DUKE POWER COMPANY

CATAWBA NUCLEAR STATION

SPECIAL REPORT

RESIDUAL HEAT REMOVAL PUMP VIBRATION

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1.0 EXECUTIVE SUMMARY

This is a special report submitted by Duke Power Company's Catawba Nuclear Station at the request of the NRC. It contains detailed technical information as well as information relative to the management involvement and decision making process surrounding the vibration of 1A Residual Heat Removal Pump.

Background

The background section of this report contains detailed descriptions of pertinent Catawba Nuclear Station processes, programs, and analyses. The information should be used by the reader to gain a better understanding of issues discussed in the Time Line and Conclusion sections of this report.

Time Line

Catawba Unit 1 was taken offline on October 29, 1993 for a scheduled refueling outage. Preplanned outage work included replacement of Residual Heat Removal (ND) pump 1A due to a seal leak. The pump work was conducted with the plant in No Mode (Defueled) and was completed on November 30. During post-maintenance ASME Section XI IWP testing, the vibration monitoring results were in the IWP program Alert Range. This prompted additional vibration monitoring which was coordinated and reviewed by the Station Vibration Engineer. As additional vibration data sets were obtained, meetings were held with station management to discuss pump status, operability, and reliability.

From 11/30 to 12/14 the plant proceeded from No Mode through Mode 6 (Refueling) and Reactor Coolant (NC) system draindown to Reduced Inventory. Vibration monitoring, data collection, and evaluations continued throughout this time period. Based on review of data and previous experience, it was determined that the pump was operable as the outage progressed through these evolutions. Some factors that supported this determination were:

- vibration levels remained essentially constant until 12/13
- no Bearing Defect Frequencies
- bearing loads were well below dynamic load rating for the bearing
- vibration was near system/structure resonant frequency, therefore shaft to housing force was less for a given amplitude of vibration
- bearing temperatures remained normal
- pump was run as much as possible to demonstrate continued reliability

From 12/13 to 12/14 vibration results began to increase from the levels previously seen. On 12/14, due to an unacceptable upward trend in data, ND pump 1A was declared inoperable. At that time, Unit 1 was in Mode 5 (Cold Shutdown) with NC level at Reduced Inventory (8.5%) and all Steam Generator (S/G) primary manways installed. Technical Specifications and the Catawba Shutdown Risk Management program requires two ND Trains operable/available. Both ECCS Trains (two NV Centrifugal Charging and two NI Safety Injection pumps) were available for forced injection and both Emergency Diesel Generators (D/Gs) were available. ND Train B remained operable; there was no interruption of core cooling.

Meetings were held by station management to determine options for proceeding. The options discussed were:

1) Remain at Reduced Inventory until ND pump is replaced.
2) Proceed with NC atmospheric Fill and Vei in parallel with ND pump replacement.
3) Perform NC vacuum Fill and Vent (requires draining to midloop) in parallel with ND pump replacement.
4) Return to midloop to open a large vent path until ND pump is replaced.

The management team chose Option 2 because it provided an increase in time to core boiling resulting from increasing NC level and the availability of both ECCS Trains and D/Gs should a loss of ND occur. The option to lower NC level and remove a S/G manway was eliminated due to the increased probability of losing the operable ND pump due to loss of suction. To comply with Technical Specifications, action was immediately initiated to begin the replacement process of ND pump 1A. The NRC Resident was briefed on the option chosen to proceed and compliance with Technical Specifications. On 12/15 at 1905, Reduced Inventory was exited; on 12/17 at 0347 NC loops were filled and vented; on 12/18 at 1610 ND pump 1A repair and post-maintenance testing was completed and the pump was declared operable.

Corclusions

Following the repair of ND pump 1A the Catawba management team initiated a review of the activities associated with the vibration problem and subsequent inoperability. This section summarizes the conclusions reached from this review.

The technical analyses made by the Vibration Engineer were reviewed. Also, an independent review of the vibration data was performed by another qualified Duke Power Vibration Engineer. The vibration analysis techniques were determined to be sound and appropriate. Analysis of the data during this time period showed no indications of imminent pump failure. This was confirmed by the independent data review.

The motor assembly removed from the ND pump 1A location was shipped to Westinghouse for analysis. This analysis concluded that the vibration problem was caused by a loose upper bearing runner. The installation process used at Catawba for the upper bearing runner was reviewed and determined to be of insufficient detail to ensure proper installation. Maintenance procedures will be revised to detail proper installation methods, and a special tool that simplifies the installation process has been obtained. A motor test stand will also be completed to allow pre-installation testing for this type of motor.

