiator type. Figure 3-4 provides a breakdown of initiator types for the time period 1990 to 2009, showing their relative contributions to the total. The types of initiator are categorized as follows:

- ISORHR - RHR and Reactor Vessel Isolation
- LOPUMP - Loss of [RHR] Pump
- LOOP - Loss of Offsite Power
- LORHCOOL - Loss of RHR Cooling
- LORHFLOW - Loss of RHR Flow
- LO1BUS - Loss of One Electrical Bus
- DRAIN - Loss of Inventory (resulting in a Loss of DHR)

Table 3-1
Loss of DHR Events 1990 to 2009

	ISORHR	LOPUMP	LOOP	LORH-COOL	LORH-FLOW	LO1BUS	DRAIN	TOTAL
1990	22	0	2	0	0	2	0	**26**
1991	14	2	4	1	0	2	4	**27**
1992	17	1	4	2	1	2	4	**31**
1993	14	1	6	1	2	2	1	**27**
1994	19	1	1	1	0	0	0	**22**
1995	7	1	2	1	0	0	2	**13**
1996	3	1	2	0	1	1	0	**8**
1997	7	0	4	0	0	0	1	**12**
1998	5	1	2	0	1	0	0	**9**
1999	3	0	1	0	0	3	3	**10**
2000	3	1	1	0	0	2	2	**9**
2001	3	0	0	0	0	0	4	**7**
2002	2	0	0	1	0	0	0	**3**
2003	3	0	2	2	1	0	0	**8**
2004	0	0	0	0	0	4	1	**5**
2005	2	1	1	1	1	3	0	**9**
2006	2	0	1	1	0	1	0	**5**
2007	4	1	0	1	0	0	0	**6**
2008	3	1	1	1	0	2	1	**9**
2009	4	2	0	0	0	2	1	**9**
ALL	**137**	**14**	**34**	**13**	**7**	**26**	**24**	**255**

RHR and Reactor Vessel Isolation (ISORHR)

These events involve the closure of one or more RHR or SDC isolation valves. A majority of the RHR Isolation events (90%) occurred at BWR plants. Many of the BWR events are the result of loss of power to RPS or inadvertent actuations during testing and other maintenance. In order to recover SDC following isolation events, the closed valve(s) must be re-opened and a pump restarted. This may require aligning alternate power sources and/or resetting trips. Events in which the RHR pump tripped due to a false closure signal, but the valves did not close, are not considered isolation events. The number of isolation events has decreased substantially since the early 1990s, when there was an average of 17 events per year (1990 to 1994). The average isolation events were 5 per year from 1995 to 1999, and less than 3 events per year from 2000 to 2009. However, there were 4 events per year in both 2007 and 2009.

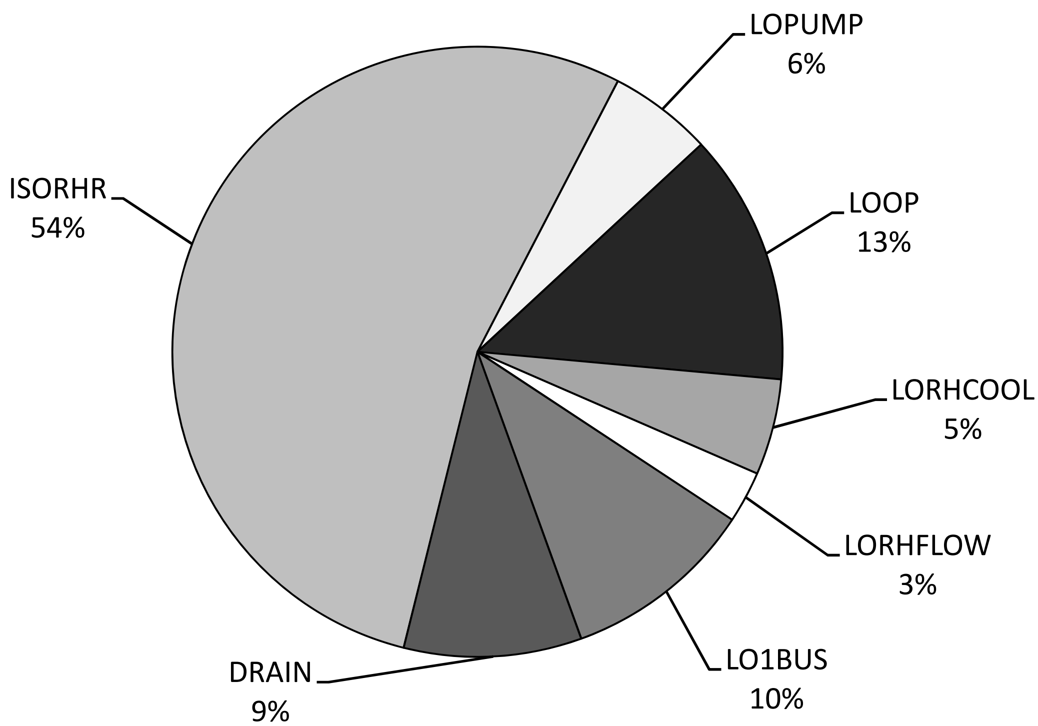

Figure 3-4
Types of Initiators for Events from 1990 to 2009

Loss of Pump (LOPUMP)

These events are due to the running RHR pump stopping, requiring it to be re-started or the standby pump started. The events are primarily due to pump failures, inadvertent tripping by the operator, or false isolation signals resulting in a pump trip. Pump trips due to an electrical bus de-energizing are not included in this category. There have only been 14 Loss of Pump events since 1990, spaced out fairly evenly over the years.

Loss of Offsite Power (LOOP)

These events are loss of offsite power to all (generally two or three) Engineered Safety Features (ESF) buses, causing a trip of the running RHR pump or pumps. Many of the events are typical Loss of Offsite Power events, such as those occurring at power. However, there are several that involve spurious actuations causing the buses to be de-energized (e.g., by all breakers opening) and the Emergency Diesel Generators (EDG) starting and loading onto the buses. RHR pumps in most plants must be manually restarted by the operator, although several plants have RHR pumps that automatically start. Events where power is lost to only one electrical bus, resulting in the RHR pump tripping, are not considered in this category. There was an average of nearly 3 LOOP events per year in the 1990s, and less than 1 per year since 2000.

Loss of One Electrical Bus (LO1BUS)

Loss of electrical power to the electrical bus supplying the running RHR pump, whether momentary or sustained, is classified as a LO1BUS event. Most events result in a momentary loss of power, allowing the RHR pump to be restarted relatively quickly. Bus failures are also included in this category. Single bus failures are generally easier to recover from if a standby RHR pump is available. LO1BUS events, together with the LOOP events, account for over 20% of all loss of DHR events from 1990 - 2009.

Loss of RHR Cooling (LORHCOOL)

This category includes events with a loss of cooling to the RHR system. RHR flow continues, but is no longer being cooled. Examples of this are loss of the Component Cooling Water (CCW) cooling or flow to the RHR HX. This category also includes two events involving the loss of service water (which cools CCW). Although this could be considered a different initiator, it is binned with the LORHCOOL.

Loss of RHR Flow (LORHFLOW)

There were seven events in this category. Three involve the loss of RHR flow through the RHR HX (i.e., the HX inlet/outlet valve closes but the bypass is available for continued RHR flow. The other four events involve loss of flow to the RCS or RV. This is primarily due to flow diversion; the RHR pumps continue to run, but flow is not adequate to cool the core.

Loss of Inventory (DRAIN)

Events in this category are losses of DHR due to inventory losses. Although numerous losses of inventory have occurred (see Section 4), less than 20% of the Loss of Inventory events progress to the point that DHR is lost. Procedures often require isolation of the RHR/SDC system in attempting to stop the loss of coolant. Additionally, automatic isolations may result due to low RV levels. Only two events are the result of over-draining and causing RHR pump vortexing, a problem that had been prevalent in the 1980s; the two events occurred between 1991 and 1992. Several events occurred as the result of lining up or starting SDC as the reactor was being cooled down (i.e., in Hot Shutdown). Other loss of SDC events (not involving inventory loss) that occurred during such situations are treated as separate events in this report (see Figure 3-9). Due to the consequences, Loss of Inventory events during SDC initiation are included in this (DRAIN) category. More than half (10 of 17) of the PWR Loss of Inventory events resulting in a loss of SDC occurred in Mode 4. Only 1 (of 7) BWR events occurred in Hot Shutdown.

Further Analysis of Initiators Types

It is clear from a review of the initiator data that BWR RHR Isolation events are the most prevalent contributor to Loss of DHR events from 1990 - 2009. As discussed previously, the number of isolation events has decreased substantially since the early 1990s. Additionally, the relative number of events of each type has changed (although less dramatically) between the 1990s and 2000s. Therefore, a different initiator breakdown is provided in Figure 3-5, including events from 2000 to 2009 only.

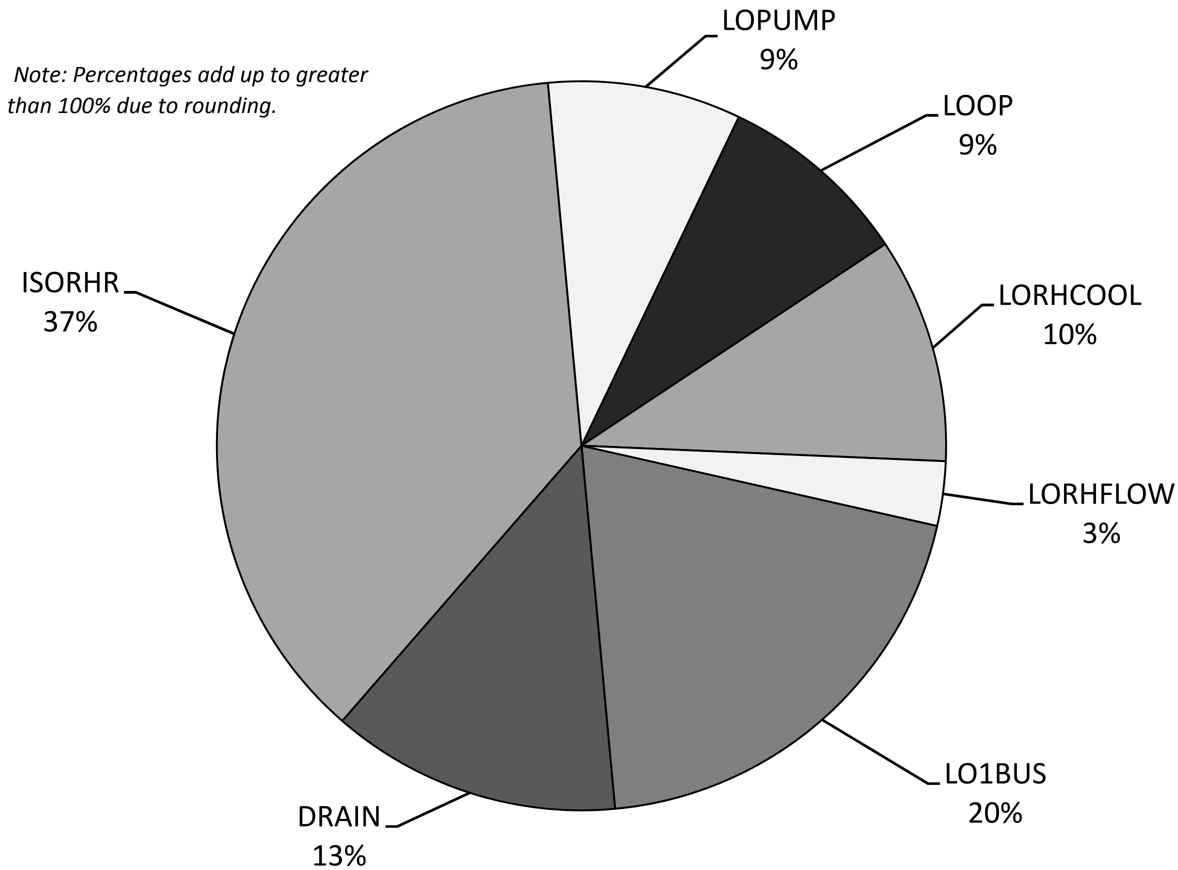

Figure 3-5
Types of Initiators for Events from 2000 to 2009

The relative contribution of certain initiators changed substantially when comparing the time frames 1990 - 2009 (Figure 3-4) and 2000 - 2009 (Figure 3-5). The largest change is seen in the RHR Isolation events (ISORHR), which decreased in contribution from 54% to 37%. [It is noted that just removing the years 1990 - 1994 from the data reduces the ISORHR contribution to 42%, a substantial portion of the reduction seen in ISORHR.] The majority of the remaining contribution change is seen as an increase for Loss of One Electrical Bus (LO1BUS), which goes up by about 10%, Loss of RHR Cooling (LORHCOOL) and Loss of RCS Inventory (DRAIN), each of which increase by nearly 5%. Loss of Offsite Power (LOOP) contribution decreases by 4%. These charts just show the relative contribution; the total number of events since 2000 is less than one-third of the number of all events between 1990 and 2009.

Number of Events per Unit

During the review of the events, it was noted that many plants had no Loss of DHR events during the time frame 1990 - 2009, and certain plants appeared to have an inordinate number of events compared to the average. Considering the time period starting in 1990, approximately one-fourth of the units had 0 events and about one-third had 1 event. Twenty units had two events and several units had 3 or more events each, including up to 13 events for one plant. A majority of the units with the higher number of events were BWRs, and many of the events occurred in the 1990s. As seen in Figures 3-2 and 3-3, the number of events throughout the industry has decreased substantially since the 1990s and has a relatively flat trend over the last 10 years. Therefore, Figure 3-6 shows the number of events per plant between 2000 and 2009.

Figure 3-6 shows that nearly two-thirds of U.S. nuclear units have had no Loss of DHR events since 2000, nearly one-quarter had only 1 event, and about twenty units have had 2 or more events. No unit had more than 4 events during the time frame 2000 to 2009. BWR units accounted for all but one unit with 3 or more events.

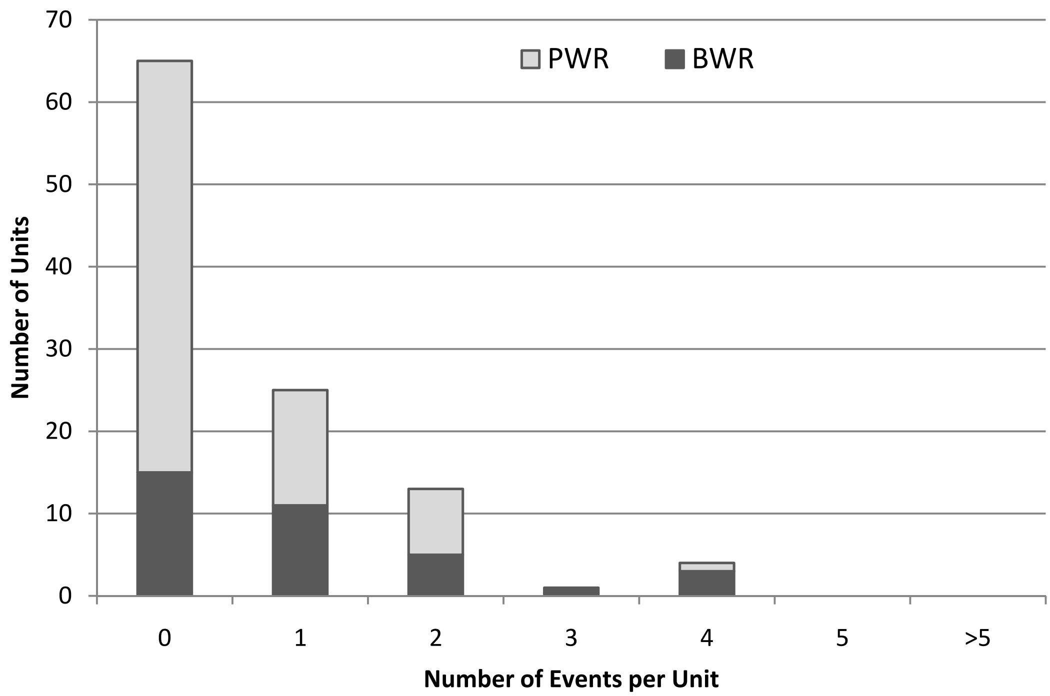

Figure 3-6
Number of Events per Unit from 2000 to 2009

Severity of Individual Events

The previous report [2] presented the concept of event severity, which is determined by the fraction of thermal or inventory margin used during the event. For example, if the RCS heated up 30 degrees Fahrenheit from an initial temperature of 140 degrees, the thermal margin used would be 30/(212-140) = 0.42. Alternately, if the RCS lost 5,000 gallons with an initial inventory of 50,000 gallons (prior to loss of decay heat removal), the severity would be 5,000/50,000 = 0.1. An event severity of 0.1 indicates that an event used one-tenth of the thermal or inventory margin. Severity calculations for Loss of DHR events that are the result of a Loss of Inventory include the severity associated with both the inventory loss and the temperature increase. This is done because both of these parameters are affected by the event, and ultimately the overall margin is reduced. This is also consistent with the previous report [2].

Figure 3-7 shows the severity for each event as a point (distinguished between BWR and PWR) and the year in which the event occurred. Only events from 2000 to 2009 are displayed. The average severity per event has decreased substantially since the 1990s, from a value of approximately 0.11 to about 0.07. Additionally, there have been much fewer high-severity events since 2000, when compared to the 1990s.

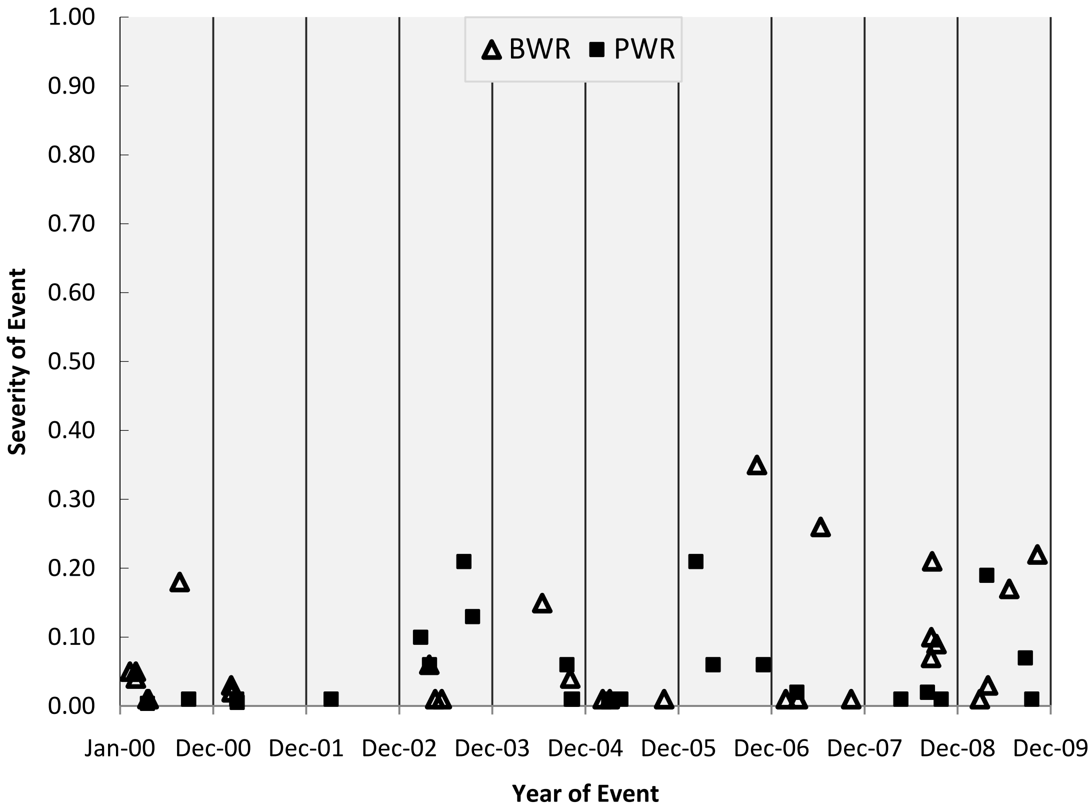

Figure 3-7
Severity of Events from 2000 to 2009

"Significant" Events

The previous report [2] also provided a definition, albeit arbitrary, for "significant" events, based on the calculated severity. A significant event is any event with a severity greater than or equal to 0.2, or 20% of the thermal/inventory margin used. As expected, the number of significant events has dropped substantially; there were 23 significant events from 1990 to 1999, and only 6 from 2000 to 2009. The most severe event since 2000 has a calculated severity of approximately 0.4, whereas there are several events with a severity of 1.0 in the 1990s. A severity of 1.0 indicates a loss of all thermal margin (i.e., boiling).

A graph of the number of significant events is provided in Figure 3-8. This figure also shows that BWRs have nearly twice as many significant events as PWRs (19 vs. 10 from 1990 to 2009), although the overall average severity for BWR events is essentially equal to the average PWR severity. This graph does not completely correlate with the one in the previous report [2]; a few events in the 1990s with high severity were Loss of Inventory events that did not result in a loss of DHR. As discussed previously, these are not considered in this portion of the report. Also, some new events were identified during the review of INPO data that were not included in the previous report.

Severity is not calculated for about 10% of the loss of DHR events, due to the lack of data for certain events. Operating Experience (OE) reports and Licensee Event Reports (LER) are the primary sources for providing the information needed to calculate severity. The parameters needed (e.g., RCS temperature increase, volume available) are not required to be entered in any report. For many events, the report indicated that no temperature increase was noted; in these cases, the severity was assumed to be 0.01 for graphing and trending purposes.

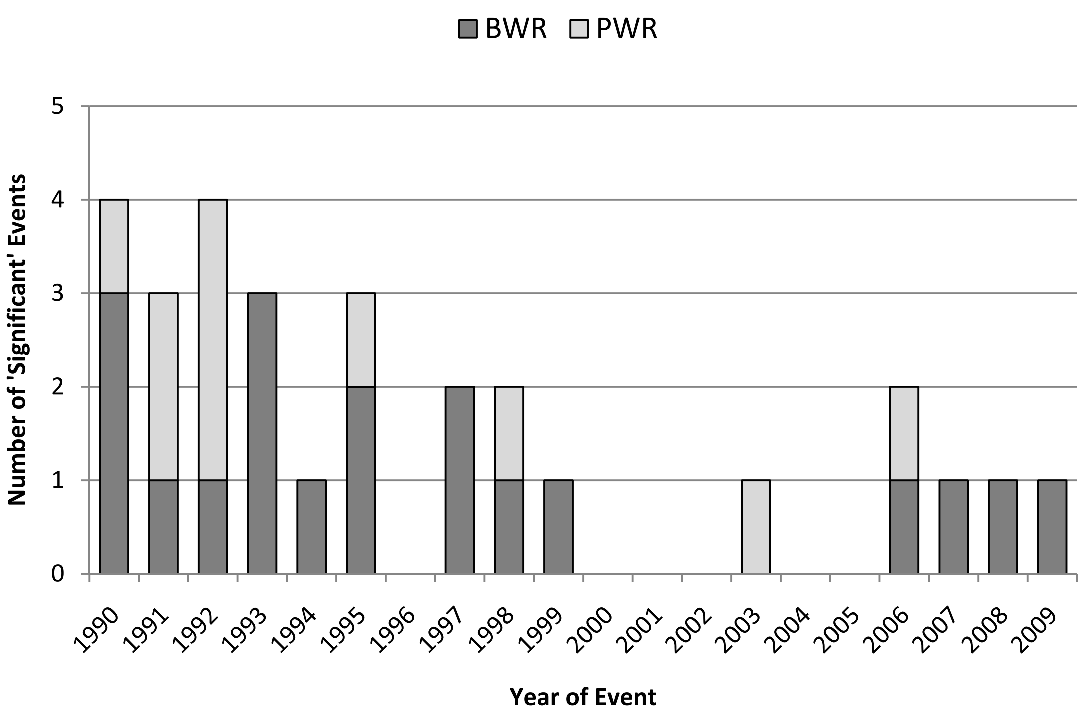

Figure 3-8
Number of 'Significant' Events from 1990 to 2009

Average Severity of Events

The average severity for all events is provided in Table 3-2. This reflects severity data for 231 events from 1990 to 2009, about 90% of the 255 Loss of DHR events collected. As described previously, not all events had adequate information to calculate a severity. As seen in Table 3-2, the average severity is on the order of 0.1 for the entire date frame of 1990 - 2009. The severity is slightly lower from 2000 - 2009, but this has less impact on the total due to the lower number of events since 2000.

The average severity values reflect the many low severity events (less than 0.1) and a few high severity events. The values associated with the high severity events have a marked impact on the average value. During both time frames (1990 - 1999 and 2000 - 2009), the percentage of low severity events is about the same, 77% and 76% respectively. However, the average severity of events greater than 0.1 is approximately 0.4 for 1990 to 1999, and 0.2 for events from 2000 to 2009. The average values of the high severity events are what drive the difference between the time frame averages.

Median values were also calculated. The median severity for BWRs is 0.03 and the median for PWRs is 0.04. The median for all 231 events is approximately 0.03.

Table 3-2
Average Severity of Events

Year	BWR	PWR	Total
1990 - 1999	0.11	0.13	0.11
2000 -2009	0.08	0.05	0.07
1990 - 2009	0.10	0.11	0.10

A further breakdown of average severity is provided in Table 3-3. The number of events (for which severity data is calculated), average severity, and observations of the data for each initiator type is listed in this table. RHR isolation, loss of pump, loss of RHR cooling and LOOP events all have averages near the overall average for the data. The loss of single bus events (LO1BUS) generally have lower severities than average. Loss of RHR flow and Loss of Inventory events have average severities more than twice that of the entire data set. The average severity for these initiators is driven by a few very severe events, as discussed in the Comments column of Table 3-3.