The currently installed ND pump 1A configuration was last disassembled in 1983. It has been in service since that time with satisfactory performance indicators. The current configuration exhibits some amplifications of vibration due to system/structure resonance. The magnitude of vibration is satisfactory and the pump is reliable and operable. Options are being evaluated to determine if improvements can be accomplished to reduce the system/structure resonance.

Catawba was recently granted a Relief Request for the ASME Section XI IWP program to use velocity vibration monitoring and the vibration acceptance criteria table from OM-6. There was not a consistent understanding of when to apply the IWP program Required Action limit. IWP program requirements and OM-6 acceptance criteria will be clearly defined and placed in Site Directive 3.1.14, Operability Determination. In addition, appropriate Engineering personnel and management will be trained on these requirements.

From 11/30 to 12/14 evaluations were being made that concluded ND pump 1A was operable/reliable. On 12/12 the IWP program Required Action limit was exceeded for the first time. The Vibration Engineer continued to consider the pump operable due to the technical reasons listed earlier and his understanding of the IWP program limit. At this point, the formal process for determining continued operability was not properly entered. Benefits from using this process are formal management involvement and interface with Operations. The operability process and related management expectations have been reviewed with Component and System Engineers.

Throughout this time period, management was pursuing resolution of the ND pump vibration and was involved in the decision making process, focusing on the technical operability and reliability of the pump. The decision to defer pump replacement was based on the current operability of the pump and the data not showing any predication of imminent pump failure. A decision to replace the pump during the early portion of this review, when a window existed to replace the pump, would have provided additional assurance consistent with a conservative approach to operation and therefore would have been a better alternative than continued evaluation. The need to consider plant conditions and associated risk when evaluating degraded components/systems will be emphasized to management and engineers. In addition, a management signoff will be required prior to Reduced Inventory to ensure an overview of the status of key components/systems.

The relative risk of core damage during this period of inoperability did not significantly increase. The core damage frequency during this period with two operable ND pumps is estimated to be 8E-09, and increases to an estimate of 4E-08 with only one ND pump operable. The Shutdown Risk Management program requires safety equipment available beyond that required by Technical Specifications. Two Trains of NV, two Trains of NI, and an operable ND Train (1B) were available, any one of which is capable of removing core decay heat.

<u>Summary</u>

- The Catawba Shutdown Risk Management program ensures a conservative approach to outage planning and execution. The additional safety systems and management controls required provided appropriate levels of defense to prevent loss of decay heat removal.
- The overall vibration technical analysis and decision making was sound and appropriate. Analysis of the data showed no indications of imminent pump failure. This conclusion was supported by an independent data review.
- Throughout this time period, management was actively pursuing resolution of the ND pump vibration. A decision to replace the pump during the early portion of this review, when a window existed to replace the pump, would have provided additional assurance consistent with a conservative approach to operation and therefore would have been a better alternative than continued evaluation. When the IWP Required Action limit was exceeded, the threshold for entering the formal operability process was not clearly understood. Once the ND pump was declared inoperable appropriate actions were taken to manage reactor coolant inventory and restore the ND pump.
- Analyses performed by Probabilistic Risk Assessment personnel indicates that the core damage frequency did not significantly increase during this period of inoperability. There was no interruption of core cooling and all Technical Specification Action requirements were met. The health and safety of the public were not affected.

2.0 BACKGROUND

2.1 Reactor Coolant (NC) System Description

The purpose of the NC system is to transport heat from the Reactor core to the Steam Generators (S/G), where heat is transferred to the Main Feedwater and Main Steam systems of the secondary side. The NC system consists of four identical heat transfer loops connected in parallel to the Reactor Vessel. Each loop contains an NC pump and a S/G. In addition, the system includes a pressurizer, a pressurizer relief tank, piping, valves, and instrumentation necessary for operational control.

2.2 Residual Heat Removal (ND) System Description

The primary purpose of the Residual Heat Removal System is to remove thermal energy from the reactor core and Reactor Coolant System during plant cooldown and refueling operations. The ND system provides two parallel cooling trains (A & B); each train consisting of one pump, one heat exchanger and the associated piping, valves, and instrumentation required for operational control. The ND system is also used as part of the Emergency Core Cooling System (ECCS). In its capacity as the low head portion of the ECCS, the ND system provides long term recirculation capability for core cooling as needed during accident conditions.

2.3 Technical Specifications

Technical Specification 3.4.1.4.1

This specification requires that in Mode 5, Cold Shutdown, with NC loops filled one ND loop shall be operable and in operation, and either:

a. One additional ND loop shall be operable, or
b. The secondary side water level of at least two S/Gs shall be greater than 12%.