Table 3-3
Event Severity per Initiator Type

Initiator	Description	No. of Events	Average Severity	Comments
ISORHR	RHR and Reactor Vessel Isolation	129	0.09	The average severity is primarily driven by BWR events, as they are 90% of all ISORHR events. The events prior to 2000 are more severe, with 15 events having a severity of greater than 0.15 and 4 events with a severity of 1.0
LOPUMP	Loss of Pump	13	0.10	There are a few significant events, primarily PWR. 5 of the events have severity value of about 0.2.
LOOP	Loss of Offsite Power	26	0.07	BWR and PWR events, both in the 1990s and 2000s have very similar average severity values. BWR LOOP events in the 1990s have the lowest average, but there are few events. There are 3 PWR events in the 1990s with severity values from about 0.2 to 0.4.
LORHCOOL	Loss of RHR Cooling	12	0.13	Since there are only 12 events, the one PWR event with a severity of 1.0 essentially drives the average for this initiator. Otherwise, the average would be less than 0.1.
LORHFLOW	Loss of RHR Flow	6	0.26	One BWR event in the 1990s had a severity of 1.0. With only 6 total events, that one event is responsible for the high average.
LO1BUS	Loss of One Electrical Bus	24	0.04	Only one PWR event is significant ($\geq$ 0.2). All other events have a severity less than 0.2. PWR average is slightly higher.
DRAIN	Loss of Inventory	21	0.23	Three high severity events drive the average. They are PWR events in the 1990s, two of which have severity values at or near 1.0 and one event has a severity of approximately 0.7.

Failure to Establish Shutdown Cooling

As discussed in a previous section, events involving the failure to establish shutdown cooling are for the most part tracked separately from other events. This is a change from the previous report [2], wherein events that occurred in Hot Shutdown (Mode 4 for PWR, Condition 3 for BWR) were generally screened. During the data collection and review, a substantial number of such events were captured. This data is provided for potential use in shutdown risk analyses, particularly for events during transition modes. As described earlier, these are events that occur while cooling down and transitioning to Cold Shutdown (Mode 5 for PWR, Condition 4 for BWR). Failure to establish shutdown cooling while in Cold Shutdown or Refueling Modes (e.g., re-establishing shutdown cooling following a hydrostatic test), is considered a Loss of DHR and are part of the data provided in previous sections. Loss of Inventory events that prevent establishing SDC are also considered Loss of DHR events, due to the potential consequences of these types of events. For example, the Loss of Inventory may prevent the previous decay heat removal process (e.g., Steam Generator Heat Removal) from being re-started.

Failure to Establish SDC events are divided into two categories, those associated with isolation valves (e.g., spurious isolation, stuck valves) and those associated with the RHR/SDC pumps (e.g., failure to start or run). Since this data was not presented in the previous report [2], all the events data from 1990 to 2009 are presented herein. Figure 3-9 shows the number of events per year, broken out by reactor type.

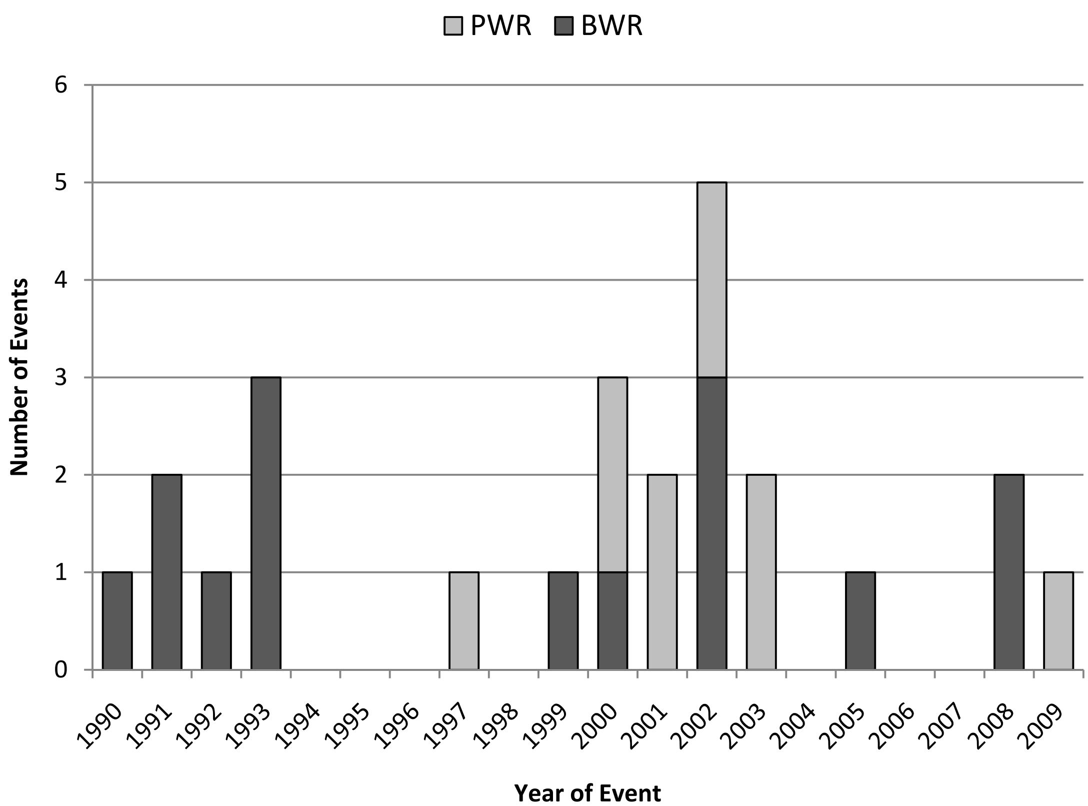

Figure 3-9
Number of Failure to Establish SDC Events from 1990 to 2009

The events appear to be spread fairly randomly throughout the time frame, with some periods of multiple years without events. The average is over 1 event per year; BWRs accounted for 60% of the events. Three plants (all BWR) had multiple events, with one having 5 events, including two on the same day. BWRs events were mainly due to isolation valve problems or closure, while PWRs events were split between pump and valve problems. Nearly three-quarters (18 of 25) of the events were valve-based, while 7 events were due to pump problems.

4
LOSS OF INVENTORY DATA AND TRENDS

During the data collection phase, substantially more Loss of Inventory events were found than for the previous report [2]. About 30 more events were identified in the latest data collection effort between 1990 to 2000, as compared to the previous analysis [2]. Most of this is attributed to additional records that were added to the INPO databases since the last time data was collected in the 2000 - 2001 time frame. A separate section is provided in this report for Loss of Inventory events due to the large number of these events (122), and the various causes and impacts of losses of inventory. One specific distinction that is made in this report is whether the Loss of Inventory resulted in a Loss of DHR. Events that did result in a Loss of DHR are included in the data in Section 3 as well as in this section. All other Loss of Inventory events (i.e., those that did not result in a Loss of DHR) are only discussed in this section.

The number, trends, type, and severity of events results are presented in Figures 4-1 through 4-11 and Tables 4-1 through 4-4, and are discussed below.

Number and Trend of Events

The number of Loss of Inventory events and their trend from 1990 through 2009 is presented in Figure 4-1. Unlike the trend in Loss of DHR events seen in Figure 3-1, the Loss of Inventory event trend appears to be more random, or even somewhat cyclical in nature. From 1990 to 1995, there were, on average, 7 events per year. There is a reduction in events through 1998, and then a large spike from 1999 to 2001, and again in 2003. Similar to the Loss of DHR trend, there are several years between 2002 and 2006 with relatively few events, and then what appears to be an upward trend in the last three years of the decade.

PWRs account for nearly 75% of all the Loss of Inventory events from 1990 to 2009. However, PWR units account for approximately 70% of all the commercial nuclear units in the U.S. The average number of events for the entire U.S. fleet is approximately 1.1 per unit. The PWR average (1.2 events per unit) is slightly higher than the BWR events (0.9 per unit). Thus, the relative number of events should be considered essentially the same for BWRs and PWRs.

Figure 4-1 shows all events that are considered Loss of Inventory. Only 20% of the Loss of Inventory events result in a Loss of DHR. Figure 4-2 shows the number and trend of Loss of Inventory events resulting in a Loss of DHR. The trend appears to follow the overall Loss of Inventory trend somewhat, with a relatively large number of events in the early 1990s and between 1999 and 2001. There were a total of 24 events, 17 PWR and 7 BWR. The ratio of events based on reactor type is very close to the overall ratio.

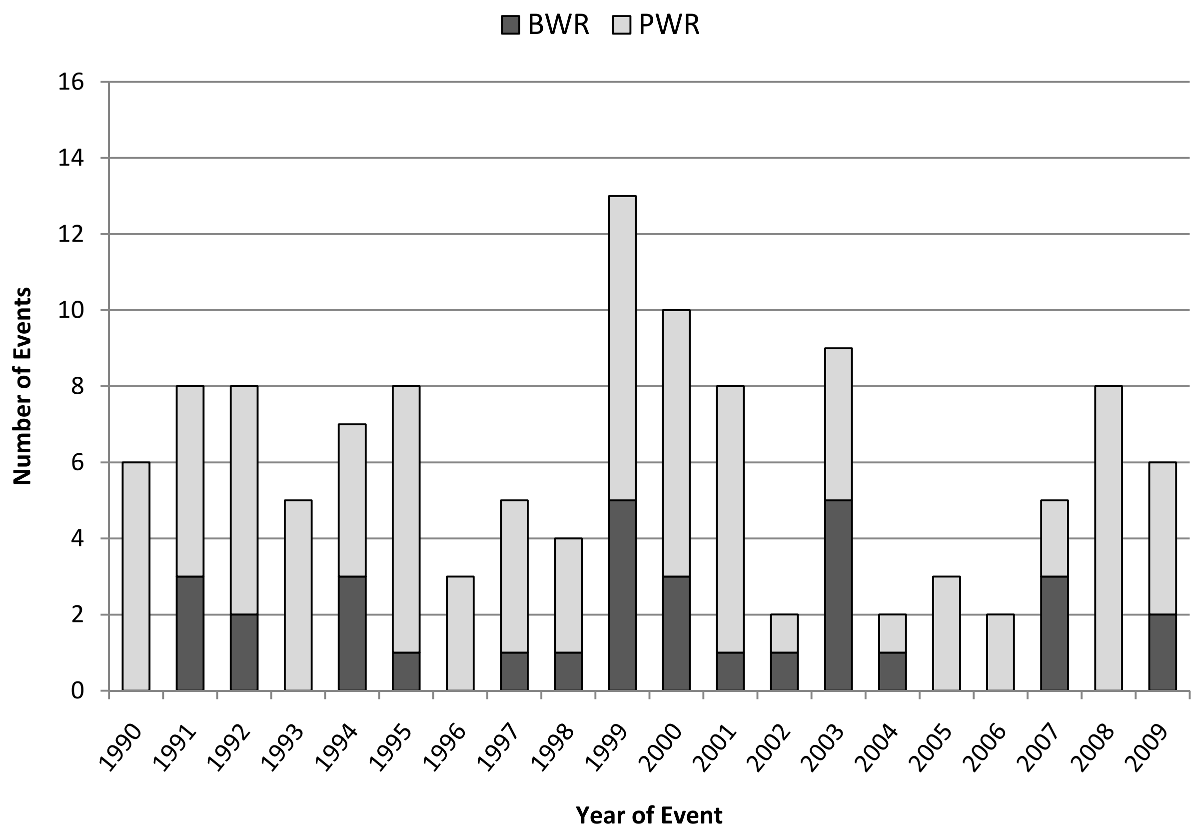

Figure 4-1
Number of Loss of Inventory Events by Plant Type from 1990 to 2009

Types of Loss of Inventory Events

Table 4-1 lists the number of events, per year and type of event. Figure 4-3 provides a breakdown of event types for the time period 1990 to 2009. Loss of Inventory events are categorized as follows:

- LOSSINV - Loss of Inventory
- DRAINLO - Drain Below Target Level
- LOSSLVL - Loss of Level

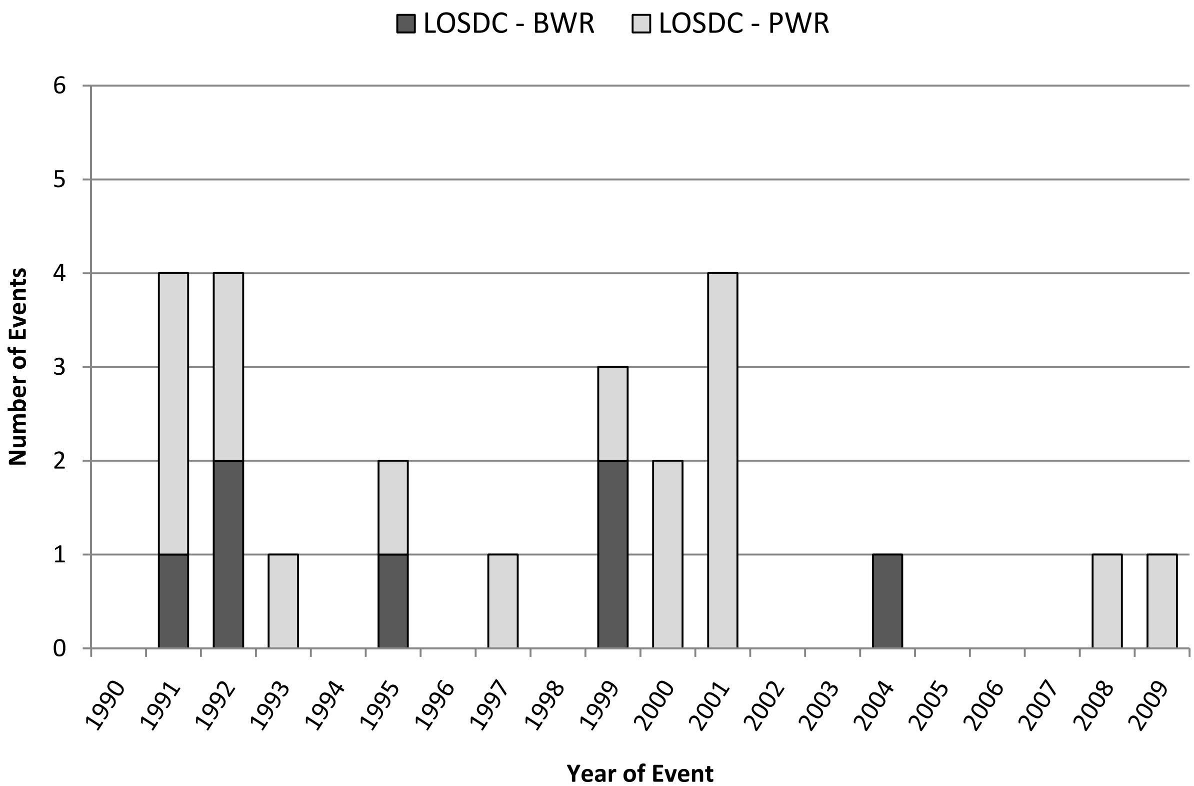

Figure 4-2
Number of Loss of Inventory Events Resulting in Loss of DHR (1990 to 2009)

Table 4-1
Loss of Inventory Events 1990 to 2009

	LOSSINV	DRAINLO	LOSSLVL	TOTAL
1990	5	1	0	**6**
1991	6	1	1	**8**
1992	6	2	0	**8**
1993	3	2	0	**5**
1994	6	0	1	**7**
1995	7	1	0	**8**
1996	2	0	1	**3**
1997	3	2	0	**5**
1998	3	0	1	**4**
1999	9	4	0	**13**
2000	6	0	4	**10**

	LOSSINV	DRAINLO	LOSSLVL	TOTAL
2001	8	0	0	**8**
2002	2	0	0	**2**
2003	5	1	3	**9**
2004	2	0	0	**2**
2005	3	0	0	**3**
2006	2	0	0	**2**
2007	4	0	1	**5**
2008	5	1	2	**8**
2009	5	0	1	**6**
ALL	**92**	**15**	**15**	**122**

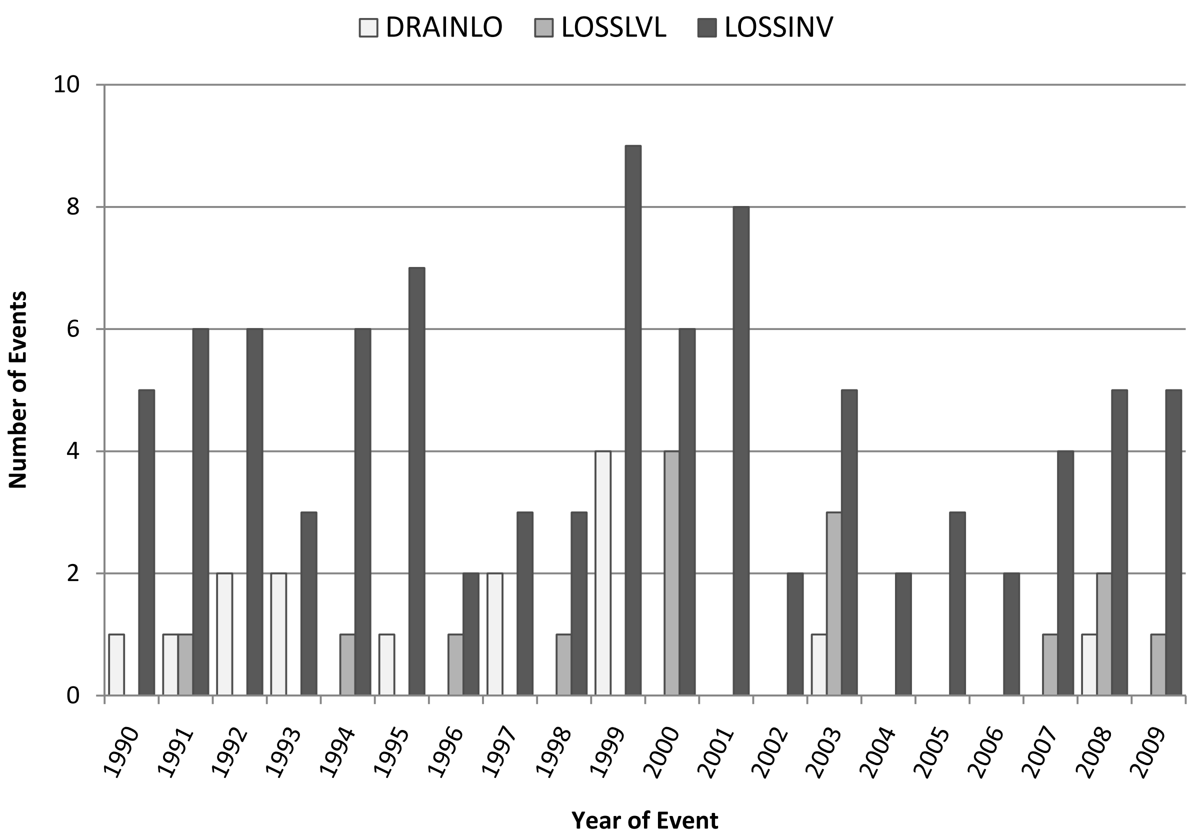

Figure 4-3
Number of Loss of Loss of Inventory Events by Type from 1990 to 2009

Loss of Inventory (LOSSINV)

These events involve the inadvertent loss of inventory from the RCS, Reactor Vessel, Reactor Cavity, Refuel Pool and RHR/SDC system (when connected to the RCS or reactor vessel). For this initiating event, the inventory is lost from the system, thus reducing the overall inventory available for cooling the core. Typical causes of LOSSINV events are relief valves lifting, inventory loss through open drain valves, incorrect system alignments, and intentional draining of inventory due to faulty level indication. In all these cases, inventory has been lost from the system and must be replaced via some form of injection. There are events in which inventory is displaced but still directly available for core cooling; these events are not considered Loss of Inventory (LOSSINV) events, they are classified as Loss of Level (LOSSLVL) events, and are described separately. Examples included inventory displacement due to the presence of voids in the RHR system or gas bubbles displacing inventory from the reactor vessel to the Pressurizer.

The LOSSINV event is the most prevalent of the three Loss of Inventory event categories. Approximately 75% of all inventory events are classified as LOSSINV. Since this represents the majority of events, the trend of these events is similar to the overall trend, discussed previously and seen in Figure 4-1. The average number of events is about 4.6 per year, although the number varies from 2 to 9 events per year. The average number of events was about 20% higher during the 1990s than since 2000. PWRs account for about 75% of the events, very similar to the total ratio for all Loss of Inventory events.

Drain Beyond Target Level (DRAINLO)

These events are due to over-draining. Evolutions for reducing inventory establish a target level; if the target level is passed and the inventory is lowered beyond the planned level, it is counted as a DRAINLO event. These are a special case of LOSSINV events, where an intentional reduction in inventory is desired, but excessive inventory is removed from the system. The main cause of these events is inaccurate level instruments. Other causes are operator inattention while draining and inadequate procedural guidance for draining.

Some events related to drain-down problems, especially those due to instrument errors, are not included. For example, it would not be considered an event if the draindown was stopped and the problem was corrected before reaching or going below the target level (e.g., level tracking higher than actual, stopped and fixed level indication before going below target level, losing SDC, or inadvertently enter reduced inventory). There were several such events that were excluded from this analysis. One of these events (9/11/92) was considered a drain-down event in the previous analysis.

There were only 15 events in the 20 years from 1990 to 2009. A majority of these events occurred prior to 2000; 13 of 15 events occurred from 1990 to 1999, and only 2 events have occurred since 2000. The trend appears to be a reduction in this type of event, although there were not a significant number of events in the 1990s. The average between 1990 and 1999 was about 1.3 events per year, ranging from no events in 3 years and a high of 4 events in 1999. 13 of the over drain events occurred at PWRs.

Prior to 1990, over drain events were a relatively frequent occurrence [6,7]. Over drain events that result in a loss of shutdown cooling or inadvertent entry into reduced inventory conditions are of particular concern from a nuclear safety standpoint. As noted in the previous paragraph, there have only been 2 over-drain events since 2000; both of these occurred at PWR plants and neither resulted in a loss of SDC or entry into reduced inventory. Prior to 2000, 3 of the 13 over drain events resulted in loss of SDC, although in 2 of the events decay heat removal capability was still available. 2 over-drains inadvertently lowered RCS level into the reduced inventory range, and 2 events occurred while draining from a reduced inventory level.

Loss of Level (LOSSLVL)

These events are not loss of inventory, per se, in that they are inventory displacement. The events are typically loss of RCS level during or following an evolution, such as venting the RCS or aligning SDC. The inventory is not lost from the system, but the level that was being maintained was not the true level. These events are captured because they could still result in a loss of SDC, if the level displacement was large enough. Also note that 4 of the events were in transition to SDC, 1 of which resulted in not entering SDC (the isolation valve was closed).

Two-thirds of the Loss of Level events occurred at PWRs. There does not appear to be a trend in the events. There were a few years in the 1990s with an event, with spikes of 4 events in 2000 and 3 in 2003. It should be noted that there have been 4 events in the last 3 years (2007 to 2009). One event in 2000 resulted in the isolation of SDC, due to a 6% Pressurizer level drop while placing SDC online. The cause was filling voids in the SDC system when the isolation valves were initially opened.

Number of Events per Unit

An analysis was performed of the distribution of events among units. In Section 3, a similar analysis was performed for Loss of DHR events; it showed that a majority of units had no events, and relatively few units had multiple events since 2000. For Loss of DHR events, the events per unit data from the 1990s was not displayed, primarily because the data from the early 1990s did not appear to be representative, as the number of events declined substantially after 1995 (especially BWR RHR Isolation events). However, the Loss of Inventory event trend is not as definitive. The number of events has varied over the years since 1990, including a large spike in the early 2000s. Therefore, Figure 4-4 shows the number of events per unit from 1990 to 2009.

Slightly more than one-third of the units have had no Loss of Inventory events since 1990. It should be noted that from 2000 on, nearly two-thirds of the units had no events, although there are less than half the total events during the 2000 to 2009 time frame, when compared to the entire date range. From 1990 to 2009, another one-third of the units only had one event, and the remaining units had multiple events. There were 6 units that had 3 events, and only 3 units that had 4 or more events (all 3 are PWRs). The maximum number of events per unit is 7, with 6 of those events occurring since 2001.

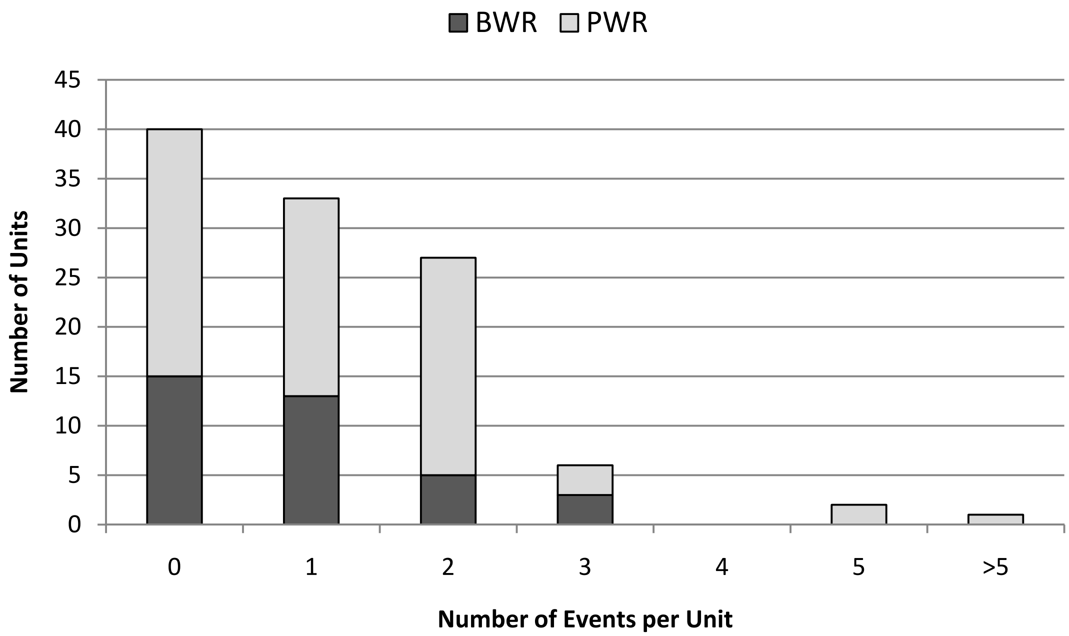

Figure 4-4
Number of Loss of Loss of Inventory Events per Unit from 1990 to 2009

Severity of Individual Events

The background to the severity methodology is provided in Section 3. A majority of the Loss of Inventory events do not result in a Loss of DHR, so severity is calculated based on the inventory lost and inventory margin. For PWRs, the margin is the inventory available from the start of the event until SDC would be lost (typically just below midloop). Inventory margin for BWRs is the amount available between the start of the event and the Top of Active Fuel (TAF). This is consistent with the calculations done in the previous report [2].