With one of the ND loops inoperable and with less than the required S/G level, action is required to immediately initiate corrective action to return the inoperable ND loop to operable status or restore the required S/G level as soon as possible.

Technical Specification 3.4.1.4.2

This specification requires that in Mode 5, Cold Shutdown, with NC loops not filled, two ND loops shall be operable and at least one ND loop shall be in operation. With less than the required ND loops operable, action is required to immediately initiate corrective action to return the required ND loops to operable status as soon as possible.

Note: When refilling the NC system following draindown the loops cannot be considered "filled" until completion of the one minute NC pump runs during the atmospheric fill and vent procedure.

Technical Specification 3.9.8.1

This specification requires at least one ND loop to be operable and in operation while the Unit is in Mode 6, Refueling, when the water level above the top of the Reactor Vessel flange is greater than or equal to 23 feet.

Technical Specification 3.9.8.2

This specification requires that two ND loops be operable and at least one ND loop in operation while the Unit is in Mode 6 when the water level above the top of the Reactor Vessel flange is less than 23 feet.

2.4 Catawba Shutdown Risk Management Program

The purpose of this section is to describe the Shutdown Risk Management program at Catawba. This includes descriptions of procedures, preoutage planning philosophy, NC level instrumentation, and requirements for Reduced Inventory during low decay heat conditions.

Shutdown Risk Management

Shutdown Risk Management continues to have the highest priority for outage management at Catawba Nuclear Station. This focus has resulted in significant improvements in the recognition of risks and the management of our work to avert or minimize the risk associated with unit shutdown. The following is a brief description of work management practices that have been implemented to assure continued safe operation during unit shutdown conditions.

Procedures

The following directives describe the Shutdown Risk Management program at Catawba and implement the guidance in NUMARC 91-06, Guidelines for Industry Actions to Assess Shutdown Management, and NUREG 1449, Shutdown and Low-Power Operation at Commercial Nuclear Power Plants in the United States.

Nuclear System Directive 403, Shutdown Risk Management, establishes Duke Power's corporate policy concerning shutdown risk management. This directive contains the senior management policy by stating the outage nuclear safety philosophy, and provides generic guidelines for outage control, outage risk assessment, outage training, and outage procedures. Each of Duke Power's nuclear stations are required to comply with this directive.

Site Directive 3.0.10, Unit Shutdown Management, establishes the Catawba Nuclear Station policy concerning shutdown and shutdown risk management. The directive includes senior management policies for the scheduling and execution of all planned and forced shutdowns. Included are specific responsibilities, outage planning and execution requirements, and details of the outage assessment process.

Site Directive 3.1.30, Unit Shutdown Configuration Control (Mode 5, 6, or No Mode), defines the requirements and plant conditions necessary to maintain safe unit shutdown configuration control with fuel in the core or in the spent fuel pool. The directive stresses the outage risk assessment process which focuses on maintaining Defense In Depth commensurate with plant conditions during the outage, maximizing safety system availability, adequacy of contingency plans, and minimizing high risk evolutions. The directive contains specific requirements for equipment and safety systems that are to be available during each phase of the outage.

Preoutage Planning

The Operations Planning Group was formed and is comprised of several Senior Reactor Operator (SRO) qualified engineers and other Licensed Operators to plan the outage. This group develops, reviews, and uses "Work Windows" as tools to maintain safe configuration control to schedule work into the outage.

A pre-outage planning schedule requires the early identification of work and a work cutoff date. Late identified work must be accompanied by a "Late Work Identification and Justification" form that must be approved by management prior to being submitted to the Outage Manager for late work addition approval.

Outage specific training is prepared by the Outage Manager and presented to key personnel prior to the outage. This training emphasizes the importance of safety system availability, thermal margin for specified unit conditions, control of work, Defense In Depth, and other aspects of shutdown safety.

An Independent Review of the Outage Plan and schedule is conducted prior to the scheduled start of the outage. The group providing this review includes qualified personnel from the Duke Power General Office and two other plant sites, as well as onsite personnel. The same group provides daily observation of outage activities. A Post Outage Critique with primary focus on Shutdown Safety is also provided by this group.

A graphic illustration of Catawba's Defense In Depth (DID) is used to communicate Safety System availability. This is a three color form that is completed for planned unit conditions and Safety System availability as part of the independent pre-outage review. It is also prepared each shift or each time unit conditions change during the outage and is compared to the "as planned" unit conditions. This graphic form is used to communicate unit conditions and Safety System availability relative to thermal margin to management and outage personnel performing or directing work.

Work Orders are reviewed and the Plant Condition or Mode Change (PCMC) for which they are required to be completed for is entered into our Work Management System (WMS). Reports are generated from WMS prior to a condition or Mode change to assure that all requirements are met prior to entering the condition/Mode. These are menu driven reports available to all outage personnel that have a need.

Management Oversight of the Outage Plan is maintained. The Outage Plan is approved by site management prior to the start of the outage. A Management Oversight Meeting is held every morning of the outage to review and discuss near term activities. One focus area of this meeting is shutdown safety. This meeting is typically attended by the Site Vice President and his direct reports (Station Manager, Engineering Manager, etc.) and at times the Senior Vice President, Nuclear Generation. Daily outage meetings are also regularly attended by this level of management.

The ten year Reactor Vessel Inservice Inspection was performed during this outage (1EOC7). As a result, the refueling canal was required to be kept at 23 feet for a major portion of the No Mode period for shielding purposes. A "No Mode NC drained" period of 24 hours (critical path) was scheduled. Reactor Coolant pump seal work can only be performed with NC level less than 10%. The Reactor Coolant Pump seal inspection was scheduled for a period of 90 hours. This block of work was scheduled for the Reduced Inventory period following core reload (low decay heat). The Reduced Inventory period was scheduled for 136 hours to perform Reactor Vessel head work which created an available window for Reactor Coolant pump seal work. This decision was supported by a safety analysis showing that the seal area opening on the cold leg is small enough that it does not present a significant risk.

Availability of NC system level indication systems are maximized during outages. Per Operations procedures, prior to draining to less than 17% PZR cold cal level, two Wide Range (0-100%) level instruments are placed inservice. In addition, when NC level is below the Reactor Vessel flange two Mid Range (0-25%) level instruments are available. Prior to draining below 12%, either the NC system sightglass or tygon tubing is required to be inservice. If NC level is to be less than 7.25%, both trains of Ultrasonics level indication are required. When NC level is below the Reactor Vessel Flange, a minimum of two level indication systems are required. However, as described above, additional level indication is available and in use when possible.

Specific requirements listed in S.D. 3.1.30 for equipment/system availability during Low Decay Heat Reduced Inventory are as follows:

1) Two operable trains of ND and functional support trains

2) One operable Centrifugal Charging Pump and one functional Safety Injection Pump (the Safety Injection Pump is not required if the Reactor Coolant System is vented via a large vent path).

3) Two independent makeup paths of borated water

4) Two gravity flow paths and FWST level > 80% whenever the Reactor Coolant System is vented via a large vent path.

5) Two trains of containment sump recirculation

6) Containment Closure must be established (up to 10 exceptions are allowed including the personnel airlocks and the equipment hatch)

7) Two independent offsite power sources

8) Two emergency diesel generators

9) Two trains of DC channels and AC buses and inverters

10) Fire protection/detection equipment that is used for equipment required to be available during this period

11) Two independent differential pressure type NC level indications with backup battery power supplies

12) Access control for electrical power systems in the switchyard, transformer yard, Diesel Generator rooms, 4160V essential switchgear rooms, Vital Battery rooms, and 6900V switchgear room

2.5 Loss of Decay Heat Removal (DHR) and Reactor Coolant System Vent Path Engineering Analysis

2.5.1 NC System Geometry

Elevations are as follows, referenced to mean sea level and rounded to the nearest foot (except for key midloop levels).

- Elevation of reactor vessel top/bottom: 582'/530'
- Elevation of reactor vessel flange: 574'
- Elevation of pressurizer (PZR) top/bottom: 632'/581'
- Elevation of refueling water storage tank (FWST) top/bottom: 634'/594'
- Elevation (overflow) of the 3" alternate head vent: 603'
- Elevation (overflow) of the S/G manways (HL and CL): 569'-8"
- Elevation of NC loop (HL and CL) centerlines: 567'-2.5"
- Elevation of core top/bottom: Approximately 558'/546'
- PZR surge line connection to B loop HL at the loop centerline 567'-2.5" on the horizontal plane
- PZR surge line inner diameter: 11.5" with top i.d. at elevation 567'-8"
- ND suction lines connect to B and C HLs at 45 degrees below horizontal; the ND piping downstream has a high point at the containment penetration equal to the HLs centerline elevation.
- Minimum NC level elevation for full ND flow is 568'-2"; below which ND flow must be throttled, proportionally down to 1100 gpm at minimum NC level elevation of 567'-10"
- Intact NC system low temperature overpressure protection (LTOP) is provided by 2 PZR PORVs; open setpoint is 400 psig
- Per Tech Spec 3.4.9.3b, Alternate LTOP can be provided by an open vent of at least 4.5 square in. This is met by the new reactor vessel head vent installed at an abandoned upper head injection (UHI) head penetration, with double isolation valves specified as a minimum of 4.5 square in. open area.
- With the reactor vessel upper internals installed and reactor vessel head secured, a path from the top of the core to the cold leg exists; this path is via the upper internals to the upper head area and from the upper head to the cold legs via the "upper head cooling nozzles"
- When reactor coolant pump seal work is in progress, an opening in the cold leg is created of approximately 0.5 square in. per pump
- CNS S/G nozzle dams are rated for an operating pressure of 13 psig, hydrostatically tested to 20 psig, and have been analyzed to an ultimate pressure of 65 psig.