Severity calculations for Loss of Inventory events that also result in a Loss of DHR include the severity associated with both the inventory loss and the temperature increase. This is done because both of these parameters are affected by the event, and ultimately the overall margin is reduced. This is also consistent with the previous report [2].

There are 91 Loss of Inventory events for which a severity could be calculated, based on the data and event descriptions available. This is about 75% of all events, similar to the Loss of DHR results. Only 3 of the 24 events resulting in Loss of SDC do not have severity calculations; the volumes drained during these events could not be determined.

In many cases, the available inventory had to be estimated. If the plant-specific inventory at the beginning of the event could not be determined, the inventory was usually conservatively estimated based on the description of the event. Representative inventories, based on assumed RCS and RV levels, were taken from level vs. inventory tables in NSAC 175L, NSAC 176L [4,5], and information from plants of similar design.

Figure 4-5 shows the severity for each event as a point (distinguished between BWR and PWR) and the year in which the event occurred. The severity for all the Loss of Inventory events from 1990 to 2009 is displayed. The previous report included the severity for Loss of Inventory events together with Loss of DHR events [2]. Since the Loss of Inventory events have not been evaluated separately, the time frame 1990 to 2009 is used for Figure 4-5.

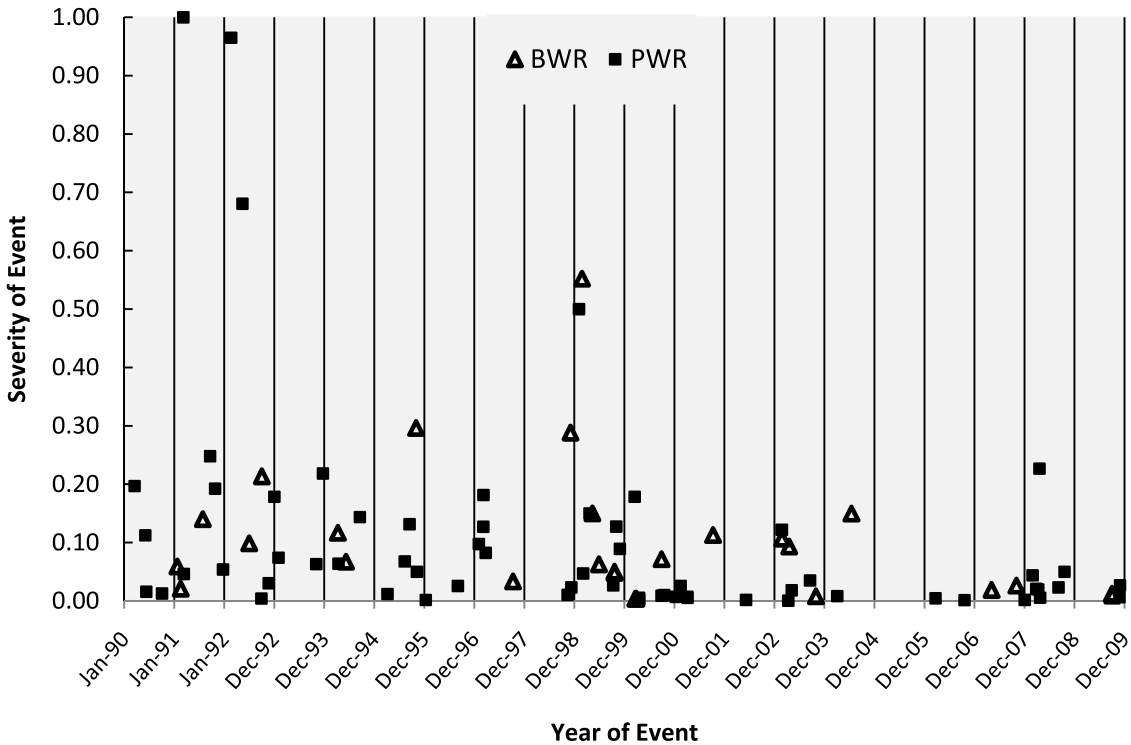

Figure 4-5
Severity of Events from 1990 to 2009

Event severity appears to follow a trend similar to the overall Loss of Inventory trend (Figure 4-1). There are several high severity events in the early 1990s, a spike around 1999, and one more severe event in 2008. The average severity appears to be lower in the 2000s as compared to the mid-1990s. Average severity is discussed in a subsequent subsection.

"Significant" Events

A significant event is any event with a severity greater than or equal to 0.2, or 20% of the inventory or thermal margin used. This is discussed further in Section 3 and in the previous report [2]. A graph of the number of significant events is provided in Figure 4-6.

There have only been 11 significant Loss of Inventory events between 1990 and 2009; 10 of these events occurred prior to 2000. There were no significant events from 2000 to 2007, but there was one significant in 2008. PWR units account for 7 of the 11 significant events. Loss of

Inventory (LOSSINV) events account for 8 significant events, with the remainder associated with Drain Beyond Target Level (DRAINLO) events. 6 of the significant events resulted in a Loss of DHR.

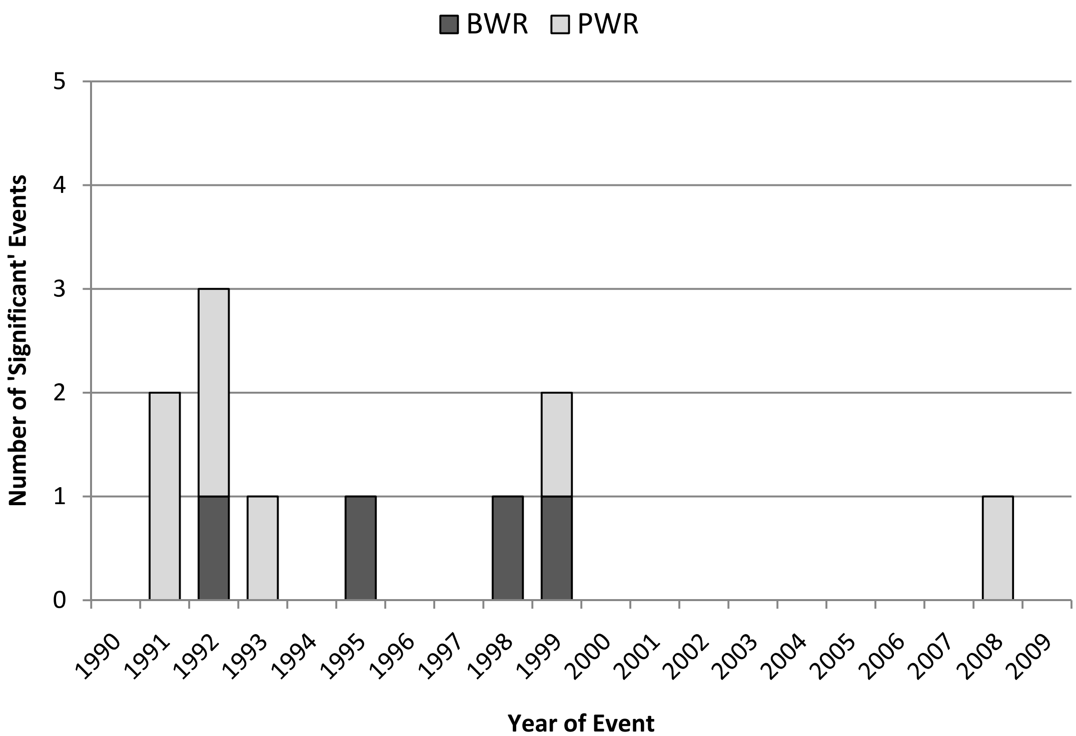

Figure 4-6
"Significant" Events from 1990 to 2009

Average Severity of Events

The average severity for all events is provided in Table 4-2. This reflects severity data for 91 events from 1990 to 2009, about 75% of the 122 Loss of Inventory events collected. As described previously, not all events had adequate information to calculate a severity. As seen in Table 4-2, the average severity is on the order of 0.1 for the entire date frame of 1990 to 2009. From 2000 to 2009, the severity is approximately one-quarter of the event severity in the 1990s.

Table 4-2
Average Severity of Loss of Inventory Events

Year	BWR	PWR	Total
1990 - 1999	0.15	0.16	0.16
2000 - 2009	0.05	0.03	0.04
1990 - 2009	0.10	0.11	0.11

The average severity values reflect the many low severity events (less than 0.1) and a few high severity events. The values associated with the high severity events have a marked impact on the average value, as seen in the Loss of DHR events (see the discussion associated with Table 3-2). Although this is also true for Loss of Inventory Events, the data shows that the ratio of low-to-high severity events has more impact on the difference in average values for the two time frames. The percentage of events with a severity <0.1 is 56% in the 1990s to about 82% since 2000 (i.e., there are more low severity events from 2000 to 2009 when compared to the 1990s). The average for events with severity greater than or equal to 0.1 is approximately 0.3 from 1990 to 1999 and about 0.2 for 2000 to 2009.

Median values were also calculated for the time frame 1990 to 2009. The median severity for BWRs is 0.07 and the median for PWRs is 0.04. The median for all 91 events is approximately 0.05.

Table 4-3 lists the average severity for the three Loss of Inventory event categories. The Drain Beyond Target Level (DRAINLO) has the highest average severity at just over 0.2. There are only 12 DRAINLO events that have calculated severity values, 7 of which have a severity greater than 0.1. One of these events has a severity very near 1.0, and another has a severity of 0.5. The Loss of Inventory (LOSSINV) average severity is about 0.10, which is essentially the same as the overall average for all categories of Loss of Inventory events (see Table 4-2). This is consistent with the fact that LOSSINV is the majority event type; nearly 75% of the events with severity values are LOSSINV events. The final type, Loss of Level (LOSSLVL), has the lowest average severity of 0.04. The inventory lost through Loss of Level events is generally small (e.g., filling voids in RHR piping after opening isolation valves).

Table 4-3
Average Severity per Event Type

Type of Event	Description	Average Severity (BWR)	Average Severity (PWR)	Average Severity (TOTAL)
DRAINLO	Drain Beyond Target Level	0.18	0.22	0.21
LOSSINV	Loss of Inventory	0.10	0.10	0.10
LOSSLVL	Loss of Level	0.08	0.02	0.04

Amount of Inventory Lost During Events

The volume of inventory lost during Loss of Inventory events is another characteristic that was determined during the data collection and review phase. The lost inventory amount was determined for approximately two-thirds (81) of the Loss of Inventory events. The range of estimated volumes lost is from 25 gallons to 38,000 gallons. The average amount lost is approximately 3,900 gallons, with a median value of about 1800 gallons. The average inventory lost for BWR events is more than 2 times the inventory lost for PWR events (8000 vs. 3000 gallons). The BWR average is strongly affected by 4 (of a total 15) events with volumes greater than 10,000 gallons, including 24,000 and 38,000 gallon losses. For all events, the average volume lost is nearly 4 times less since 2000 than during the 1990s (1600 vs. 5700 gallons).

The previous report [2] distinguished between "Large" and "Small" draindown events. Small Draindowns are less than or equal to 10,000 gallons inventory lost, while Large Draindowns are considered to be losses of greater than 10,000 gallons. Since there were many events with very small inventory losses, a third category (Minor Draindown) was developed in this report to capture events with less than 1,000 gallons of inventory lost. 1,000 gallons was arbitrarily chosen as the break point between Small and Minor Draindowns. The average volumes are provided in Table 4-4.

Table 4-4
Average Inventory Lost per Draindown Size (1990 to 2009)

Draindown Size	Number of Events	Average Inventory Lost
Minor (<1,000 gallons)	24	390 gallons
Small (1,000 - 10,000 gallons)	51	3,700 gallons
Large (> 10,000 gallons)	6	19,000 gallons
All Events	81	3,900 gallons

Figure 4-7 shows the relative occurrence of each size draindown. Two additional figures display the breakdown of events by size and plant type (4-8) and time frame (4-9). The majority of the Loss of Inventory events resulted in losing between 1,000 to 10,000 gallons. All the large draindowns (>10,000 gallons) occurred prior to 2000; 4 of the 6 large events were at BWR units.

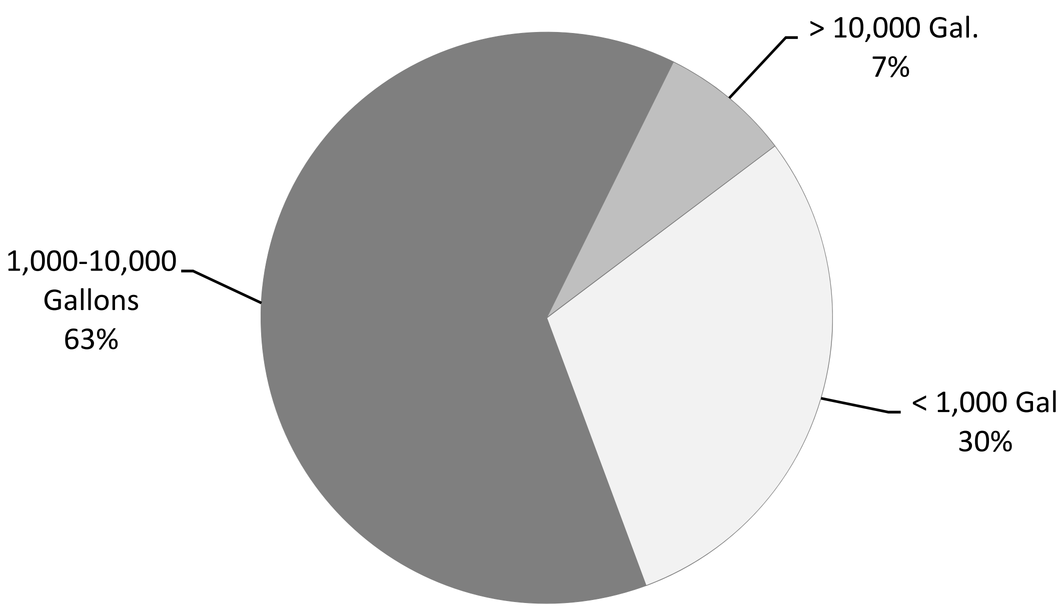

Figure 4-7
Draindown Volumes from 1990 to 2009

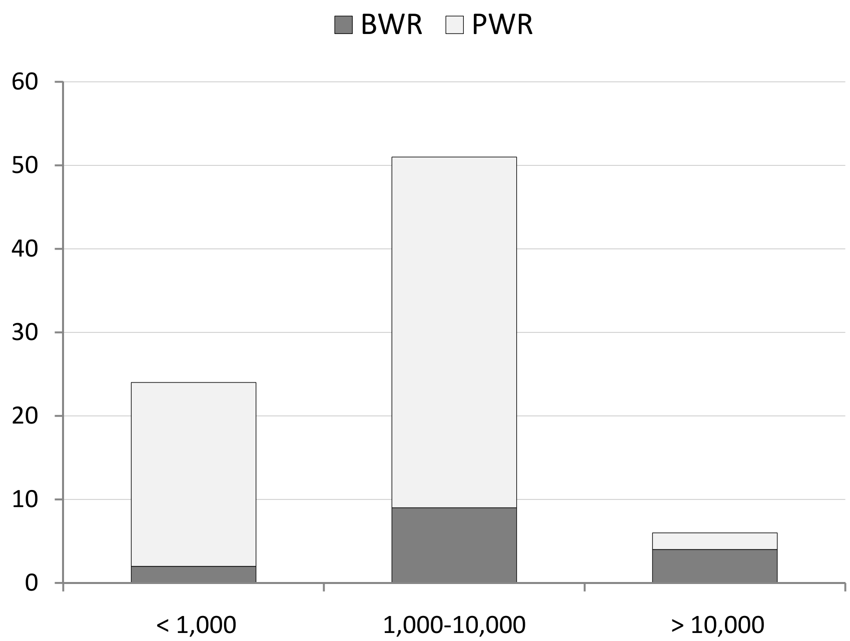

Figure 4-8
Draindown Volumes per Plant Type from 1990 to 2009

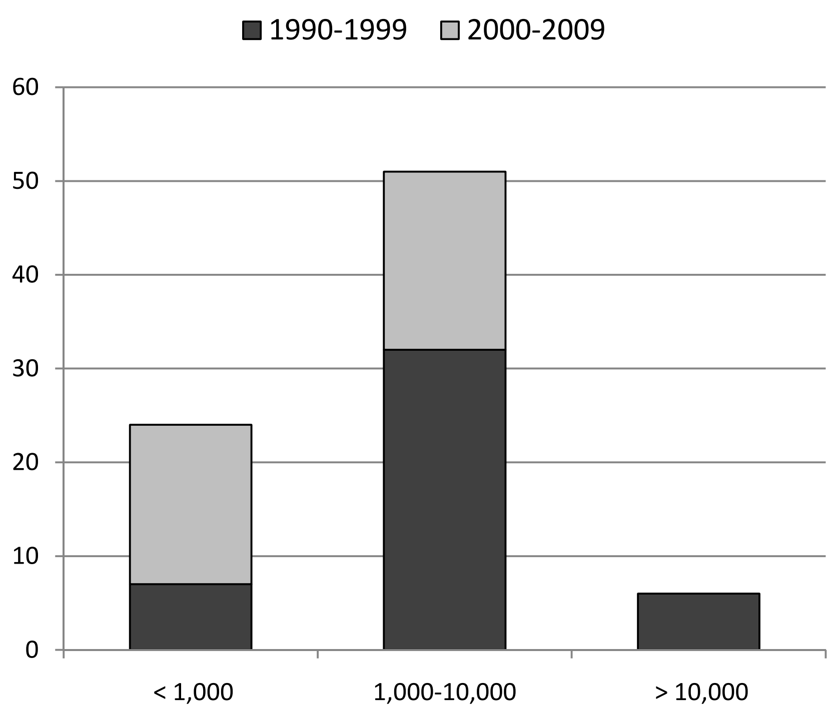

Figure 4-9
Draindown Volumes per Time Frame

A review of the Loss of Inventory events leading to Loss of DHR was performed, to determine the distribution of draindown sizes for only these events. There were 15 Loss of DHR events with volume data (from a total of 24 Loss of DHR events from 1990 to 2009). Figure 4-10 shows the breakdown of draindown volumes for events leading to a Loss of DHR; it is very similar to the data shown in Figure 4-7 for all Loss of Inventory Events. The absolute volume lost during an event is not the determining factor for whether or not DHR is lost. For example, a large loss of inventory while the cavity is flooded is less likely to lead to a loss of shutdown cooling than a smaller loss while at midloop.

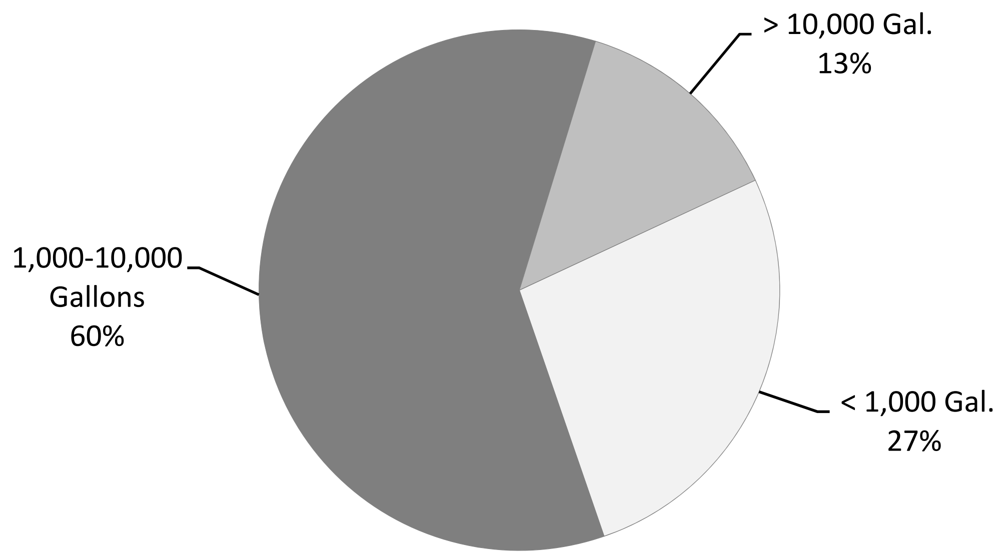

Figure 4-10
Draindown Volumes for Events Leading to a Loss of DHR

Inventory Lost vs. Severity

The last analysis performed for Loss of Inventory events is to compare the severity of each event with the volume lost. As discussed previously, loss of DHR due to a Loss of Inventory event does not necessarily correlate with the absolute volume lost during an event. However, the severity calculation is intended to provide an indication of the amount of inventory (and thermal) margin used during the event.

Figure 4-11 plots each event that has inventory data and a severity value. There are 74 events plotted in this figure. It is possible to know the amount of inventory lost and not be able to calculate the severity, if the starting or ending RCS volume is unknown. Likewise, but less frequent, the fraction of available volume lost during the event may be known (i.e., severity), when the absolute volume lost is not known.

The plot shows that there appears to be a proportional relationship between severity and volume lost, at lower values. However, as expected, there are a few high severity events with low volumes lost and low severity events with high volumes lost.

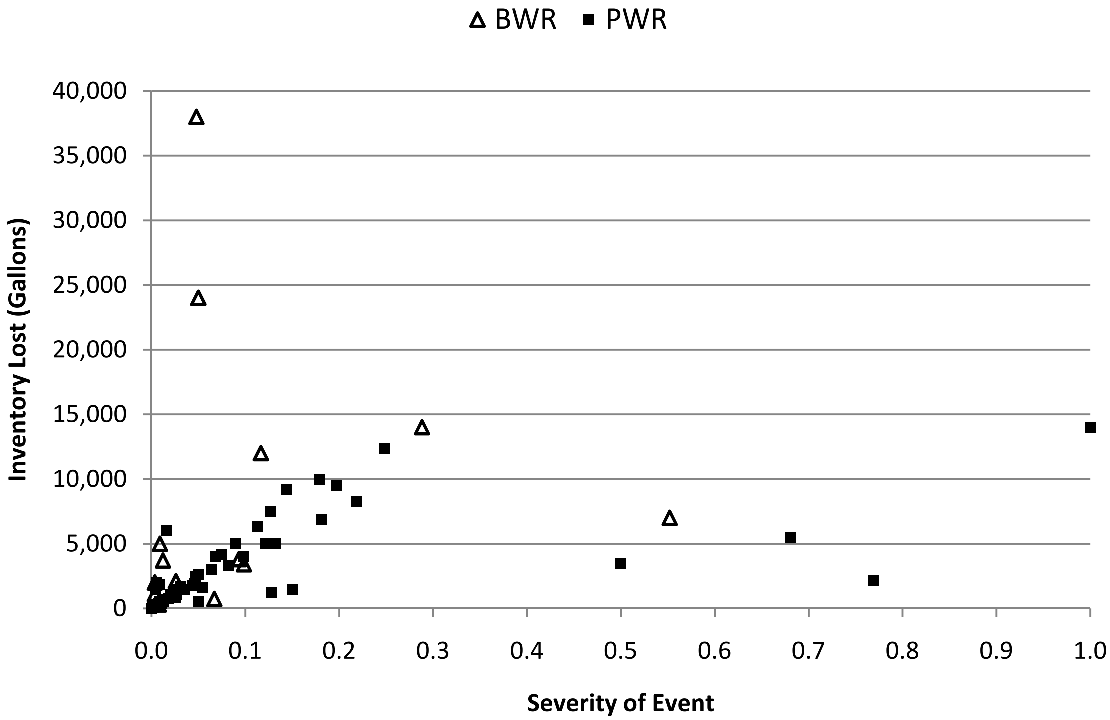

Figure 4-11
Severity of Events vs. Inventory Lost for Events from 1990 to 2009

5
ANALYSIS OF OTHER EVENT DATA

This section presents additional data and information about the events reviewed for this report, beyond the number, type and severity of the events discussed in Sections 3 and 4. Two previous decay heat removal reports included information from incidents and incident precursors from 1989 to 1998 [3] and 1999 to 2000 [2]. This section focuses on the date period 2000 to 2009. Precursors, Loss of Spent Fuel Pool inventory and heat removal events, and international events that were analyzed in previous reports [2,3] are not included; this report focuses only on actual Loss of DHR and Loss of Inventory events while the fuel is in the reactor vessel.

The type of activity involved during the events and the causes of the events were reviewed and evaluated. Loss of DHR and Loss of Inventory events are treated separately, although Loss of Inventory events that resulted in a loss of SDC are included in both data sets.

Type of Activity Involved During Loss of DHR Events

The type of activity involved when the event occurred is presented in Figure 5-1. The activity type is divided into Operations, Maintenance, and Other/Equipment.

- Operations activities include system operations and alignments, tagging and clearance activities, and pump starts/stops.
- Maintenance activities are calibration, testing (including surveillance testing), and other activities, such as performing preventive or corrective maintenance. It should be noted that all testing is considered a maintenance activity, even if performed by operations or for operational purposes. The reason for this is to allow for comparison with previous years, and do to the difficulty in distinguishing between test types on the basis of event reports.
- Other/Equipment is for events that occur during normal operations due to equipment failures or during other miscellaneous activities.

From 2000 to 2009, Operations and Maintenance activities are nearly equal at approximately 39% and 45%, respectively. The Other/Equipment category accounts for 16%. The previous two reports [2,3] indicated an increasing trend in Operations events and a small decreasing trend in both Maintenance and Other events. The data from 2000 to 2009 shows the opposite. Operations events have decreased substantially from about 60% to less than 40%. On the other hand, Maintenance events have increased from about 30% to 45%. The Other events show an increase from about 10% to 16%.

A further breakdown of the Operations and Maintenance event categories are provided in Figures 5-2 and 5-3.

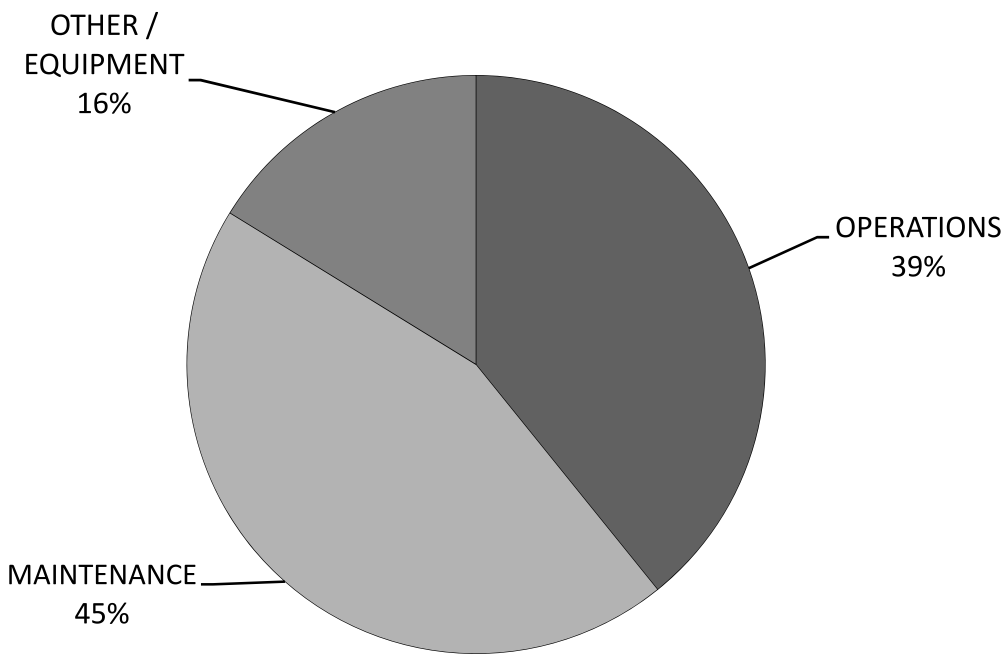

Figure 5-1
Loss of DHR Events from 2000 to 2009 by Type of Activity

Operational Activity Trends - Loss of DHR

The types of Operations activities occurring during the events from 2000 to 2009 are presented in Figure 5-2. The Operations activities are divided into four types:

- System Operations - The system involved is typically the RHR or SDC system. This activity type is for normal system operations.
- System Alignments - This is primarily the alignment of the RHR or SDC system, such as placing the system on-line or changing running trains. An electrical system alignment, such as changing RPS power supplies, is also a common activity coded as System Alignment. If the event involves starting or stopping a pump, the event will be assigned to both the System Alignment and Pump Start/Stop bins.
- Tagging and Clearance - Hanging or clearing tags for maintenance is performed by operations personnel. Valve or breaker manipulations associated with the tagging activity are included in this category. Typical events are placing tags and manipulating the wrong equipment (e.g., the operating train), repositioning components (e.g., valve or breaker) as part of the tagging evolution when not directed to do so, or clearing tags and manipulating components prior to the maintenance being completed.
- Pump Starts and Stops - Pump starts and stops cause pressure changes in the RHR, SDC and/or RCS systems. A common occurrence during these evolutions is a relief valve lifting, which causes a Loss of Inventory event which may ultimately lead to a Loss of DHR.

System Alignment changes are the primary Operations contributor to Loss of Shutdown cooling. Nearly half of the activities involve system alignment changes. The other types have very similar contributions, between 13% and 22%. Note that some events may be assigned to more than one activity type, such as starting an RHR pump while establishing SDC (System Alignment and Pump Start). System Alignment changes are the most common Operations activity type in previous years [2,3]. The major change is that System Operation now contributes the least compared to the second most frequent type in the past (13% vs. 27%).

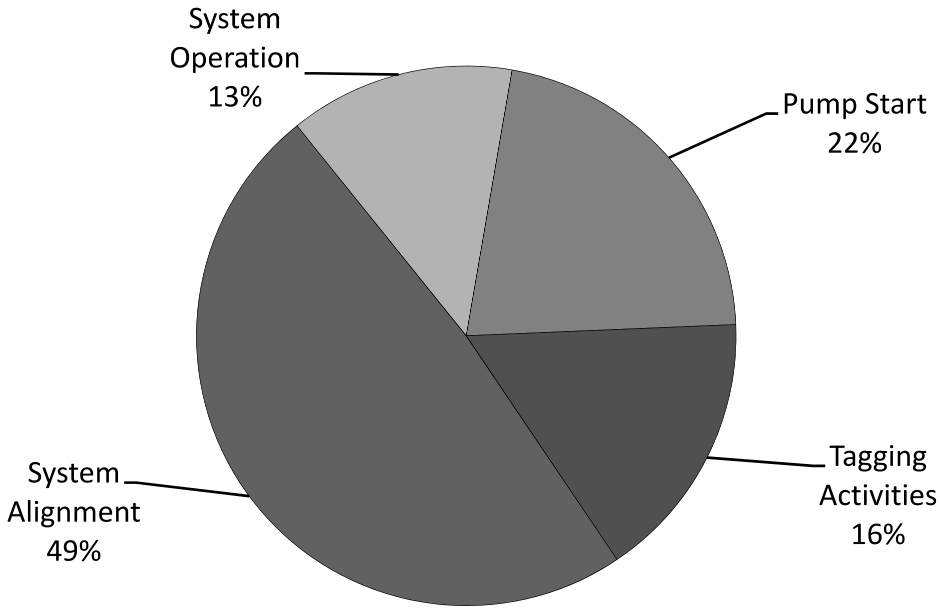

Figure 5-2
Loss of DHR Events from 2000 to 2009 by Type of Operations Activity

Maintenance Activity Trends - Loss of DHR

The type of maintenance activity involved when the incidents occurred is presented in Figure 5-3. The Maintenance activities are divided into four types:

- Testing - This primarily involves surveillance testing, whether performed by operations or maintenance personnel. Other types of testing include switchyard testing and post-maintenance testing.
- Calibration - The few Calibration events involve instrument calibration. Testing following calibration would be classified as Testing.
- Other - These events are typically associated with preventive maintenance of any type: mechanical, electrical or instrument. Examples of events include working on the incorrect equipment, bumping or jarring instruments or electrical components, and evolutions involving the installation of jumpers. Component manipulation required during maintenance (but not involved with tagging or testing) would also be considered in this category.

Testing is clearly the most common Maintenance activity involved in Loss of DHR events, accounting for more than half of them. Calibration is the least frequent activity type; only two Maintenance events involved Calibration activities. The remainder (nearly 40%) were due to Other events.

During the 2000 to 2009 time frame, calibration activity contribution has dropped significantly and testing has increased significantly. From 1999 to 2000, calibration activities contributed about 30% and testing less than 40%. The categories used for this report are the same as those in the most recent previous report [2]. It should be noted that comparison between reports may not necessarily reflect the true trend due to more data gathered over a longer time period. The data for types of activities only covers two years (19 events) in the previous report; the data shown here represent 70 events over 10 years (one of which is included in the previous report).

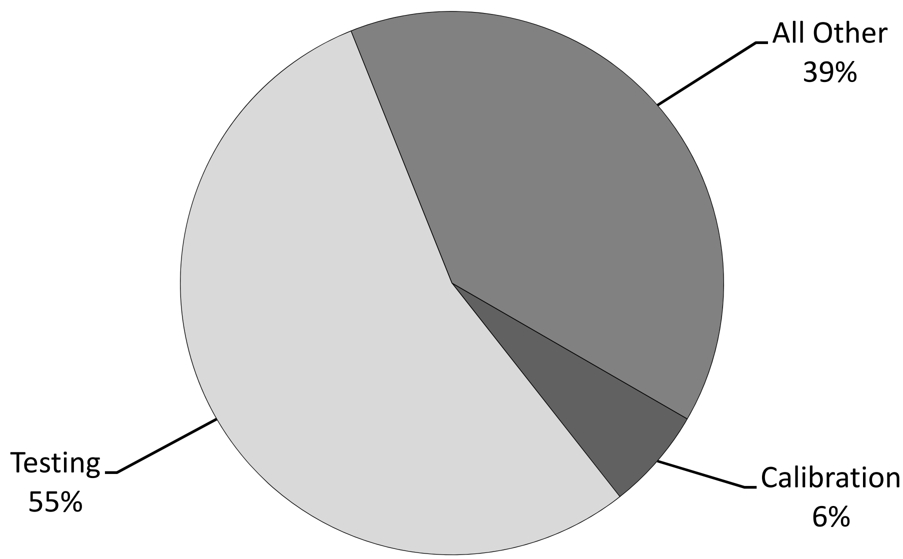

Figure 5-3
Loss of DHR Events from 2000 to 2009 by Type of Maintenance Activity

Event Causes for Loss of DHR Events

In addition to activity type, one or more causes were assigned to each event from 2000 to 2009; the results are shown in Figure 5-4. In many cases, there was more than one cause (e.g., inadequate procedures and poor work practices). About one-third of the events had more than one cause assigned. Two new categories were added for this report: Procedures and Equipment Failure. In previous reports, the Written Communications category included inadequate or incorrect procedures. During review of the data from 2000 to 2009, it was noted that procedure problems were involved in nearly 25% of all events. Any non-procedural written communication causes were binned with verbal communications in one category: Communication. Equipment failures were previously included in the Other category. However, there were a significant number of equipment failures (13) to warrant a separate category.

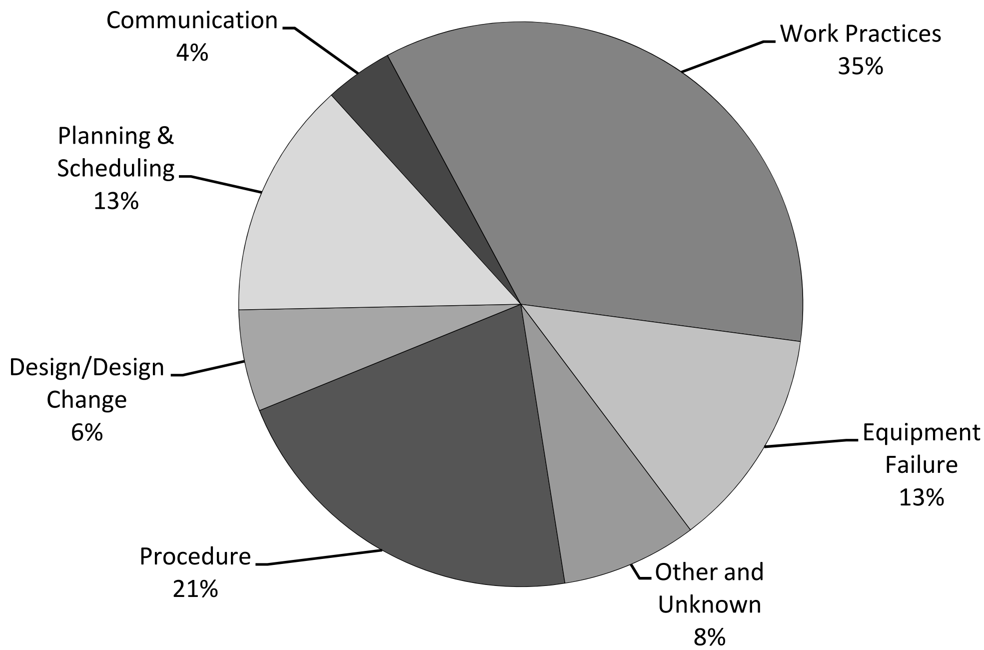

Figure 5-4
Causes of Loss of DHR Events from 2000 to 2009

Work practices were the most likely cause of Loss of DHR events from 2000 to 2009. Consistent with previous years, Procedures (Written Communications), Planning & Scheduling, and Equipment Failures were also large contributors.

Work Practices were involved in 36 of the causes. Work Practices includes operator or technician error (e.g., selecting the wrong switch), failure to follow processes (e.g., tagging violations) and general human performance issues. Inadequate or incorrect procedures were involved in 22 events. Planning and scheduling problems were cited in 14 events. Example of this event type would be scheduling two incompatible evolutions simultaneously or improper sequencing of evolutions. There were 13 events categorized as Equipment Failures.

Type of Activity Involved During Loss of Inventory Events

Loss of Inventory events are categorized separately from Loss of DHR events; Recall that not all Loss of Inventory events resulted in a Loss of DHR. As seen in the following charts (for events from 2000 to 2009), there are some notable differences between the types of activities and the causes associated with Loss of Inventory events compared to Loss of DHR events. The type of activity involved when the event occurred is presented in Figure 5-5. The activity type is divided into Operations, Maintenance, and Other/Equipment. These are the same categories used for Loss of DHR events.

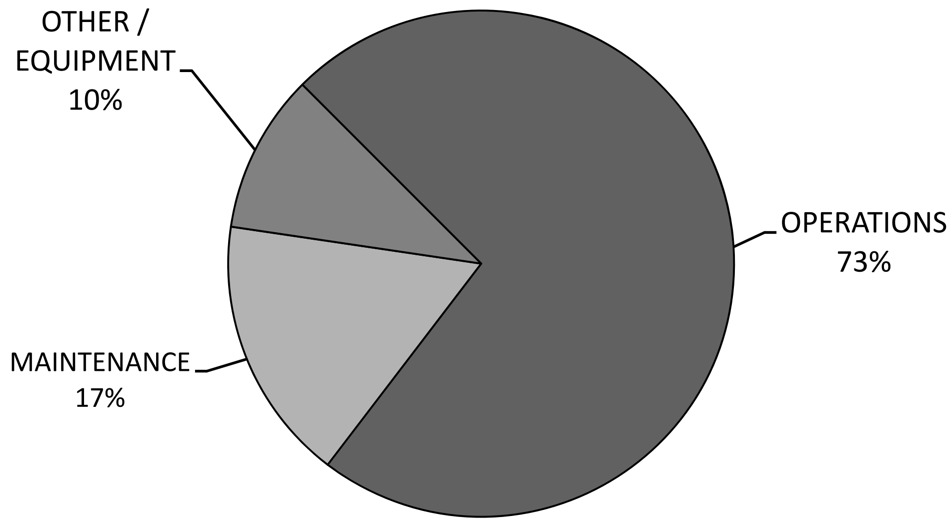

Figure 5-5
Loss of Inventory Events from 2000 to 2009 by Type of Activity

For Loss of Inventory events, Operations activities are clearly the majority at nearly 75% of the 55 Loss of Inventory events from 2000 to 2009. For Loss of DHR events (Figure 5-1), the activities in progress were split nearly equally between Operations and Maintenance (39% and 45%, respectively). A further breakdown of the Operations and Maintenance event categories for Loss of Inventory events are provided in Figures 5-6 and 5-7.

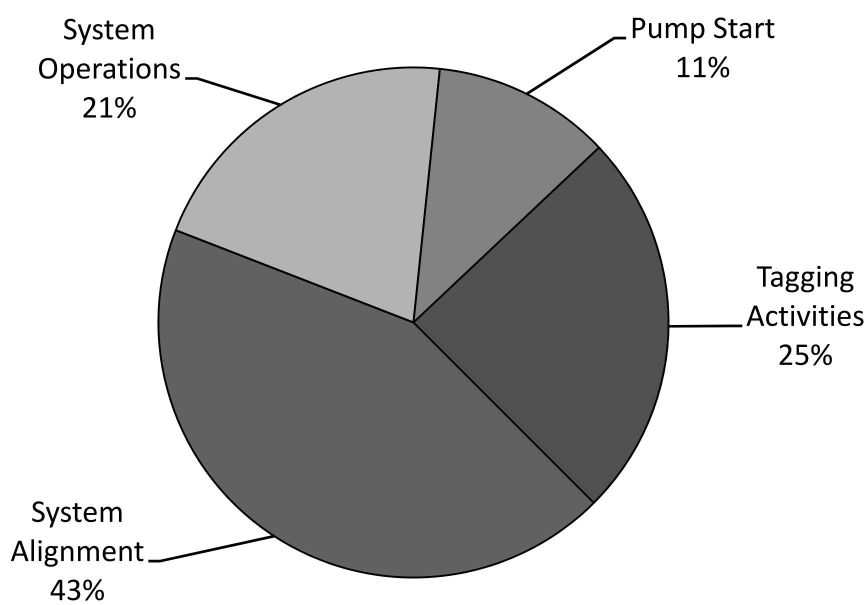

Figure 5-6
Loss of Inventory Events from 2000 to 2009 by Type of Operations Activity

For the Operations events, System Alignment changes account for 45%, with System Operations and Tagging Activities having nearly equal contributions at 21% and 25%, respectively. Note that System Operations includes draining the RCS to change level (2 events). The contribution of System Alignment is nearly the same for Loss of Inventory and Loss of DHR events. The other activity categories have somewhat different contributions between the two event types, but with relatively similar percentages.

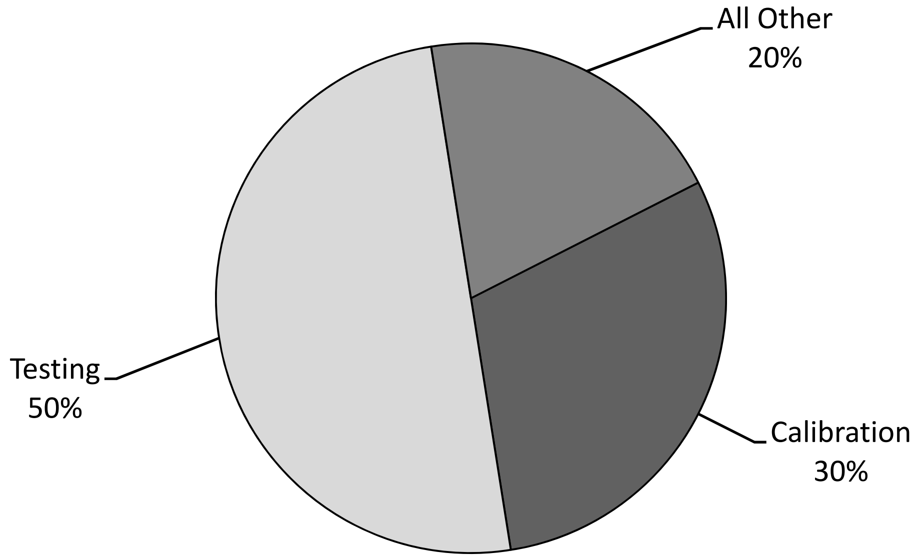

Figure 5-7
Loss of Inventory Events from 2000 to 2009 by Type of Maintenance Activity

For Maintenance activities, Testing is the primary activity type associated with Loss of Inventory events, with only slightly less contribution than Testing is for Loss of DHR events. Recall that Testing primarily involves surveillance testing, whether performed by operations or maintenance personnel. The main difference between Loss of Inventory and Loss of DHR events, with respect to Maintenance activities, is the number of events and contribution associated with Calibration. For Loss of Inventory, Calibration is a significant contributor, which is logical as many events involve incorrect or contradicting level indications. Other activities, primarily preventive or corrective maintenance, are still a significant portion (20%).

Event Causes for Loss of Inventory Events

Consistent with the Loss of DHR events, one or more causes were assigned to each event from 2000 to 2009; the results are shown in Figure 5-8. About 20% of the Loss of Inventory events had more than one cause assigned. The distribution of incident causes is shown in Figure 4-4. For consistency, the same categories used for Loss of DHR events, shown in Figure 5-4, are used for Loss of Inventory events.

Work Practices and Procedures were the primary causes of Loss of Inventory, contributing to 24 and 21 events, respectively. The percent contribution for Work Practices is very similar to the Loss of DHR causes, although the contribution of Procedures is greater than for Loss of DHR.

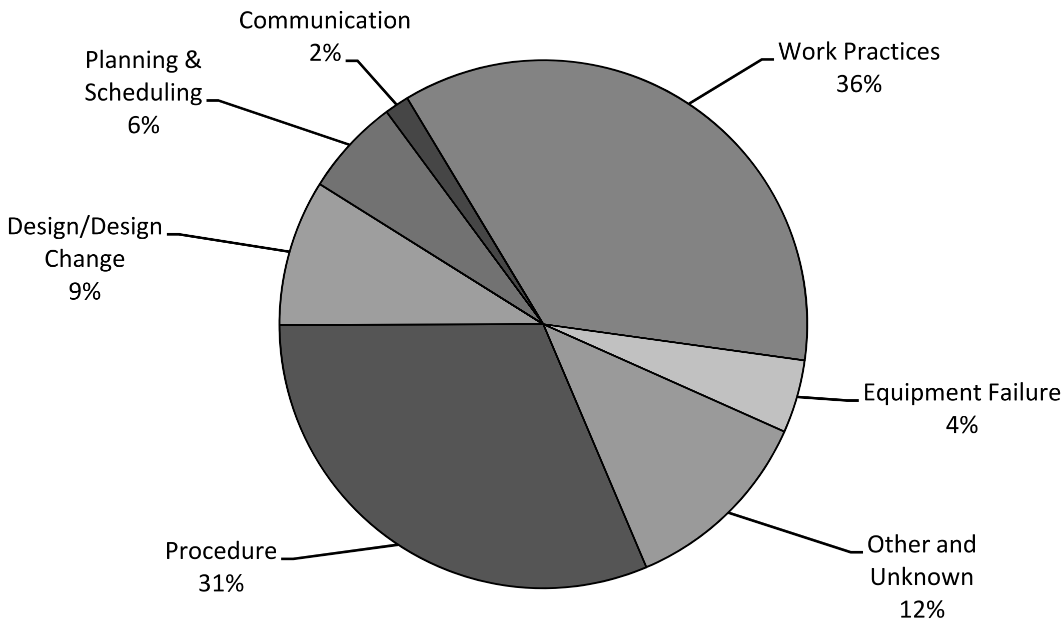

Figure 5-8
Causes of Loss of Inventory Events from 2000 to 2009

6
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Acronyms and Abbreviations

BWR	Boiling Water Reactor
CCW	Component Cooling Water [system]
CR	Control Room
CRD	Control Rod Drive
DHR	Decay Heat Removal
DRAIN	Loss of Inventory (resulting in a Loss of DHR)
DRAINLO	Drain Below Target Level
ECCS	Emergency Core Cooling System
EDG	Emergency Diesel Generator
ERV	Electromatic Relief Valve
ESF	Engineered Safety Features
gpm	Gallons per Minute
HCU	Hydraulic Control Unit
HX	Heat Exchanger
ISORHR	RHR and Reactor Vessel Isolation
LO1BUS	Loss of One Electrical Bus
LOOP	Loss of Offsite Power
LOPUMP	Loss of [RHR] Pump
LORHCOOL	Loss of RHR Cooling
LORHFLOW	Loss of RHR Flow
LOSSINV	Loss of Inventory
LOSSLVL	Loss of Level
LPCI	Low Pressure Coolant Injection
LPSI	Low Pressure Safety Injection
LTOP	Low Temperature Overpressure Protection
MCR	Main Control Room
MSL	Main Steam Line
OE	Operating Experience
O/P	Offsite Power
PORV	Power Operated Relief Valve

PRA	Probabilistic Risk Assessment
PRT	Pressurizer Relief Tank
psia	Pounds per Square Inch (absolute)
psig	Pounds per Square Inch (gage)
PWR	Pressurized Water Reactor
Pzr	Pressurizer
RCIC	Reactor Core Isolation Cooling
RCP	Reactor Coolant Pump
RCS	Reactor Coolant System
RHR	Residual Heat Removal [system]
RPV	Reactor Pressure Vessel
RV	Reactor Vessel
RVLIS	Reactor Vessel Level Instrumentation System
RWCU	Reactor Water Cleanup [system]
SDC	Shutdown Cooling
SFP	Spent Fuel Pool (or Spent Fuel Pit)
SG	Steam Generator
SI	Safety Injection
SRV	Safety Relief Valve
TAF	Top of Active Fuel
TTB	Time to Boil
VCT	Volume Control Tank

A
LOSS OF DHR EVENTS

Table A-1 provides a list BWR Loss of DHR events from 2000 to 2009. Table A-2 provides the data for PWR events.