2.5.2 Vent Path Analysis

2.5.2.1 General

In order to support the maximum probability of a successful recovery of DHR, an adequate vent path must be maintained. The requirement for a large Hot Leg vent path is not applicable to all NC pressure boundary openings.

The existence of a possible pressure boundary failure (due to S/G nozzle dams or Incore Instrument Table Low Pressure Seals) as well as the core decay heat (high or low) form the basis for the adequacy of an atmospheric or a pressurized response to loss of DHR.

Vent paths are designed and analyzed in order to ensure:

- an acceptable core cooling configuration in the moments following a postulated loss of DHR event,
- a low enough peak pressure to prevent the failure of S/G nozzle dams or Incore Instrument seal table low pressure seals with margin for uncertainty,
- an acceptable short term core cooling flow path given the gravity flow capabilities or ECCS forced flow paths available at that stage of the outage,
- an acceptable long term core cooling flow path including the return of containment sump water via the containment sump recirculation structure.

It is preferable from a human factors standpoint to reduce the vent path choices to as few combinations as possible. These choices are factored into the Shutdown Risk Management program, and are listed and discussed below.

1. **When the NC pressure boundary is intact**, the PZR PORVs or an equivalent LTOP vent path is used. A detailed discussion of equivalent vent paths is presented in this report, but any of these vent paths is considered acceptable to preclude cold overpressurization at any time during Mode 5, Cold Shutdown, including the transitions into higher or lower operating modes. During these times the gravity flow option for recovery from a loss of DHR is limited and requires operator response prior to the initiation of core boiling to be viable. Procedures do list it as a means of short term core cooling and calculations have shown it is successful for certain combinations of NC pressure and Refueling Water Storage Tank (FWST) level. Due to our unique ND suction line layout (discussed in Section 2.5.3), as compared to other Westinghouse and Combustion Engineering Plants, there are certain advantages to closing the S/G nozzle dam vent path to allow flooding to a higher NC level

and NC system pressurization. These factors tend to reduce the distinctions in perceived risk between the S/G manway as compared to the 3" alternate vessel head vent path.

2. **When steam generator nozzle dams or any other low pressure device is to be imposed into the NC pressure boundary**, a S/G hot leg is vented through an open hot leg nozzle (no nozzle dam) and corresponding open hot leg or cold leg manway including its corresponding stainless steel diaphragm. Removal and replacement of the reactor vessel head must be coordinated with the placement of nozzle dams such that one S/G hot leg vent path is open at all times the head is in place. Maximum gravity flow potential exists in this configuration, but there is still a limit due to containment backpressure against FWST check valves.

3. **When any cold leg opening is to be made on the vessel side of the crossover loop seal and no S/G nozzle dams are present**, including when NC pump seal work is to be done (no nozzle dams), a S/G hot leg vent path must be available or vessel head must be removed if decay heat is high. Note that by analysis of the worst case pressurization that an open 3" vessel head vent is not adequate to preclude core uncovery and damage if nozzle dams are installed and fail, so for human factors considerations a 3" vessel head vent is never considered protection for Station Blackout, but rather is tied to the adequacy of the LTOP function only

4. **Following refueling when decay heat is low** (typically 40 days decay and approximately 1/3 the core replaced with new fuel), Engineering Studies support a different approach. When any cold leg opening is to be made on the vessel side of the crossover loop seal and no S/G nozzle dams are present, including when NC pump seal work is to be done (no nozzle dams), no S/G hot leg vent path is needed, the reactor vessel head does not need to be removed, and the 3" vessel head vent need not