Table A-1
BWR Loss of DHR Events: 2000 to 2009

Event Type	Event Date	Event Description	Severity	Loss of DHR Duration
ISORHR	2/9/2000	Reactor scram and several group isolations, including shutdown cooling, due to instrument maintenance associated with reactor pressure instrument sensing lines. Had been shut down for 19 days. 5˚F rise in temperature. Assume started at 120˚F.	0.05	15 min
LOOP	3/3/2000	Loss of offsite power during scheduled testing of switchyard equipment when the load breakers for the balance of plant busses opened. Both DGs started and picked up loads. Temp 80 - 100˚F. Day 6 of refueling outage with half fuel in SFP. Maximum localized heat-up rate in the vessel was ~14.6˚F/hr, which equates to a TTB >8 hours. Since shutdown cooling was restored in 21 min, estimate that temperature increased ~5˚F.	0.05	21 min
LO1BUS(1)	3/3/2000	About 2-1/2 hours after a LOOP, with power supplied by diesel generators, one diesel generator tripped due to short between turns of the secondary winding in generator excitation transformer, which was caused by insulation breakdown. Temp 80 - 100˚F. Day 6 of refueling outage with half fuel in SFP. Maximum localized heat-up rate in the vessel was ~14.6˚F/hr, which equates to a TTB >8 hours. SSince shutdown cooling was restored in 18 min, estimate that temperature increased ~4.5˚F.	0.04	18 min
ISORHR	4/17/2000	B residual heat removal (RHR) pump tripped on low suction pressure causing loss of shutdown cooling. The low suction pressure was caused by inadvertent closure of the RHR shutdown cooling inlet valve. 21 minute loss of DHR with cavity flooded and low decay heat. No increase in core temperature observed.	<0.01	21 min

Event Type	Event Date	Event Description	Severity	Loss of DHR Duration
ISORHR	4/22/2000	With Core alterations in progress, the operating residual heat removal (RHR) pump tripped on low suction pressure causing loss of shutdown cooling. The low suction pressure was caused by unplanned closure of the RHR shutdown cooling inboard isolation valve when an operator removed the wrong fuse while implementing a tagout. 1˚F rise in temperature over 48 minute period (flooded, low decay heat). Assume 120˚F starting temperature.	0.01	48 min
LOPUMP	8/22/2000	A planned shift of SDC trains was delayed by failure of an interlock relay common to both pump motor circuit breakers in one train. The A train pumps were secured in preparation for aligning the B train for SDC. After completing the lineups, both pumps in the B train failed to start. The lineup was changed back to the A train and a pump was started Temperature increased from 103 to 123˚F.	0.18	44 min
ISORHR	3/12/2001	While replacing relays, one of the relays shifted while a technician was holding it in place and attaching its seismic strap. This caused fuses to blow due to the relay shorting to ground, causing a Group 1 isolation and loss of decay heat removal. Temp increased from 99 - 102˚F. TTB was 28 hours.	0.03	111 min
ISORHR	3/14/2001	An electrical fault in the MG set generator caused the loss of division 1 RPS power, which resulted in closing the RHR shutdown cooling (SDC) common suction valve and isolate shutdown cooling. A supplemental decay heat removal (SDHR) system was in service at the time, but was not considered fully capable of decay heat removal. 2˚F rise in temp in 37 minutes; Assume 120˚F starting temperature.	0.02	37 min

Event Type	Event Date	Event Description	Severity	Loss of DHR Duration
ISORHR	6/8/2001	A RHR pump suction valve was isolated as the result of inadequate scheduling of work order tasks, inadequate review of the work package, and inadequate communication between the production SRO and the control room supervisor. A work order was incorrectly authorized on equipment that had an impact on the operating shutdown cooling train. Long time to boil due to decay heat level.	--	12 min
ISORHR	2/14/2002	A primary containment isolation of the reactor water cleanup system occurred when the electrical power supply to a high temperature switch was swapped. Removing power to the temperature switch closed the contacts associated with the alarm and protective action. Upon restoration of power, the closed contacts provided a false indication of a high temperature condition. Temperature, decay heat and inventory information not provided.	--	5 min
ISORHR	4/28/2003	Division 1 & 2 Shutdown Cooling Suction Outboard Containment Isolation Valve went closed due to an error following transfer of Reactor Protection System (RPS) "B" power supply to alternate power. Although the System Operating Procedure provides direction on performing the RPS power transfer without causing the isolation, the steps were not performed correctly. The RHR pump tripped on interlock and a loss of shutdown cooling occurred. Reactor coolant temperature rose from 93˚F to 100˚F. There was very low decay heat present (Day 30 of outage) and the rise in temperature seen was within the bounds of the expected response.	0.06	38 min
ISORHR	5/21/2003	An RHR inboard isolation valve closed as the result of a spurious close signal caused by technicians lifting the neutral on the incorrect relay. The cause was that technicians worked on the wrong relay due to a failure to validate information used to identify the equipment piece number. This failure was influenced by inadequate implementation of the labeling program. Flooded greater than 22' above the flange. Final temperature was 76˚F. Assume 1˚F temperature rise.	0.01	31 min

Event Type	Event Date	Event Description	Severity	Loss of DHR Duration
ISORHR	6/16/2003	An RHR outboard containment isolation vlave in the common suction line was closed as the result of an inadequate test procedure and inadequate preparation by operators performing the test. The RHR SDC isolation occurred while performing a containment isolation Logic test. Closure of the valve tripped the running RHR SDC pump. 1˚F heatup in 12 minutes, with a starting temperature of 112˚F.	0.01	12 min
LO1BUS	11/1/2004	During the performance of a preventive maintenance (PM) task on the station preferred transformer sudden pressure relays, technicians did not obtain the desired response. While troubleshooting, the sudden pressure relay circuitry for the transformer actuated the sudden pressure relay causing the loss of the preferred station 230 kV line. This caused a loss of power to the safety related Division 2 switchgear, auto-started the diesel generator and caused a temporary loss of shutdown cooling. Bulk coolant temp increased 4˚F. Highest temperature was below 103˚F. Cavity was flooded > 23 feet.	0.04	50 min
ISORHR	2/7/2005	Manual Scram Instrumentation checks were in progress. As part of the procedure restoration steps, the tripped channel was reset. When this was step was performed, alarms and isolations associated with loss of the 2A RPS bus immediately occurred, including isolation of shutdown cooling. The apparent cause of this event is poor manufacturing workmanship in the soldering and lack of mechanical restraint on voltage regulator printed circuit card for the 2A RPS MG set. Sufficient alternate core cooling backup systems were available. Core forced circulation was maintained the entire time.	--	50 min

Event Type	Event Date	Event Description	Severity	Loss of DHR Duration
LOPUMP	3/8/2005	While in the process of performing equipment isolation to support replacement of the SRV solenoids, several unexpected alarms annunciated in the Control Room. The Shift Supervision decided to remove the isolation and re-evaluate the tagged components. When the isolation was removed the running pump logic sensed a loss of suction flow path because the position indication for the shutdown cooling suction valves had been lost due to the equipment isolation. The indicated loss of suction flow path caused the pump to trip. The reactor head was removed and the RPV was flooded up to the flange with the main steam-line plugs installed. The reactor water temperature was 98˚F. No change in temperature.	<0.01	13 min
LORHCOOL	4/5/2005	During performance of the Loss of Offsite Power surveillance test set-up, steps were performed out of sequence. Resistance checks were taken across energized terminals, which completed the circuit allowing two Emergency Closed Cooling valves to close. These valves were supplying cooling water flow to two Fuel Pool Cooling and Cleanup heat exchangers, which were providing the means of alternate decay heat removal. Temp increased 1˚F. Assume 120˚F starting temperature.	0.01	60 min
ISORHR	11/4/2005	During transfer of the "A" Reactor Protection System (RPS) Bus power source from Alternate to Normal, the plant experienced a loss of Shutdown Cooling. The power transfer is a break before make, and the "B" division was in an unusual configuration and not powered up as expected. As a result, a Primary Containment Isolation Signal (PCIS) actuation occurred, causing the shutdown cooling isolation valves to go shut, which in turn, tripped the shutdown cooling pump. Reactor vessel coolant temperature increased approximately 1.3 degrees while Shutdown Cooling was off line. Assume 120˚F starting temperature.	0.01	18 min

Event Type	Event Date	Event Description	Severity	Loss of DHR Duration
LO1BUS	11/6/2005	An Engineering Change work package was being performed, to rewire the overcurrent relays for the Reserve Auxiliary Transformer and the Unit Auxiliary Transformer, which feed two 4 kV buses. Problems with the work package resulted in a false overcurrent signal, which caused a loss of the 4kV and 480V buses and loss of the running SDC pump. There was a small heatup (unspecified) of the reactor cavity and spent fuel pool.	--	30 min
ISORHR	11/3/2006	An error in a procedure resulted in the unexpected trip of the running shutdown cooling pump on closure of the containment inboard suction isolation valve. The isolation occurred when a reactor protection system train was transferred to its alternate power supply. The intent of the procedure was to maintain the shutdown cooling pump running while disabling the containment isolation function of the suction valve. Temperature went from 114˚F to 148˚F. Vessel level was +70". The TTB was calculated to be 2.3 hours at the onset of the isolation.	0.35	46 min
ISORHR	2/24/2007	B' RPS bus de-energized during grid instability period, resulting in Group 1 through 5 isolations. Shutdown Cooling isolated on the Group 4 signal and RWCU isolated on the Group 5 signal. The plant continued to experience degraded voltage conditions resulting in the 'A' train buses isolating from the Startup Transformer and loading onto their respective diesels. Shutdown Cooling was restored 27 minutes after it was first lost. Flooded up. Lost SDC for 27 min with TTB = 36.8 hours.	0.01	27 min
ISORHR	4/13/2007	Shutdown cooling was lost due to calibration of the wrong instruments. Instrument technicians resumed a previously interrupted test without verifying test prerequisites were met. The I&C technicians initiated isolation of shut down cooling during the calibration sequence. Temperature information not provided. TTB was 36 hours.	0.01	20 min

Event Type	Event Date	Event Description	Severity	Loss of DHR Duration
LOPUMP	7/11/2007	During performance of a functional system test, leads were lifted from a RCIC relay terminal causing several relays to chatter in the control room panel. The chattering relays created electrical noise which was coupled to adjacent SDC suction permissive circuitry, introducing an erroneous suction configuration signal and tripping the running RHR pump. The RWCU system was placed in the Alternate Decay Heat Removal Mode within 37 minutes of the loss of SDC. Although the cooling capacity is not adequate to remove all decay heat early in a shutdown, RPV heatup rate was decreased. Shutdown for ~12 days with limited operating history for the fuel. TTB conservatively calculated at over 4 hours. This calculation did not include heat removed by RWCU. Temperature was 139˚F when RHR A placed in service. Assumed starting temperature of 120˚F results in severity of 0.26. If severity is calculated as ratio of time with no SDC to TTB (117 min/240 min), severity would be 0.49, which is conservative given the final temperature and the note that TTB was conservatively calculated as "over 4 hours." Therefore, use 0.26 severity.	0.26	117 min
ISORHR	10/22/2007	Division 2 of Residual Heat Removal (RHR) was being placed in Shutdown Cooling (SDC) following completion of a SDC outage. Reactor Protection System (RPS) A was de-energized for maintenance. RPS B was being supplied by the alternate supply because the B RPS Motor Generator was removed from service for maintenance. Upon start of the RHR D pump motor the RPS B Alternate Supply Electrical Protection Assembly (EPA) breakers tripped due to sensed undervoltage. The loss of power to RPS B resulted in RHR SDC outboard valve isolation. Temperature information not provided.	--	Unknown

Event Type	Event Date	Event Description	Severity	Loss of DHR Duration
ISORHR	11/8/2007	RHR Pump 2A tripped due to the inboard isolation suction valve going closed. At the time the event occurred, a clearance was being hung on a breaker in support of a work activity not associated with RHR. it was determined that opening the breaker for a pressure transmitter created a false high temperature containment isolation signal, closing the Residual Heat Removal Inboard Isolation Suction Valve. The personnel involved in the preparation of the work package failed to assess the impact of opening the breaker for performing the test. Operators responded and restored shutdown cooling in approximately 11 minutes. Started at 90˚F, temperature did not change.	<0.01	11 min
ISORHR	9/16/2008	Shutdown cooling (SDC) was isolated unexpectedly when the common RHR pump suction isolation valve closed while operators were hanging a protective tag in the reactor protection system (RPS). The valve closed in response to an invalid primary containment isolation system (PCIS) signal that was generated when a fuse was removed in a control room panel. The work had been planned for plant configuration that would exist when SDC was out of service but the plan did not receive an adequate risk assessment or impact review when the schedule was changed. Temperature rise from 100 to 108˚F. Cavity flood-up in progress, TTB ~5.5 hours.	0.07	53 min
LOOP	9/17/2008	A man-lift being serviced by a vendor came into contact with a 115 kV line, de-energizing a transformer and causing a Loss of Normal Off-site Power. The station lost Shutdown cooling for approximately 90 minutes. 6 days after shutdown. Assuming 95˚F coolant it would take about 15 hrs to boil to the TAF. If used time to TAF, severity = 0.1.	0.10	86 min

Event Type	Event Date	Event Description	Severity	Loss of DHR Duration
ISORHR	9/20/2008	During a CRD pump start, the plant experienced a Reactor Water Low-Low Level signal that resulted in the actuation of various group isolation signals, including the isolation of Shutdown Cooling. Although actual level remained steady throughout the event, the Operating Procedure for starting the CRD pumps did not include steps to ensure the RPV Reference Leg Backfill System was isolated prior to starting the system and pump when susceptible to level transients. 9 days after shutdown. Assuming 95˚F coolant it would take about 12 hrs to boil to the TAF. If used time to TAF, severity would be 0.21.	0.21	150 min
LO1BUS	10/7/2008	During testing of a lockout relay on the one bus, another bus was temporally de-energized, resulting in the loss of the "B" RPS Bus, which caused an interruption of SDC. A schedule change was made moving testing of the lockout relay to a different outage work window. This activity resulted in a trip of the feeder breaker to the other bus, which de-energized it. This schedule change was implemented without an adequate outage risk assessment being performed. 6˚F temperature rise with greater than 70˚F margin to boil.	0.09	6 min
ISORHR	11/3/2008	On initial cool down for entry into refueling outage, a recirculation pump suction line temperature element (TE) failed upscale. The TE contacts in the shutdown cooling (SDC) logic isolated the SDC system per design. The cause of the TE failure was attributed to fatigue of the sealed thermocouple assembly in the temperature element probe. The fatigue led to increased resistance of the thermocouple loop, resulting in an increase in indicated temperature. Actual temp was ~217˚F.	--	Unknown

Event Type	Event Date	Event Description	Severity	Loss of DHR Duration
LOPUMP	3/26/2009	A technician was tasked to install a dust cover or stem protector on a RHR valve, which was in a "protected" status. While the technicians were installing the dust cover, it was determined that the valve stem position needed to be verified to preclude interference with the dust cover. The technicians engaged the hand wheel and rotated it in the shut direction. This act resulted in MOV valve stem position limit switch actuation, causing the RHR pump to trip, resulting in an interruption of Shutdown Cooling. TTB = 35 hrs, 54 min. Flooded, with gates removed. Temp 80 - 105˚F. The plant had successfully demonstrated sufficient core cooling with natural circulation.	<0.01	*"Promptly restored"*
ISORHR	4/27/2009	The RHR shutdown cooling outboard common suction isolation valve received an invalid isolation signal. This caused the running RHR pump to trip, which was providing SDC. When the valve isolated, both the RHR trains became inoperable. 24 vdc electrical power was lost to the Trip Unit for "Reactor Pressure High" due to a blown fuse. A relay de-energized, which caused automatic closure of the valve and the subsequent automatic tripping of the RHR A pump, as designed. 3˚F temperature rise (94 - 97˚F).	0.03	64 min
ISORHR	7/20/2009	Isolation and trip of both RHR pumps when the inboard SDC suction isolation valve closed. The pumps were running to support a dual system flush to lower the dose rates. Just prior to the event, technicians were removing jumpers that bypass SDC isolation trip instruments. The event was caused by high resistance contacts of a relay. Oxidation buildup caused a high contact resistance resulting in a downstream relay momentarily dropping out and causing the inboard SDC suction valve to close. This condition was exacerbated by the installation of a contact jumper since the jumper dropped the amount of current through the high resistance contacts while it was installed. Reactor coolant temperature raised 12 degrees in 12 minutes. Assume 140˚F starting temperature.	0.17	12 min

Event Type	Event Date	Event Description	Severity	Loss of DHR Duration
ISORHR	11/2/2009	The Shutdown Cooling (SDC) System high temperature isolation logic actuated causing the SDC isolation valves to shut. A temperature element thermocouple failed. A Resistance Temperature Detector (RTD) housed in the same assembly had previously failed and was out of service. The presence of an open signal from both instruments in the same recirculation loop caused the isolation logic to activate, as designed. The temperature element failed due to failure at the soldered thermocouple junction. Reactor Recirculation (RR) system temperature was approximately 224˚F based on alternate indications. SDC was restarted at with Recirculation loop temperature at 260˚F.	--	36 min
ISORHR	11/7/2009	Loss of Shutdown Cooling (SDC) was caused by drawing a vacuum on the reactor vessel, due to time delays in both the vacuum pumps and aligning a vent path for the vessel. The operating SDC pump tripped and SDC isolation valves closed due to a pressure spike caused by flashing in the Reactor Recirculation (RR) piping with bulk coolant temperature about 165˚F. The schedule was changed and the new plan was not adequately reviewed to ensure all required actions had been taken to proceed. The procedure was also deficient, not providing any cautions regarding vent and vacuum pump alignment. According to OE, the temperature increased from 167 to 174 deg F in the operating loop. The narrative in the LER says a 10˚F increase. Assumed 10˚F rise. TTB was greater than 4 hrs.	0.22	114 min

Notes:

LO1BUS(1) = Loss of power to bus, but EDG failed to re-energize.

Table A-2
PWR Loss of DHR Events: 2000 to 2009

Event Type	Event Date	Event Description	Severity	Loss of DHR Duration
LO1BUS(1)	4/4/2000	A reserve station service transformer (RSST) unloaded from opening the incorrect potential transformer fuse drawer due to personnel error. The emergency diesel generator (EDG) failed to automatically start on the emergency bus that lost power. Offsite power supply to the opposite train remained available. The operator restored SDC using the residual heat removal pump in the unaffected train. No temperature rise discussed; post refueling.	--	2 min
LOSSLVL(1)	4/17/2000	In Mode 4, preparing to go on shutdown cooling. A sudden drop in Pzr level (6%) occurred when the last SDC isolation valve was opened. The valve was immediately closed and Pzr level stabilized. A field operator saw leakage from an isolation valve telltale drain of 1 - 2 gpm. Operations determined that the Pzr level behavior was consistent with changes seen when filling SDC piping in the past. Later that day while placing SDC online, a similar event occurred but with significantly less inventory loss. It was later determined that the level drop was not solely due to filling and venting the SDC system. 200 gal of RCS inventory was transferred inter-system. This was considered as one event. 200 gallons lost with assumed 50,000 gallon margin.	<0.01	3 min*
LOSSINV	9/26/2000	While in Mode 4, RHR A was started as part of placing Shutdown Cooling (SDC) in service. Following the pump start, the Train B RHR discharge relief valve lifted and did not reseat until Pump A was secured and the RHR system was isolated from the RCS. The cause was determined to be a compression of a non-condensable gas pocket causing a pressure surge when starting the RHR pump. The relief valve did not close until the pump was secured, which lowered the pressure below the reseat pressure for the valve. Contributing to the event was very little pressure margin available. 500 gallons lost with assumed 56,000 gallon margin (NSAC 176L - 25% Pzr level).	0.01	10 min*

Event Type	Event Date	Event Description	Severity	Loss of DHR Duration
LOSSINV	4/2/2001	During cooldown for a refueling outage, the A SDC loop suction relief valve lifted as the system was being place in service. The open relief valve caused Pzr level to decrease approximately 4 percent over 5 minutes (~ 80 gallons per minute). Operators terminated the leak by closing the A SDC loop inlet isolation valve. This event was attributed to inadequately venting the SDC system prior to placing it in service. Air pockets produced dynamic pressure changes that caused the relief valve to lift when the pump was started. Approximately 400 gallons lost (5 minutes @ 80 gpm). Assume 56,000 gal margin (NSAC 176L - 25% Pzr level).	0.01	5 min*
LOSSINV(1)	4/4/2001	While placing a train of SDC in service, a SDC relief valve lifted when the hot leg suction valve was opened. Approximately 300 gallons of RCS was lost over a period of 2 minutes (i.e., 150 gpm). Reclosing the hot leg suction valve terminated the event. Shutdown for approximately 50 hours. 300 gallons lost with assumed 56,000 gallon margin (NSAC 176L - 25% Pzr level).	0.01	2 min*
LOSSINV(2)	11/10/2001	Operating in Mode 4. The SDC system had been secured for ~15 minutes when a realignment sequence was initiated to place it back in service. During the evolution, a thermal relief valve opened and did not immediately reseat. The LPSI pump was secured and the relief valve reseated. Subsequent analysis of the event determined that the flow rate from the relief valve was greater than 10 gpm.	--	Unknown
LOSSINV(1)	11/26/2001	A relief valve in the SDC system lifted while placing SDC in service during cooldown for a scheduled refueling outage. The relief valve setpoint is 350 psia, and the RCS pressure was 268 psia. The relief lifted with the RCS hot leg suction valve was opened. The leak was isolated and terminated by reclosing the valve.	--	Unknown

Event Type	Event Date	Event Description	Severity	Loss of DHR Duration
ISORHR	3/1/2002	While attempting to realign the RHR system from RWST supply to RCS loop operation and simultaneously performing a full flow RHR test and filling the reactor cavity, operators isolated the common suction to the Residual Heat Removal (RHR) pumps on two occasions over a three minute span. Power had been removed from a rack which provided a permissive pressure switch signal to two valves which required manipulation during the realignment. Two isolations, but can be considered one. 3 minutes total time from first isolation to restoring SDC after 2nd isolation. RCS was 100˚F with cavity flooded or nearly flooded.	--	3 min
LORHCOOL	4/7/2002	There was a loss of CCW flow to the in-service residual heat removal (RHR) heat exchanger A because the trip valve for CCW to the RHR heat exchanger A had closed. RHR heat exchanger B was placed in service. The breaker that powers the trip valve for CCW to RHR heat exchanger A from its uninterruptible power supply (UPS) had tripped open. A temporary power supply in parallel with the normal power supply caused the supply breaker powered from UPS 2A to trip open. 1.2˚F rise starting at 77˚F.	0.01	39 min
LOOP	3/25/2003	A loss of offsite power occurred while installing a signpost. The signpost penetrated a buried conduit, damaging a control power cable associated with both offsite power feeds. Shutdown cooling flow was lost on the loss of offsite power. SDC flow was restored with the emergency diesel generators providing power. No written process existed for excavating, trenching or piercing the ground. Temperature increased from 92˚F to 104˚F. TTB 3.3 hrs.	0.10	20 min

Event Type	Event Date	Event Description	Severity	Loss of DHR Duration
LORHCOOL	4/28/2003	A surveillance test was in progress, requiring the CCW pumps to be tripped and then restarted. Preparations were simultaneously underway to install a freeze seal on a CCW return line from the RCPs. As part of the preparations, the CCW return isolation valve from the RCPs was closed. When the CCW pumps were restarted, a pressure spike occurred causing a relief valve to lift. The relief valve did not reseat as expected, but did reseat when one CCW pump was shut down. CR operators, unaware that the leak had stopped, shut down the remaining CCW pump in accordance with the AOP for loss of CCW inventory. CCW surge tank level decreased 66 percent to 4 percent. CCW surge tank level was restored, and a CCW pump was restarted in about 5 minutes. Level was 23" below vessel flange (reduced inventory is 36" below flange). Time to Boil was calculated at 31 minutes. Temperature went up 4.7˚F to 134.7˚F. (Note that one document says temperature was 140˚F, but does not discuss temperature rise). 130˚F was assumed for the starting temperature.	0.06	5 min
LOOP	8/14/2003	Loss of offsite power during August 14 grid disturbance. In extended outage at the time.	--	Unknown
LORHCOOL	9/10/2003	Performing a Loss of Offsite Power with Safety Injection Test on train A. Core cooling was provided by train B RHR, which received cooling flow from a swing CCW pump that was powered by the A train. Therefore, CCW flow to the B-train RHR heat exchanger was lost when the test was initiated. Although the OE states that there was "no loss of reactor coolant heat sink" due to availability of steam generators, it does that decay heat removal was lost as temperature increased 15˚F in 10 minutes. SGs may have been available and would have turned the temperature increase later, but it is difficult to establish this with certainty. Therefore, this is considered a loss of DHR. 15˚F rise in 10 min. Assume 140˚F starting temperature.	0.21	10 min

Event Type	Event Date	Event Description	Severity	Loss of DHR Duration
LORHFLOW	10/14/2003	Shutdown cooling was temporarily lost when the SDC exchanger outlet valve inadvertently closed and the heat exchanger bypass valve opened. The valves changed position due to an instrument bus power failure caused by an error in the procedure to synchronize the power supplies to the instrument bus. 14˚F heatup, from starting temperature of 101˚F. Had not completed preparations to draindown, although appears to be early in the outage. RCS vented and Pzr Level at 27". TTB ~1.3 hrs and TTCU ~8.5 hrs.	0.13	13 min
LO1BUS	10/18/2004	The 'A' RHR train was providing shutdown cooling, and the 'B' RHR train was operable but not in service. A maintenance surveillance test for Under Voltage Relay Channel Calibration was in progress on 'A' Emergency Bus, which involved lifting multiple leads. 'A' Emergency Bus lost power when its power supply breaker unexpectedly opened, de-energizing the 'A' RHR pump. The 'A' EDG automatically started and re-energized the bus. Operators restarted the 'A' RHR pump. RCS depressurized and level at 50% Pzr; RCS temperature rose approximately 6˚F (116 to 122). Expected time to boil was 70 min. SDC lost for 4.65 min.	0.06	5 min
LO1BUS	11/5/2004	An inadvertent 'B' Train Loss of Offsite Power (LOOP) occurred when the normal power supply breaker to the Train 'B' 4kV bus opened during testing. One test was being performed while the system was aligned for a different and incompatible test. The EDG started and powered the bus, but the 'A' Train RHR pump was manually started to provide SDC. Core alterations were in progress for reload and were suspended upon the event. No indication of heatup.	<0.01	<1 min

Event Type	Event Date	Event Description	Severity	Loss of DHR Duration
LO1BUS(1)	11/9/2004	A planned evolution to tie two 480 VAC safety buses together was in progress. When the normal supply breaker to one bus was opened, an unexpected loss of power to that bus occurred. The de-energized bus caused an undervoltage/blackout signal to be generated that automatically started 2 of 3 EDGs and powered their assigned buses. The EDG for the de-energized bus was out of service for planned maintenance and therefore the bus, which had been providing power for the in-service RHR pump, remained de-energized, . RHR cooling was manually restored from the other train RHR pump. The cause of the event was missing primary disconnect contacts on the bus tie breaker; thus the bus was not actually energized via the bus-tie. The missing contacts were a result of poor preventive maintenance in the previous year. After refueling, cavity flooded. TTB approximately 12 hours. Final temperature 94˚F.	0.01	5 min
LO1BUS	4/1/2005	The plant load was being supplied by two offsite power sources, which were split between the two trains. The offsite power source supplying 'B' train safeguards buses was lost, causing an automatic start of Emergency Diesel Generator 'B', which re-energized the 'B' train busses. Core cooling was momentarily interrupted and was restored upon safeguards bus re-energization. This partial loss of power was due to a distribution circuit lightning arrester fault to ground. The circuit and its lightning arresters are owned by the local utility, which considers them as run to failure components. RCS temperature was maintained at 74˚F.	<0.01	*"Promptly restored"*

Event Type	Event Date	Event Description	Severity	Loss of DHR Duration
LORHFLOW	4/19/2005	The RHR system alignment was with the RHR heat exchanger inlet and outlet cross-connects open, 'A' train RHR pump running, and cooling aligned through the 'B' train RHR heat exchanger. A Danger Tag clearance was written to work the "B" SI pump which also included MOVs which interfaces between the "B" train RHR to "B" SI pump suction valve. Before hanging the tags, the Work Control Center did not verify that the B RHR HX was not aligned for SDC. When the tagger closed the manual inlet to the in-service "B" train RHR heat exchanger, low RHR flow conditions occurred and the Control Room secured the "A" train RHR pump as flow decayed to about 400 gpm. RHR flow and CCW were reestablished through the "A" train RHR pump and "A" RHR heat exchanger. Flooded, with TTB greater than 20 hours.	0.01	12 min
LO1BUS	5/18/2005	During performance of relay testing, a differential lockout was manually actuated, resulting in lockout of two transformers. This resulted in a loss of all balance of plant buses, loss of 'B' vital bus, an auto start of 'B' EDG, and the sequencing of required ESF loads (which included the RHR pump). Review of plant response data showed the RHR flow was in the process of coasting down and was restored to full flow within 20 seconds. The inlet temperature of the RHR Heat Exchanger increased approximately 0.3 deg F due to this event. RHR flow never stopped, but the pump did trip.	<0.01	<1 min
LOOP	8/29/2005	The plant was in Mode 4 with two Reactor Coolant Pumps (RCP) were operating as well as Shutdown Cooling (SDC) Train A. Due to the approach of a hurricane, several electric plants that connect to the switchyard were shutdown. A Loss of Offsite Power (LOOP) occurred as the plant site was experiencing tropical storm winds of about 48 miles per hour. All loads supplied by the non-safety 6.9 kV busses were lost including the RCPs. The two emergency diesel generators (EDG) started and SDC Train A was placed back in service manually. The plant safety loads remained energized from the two EDGs with temporary diesel generators available if a plant EDG was lost. No discussion of temperature increase.	--	16 min (SDC)

Event Type	Event Date	Event Description	Severity	Loss of DHR Duration
LO1BUS	3/8/2006	A loss of the A 4 kV electrical distribution bus occurred during restoration of a load center (LC) following maintenance. The A 4kV bus load sequencer performed load stripping and a loss of offsite power occurred due to a degraded voltage condition that was sensed on the LC. This was caused by a misaligned auxiliary switch contact on the newly refurbished 480V LC feeder breaker. The emergency diesel generator automatically started and restored power to the A bus. Core cooling was reestablished utilizing the B Residual heat removal (RHR) pump on the B 4 kV bus which was unaffected. The cause was a vendor error during breaker refurbishment in the configuration of the auxiliary switch contacts, which went undetected by the vendor test and inspection program and site pre-installation checks. In the process of draining the reactor coolant system (RCS) to approximately 1.5 feet below the reactor vessel flange in preparation for refueling. The RCS was at 60% drain down level when the bus was lost. Draining was stopped and level was stabilized via the chemical and volume control system. 22˚F rise in 7 to 9 min. Starting temperature was 108˚F. Draining at the time, level at 60% drained on way to 1.5' below flange.	0.21	8 min
LORHCOOL	4/19/2006	Near the end of a Refueling Outage, most Decay Heat (DH) removal flow was bypassed around the DH cooler in order to maintain desired RCS temperature. A DH pump and valve test was planned for the operating DH train, requiring full DH flow through the cooler to test a check valve. To maintain RCS temperature within a temperature band, a contingency plan was established to remotely close the Component Cooling Water (CCW) isolation valve to the DH cooler if the RCS temperature lowered rapidly. When the test was started and temperature did rapidly lower, the CCW isolation valve was closed remotely. RCS temperature slowly increased but remained within the desired temperature band. At the end of the testing, the CCW isolation valve failed to open from the Control Room. An operator manually opened the valve locally to restore cooling water flow. The valve had been identified as degraded, but was not flagged with deficiency tags or tracking mechanism entries. Performing Heatup at 1˚F/hr. A slight increase in RCS temperature occurred until component cooling water flow through the decay heat cooler was restored.	--	Short

Event Type	Event Date	Event Description	Severity	Loss of DHR Duration
LOOP	5/15/2006	During performance of a maintenance activity, a technician inadvertently jarred an open electrical cabinet door, causing an actuation of a lockout relay for the start-up auxiliary power transformer that was supplying power to the unit. A loss of power occurred, resulting in an actuation of the emergency on-site power source. Power was restored automatically after and decay heat removal was restored manually. Temp increased from 81 to 89˚F. TTB estimated at greater 24 hours.	0.06	14 min (SDC) 10.1 hr (O/P)
ISORHR	11/27/2006	The plant was being cooled down and depressurized. After SDC was initiated. it was desired to maintain a RCP operating to cool down the RV head with the RCS. Two RCPs in the same loop were kept operating, which provided more main spray flow than had been available in the past with only one RCP. The pressure band for operating reactor coolant pumps while SDC is in service is 225 psia (RCP NPSH) to 250 psia (SDC suction valves interlock setpoint). The operator maintained the RCS in a band of 225 - 235 psia for several hours prior to the event, controlling pressure with Pzr heaters and modulating the main spray control valves. The RCPs were secured to commence a Pzr cooldown. RCS pressure rose when the first RCP was secured, but was not noticed. When the second RCP was secured, RCS pressure reached the SDC suction isolation valves interlock setpoint, which closed the valves. The running SDC pumps were conservatively stopped to preclude any possibility of pump damage. RCS pressure was lowered, the shutdown cooling suction isolation valves were reopened, and SDC reinitiated. RCS temperature (CET) rose from 128°F to 133°F.	0.06	12 min
LORHCOOL	4/8/2007	The Reactor Operator was securing a RCS heat up to 120˚F and noted that the Train B RHR cooling discharge valve would not reopen via its indicator and the lack of flow and temperature change. RCS temperature rose to about 122˚F. Immediate action was taken to switch to the other RHR cooling loop, including transferring of CVCS letdown to this loop. Train B RHR was declared inoperable by the Control Room. The cause was a failed positioner on the valve. Note: This was classified LORHCOOL based on the detailed description of the event. The description implied that RH flow continued (via the heat exchanger bypass) but the heat exchanger outlet valve could not be opened, so cooling was unavailable. 1.6 deg F increase in temperature to 121.6˚F.	0.02	Short

Event Type	Event Date	Event Description	Severity	Loss of DHR Duration
LORHCOOL	5/20/2008	Power was lost to the #2 non-vital instrument bus, resulting in closure of the shutdown cooling temperature control valve. This interrupted the cooling from the in service shutdown cooling loop. While cycling a condenser motor operated valve a 480 volt ground occurred, which resulted in tripping the feeder breaker to the motor control center that was supplying power to Instrument Bus 2 via the Inverter 2 test transformer. Inverter 2 was being replaced. The valve was manually opened to restore cooling. Flow through the core was maintained throughout the event, as the shutdown heat exchanger bypass valve responded by opening to maintain flow. Only one-third of the core had been reloaded. 1˚F increase in SDC temperature. TTB conservatively calculated at 22.5 hours (only 1/3rd of fuel assemblies in vessel, but calculation was done assuming all fuel loaded). SDC temperature started at 88˚F.	0.01	23 min
LOSSINV(1)	9/1/2008	During plant shutdown in anticipation of a hurricane, a Low Temperature Overpressure Protection (LTOP) relief valve opened while placing the SDC system in service. A design change had been implemented where the SDC isolation valves were changed from hydraulic actuators to air operated actuators, affecting the valve stroke characteristics and resulted in a system pressure surge sufficient to lift the LTOP relief valve momentarily when the SDC valve was opened. 1300 gallons lost with assumed 56,000 gallons (NSAC 176L - 25% Pzr level).	0.02	Short
LO1BUS	10/25/2008	During a Solid State Protection System (SSPS) Logic Train Functional Test. a circuit failed to test properly. A work package to troubleshoot the failed circuit was planned and work was started without performing a work risk assessment by operations. When a circuit card was removed, a Safety Injection signal was generated, resulting in the tripping of the two in-service RHR pumps, as well as other engineered safety features actuations. The crew placed the SSPS trains in test, reset the Safety Injection Signal and restarted the two RHR pumps. No discernable heatup. Note that the HXs had been bypassed earlier to allow RCS to heatup in preparation for entering Mode 4 (end of refueling outage).	<0.01	4 min

Event Type	Event Date	Event Description	Severity	Loss of DHR Duration
LOPUMP	10/26/2008	'A' train Safety Injection System check valve cold shutdown testing was in progress. With the refueling cavity filled, the surveillance requires that the 1A Low Pressure Safety Injection (LPSI) Pump be run on recirculation for twenty minutes. While the surveillance is performed on the A-train, the B-train shutdown cooling is protected and in service to remove decay heat. At the end of the 20-minute pump run, the operator inadvertently secured the 1B LPSI Pump instead of the intended 1A LPSI Pump. This secured all shutdown cooling flow. About five minutes elapsed before it was identified that there was no shutdown cooling flow to the core. Once the cause was determined, shutdown cooling was restored. Time-to-boil was several hours and there was coolant temperature rise was very low.	--	>5 min
LOPUMP	4/22/2009	During restoration from a Safety Injection/Loss of Offsite Power (SI/LOOP) surveillance test, both RHR pumps were secured although plant conditions required one RHR pump to be in operation. The procedure directs stopping 1A AND/OR 1B RHR pump. Stopping both pumps would be allowed if the test was performed with the core unloaded. However, the correct interpretation of the step, in this case, was to secure either the 1A OR 1B RHR pump. The team misapplied this step and secured both pumps. Although the crew questioned the step, the test coordinator thought the procedure would subsequently restart one of the RHR pumps, but did not confirm this. Flooded. The time to boil was over 23 hours and RCS temperature increased from approximately 83 degrees to 107 degrees.	0.19	39 min
LOSSINV(1)	4/25/2009	During a scheduled cooldown, the Decay Heat Drop Line Thermal Relief Valve opened when the Reactor Coolant System (RCS) was valved into the Residual Heat Removal system. The valve remained open, causing an RCS leak of 2.5 - 5 gpm. Operations entered abnormal procedure (AP) for Excessive Leakage. This eventually resulted in isolating the RHR system which stopped the leak but caused a Loss of Decay Heat Removal. RCS heat removal was transferred back to the Steam Generators.	--	Unknown

Event Type	Event Date	Event Description	Severity	Loss of DHR Duration
LO1BUS	9/20/2009	The "A" SDC train was in service and "B" SDC train was in standby. Offsite power transfer testing was being performed on train 'A', which causes an automatic transfer between two offsite power sources. When the under voltage was simulated, the expected fast transfer did not occur. A slow transfer occurred, which caused the vital bus to experience a momentary under voltage, de-energizing the loads on the vital bus, including the 'A' train SDC pump. Operations restored SDC by restarting the "A" pump. This event was the result of performing an offsite power transfer test on the electrical bus supplying power to the SDC system and the failure of a relay to actuate as required by the test. 5˚F heatup, after core reload. Assume 140˚F starting temperature.	0.07	3.5 min
LO1BUS	10/15/2009	Safety Injection (SI) Pump 'A' was started to refill the 'A' SI Accumulator. Upon pump start, the station Tertiary Auxiliary Transformer (TAT) supplying the train 'A' 4160V safeguard bus experienced a differential lockout, deenergizing the bus and the RHR pump 'A' that was providing SDC. Operators started RHR pump 'B', which was 'protected', to recover core cooling. It was determined that the new differential current protective relays for the TAT had an improper input parameter programmed into the solid state digital differential relays. No heatup.	<0.01	2 min

Notes:

LO1BUS(1) = Loss of power to bus, but EDG failed to re-energize.

LOSSINV(1) = DHR lost when operators isolated SDC.

LOSSINV(2) = DHR lost when operators stopped SDC pump.

LOSSLVL(1) = DHR lost when operators isolated SDC.

Duration* = Time before inventory loss was stopped.

B
LOSS OF INVENTORY EVENTS

Table B-1 provides a list BWR Loss of Inventory events from 2000 to 2009. Table B-2 provides the data for PWR events.

Table B-1
BWR Loss of Inventory Events: 1990 to 2009

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
LOSSINV	1/24/1991	No	With RV water level approximately 20" below the main steam lines, the shutdown cooling suction valve was opened without notifying operations as required by the test plan. This action resulted in initially losing 5" of coolant through open shutdown cooling vent and drain valves. An additional 9" inches was lost as voids were filled when the shutdown cooling suction header refilled as it was restored to service.	0.06	14"
LOSSINV	2/18/1991	No	Operator error resulted in a loss of station and instrument air. SCRAM valves started to drift open resulting in leakage from the reactor vessel to the scram discharge volume; vent and drain valves on the SCRAM discharge volume were in their normal open position, providing a flow path for reactor water to drain through the SCRAM discharge volume. RV level decreased from 79" to 74". The condensate pump was tripped to prevent runout, stopping flow to the vessel. To minimize the loss of vessel inventory, a manual SCRAM signal was inserted.	0.02	5"
LOSSLVL	7/29/1991	Yes (5,11)	While placing RHR "A" shutdown cooling system in service, reactor vessel level dropped approximately 27 inches. The low level (Level 3: 11.4 inches) scram and shutdown cooling isolation setpoint was reached. The level transient terminated when piping voids filled with coolant. Prior to placing RHR loop "A" in service, it had been flushed and warmed per the operating instructions.	0.14	27"
LOSSINV	7/2/1992	Yes	RV level decreased 20" from normal operating range to +18" when approximately 3400 gallons of RWCU return flow was inadvertently diverted into a voided section of Feedwater System piping. In response to the loss of coolant, CRD cooling flow to the vessel was increased, although the loss rate (400 gpm) exceeded CRD pump cooling flow. A controlled injection was initiated using RHR-P-2A in LPCI mode. Level recovered to between +30" and +45". RWCU letdown flow was isolated.	0.10	3,400 gal

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
DRAINLO	10/2/1992	Yes (11)	The RWCU system out of service and RHR loop B was providing shutdown cooling. Reactor water level was being controlled by allowing the CRD cooling water flow to increase level to approximately 240" above the core and then reducing reactor level to approximately 200" above the core by rejecting coolant to Radwaste via RHR. This batch processing of level was necessary at intervals of 3.5 hours. During the course of one drain down, the operator was distracted and did not monitor reactor level. Level decreased to the trip setpoints (166") for the RPS and various group isolations, including shutdown cooling.	0.21	34"
LOSSINV	4/10/1994	No	RV level decreased due to a test procedure deficiency established a flow path from the SDC system to LPCI A loop drywell spray header through the LPCI cross-connected piping. Approximately 12,000 gallons of reactor coolant was sprayed into the drywell. The loss of reactor coolant was quickly recognized, but the time required to close the appropriate valves allowed for the large level decrease.	0.12	12,000 gal
LOSSINV	6/8/1994	No	While intending to drain torus water to the Waste Surge Tank, the RHR to Radwaste Discharge valves were opened. Operators failed to realize that the RHR to Radwaste interconnection is associated with the "A" RHR train, which was operating in the SDC mode. This resulted in the draining of RPV water from the RHR system to the Waste Surge Tank. RPV water level started at +44" and decreased to +30" (165" above top of active fuel). Both RPV cooling and circulation remained in service throughout the event and no increase in reactor temperature was experienced.	0.07	730 Gal
LOSSINV	12/19/1994	No	The operating crew noted an increasing trend in HCU accumulator pressure, so the CRD accumulator vent valves were opened to provide a release path. A manual scram was inserted to support other maintenance. The scram signal caused the scram inlet valves to open and established a flowpath from the RV through the CRD, open scram inlet valve and open accumulator vent valve. This flowpath existed for approximately 13 minutes, causing about 1800 gallons to drain.	--	1,800 gal

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
LOSSINV	11/2/1995	Yes	RHR loop A was operating in SDC mode. Troubleshooting was in progress for a problem with RHR valves at the remote shutdown panel (RSP). When RHR B SDC suction valve was opened from the RSP, the RHR B suppression pool suction valve also unexpectedly opened, creating a flow path from the RV to the suppression pool. The operator immediately placed the control switch for the SDC suction valve in the close position, but during the stroke time of the valves, the water level decreased to the low level isolation setpoint, resulting in isolation and loss of SDC. The cause was improperly set interlock limit switches on the valves.	0.30	64"
LOSSINV	10/9/1997	No	CRD system tagout activities resulted in an equipment alignment which allowed water to drain from the RV through control rod drive seals, through the SDV to the suppression pool. The Reactor Operator initiated an RPS actuation to terminate the RPV level decrease; RV level decreased 12" to 348".	0.03	12"
LOSSINV	12/2/1998	No	A maintenance-induced leak in the reference leg of a temporary level indicator on the refuel floor caused the reactor operators to inadvertently lower RV level 100" below the vessel flange, while attempting to maintain constant indicated level. The leaking reference leg caused an increase in indicated level, prompting operators to lower feed flow and increase the drain rate to compensate. This continued for over an hour before corrected.	0.29	14,000 gal
LOSSINV	2/24/1999	Yes (1)	Transfer of SDC trains was performed concurrently with a recirculation loop drain evolution. Neither evolution was evaluated for potential to drain the RV. Steps were performed out of sequence, resulting in running the pump with the minimum flow recirculation valve open. Reactor water level dropped and a drywell equipment drain sump alarm annunciated. Because the recirculation loop was being drained, operators were initially unsure which evolution was causing level decrease. They eventually determined that SDC operation was causing the reactor level decrease and secured SDC. Approximately 6,000 gallons were lost.	0.55	7,000 gal

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
DRAINLO	5/11/1999	No	5 gpm water leakage into the RV required operators to reduce reactor level every 12-18 hours. When RV level approached the high end of a level band, the control room commenced a RV drain through an RHR vent valve to the suppression pool. After starting letdown, the lead control room operator shifted focus from monitoring letdown to temperature. When the high reactor water level alarm cleared, the operator realized that level was below the assigned band. Level was almost 40" below the bottom of the band before draining was stopped.	0.15	37"
LOSSINV	6/28/1999	No	Operators were removing protective tags and changing RHR system lineup from SDC mode to LPCI mode. When the minimum flow valve associated with the A and C RHR pumps were opened, a flow path from A recirculation loop to the torus was created, because the suction valves to both pumps were also open. The flow path was isolated after the RV low level alarm sounded. The cause of the problem was that the system lineups were being performed without controls to ensure the restoration sequence was correct. About 10" were lost.	0.06	10"
LOSSINV	10/19/1999	Yes (12)	An unexpected loss of approximately 5" of level occurred when water drained through a stuck open electromatic relief valve (ERV) to the suppression pool. The drain path through the ERV was created when the main steam line plug seal pressure was released earlier, although the leakage was not noticeable until the plug was fully removed. The main steam line plug was reinstalled and the open ERV was closed by mechanical agitation. The drain rate was estimated at 833 gpm and about 30,000 gallons were drained. There was no SDC in service at the time of the event. Spent fuel cooling pumps were in service and were lost when the level decreased in the spent fuel pool.	0.05	38,000 gal
LOSSINV	10/20/1999	No	A safety relief valve (SRV) lifted after the main steam line plugs were removed, draining about 200 gpm to the suppression pool. Make-up to the reactor vessel was supplied by the condensate transfer system. The main steam line plugs were re-installed approximately two hours after the initial removal. The SRV air actuator had corroded, keeping the 2nd stage pilot open, so that any pressure in the steam lines at the main seating surface of the SRV would result in lifting the main plug of the SRV.	0.05	24,000 gal

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
LOSSLVL	3/19/2000	No	An operator opened a valve connecting the operating RHR loop with a drained RHR loop while performing a clearance order release. The fuel pool cooling system tripped on low level in the surge tank. The draining and RHR flow reduction ended when the out-of-service RHR loop filled. The cause of the problem was an inadequately prepared and reviewed clearance order release. The affected valve was closed and fuel pool cooling was restored. Approximately 1" (2,000 gallons) of water unintentionally drained from the cavity.	<0.01	2,000 gal
LOSSINV	3/27/2000	No	Several RWCU system work activities were in progress. Failure to isolate the RWCU system from the reactor vessel prior to performing a RWCU drain procedure allowed water to drain from the reactor vessel. After receiving a Back Wash Receiving Tank (BWRT) high-level alarm, the drain down was terminated when the drain valves were closed. 1100 gallons were lost.	<0.01	1,100 gal
LOSSLVL	9/27/2000	No	Voids in the RWCU system were filled with reactor water resulting in reactor water level dropping from 66 to 49.5 inches. The cause was Inadequate filling and venting of the RWCU system prior to placing it online. Historically, operators experienced a 4-inch level decrease during this evolution, so the control rod drive (CRD) system was the only method available for routine level control.	0.07	16.5"
LOSSINV	10/8/2001	No	The reactor level decreased from about 200 inches to 158 inches over a 4-1/2 minute period during a planned flush of the RHR system crosstie line. The D RHR pump within the B RHR loop was cross-tied to the A RHR loop torus cooling return line to flush the hot spot. The lineup was intended to be from the torus to the torus. However, because the non-operating B RHR pump was still aligned to the reactor vessel for shutdown cooling (SDC), when the torus cooling return valve was opened, an unanticipated drain down path existed from the reactor vessel to the torus.	0.11	42"

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
LOSSINV	9/16/2002	No	For several hours, operators were varying flow through "A" RHR train, trying to enhance water clarity, by throttling shut the RHR heat exchanger outlet valve. High piping noise levels were reported by a number of operators in the auxiliary building during this evolution. Intermittent "A" RHR conductivity alarms had been received, when the "A" RHR room sump annunciator alarmed. A piping failure had occurred at the RHR heat exchanger conductivity cell isolation valve, and in the pressure-locking bypass line for the test return to suppression pool valve. With the leak being minor, the decision was made to secure the "A" RHR train and place the standby train in service in a controlled manner.	--	Unknown
LOSSINV	2/23/2003	No	While shifting Shutdown Cooling (SDC) loops, RHR Loop 'B' minimum flow valve auto opened on low flow conditions. This provided a path for RV water to be directed to the suppression pool. It was the plant's practice to danger tag the RHR minimum flow valve power supply in order to defeat the auto-open logic of the valve, to prevent such an event. However, a procedure revision was written to allow one SDC train to be started while the other was still running (due to high decay heat). Level decreased approximately 21".	0.11	21"
LOSSINV	3/3/2003	No	Shutdown cooling suction piping flushes were being performed. The flush sequence first opens the suppression pool suction valves and then the RHR suppression pool return valve. About 10 seconds after the hand switch for the SDC suction valve was placed to open (before the suppression pool return valve was opened), the SDC Header High Pressure annunciator alarmed and reactor level dropped about 10". The cause of this event was the existence of voids in the RHR SDC suction line. When the SDC suction valves were opened, water flowed into an empty section of piping. The sudden filling of this piping resulted in a momentary high pressure alarm and lifted the suction relief valve.	--	10"

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
LOSSLVL	4/16/2003	No	Plant in Hot Shutdown, warming up the RHR System in order to initiate shutdown cooling and enter Mode 4. While performing the valve lineup to establish SDC, the RPV level decreased approximately 20" (3,800 gallons). The level loss was due to filling a void in the discharge piping. The RPV level was restored when the startup level control valve automatically opened to provide feedwater to the vessel. The cause was the procedure contained inadequate guidance for pre-warming the RHR discharge piping.	0.09	3,800 gal
LOSSLVL	9/30/2003	No	With SDC in service using the "A" Loop of RHR, reactor water level began to decrease unexpectedly and dropped about 4" in 3 minutes. Control room operators responded and promptly restored level to within the normal shutdown band. A definitive cause was not found; the most probable cause was determined to be steam formation and subsequent condensation in the "B" RHR shutdown cooling line.	--	4"
LOSSINV	10/29/2003	No	Fill and vent of the SDC suction line was in process. The sequence of steps established a flow path between the Reactor Coolant System RCS and the condensate makeup header in the reactor building. A small drop in level occurred (~1.5" / 300 gallons) due to inadvertently transferring coolant to the Condensate Storage Tank.	0.01	300 gal
LOSSINV	7/14/2004	Yes (11)	During warm-up of the B RHR train, voids were introduced into the RHR piping. Due to confusion by operations during warm-up, reactor vessel was drained even though the start-up level controller was at maximum demand. A reactor scram and Group 3 isolation occurred after losing more than 20". The cause was the procedure did not adequately address system design constraints in that it introduced a latent error in valve sequencing.	0.15	>20"

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
LOSSINV	5/3/2007	No	The reactor head operating vent valve was danger tagged in the closed position as part of a Main Steam tag-out. The manual head vent valves were open to maintain the vessel at atmospheric pressure. Preparations were underway for performance of the reactor vessel leakage test. As such, the danger tag on the vent valve was removed, but the valve was incorrectly placed in the open position. The 'A' main steam line tap for the vessel operating vent, and the manual head vent valves are all 8 feet below the water level at the time. Thus, once the valve was opened, water drained from the vessel through the 'A' main steam line and the manual head vent valves to the drywell equipment sump. Level decreased about 6" before the draining was stopped.	0.02	6"
LOSSINV	10/29/2007	No	During Main Steam line (MSL) plug removal activities, reactor cavity water was drained into the drywell, due to two RCIC steam line drain valves being open when the steam line plugs were deflated. The MSL plugs were on two different tagouts, but it was assumed that the RCIC work would be completed before the MSL plugs were removed. The possibility of the MSL tagout being released before the RCIC drain valve tagout did not occur to either the tagout preparer or tagout reviewer, and consequently no instructions were placed in the MSL plug tagout requiring verification of the RCIC drain valve positions prior to the MSL tagout release.	--	Unknown
LOSSINV	10/31/2007	No	During I&C functional testing activities on the main steam safety relief valves (SRV), the reactor vessel level dropped about 10" (2,100 gallons) from the RV flange. With the reactor cavity filled, steam line plugs removed, and steam lines filled, a reactor water transfer path to the suppression chamber was established. The ADS functional test caused the SRV's pilot solenoid to momentarily energize. The motive force gas accumulator was isolated but not vented and the isolation valve apparently leaked causing partial pressurization. This partially pressurized SRV accumulator contained sufficient pressure to open the SRV when it was actuated by the test. The reactor cavity water height was sufficient to partially open the SRV.	0.03	2,100 gal

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
LOSSINV	9/27/2009	No	Approximately 4" (3,700 gallons) were drained due to a flow path created by a clearance order. The clearance order input a manual scram signal and opened the accumulator drain valve. Once that was accomplished, the drain valves were to be closed and the scram signal reset. The drain path was subsequently identified as reverse flow through the Hydraulic Control Unit (HCU) inlet valve, the open SCRAM inlet valve, and through the respective open HCU drain valve.	0.01	3,700 gal
LOSSINV	9/29/2009	No	During ECCS testing with level greater than 23 feet in the upper reactor cavity pool, an extended loss of air occurred to the MSL plugs. As a result, approximately 5000 gallons of water leaked past 4 SRV flanges into the drywell. During the ECCS test, service air (SA) was isolated to the containment. This isolated the air supply to the secondary seal of the MSL plugs. With the O-ring seal not set for the MSL Plug A and the secondary seal supplied having no air source, the secondary seal began to lose pressure. The MSL plug's seal deflated and water rushed past the plug. Since the bolts on the replacement SRVs on one of the Main Steam Lines had not yet been torqued, water began to spill into the drywell from the SRV flanges.	0.01	5,000 gal

Notes for Loss of SDC?:

Yes (1) = Operators Tripped by procedure

Yes (5) = SDC unisolated at time of event, but isolated to terminate event

Yes (11) = SDC isolated on low level actuation, although FW still available.