be open if the PZR PORVs or another LTOP path is operable. For low decay heat and with the vent on the cold leg (not the S/G manway), the steam produced in the core following a loss of DHR will vent through the upper head cooling nozzles and exit the cold leg opening, and no core uncovery will occur. Excessive steam entering the hot leg will equalize pressures between the hot and cold legs via the S/G tubes, pressurizing the NC system to an equilibrium pressure to flow out the PZR PORV or any of the equivalent LTOP paths. If the operator initiates forced injection (ECCS) the same flow path(s) will exist with the added benefit that inventory losses will be made up. Pressure buildup in the combined NC and ND systems would be arrested by the occurrence of natural circulation if inventory is present in the S/G, or by automatic response of the PZR PORVs, if operable. Additional overpressure protection is provided by the ND suction relief valves, which open at 450 psig with flow capacity exceeding that of the PZR PORVs. Until pressurization occurs, gravity flow is possible to the same or a greater extent than described for the LTOP case in Section 2.5.2.1 item 1 (above).

2.5.2.2 Specific Vent Path Requirements During Reactor Coolant Pump Seal Work

The equivalent vent paths which are acceptable to preclude cold overpressurization during Mode 5 Cold Shutdown and Mode 6 Refueling are listed in the CNS Tech Spec Interpretation 3.4.9.3b.

1. Two OPERABLE PORVs with a lift setting of </= 450 psig are required for overpressure protection in the operable MODES with consideration of a single failure. If the emergency nitrogen supply of the PORVs is not available, the 4.5 sq. in. vent space requirement can be satisfied as described below.

2. The 4.5 sq.in. vent space can be met by use of the following vent paths whose open areas are shown:

a. Head vent path through NC298 and NC299 with the blind flange removed or the same head vent piping with the spool piece removed. (4.524 sq. in.)

b. Head vent path through the head vent valves (NC250A, NC251B, NC252B, NC253A), through NC223, NC224, and NC225, and open to the Pressurizer Relief Tank. The flow path must avoid orifice NCFE6330. Controlled distribution flow diagrams shall be used for actual alignments. (0.35 sq. in.)

c. NC Safety Valve- when removed. (21.10 sq. in.)

d. NC PORV- when removed. (5.40 sq. in.)

e. NC PORV- blocked open. (4.155 sq. in.)

If one PORV is to be blocked open in an attempt to meet the 4.5 sq. in. vent space requirement, additional vent area must be provided. Additionally, even though one open NC PORV vent path does not provide 4.5 sq. in. of vent space, Engineering calculations support the ability of one OPERABLE NC PORV to relieve the input of one centrifugal charging pump in the applicable MODES. The 4.5 sq. in. requirement came from the "Standard" Tech Specs and were not removed from this Specification even though calculations supported the ability of one OPERABLE NC PORV to provide adequate relief. Flow orifice NCFE6330 must be avoided since it has a 0.375" diameter opening and does not provide the required 0.35 sq. in. area needed for use with a blocked open NC PORV.

In the case of the NC pump seal work in progress from 12/12/93 to 12/14/93, the 3" reactor vessel vent was open for LTOP (cold over pressure protection) purposes, not to limit the pressure buildup following a postulated loss of DHR. This work was being performed after S/G nozzle dams were all removed and S/G manways bolted closed (following refueling when decay heat was low) and the discussion of vent paths in paragraph 2.5.2.1(4) applied.

2.5.3 Pressurizer Flooding and ND Suction Issues

This section will discuss the reason why the pressurizer vent paths are not considered acceptable as a large hot leg vent path to protect from nozzle dam failure.

At Catawba Nuclear Station, the pressurizer vent paths are acceptable for LTOP purposes, but are unacceptable as an atmospheric pressure steam release vent path to keep system pressure low enough to utilize gravity fill due to the pressurizer flooding issue. This issue, introduced by Westinghouse as a generic industry issue in 1989, involves the geometry of the pressurizer surge line and Residual Heat Removal (ND) suction connections to the NC hot legs. The ND suction lines at Catawba connect at a 45 degree angle below horizontal on hot legs B and C. These lines drop down a few feet to the ND suction isolation valves, then return to the same centerline elevation as the NC hot leg (refer to Enclosure 7.1). As a result of these two factors, and factoring in the expected instrument loop accuracies for both level and temperature, a relatively high level must be maintained to prevent loss of suction to the Residual Heat Removal pumps at normal ND flow rates (3300-3500 gpm) due to either air entrainment (vortexing) or flashing in the high point between the ND takeoff and the ND pump. Alternately, when it is necessary to drain to a lower level to perform S/G draindown or Vacuum Refill, ND flow must be throttled to reduce friction losses.