Yes (12) = SFPC was DH cooling, SDC not inservice. SFPC lost on low level.

Table B-2
PWR Loss of Inventory Events: 1990 to 2009

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
LOSSINV	3/18/1990	No	Operators inadvertently transferred about 9500 gallons of reactor coolant to the RWST while preparing to switch operation of the RHR trains. RHR train B was in operation with train A operating in the recirculation mode to the RWST. An operator inadvertently opened the RHR train A hot leg suction valve in preparation for shifting from train B operation to train A operation. Opening this valve established a flow path from the RCS to the RWST. Prior to the evolution, Pressurizer level was at approximately 45%.	0.20	9,500 gal
LOSSINV	3/20/1990	No	During RCS fill and vent operations, the RCS and RHR systems were inadvertently pressurized because the wide-range RCS pressure instruments were isolated. The reactor coolant system pressure reached approximately 455 psig before a RHR suction piping relief valve lifted. The desired reactor coolant system pressure was 100 psig. The RCS was solid and was being pressurized to 100 psig by increasing charging flow and minimizing letdown flow. After about 2-1/2 hours, the level in the Pressurizer relief tank was observed to be increasing. Pressurization of the RCS was stopped	--	Unknown
DRAINLO	5/1/1990	No	In the process of draining the refueling canal and placing the upper plenum assembly back in the RV. The drain flowpath was from the hot leg, through one DHR pump, to the BWST. The initial drain rate was 1500 gpm. The other DHR pump was being used for heat removal. When the refueling canal level decreased to approximately 5' the operator noticed that the RV level was still decreasing, but the refueling canal level had stopped decreasing. The draining was stopped, but by that time, about 1' of the upper plenum assembly had become uncovered. The flange-to-flange fit of the indexing fixture to the RV was tight enough that at the drain rate being used, not enough leakage by the flange existed to allow the canal to drain along with the reactor vessel.	--	Unknown

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
LOSSINV	6/4/1990	No	RCS fill and vent operations were being performed to remove air from the SG tubes and RV head following refueling. The RCS was being filled with water and pressurized with nitrogen to allow venting of the RV. Due to voids in the common Pzr level instrument piping, the Pzr level readings were inaccurate. This resulted in inadvertently draining the RCS of about 6300 gallons. A subsequent check of the RV level indication system revealed that the RCS was only approximately 80% full, indicative that a nitrogen bubble had formed in the reactor head. The actual RCS level was below the bottom of the Pressurizer for 3 hours.	0.11	6,300 gal
LOSSINV	6/11/1990	No	Between 5000 to 6000 gallons of water from the RCS were transferred inadvertently to the RWST. This coolant was transferred because the reactor operator ordered isolation valves to be opened while performing RHR check valve testing before ensuring that the manual isolation valve to the RWST was closed. The loss of RCS inventory occurred over a 30 second period while a motor-operated cross-tie RHR isolation valve was partially open.	0.02	6,000 gal
LOSSINV	10/4/1990	No	550 gallons of coolant (4.5% in Pzr level) spilled as result of improper valve sequencing. Cause was poor coordination between control room and Auxiliary Building personnel. The operator opened an RHR isolation valve to align the system prior to restoring from the configuration test with a vent valve opened. This resulted in increased pressure in the RH suction header and flow through the 3/4" vent line.	0.01	550 gal

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
LOSSINV	3/8/1991	Yes	Water level was initially at the flange with the RV head removed. Technicians installed a blank flange on the wrong LPI pump suction pipe, in preparation for a valve stroke test. When the valve stroke was started, water started draining out of the RCS. Operators secured the running LPI pump when fluctuations in amperage were noted; the pump was not running for about 18 minutes. Isolation valves from the borated water storage tank (BWST) were opened, but the RCS level did not increase, so they were closed. Eventually, the valve that had been incorrectly opened was closed, but not before approximately 14,000 gallons of water flooded the reactor building basement (of which 9,700 gallons originated from the RCS, the rest was from the BWST). The water level in the vessel fell to approximately 4' above the top of the core.	1	14,000 gal
LOSSINV	3/12/1991	No	An improper valve line-up was established while preparing to fill safety injection tanks (SIT). This fill activity required that the discharge cross-connect valve for both of the SDC heat exchangers be shut and the discharge cross-connect isolation valve between the LPSI and the containment spray (CS) pumps be opened. RCS was discharged through the CS header into containment because operators failed to verify the CS header isolated. Approximately 1900 gallons lost.	0.05	1,900 gal
LOSSINV	9/20/1991	No	DHR system pump suction relief valves opened while increasing RCS pressure during a start up. The system had not been re-aligned as required because the operators overlooked the required steps. All Pressurizer heater banks were energized. RCS pressure was increased from 60 psi; when the RCS pressure reached 200 psi, relief valves in the LPI system opened. After determining that RCS coolant was being lost, additional make-up was initiated and action was taken to de-pressurize by using Pressurizer Auxiliary Spray and de-energizing the Pressurizer Heaters. A total of approximately 12,400 gallons was lost.	0.25	12,400 gal
DRAINLO	10/26/1991	Yes (7)	Drained to very low level due to use of improper level instruments. Pump vortexing and loss of RHR cooling occurred. Reduced shutdown cooling was reestablished within 16 minutes from the time the pump started showing indication of vortexing, and full shutdown cooling was reestablished within 50 minutes.	0.19	Unknown

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
LOSSINV	12/23/1991	Yes	Preparing to start up from refueling. A relief valve in operating SDC train lifted unexpectedly and stuck open, resulting in loss of 1,600 gal. The SDC train isolated for 40 min. Unable to identify specific relief valve that lifted.	0.05	1,600 gal
DRAINLO	2/21/1992	Yes	Drain-down of the RCS to mid-loop was started 2 days after shutdown with RCS at 135˚F. A 6 psig nitrogen overpressure was established. RCS level was being monitored in containment with a tygon tube connected to a low point of a loop and open to the containment atmosphere. Due to the nitrogen overpressure, correction of the indicated level of the RCS was required to compute actual RV level, and the electronic level instrument was unavailable. Level correction calculations were often optimistic and lagged actual level . After about 3.5 hours of draining, progress was checked by comparing the level increases in the holdup tank. It was determined that ~1600 gallons remained to be drained to reach midloop. About 10 minutes later, the corrected tygon tube level indicated below mid-loop. The RHR pump became gas bound and was secured. Charging pumps were started to inject. At 190˚F, RHR injection was aligned to the RCS at 1000 gpm. 5 minutes after temperature reached 221 deg F, the RHR was aligned for SDC and flow restarted with the standby pump.	0.97	Unknown
LOSSINV	4/28/1992	No	Following repairs on one of the RHR headers, which required partially draining the header, the isolation discharge valves was opened to return the system to a normal lineup. This caused a water hammer that lifted the header relief valve. The valve did not reseat until approximately 5,000 gallons had been discharged. The primary cause of the water hammer event was inadequate filling and venting of part of the piping and premature opening of the isolation valve.	--	5,000 gal

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
LOSSINV	5/13/1992	Yes (7)	About 5,500 gallons of reactor coolant were lost when a Containment Spray (CS) cross-connect valve to the in-service RHR train was opened. Core cooling was temporarily disrupted and temperatures increased from 180 deg F to 198 deg F. Water in the Pressurizer and surge line, and ~200 gallons of water in the RV was lost and the reactor coolant pressure dropped from 390 psig to atmospheric pressure. RHR A train was shutdown and the pump suction isolation valve was closed. RHR B train was in service and remained operating throughout the event. The A and B trains of RHR were cross connected down-stream of the two RHR pumps so that when the CS valve was opened, the RHR system pumped water to the CS header. Operators missed a precaution in a surveillance test procedure.	0.68	5,500 gal
LOSSINV	9/13/1992	No	With indicated RV water level of 0.5 feet below the vessel flange, de-tensioning of the vessel head was started. Reactor coolant started to leak out between the reactor head and the vessel flange. Draining of the RV was performed until control room indications showed that water level in the vessel was 2 feet below the level of the flange. At the point where this indicated reactor vessel water level was reached, the leakage between the reactor head and vessel flange had stopped. Investigation showed that the reference leg of the reactor vessel level indication system had an overpressure of 1.5 PSI greater than the overpressure in the reactor vessel, causing indication to read low.	--	Unknown
LOSSINV	9/28/1992	No	Personnel testing a safety injection tank outlet motor-operated valve inadvertently released nitrogen from the tank to the RCS, causing a large wave in the refueling cavity. The wave splashed 5,678 liters [1,500 gallons] of water over the sides of the refueling cavity. The cause of this event was inadequate venting of the safety injection tank before testing the outlet valve.	<0.01	1,500 gal

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
LOSSINV	11/21/1992	No	When an RCS pump was tripped at 400 psig during a plant heatup, an RHR suction relief valve lifted due to the transient pressure condition that occurred. Pressurizer level dropped from 31% to 0%. Minimum pressure of the RCS during the transient and subsequent recovery of Pressurizer level was 330 psig. About 1500 - 1700 gallons of water was lost from the RCS.	0.03	1,700 gal
LOSSINV	1/1/1993	No	Approximately 10,000 gallons of water were drained from the RCS as a result of inaccurate level indication caused by drainage of the reference leg of the cold-calibrated level instrument. In this case, level was lost in the reference leg as a result of leakage past an instrument vent valve. Note that no specific date was provided for this event. Assumed date of 1/1/93.	0.18	10,000 gal
LOSSINV	1/31/1993	Yes (5,6)	An RCS leak inside containment occurred due to broken RHR vent line and premature opening of an RHR relief valve. Steam voids in the system collapsed when an RHR train was placed in service and the system re-pressurized. The resulting water hammer opened an RHR suction relief valve, which chattered. Investigation of the vent line determined a weld had been damaged by vibration during previous water hammer events. Approximately 4,150 gallons were lost.	0.07	4,150 gal
DRAINLO	3/9/1993	No	During a drain down of the RCS, disagreement between the three RV level indications was identified. The original problem was corrected and the drain down continued. Differences in indicated level recurred and the drain down was stopped when the lowest indicated level reached the desired value. Subsequent investigation revealed that water had entered the "dry" reference leg of the installed RV level instruments. A procedure step directed that the RV level instrumentation be valved-in while the Pzr was water solid and pressurized to 10 psig. The nitrogen overpressure caused water to carry-over into the reference leg. As a result, the installed level instrumentation was reading non-conservatively.	--	Unknown

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
DRAINLO	11/3/1993	No	Operators began a draining operation to reduce RCS water level from about 114' level to about 112.5' (near the flange). The operator became distracted and drained to approximately 108'5" (indicated). The actual RCS level did not go below 111.7' (111' is the definition of reduced inventory). There was no impact on SDC.	0.06	48"
LOSSINV	12/21/1993	No	An investigation determined that nitrogen had come out of solution creating a gas bubble in the reactor head and the steam generator tubes while the RCS was at low pressure. Nitrogen was being used as a cover gas on the volume control tank (VCT). It was determined that over 3-month period, approximately 8,300 gallons had been removed from the RCS to maintain level constant. Although level was constant during this period, the actual coolant inventory in the RCS was reduced. A final analysis determined that reactor vessel level had decreased to slightly below the top of the hot leg (5.25 feet above the core) and that the steam generator tubes were nearly empty.	0.22	8,300 gal
LOSSINV	3/29/1994	No	While filling the reactor cavity, seal leakage exceeded the 5 gpm limit, and it could not be reduced by increasing seal bladder pressure. Resolution of the problem required a cavity drain and reinstallation of the reactor head. A rubber wear strip around the inner and outer circumferences of the seal had detached and interfered with the seal bladder seating surface, resulting in the excessive leakage. The deficient seal was the result of excessive use of silicone grease during seal installation and inadequate adhesion of the wear strips to the seal bladder.	--	Unknown
LOSSINV	4/12/1994	No	While in Mode 5 with RCS level in the Pzr, it was noticed that the Reactor Vessel Level Instrumentation System (RVLIS) was indicating ~93% when it should have been 100%. It is suspected that nitrogen gas, being used as a cover gas in the volume control tank (VCT) came out of solution and accumulated in the RV head area. RCS inventory was reduced to maintain Pzr level constant during this period, thus resulting in an inadvertent loss of inventory.	--	Unknown

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
LOSSLVL	4/14/1994	No	Recent industry experience had identified a condition where the reactor head may not be completely filled due to nitrogen from the VCT coming out of solution. The reactor head vents were cycled, resulting in a Pzr level decrease of 23 % and a RVLIS level increase of about 8%, indicating a potential void existed in the RV head. The review concluded that nitrogen cover gas from the VCT was the most probable mechanism for an approximately 2500 to 3000 gallon displacement (~1.5ft). The Pzr was vented to atmosphere and Pzr level indication was being used to monitor RCS level. The RV head vent valves were closed at this time. The RVLIS system was not monitored because the procedure did not require it to be in operation, although it had been trending down for several days.	0.06	3,000 gal
LOSSINV	9/17/1994	No	Cooling down the RCS and in the process of taking the Pzr solid. RHR train A was lined up to the RCS providing cooldown and a valve line up for recirculating RHR train B to the RWST was in progress. The RHR A and B trains are cross-connected downstream of the heat exchangers with a motor operated valve at either end and a manual valve isolating the 8" return line to the RWST in between. The manual valve was opened to accomplish the recirculation of RHR train B to the RWST. The 'A' train MOV was stroked open for testing. This provided a flow path from the RCS, via RHR train A to the RWST. Approximately 9,200 gallons were lost.	0.14	9,200 gal
DRAINLO	1/10/1995	No	Draining the RCS was stopped at 120" (below the Pzr heaters) as indicated on the RCS Level Monitoring System (RCSLMS). Level continued to decrease and operators isolated flow through the VCT divert valve assuming that it was leaking by). However, RCS level continued decreasing. When RCS level reached 95" (just below the RV flange), a charging pump was started and restored level to 125". It was determined that a RV head vent valve has not been opened at 180" as required. It was theorized that a partial vacuum was created in the RV head as level was lowered into the surge line. The RCSLMS level indicator and the two permanently installed level transmitters are all connected to a common pressure tap on the hot leg near the surge line. Once draining was stopped, vacuum drew coolant into the RV and caused level to decrease in the surge line.	--	>25"

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
LOSSINV	2/14/1995	No	A draindown was abruptly terminated when an unexpected RCS level decrease of 2 feet in less than one minute occurred. The unexpected level decrease was caused by a leaking 3-way valve that allowed water to leave the RCS via an alternate path. The leaking valve was a known problem that was not repaired before draining the RCS. Additionally, procedures were not revised to compensate for the leaking valve.	--	24"
LOSSINV	4/6/1995	No (8)	The procedure for securing SDC was implemented to commence RCS heatup. Problems were encountered shutting the SDC suction valve to LPSI pumps. Because SDC had been secured, RCS temperature was directed to be stabilized around 230°F, where steam dump valves could remove decay heat. Approximately 50 minutes later the control room directed local closing of the valve, which was not immediately performed. Due to miscommunication, the control room continued with the procedure to secure SDC without consulting the procedure. When the mini-flow valves were opened, this established a flow path from the RCS through the open SDC suction valve to the RWST. About 700 gallons of water was lost to the RWST.	0.01	700 gal
LOSSINV	7/25/1995	No	Reactor coolant was inadvertently drained from the RCS while filling a safety injection tank (SIT). After aligning the containment spray (CS) system to fill the SIT, the operator noted Pzr level decreasing. An investigation determined that the operator had not completed a procedural step to isolate the SDC heat exchanger from the portion of the CS system being used to fill the SIT. This oversight caused water from the RCS to be pumped through the SDC into the RWST.	--	Unknown

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
LOSSINV	8/10/1995	Yes (5 or 6)	When a LPSI pump was started to commence SDC system operation for RCS cooldown, the transient caused a thermal relief valve to lift, which subsequently failed to reseat. Although operators noted indications of a loss of RCS inventory, a lack of expected annunciators (sump alarms etc.) and negative search results led them to conclude that a charging/letdown mismatch associated with the cooldown was the cause of inventory loss. Later, a roving watch reported water accumulation in the Auxiliary Building pipe tunnel, and SDC was immediately secured, which stopped the leak. The relief valve did not reseat because with the SDC system operating pressure and the pressure transient associated with starting the LPSI pump, the relief valve could lift, and with a minimum blowdown of 10%, system pressure could subsequently prevent the valve from reseating. Approximately 4,000 gallons were lost.	0.07	4,000 gal
LOSSINV	9/14/1995	No	RCS indicated level was at the flange to support removing the RV head. Indicated RCS level rapidly dropped 4.7 feet when the RV head was de-tensioned. Approximately 5,000 gallons of water were added to the RCS to restore level to just below the flange. The cause of the loss of RCS inventory was the RV head vent valves were tagged closed, which allowed a pressure differential to develop between the RV head and the Pzr. This pressure differential caused indicated (standpipe) RCS level to be inaccurate. Attempts to maintain an inaccurate indicated RCS level resulted in an inadvertent inventory transfer out of the RCS.	0.13	5,000 gal
LOSSINV	11/7/1995	No	Level was being maintained 5" above the hot leg nozzle (reduced inventory) for work, a drainage path was inadvertently established that allowed ~500 gal to leak from the RCS. Maintenance was being performed on check valves in the alternate charging line to a cold leg. The system configuration and previous maintenance resulted in a loss of coolant when one of the valve's stud bolts was loosened. The maintenance crew did not notify operations that they had loosened the check valves stud bolts and eventually left containment because of the continuing leakage. The CR operators noted a decrease in level and dispatched an operator to find the leak. When the operator found the leak from the check valve bonnet, maintenance was instructed to tighten the bolts.	0.05	500 gal

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
LOSSLVL	1/11/1996	No	While cooling down to cold shutdown, Pressurizer level unexpectedly decreased by approximately 6" (100 gallons) when the DHR suction isolation valve from the RCS hot leg was opened. Subsequent investigation determined that gas, entrained in the suction piping during on-line system maintenance, was displaced by water from the RCS when the suction isolation valve was opened. Based on small size and location of the air bubble, it was determined the safety function of the decay heat removal/low-pressure injection system was not affected.	<0.01	100 gal
LOSSINV	9/1/1996	No	While investigating excessive use of nitrogen over several days in Mode 5, it was determined that nitrogen had been leaking from the VCT past a closed valve in the borated water flowpath to the charging pump suction header. Approximately 5000 gallons were added to make up for the loss of inventory. The valve appears to have started leaking after it had been inadvertently cycled 4 days earlier. The nitrogen migrated into the RV collecting under the vessel head. The RV head and the Pzr were lined up to the vent header through separate hose connections. A gas bubble formed in the head because the nitrogen flow rate exceeded the vent hose capacity. This forced water from the RV to the Pzr. As the Pzr level increased, water was diverted from the RCS to maintain Pzr level in range.	--	5,000 gal
LOSSINV	9/1/1996	No	in September 1996, a void began to form but was detected because the gradual decrease in reactor vessel level was indicated by RVLIS. Approximately 1,000 gallons of makeup were needed to restore vessel level. NOTE: No specific date was provided for this event, and no other description could be found. Assumed date of 9/1/96.	0.03	1,000 gal
LOSSINV	2/1/1997	Yes (5)	An 8" valve had been replaced during the outage; the actuator for the new valve was geared to operate in the counter-clockwise direction, which is "backwards" to the design and configuration documents, and operator expectations. Consequently the valve was thought to be shut, but was actually open. A leak was performed that established a flow path from the operating train of DHR to the BWST through the mispositioned valve. Reactor coolant system level dropped about 30" (4000 gallons) in five minutes before the level decrease was recognized by operators (the alarm was disabled).	0.10	4,000 gal

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
DRAINLO	3/6/1997	No	After draining to 50% Pressurizer level, it was determined that the Pzr level indication was incorrect due to an improper vent path established. Approximately 7,500 gallons were drained beyond what was intended. SDC did not appear to be affected.	0.13	7,500 gal
LOSSINV	3/7/1997	No	Operators noted a slowly rising trend in Pzr and volume control tank (VCT) level. The RCS was vented in a controlled to maintain Pressurizer level between 60% and 85%. The amount of nitrogen vented displaced approximately 6,900 gallons of water based on calculations. The lowest level reached in the reactor vessel was estimated to be 2.6' below the vessel flange and approximately 3.7' above the point where RHR vortexing could occur. Nitrogen gas also accumulated in the steam generator tubes.	0.18	6,900 gal
DRAINLO	3/23/1997	No	During draining from Pzr water solid to 25% Pzr level, the hot calibrated Pzr level indications came on scale before the cold calibrated level. This is opposite of the normal expected response but was not questioned. Shift turnover occurred with level at 44% cold calibration and 0% hot calibration. The new crew also did not question the relative difference between the levels. Shortly after assuming the shift, it was noted that the cold calibrated level instrument was no longer decreasing from 38%; the level instrument had lost its reference leg. Draining was stopped and charging flow increased. In ~40 minutes the hot calibrated Pressurizer instrument came on scale and 20 minutes later had stabilized at 26 percent. The final level was determined to be about 2' above the surge line nozzle. About 3,300 gallons were added to return level to 26% in the Pzr.	0.08	3,300 gal
LOSSLVL	2/20/1998	No	After draining the RCS to reduced inventory, an unexpected 250 gallon decrease in RV level occurred, when the SG channel heads were vented to atmospheric pressure. Draining the RCS longer than previous evolutions; this extended time (3 hours) accounts for the probability that a higher than previously experienced gas pressure and void space build up inside the channel heads. When this pressure was equalized with the reactor vessel, the liquid levels in the RCS equalized, and an unexpected level decrease in the reactor vessel occurred (manometer effect).	<0.01	250 gal