Detailed calculations performed by Engineering account for ND line entrance losses, friction losses and the potential to flash at the high point. The ND System Operating Procedure includes a chart showing the resulting NC level vs. ND flow rate which is required to prevent vortexing as well as flashing at the ND line high point. This relationship has been further verified to remain valid for Nitrogen overpressure, which may occur due to the slight pressure used to backfill with nitrogen during NC system draindown. It has also been verified for vacuum conditions down to the maximum allowable vacuum utilized during NC vacuum refill. Here the height required to preclude vortexing (air entrainment) remains valid but the ND pump flow rate must remain throttled until a higher NC level is attained due to NPSH requirements. This requirement, including instrument loop accuracy considerations, has been appropriately specified in the procedures.

The resulting NC hot leg level that is maintained during midloop operations including S/G work and NC vacuum refill is higher than the top inside diameter of the surge line, which has a horizontal connection to the B NC hot leg. Therefore there is never a clear vent path for air or steam (following loss of DHR) to the pressurizer. The mass addition of water in response to a loss of DHR event, as well as the thermal swelling of the NC inventory during the heatup in the absence of such mass addition result in raising the NC level. NC system pressure increases are predicted following a loss of DHR event due to the rapid liquid velocity of water up the pressurizer surge line, propelled by the expansion of the fluid in the core region to create steam; hence the term "pressurizer flooding".

The potential for pressurizer flooding can be minimized by procedure, but it is a natural result when forced injection or gravity flow is initiated following a loss of DHR event. The results of transient analyses using conservative assumptions at both high and low decay heat show pressures in excess of nozzle dam capabilities. Such pressures are acceptable if the NC pressure boundary is intact, or if the NC pump seals are the only opening and decay heat is low. Otherwise, the open reactor vessel head or S/G hot leg vent path provides the only defense against these pressures.

When no S/G nozzle dams are present, and all manway enclosures are bolted closed, pressurizer flooding is no longer an issue. The ability to fill the NC system to a higher level and pressurize the NC system to a higher pressure than is possible while using the S/G manway path achieves a benefit in higher inventory and more reliable natural circulation capability. The effects are complex, and due to the more straightforward nature of "fill and spill" out the S/G path they were not credited in the PRA evaluation presented in the Safety Evaluation Section.

At full ND flow of 3300-3500 gpm, there is a 3 psig head loss between the NC system and the ND line high point between the NC system and the ND pump. Therefore, assuming NC level is at saturation temperature, and at midloop with 0 psig overpressure, in order that the fluid not flash to vapor at the high point, either its level must be above the S/G manway overflow level (11%) or there must be an overpressure of at least 3 psig at 11% level. Alternately, the hot leg may be flooded with cool water from the FWST and ND flow throttled as directed in the loss of ND procedures. Operating with the 3" head vent open following the closure of the S/G manway accomplishes both a higher level capability and a higher pressure. The initiation of the NV or NI pump flow as proceduralized in the loss of ND procedures would fill the NC system to overflowing at the alternate vessel head vent 603' elevation and pressurize the system.

2.5.4 Forced Injection or Gravity Flow

Reduced flow rates are also required to reestablish ND flow at elevated NC temperatures such as those predicted to occur following the loss of

DHR. The Loss of ND Abnormal Procedure contains a chart of the required ND flow to reestablish ND pump suction as a result of two appropriate variables. One variable is NC temperature, assuming a constant NC level, such as would occur with an open S/G manway as the vent path. Since the S/G manway will overflow water at the level of 11%, it follows that no higher level can be reestablished. Consequently the hot leg temperature would result in flashing at the ND line high point due to friction losses exceeding the saturation pressure at the recovery temperature. Adequately subcooled conditions as specified in the procedure must therefore be reestablished in the hot leg prior to restarting an ND pump.

The second variable related to the reestablishment of ND following a loss of DHR is NC level. This is the case if the S/G manways are in place and the vessel head is removed or if an LTOP path is acting as the vent path. If this is the case, there is less of a restriction on the NC system filling to a higher level, even if atmospheric boiling is occurring. Calculations for this case conservatively assume 212 degrees F boiling. NC level to adequately support normal ND pump full flow suction conditions, as specified in the procedure, must be reestablished prior to restarting an ND pump.

Alternately, if suction conditions are not successfully reestablished in the hot leg, ND suction realignment to the sump recirculation structure is specified as the next recovery option. If this is the case, ND suction conditions are those as conservatively presented in FSAR Section 6.3 for post accident sump recirculation.