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
LOSSINV	11/11/1998	No	During preparations for draining the RCS to mid-loop in order to remove nozzle dams, operators noticed an unexpected drop in RV level. This occurred when operators inappropriately opened RCS drain valves. The reactor coolant entered the SG lower bowls and a portion spilled out open manways into the reactor building. Approximately 400 gallons were lost, but reactor vessel level remained above well above the reduced inventory level.	0.01	400 gal
LOSSINV	12/8/1998	No	Heating up the RCS using an RCP, a relief valve on the common suction line to the RHR pumps lifted without warning when RCS pressure reached 375 psig. Approximately 1300 gallons discharged before the relief valve was shut. The cause was operator performing too many simultaneous tasks, as well as a changed relief valve setpoint without changes to alarms, simulator, procedures, etc.	0.02	1,300 gal
DRAINLO	2/2/1999	No	The refueling canal was being drained to the RV flange level in preparations for placing the RV head on. The "B" SDC pump was in service and "A" SDC pump was used to supplement the drain down rate. The drain rate was approximately 3.3" per minute (3500 gpm). As the canal level approached 105" (this was believed to be 15" above the reactor vessel flange but is actually flange level), preparations were made to lower the drain rate. As level approached the top of the vessel flange (105"), the RCS level started lowering rapidly. The drain rate was now excessive since lowering the drain down transitioned from draining the Refueling Canal to only draining the RCS. Despite throttling down on the drain rate and securing the "A" SDC pump, the RCS level was approximately 56" by the time the draindown was stopped (approximately 1.5 minutes). Reduced Inventory is defined as being less than 65". The onset of vortexing could have occurred at a level of 26". 3500 gallons were added to raise level to 90". The RCS was in Reduced Inventory for 7 minutes.	0.50	3,500 gal

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
DRAINLO	3/4/1999	No	After draining to 20” (indicated) in the Pressurizer, the level indication continued to lower, approaching 0”. Prior to getting to 0”, level was restored to 20” indicated. Improper equipment used for venting caused Pressurizer level indication to lag actual level during the draindown. SDC did not appear to be affected.	0.05	2,500 gal
DRAINLO	4/20/1999	No	Operators inadvertently drained the RCS below the level specified in the RCS drain-down procedure. The lowest level reached during the event was 9.5 inches below the top of loop B hot leg. This was approximately 1,500 gallons more than intended. The self-limiting nature of the drain path (a 3"drain line from the centerline of the loop B hot leg) would have terminated the drain-down before SDC was lost. The cause was inaccurate Pzr level indication due to using excessive nitrogen during the drain down, leaving a 1.5 psig overpressure. This eventually resulted in indicated RCS level reading approximately 3' higher than actual level. Although there were different levels indicated by RVLIS, ultrasonic and other level instruments, the operators did not adequately question the contrary indications.	0.15	1,500 gal
LOSSINV	9/9/1999	No	A freeze seal in the letdown system thawed and released water into a valve under maintenance. Mechanics noticed water coming out of a valve being worked on; since the valve was nearing reassembly, the mechanics backseated the valve to isolate the leak. The indications of a freeze seal failure were not recognized during maintenance on the valve.	--	Unknown
LOSSINV	10/10/1999	No	In Mode 6, RV head off, and level at flange. While performing testing of the Safety Injection system recirculation switches, the recirculation valve off the discharge of the recirculation pumps in containment was repositioned to its normal throttled position while the discharge valves for the recirculation pumps were still open. This resulted in the discharge of approximately 1100 gallons of reactor coolant from the RHR system directly to the recirculation sump. The valve was closed and level stabilized 18" below the RV flange. Cause was an error in the procedure.	0.03	1,100 gal

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
LOSSINV	10/17/1999	No	In the process of returning to normal operations from an outage, steam was observed coming through grating above the transmitter room in the vapor containment building. CR operators noted a flow indicator indicating full scale and an increase in the RCS leak rate. The root isolation valve for the flow transmitter was shut and the leak stopped. Initial leakage estimates were about 15 gpm. Calculations showed the average leak rate during this event was about 1.6 gpm.	--	Unknown
LOSSINV	11/1/1999	No	Performing a valve lineup for draining the cold leg section of piping to the suction of the RCPs to support nozzle dam removal. The valve line-up was performed in the incorrect order, resulting in draining the RCS to the RB sump. Transfer continued for 10 minutes before the drain valves were closed. The lowest level was above any pump cavitation limit or alarm setpoint. Approximately 1.2' (1200 gallons) were lost.	0.13	1,200 gal
LOSSINV	11/27/1999	Yes (5)	While opening a SDC suction isolation valve to place SDC Train B in service Pzr pressure and level dropped rapidly. RCS pressure fell to from 350 psia to 105 psia and indicated Pressurizer level dropped from 35 percent to 2 percent (~5000 gal). Operators immediately reclosed the suction isolation valve before it reached the full-open position. Operators stopped the 2 operating RCPs; core DHR was maintained through natural circulation using a SG. Subsequent investigation determined the SDC HX B to Refueling Water Storage Pool (RWSP, equivalent to RWST) Isolation valve was open due to the remote operator reach rod being disconnected due to the loss of a coupling pin.	0.09	5,000 gal
LOSSINV	3/14/2000	No	Operators were sweeping air from the RHR system hot leg injection header when an unexpected pressure pulse caused the RHR train A heat exchanger 600-psig relief valve to open. Although pressure in the RHR system was quickly reduced, the relief valve did not reseat, and approximately 10,000 gallons of reactor coolant was discharged to the Pressure Relief Tank (PRT). A level decrease was expected when the hot leg isolation valve was opened, but after about 20 minutes the crew suspected that an RHR relief valve had opened. The leak was isolated approximately 90 minutes later. SDC was maintained with the B RHR train.	0.18	10,000 gal

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
LOSSLVL	4/15/2000	No (4)	When the RHR system was placed in service for SDC (i.e., isolation valve between the RCS loop and the RHR system was opened), a rapid drop in Pressurizer level of about 5% (305 gallons) was noted. The cause appeared to be a low pressure hydrogen bubble generated by differential leak rates between two of the RHR isolation valves.	0.01	305 gal
LOSSLVL	4/17/2000	Yes (5)	In Mode 4, going on to shutdown cooling. A sudden drop in Pzr level (6%) occurred when the last SDC isolation valve was opened. The valve was immediately closed and Pzr level stabilized. A field operator saw leakage from the isolation valve telltale drain tubing of 1 - 2 gpm. Operations determined that the Pzr level behavior was consistent with Pzr level changes when filling SDC piping in the past. Later that day, while placing SDC online, a similar event occurred but with significantly less inventory loss. It was later determined that the level drop was not solely due to filling and venting the SDC system. 200 gallons of RCS inventory was transferred inter-system. This event could be considered a LOSSINV, but the loss of SDC was primarily due to the sudden drop in Pzr level, which appears to be the result of filling voids in the SDC system. Therefore, classified as a LOSSLVL and counted as one event.	<0.01	200 gal
LOSSINV	9/26/2000	Yes	While in Mode 4, RHR A was started as part of placing SDC in service. Following the pump start, the Train B RHR discharge relief valve lifted and did not reseat until Pump A was secured and the RHR system was isolated from the RCS. Approximately 500 gallons of water was lost from the RCS to the Pressurizer Relief Tank (PRT) during this event. The cause was determined to be a compression of a non-condensable gas pocket causing a pressure surge when starting the RHR pump and very little pressure margin was available to the set pressure of the relief valve.	0.01	500 gal
LOSSINV	10/15/2000	No	During a refueling outage, after primary nozzle dams were installed and the RCS level raised, the drain plugs in one SG hot leg and one SG cold leg started leaking. During the attempt to put temporary pump suctions in the bowls to control the water, the drain plug in the SG cold leg was completely dislodged creating an approximately 10 gpm leak. The drain plug was reinstalled to stop the leak.	0.01	Unknown

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
LOSSINV	10/17/2000	No	In solid water operation, the CR operator made adjustments to the letdown backpressure controller in order to raise RCS pressure, based on pressure indication from a transmitter being calibrated. Both loop SDC relief valve opened. The letdown backpressure regulator was adjusted to lower RCS pressure, stopping the pressure rise and restoring pressure to the expected band.	--	Unknown
LOSSINV	10/28/2000	No	While moving equipment in a SG Cold Leg bowl following eddy current inspections, the drain plug was accidentally knocked loose. It had previously been reinstalled tightly to recover from the first dislodging (on 10/15/00). The RCS level was at a lower level than the previous event, so the leak rate was much slower than before. The plug was then reset eliminating the leak.	--	Unknown
LOSSINV	1/8/2001	No (2)	While in Pzr solid water conditions and returning RHR Train 'B' to standby, the suction line relief valve opened for approximately 8 minutes and caused about 300 gallons of RCS water to flow to the Pressurizer relief tank (PRT). The pressure transient from opening RHR Train 'B' isolation valves caused relief valve to lift. However, the relief valve stayed open due to incorrect calibration of the valve. RHR Train 'B' was re-isolated to stop the loss of coolant.	<0.01	300 gal
LOSSINV	2/13/2001	No	During a refueling outage, RCS inventory was unintentionally lost through an open RCP seal injection drain valve, while the RCS was at 1' below the flange, in preparation for head set. During performance of check valve test, work was placed on hold and subsequent conflicting work resulted in removing the safety tags and leaving an open RCS leakage path. The drain path existed for 23 hours, draining 500 gallons from RWST and 380 gallons from the RCS.	0.03	850 gal

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
LOSSINV	4/2/2001	Yes	A SDC loop suction relief valve lifted as the system was being place in service. The open relief valve caused Pzr level to decrease approximately 4% over 5 minutes, corresponding to a leak rate of approximately 80 gallons per minute. Operators terminated the leak by closing the A SDC loop inlet isolation valve. The event was attributed to inadequately venting the SDC system prior to placing a train in service; air pockets produced dynamic pressure changes in the system when the SDC pump was started.	0.01	400 gal
LOSSINV	4/4/2001	Yes (5)	While placing a train of SDC in service, a SDC relief valve lifted when the hot leg suction valve was opened. Approximately 300 gallons of RCS was lost over a period of 2 minutes. Reclosing the hot leg suction valve terminated the event.	<0.01	300 gal
LOSSINV	4/11/2001	No	Due to inadequate communications regarding the position of the RV head vent valve, it remained closed during a period in which gas accumulated in the vessel head and affected the standpipe levels. Initially, operators believed the increasing level indications were due to thermal effects associated with filling and draining the SGs and some amount of water still trickling from the U-tubes. After confirming that the RV head vent closed, the head was vented, which decreased RCS standpipe level 16 inches. 1122 gallons were needed to raise level to bottom of operating band.	--	1,122 gal
LOSSINV	11/10/2001	Yes (6)	Operating in Mode 4, the SDC system had been secured for about 15 minutes when a realignment sequence was initiated to place it back in service. During the evolution, a thermal relief valve opened and did not immediately reseat. The LPSI pump was secured and the relief valve reseated. Subsequent analysis of the event determined that the flow rate from the relief valve was greater than 10 gpm.	--	Unknown

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
LOSSINV	11/26/2001	Yes (5)	A relief valve in the SDC system lifted while placing SDC in service during cooldown for a scheduled outage. The relief valve setpoint is 350 psia, and the RCS pressure was 268 psia. The relief lifted with the RCS hot leg suction valve was opened. The leak was isolated and terminated by reclosing the valve.	--	Unknown
LOSSINV	6/5/2002	No	In Mode 4 following an outage, while maintenance technicians were performing surveillance testing of a Pressurizer power operated relief valve (PORV), a common signal was generated which opened the PORV unintentionally. Approximately 100 gallons of reactor coolant inventory was transferred to the Pressurizer relief tank (PRT) in a 15-second period before the block valve was closed by the control room operator.	<0.01	100 gal
LOSSINV	2/21/2003	No	Unit in Mode 5 with the RCS drained to just below the top of the RV head to support work on the head vent valves. Level was being monitored using the wide range gauge glass (WRGG) with redundant monitoring provided by the Reactor Vessel Water Level System (RVWL). With the head vent system being unavailable, nitrogen gas from the VCT collected in the RV head causing a level drop of approximately 6 feet over a period of 20 hours. The level decrease was detected when an RVWL sensor above the vessel flange became uncovered. Charging and letdown were adjusted to raise the level. Approximately 5000 gal were added to the RCS.	0.12	5,000 gal
LOSSINV	4/9/2003	No	An unexpected decrease in RV level from of about 0.2% Pzr level (25 gallons) occurred. It was determined that during a tagout evolution, vents and drains were opened prior to a maintenance evolution. The vents and drains that were opened for the tagout were closed, which stopped the level decrease.	<0.01	25 gal
DRAINLO	5/4/2003	No	While draining the RCS, level was lowered to 18” below the vessel flange due to level indication problems resulting from inadequate venting of the reactor vessel head area and drawing a vacuum on the RCS. Inventory was added to raise level to the flange after the problem was discovered. The apparent target level was 12” below the flange, so the overdrain was by about 6”. SDC was not affected.	0.02	750 gal

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
LOSSLVL	9/15/2003	No	Awaiting reactor vessel head disassembly in Mode 5, with indicated level just below the flange. Control room operators noted that the RCS level was lowering at a steady rate. Within 3 minutes, RCS level was steady after dropping 2.0 feet. No signs of leakage were found. 2 charging pumps raised RCS level at about 80 gpm and returned to the original level in 18 minutes. It was determined that there was an inadequate vent path on the reactor vessel head. Venting occurred due to a maintenance evolution and caused RCS level in the Pressurizer surge line to shift downwards while the actual level in the RV head rose very slightly while indicated level lowered.	0.04	1,440 gal
LOSSINV	3/31/2004	No	In a refueling outage with the reactor cavity filled. Control room operators identified a decrease in reactor cavity water level. Approximately 1 hour later, the source had been identified and isolated. The leak rate from the reactor cavity was determined to be greater than 10 but less than 50 gpm. It was determined that when the SDC Purification System had been removed from service, an incorrect alignment was established. When the Letdown Divert Valve was stroked open as part of an unrelated maintenance activity the resulting valve configuration allowed reactor coolant to be diverted from the RCS to a Waste Holdup Tank.	0.01	1,830 gal
LOSSINV	3/8/2005	No	A tagging clearance order, which established a maximum allowed RCS level associated with a maintenance activity, was released for performance in the plant. An inaccurate level (higher than allowed for the activity) was used in the clearance. This inaccuracy was not detected, so when drain valves associated with the clearance were opened, RCS level lowered by about 1". The inventory being lost from the drain path was identified shortly after it had started to flow and the drain path was subsequently secured.	<0.01	1"
LOSSINV	3/16/2005	No	A clearance order was not released in proper sequence prior to opening the intermediate leg loop drain valves, in preparation for draindown evolution. When the drain valves were opened, a flow path was created that resulted in draining approximately 700 gallons from the RCS (at about 70 gpm) to the containment sumps.	--	700 gal

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
LOSSINV	10/31/2005	No	Approximately 2500 gallons leaked from the RCS into the CCW system, due to a tube leak in a SDC heat exchanger. The leak was caused by improper restoration of the heat exchanger following maintenance (too much flow was sent through the heat exchanger). The high flow resulted in the fretting of a single tube against an adjacent baffle plate until the tube was severed.	--	2,500 gal
LOSSINV	3/19/2006	No	An operator incorrectly opened the RCP Lower Seal Cavity Vent valves, which established a flow path out of the lower seal cavity, in preparation for hand rotating an RCP. Soon after the RCP was rotated, control room operators noted an unexpected decreasing trend in Pressurizer level. The control room determined that the valves were incorrectly opened, and ordered them closed, stopping the leak. Approximately 200 gallons were drained from the RCS over several minutes.	<0.01	200 gal
LOSSINV	10/16/2006	No	As the result of a breaker opening while closing an adjacent breaker, a Pressurizer Power Operated Relief Valve (PORV) opened. Operators immediately restored power and closed the valve, terminating the event. The breaker opening caused the overpressure bistable to de-energize, which opened the PORV. Approximately 60 gallons were discharged.	<0.01	60 gal
LOSSINV	5/14/2007	No (3)	During solid plant operation at the end of a refueling outage, operators were performing RCS Fill and Vent. Shutdown Cooling was secured and isolated in preparation for the 10 minute RCP sweeps. With three RCPs in operation, both Pressurizer PORVs lifted due to RCS pressure rising to 350 psia. All 3 running RCPs were stopped within 10 sec of the PORVs lifting. The cause of the pressure increase was a mismatch in charging and letdown flow due to the letdown pressure control valves closing as designed following the start of one of the RCPs (the one whose suction is on the same RCS leg as letdown).	--	Unknown

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
LOSSLVL	12/30/2007	No (4)	During a plant cooldown for a refueling outage, an unexpected Pressurizer level decrease of 6" was experienced during the alignment of a LPI pump to DH standby. The cause was inadequate restoration from maintenance that resulted in an approximately 14 cubic foot (at atmospheric pressure) void in the discharge piping.	<0.01	104 gal
LOSSLVL	2/25/2008	No	When the RV head vent line flange was loosened in preparation for disconnecting it as part of the reactor vessel disassembly, the RCS level unexpectedly lowered by 10 inches. Approximately 1800 gallons of make-up was added to maintain the RCS level. The cause was inadequate venting of the RV head after the draining process, potentially due to a vent line that is undersized for the purposes of the evolution.	0.04	1,800 gal
LOSSLVL	3/23/2008	No	Draining was suspended during drain down in preparation for RV head removal. Indicated level was low in the Pzr, when a sudden drop of about 9” occurred. This occurred several other times to a lesser extent during the drain down. First drop in level was estimated at 850 gal and left level at least 4’ above the flange. Cause believed to be accumulated nitrogen under the vessel head due to dissolved nitrogen coming out of solution and insufficient temporary vent of the RV head.	0.02	850 gal
LOSSINV	4/6/2008	No	When the RCS was aligned to the suction of the LPSI pumps to establish SDC, Pressurizer level started to slowly lower and refueling water storage tank (RWST) level started to slowly increase. The flow path to the RWST was isolated 74 minutes later, during which time a flow rate of 10 to 15 gpm existed. It was determined that the RWST suction valve for "B" LPSI pump was the source of the leak. During disassembly of the valve, a significant amount of foreign material was found in the body housing of the valve.	0.02	1,110 gal

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
LOSSINV	4/15/2008	No	A loss of RCS inventory occurred due to a letdown line relief valve lifting while DHR purification was in operation. The relief valves lifted when air operated valves in the purification train failed closed on loss of power. RCS level decreased from 70” to 54” at 100 gpm while operators took about 20 minutes to isolate letdown. The loss of power was caused by an unexpected generator lockout during PM on a voltage regulator circuit board.	0.23	2,200 gal
LOSSINV	4/20/2008	No	When letdown was put in service with the cavity flooded, approximately 2000 gallons of water was lost in approximately three hours from the refueling cavity to the waste liquid drain (WLD) sump. The cause was an open drain valve in the letdown system that was not closed as required while realigning the system from a tagging. Additionally, the operators did not initially investigate the almost 20 gpm mismatch between letdown and charging.	0.01	2,000 gal
LOSSINV	5/4/2008	No	A cold leg nozzle (sandbox) cover was discovered leaking after refueling cavity flood-up. Anecdotal evidence from shift personnel indicated that the leak existed from the start of cavity flood-up. The leakage was determined to be approximately 10 gpm. A camera view from the cavity side of the cover seal showed the cavity seal had rotated out of position to the inside enough so that one of the seal tabs could be seen.	--	Unknown
LOSSINV	9/1/2008	Yes (5)	During plant shutdown (Mode 4) in anticipation of a hurricane, a Low Temperature Overpressure Protection (LTOP) relief valve opened while placing the SDC system in service. Approximately 1300 gallons of reactor coolant was lost. A design change had been implemented where the SDC isolation valves were changed from hydraulic actuators to air operated actuators, affecting the valve stroke characteristics and resulted in a system pressure surge sufficient to lift the LTOP relief valve momentarily when the SDC valve was opened.	0.02	1,300 gal

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
DRAINLO	10/15/2008	No	Draining from Pzr solid to 10% - 15% in Pzr. After draining was stopped, the level continued to drop. Charging flow was raised to 5-10 gpm greater than letdown flow; level stabilized at 14% after about 8 hours. It was determined that Pzr had completely drained and nitrogen migrated to the top of RV and some SG tubes. The minimum level reached was just below the bottom of the Pressurizer. Operators expected to drain 12,000 gallons and ended up draining 14,650 gallons. The cause was the use of a level instrument with voided reference leg, which gave an erroneously high reading.	0.05	2,650 gal
LOSSINV	4/25/2009	Yes (1)	During a scheduled cooldown, the Decay Heat Drop Line Thermal Relief Valve opened when the RCS was valved into the DHR system. The valve remained open, causing an RCS leak of 2.5 - 5 gpm. The DHR system was isolated to stop the leak, but also caused a Loss of Decay Heat Removal. RCS heat removal was transferred back to the Steam Generators.	--	Unknown
LOSSLVL	4/27/2009	No	While removing a Pzr safety valve, level decreased from 108" to 77", at 4" to 8" per minute. Make-up was initiated and level restored. The cause was inadequate venting of the Pzr through the hard piped vent path prior to removing the Pzr safety valve. This resulted in levels throughout the RCS equalizing when the safety relief valve was removed. Maintenance reported that a slight vacuum was on the system when the relief valve was removed.	--	31"
LOSSINV	11/20/2009	No	While preparing for RCS fill and vent, the clearance order associated with the removal of a draindown level hose from service was performed. It was expected that no valve positions needed to be changed. While in Containment, the operator discovered two valves not in their expected positions. The valves were opened, which established a drain path from the RV to the RC Drain Tank (RCDT) was created. Approximately 270 gallons were lost at about 9 gpm. One of the valves was shut to stop the leak.	0.01	270 gal

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
LOSSINV	11/24/2009	No (8)	After transitioning to Mode 4 during a plant startup, a misalignment occurred while securing the RHR system. The 'A' RHR cross-connect valve was open, providing a direct path from the discharge of 'B' RHR pump to 'A' Train RHR Suction Relief valve through the 'A' RHR pump mini-flow line. When RHR 'A' Suction Valve was closed, 'A' RHR loop began to pressurize and the 'A' RHR Suction Relief Valve lifted at the 450 psig set point. Approximately 1500 gallons were lost before the 'A' RHR Cross Connect Isolation valve was closed.	0.03	1,500 gal
LOSSINV	3/18/1990	No	Operators inadvertently transferred about 9500 gallons of reactor coolant to the RWST while preparing to switch operation of the RHR trains. RHR train B was in operation with train A operating in the recirculation mode to the RWST. An operator inadvertently opened the RHR train A hot leg suction valve in preparation for shifting from train B operation to train A operation. Opening this valve established a flow path from the RCS to the RWST. Prior to evolution, Pressurizer level was at approximately 45%.	0.20	9,500 gal
LOSSINV	3/20/1990	No	During RCS fill and vent operations, the RCS and RHR systems were inadvertently pressurized because the wide-range RCS pressure instruments were isolated. The reactor coolant system pressure reached approximately 455 psig before a RHR suction piping relief valve lifted. The desired reactor coolant system pressure was 100 psig. The RCS was solid and was being pressurized to 100 psig by increasing charging flow and minimizing letdown flow. After about 2-1/2 hours, the level in the Pressurizer Relief Tank was observed to be increasing. Pressurization of the RCS was stopped	--	Unknown

Event Type	Event Date	Loss of DHR?	Event Description	Severity	Inventory or Level Lost
DRAINLO	5/1/1990	No	In the process of draining the refueling canal and placing the upper plenum assembly back in the RV. The drain flowpath was from the hot leg, through one DHR pump, to the BWST. The initial drain rate was 1500 gpm. The other DHR pump was being used for heat removal. When the refueling canal level decreased to approximately 5' the operator noticed that the RV level was still decreasing, but the refueling canal level had stopped decreasing. The draining was stopped, but by that time, about 1' of the upper plenum assembly had become uncovered. The flange-to-flange fit of the indexing fixture to the RV was tight enough that at the drain rate being used, not enough leakage by the flange existed to allow the canal to drain along with the reactor vessel.	--	Unknown
LOSSINV	6/4/1990	No	RCS fill and vent operations were being performed to remove air from the SG tubes and RV head following refueling. The RCS was being filled with water and pressurized with nitrogen to allow venting of the RV. Due to voids in the common Pzr level instrument piping, the Pzr level readings were inaccurate. This resulted in inadvertently draining the RCS of about 6300 gallons. A subsequent check of the RV level indication system revealed that the RCS was only approximately 80% full, indicative that a nitrogen bubble had formed in the reactor head. The actual RCS level was below the bottom of the Pressurizer for 3 hours.	0.11	6,300 gal
LOSSINV	6/11/1990	No	Between 5000 to 6000 gallons of water from the RCS were transferred inadvertently to the RWST. This coolant was transferred because the reactor operator ordered isolation valves to be opened while performing RHR check valve testing before ensuring that the manual isolation valve to the RWST was closed. The loss of RCS inventory occurred over a 30 second period while a motor-operated cross-tie RHR isolation valve was partially open.	0.02	6,000 gal
LOSSINV	10/4/1990	No	550 gallons of coolant (4.5% in Pzr level) spilled as result of improper valve sequencing. Cause was poor coordination between control room and Auxiliary Building personnel. The operator opened an RHR isolation valve to align the system prior to restoring from the configuration test with a vent valve opened. This resulted in increased pressure in the RH suction header and flow through the 3/4" vent line.	0.01	550 gal

Notes: Loss of SDC?

Yes (1) = Operators Tripped by procedure

No (2) = One train remained running, other train isolated

No (3) = SDC isolated throughout the event

No (4) = SDC unisolated at time of event and remained in service

Yes (5) = SDC unisolated at time of event, but isolated to terminate event

Yes (6) = SDC initiated at time of event, but pump was tripped to terminate event

Yes (7) = SDC flow reduced to the extent that RCS heated up - one SDC train isolated, the other remained running

No (8) = SDC isolated during event as part of evolution that resulted in problem

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