Two core cooling options are available following a loss of DHR event prior to the recovery of normal ND recirculation from the hot leg or from the containment sump recirculation structure. These options are prioritized based on whether there is a Station Blackout (Loss of all AC Power) or whether there are Emergency Diesel Generators and viable 4160 volt power paths available. The objective in the Loss of ND Abnormal Procedures is to ensure a coolable core geometry by covering and keeping the core covered with water as soon as possible. From this aspect, forced injection using the operable high pressure charging pump (NV system) is the preferred option. A backup charging pump is required available and an intermediate head safety injection pump (NI system) is kept operable (with its breaker disconnected for LTOP concerns) for high risk evolutions including all high decay heat conditions. During low decay heat conditions one charging pump and a safety injection pump are required to be available. In both cases above (high and low decay heat) the requirement for a safety injection pump is suspended if a large vent path has been established. Gravity flow core cooling options using the head provided by the Refueling Water Storage Tank (FWST) are also specified. Results from a gravity flow test in 1989 were input to a calculation performed by Engineering, and it was verified that adequate gravity flow could be maintained as long as the reactor vessel head (removed) or S/G hot leg vent path is open and containment pressure is below 10 psig. Operator update training is conducted on the Loss of ND Abnormal Procedure including the gravity flow options.

2.5.5 Reactor Coolant System Instrumentation

As a result of NUREG-0737 commitments, the reference legs of the NC System Wide Range and Mid Range Level instruments, as well as the reference leg of an additional high pressure sight glass were tied together at the top of the pressurizer in order to facilitate more accuracy and reliability in level readings. Although this resulted in improved agreement between NC level and pressurizer (cold calibrated) level readings, unexpected level transients continued to occur during the final draindown to midloop elevations. It was found that the draindown rate of the reactor vessel was being restricted by the small diameter and layout of the head vent line to the PZR Relief Tank (PRT), from which a nitrogen overpressure was supplied. When a RVLIS connection on the vessel head was opened, water being held up by this vacuum was released, resulting in sudden increases in (indicated) NC mid range and wide range instruments.

In order to relieve the local vacuum created in the upper head region during the draindown, the 3" alternate vessel head vent, described earlier, was added. However, with the advent of very accurate NC narrow range (ultrasonic) instrumentation, it was recognized that there was still not exact agreement between the readings of the mid range (0%-25% range) and the narrow range (0%-7.25% range) instruments. The pressurizer surge line comes off the side of the hot leg and the space above the water level in the hot leg and vessel is loop sealed from the space in the pressurizer at all times. (Due to ND line routing, it is not possible to expose the top I.D. of the surge line to equalize pressure, even with ND throttled, to avoid flashing/ cavitation in the ND suction high point between the NC system and the ND pump.) An error of approximately 1% (or 4" in level elevation) was attributable to this as well as evaporation in the reservoir, density changes along the length of the reference leg due to an uneven temperature distribution in containment, leakage and other maintenance and calibration problems with the wet legs.

During 1EOC7, a modification (CE-3862), was implemented to replace the wet reference legs with dry legs and to vent this dry leg to containment atmosphere during MODE 5 (Cold Shutdown) to further improve the reliability and accuracy of the NC mid range instruments when the NC system is open to the containment. The 10CFR50.59 review for this modification directly referenced a more complete 10CFR50.59 conducted earlier for the similar Unit 2 Temporary Station Modification (TSM) (92094773-01), which recognized the improvements in the error terms associated with the reference legs and considered the loss of DHR effects on such a configuration, given that the vessel head would be also be vented and at containment atmospheric pressure when it is in use. The improvement in accuracy was viewed as a benefit in avoiding the loss of ND due to level fluctuations and in responding to the (NC system level related) loss of ND procedure steps. However, the effects of the eventual pressurization of the NC system, following a loss of ND while vented through the 3" alternate head vent, specifically the effects on the dry reference leg while vented to containment, were not evaluated. Those potential effects are listed below, followed by a discussion of the benefits from such a pressurization which serve to offset the importance of the level instrumentation in the operator response to a postulated loss of DHR event.

- Postulating a loss of DHR and prior to core boiling with the vessel head removed or the S/G manway open, the improved accuracy and reliability of the new dry reference leg, vented to containment, would be realized.
- Postulating a loss of DHR and following the onset of core boiling with the vessel head removed or the S/G manway open, the improved accuracy and reliability of the new dry reference leg, vented to containment, would be realized.
- Postulating a loss of DHR and prior to core boiling with the NC system vented through the 3" alternate vent path the improved accuracy and reliability of the new dry reference leg, vented to containment, would be realized.
- Postulating a loss of DHR and the onset of core boiling, the pressurization of the vessel to approximately 40 psig (pressure postulated from either static fill of the pressurizer and the pressure at which steam flow chokes at the 3" vent), as would occur prior to the removal of the first S/G manway (before refueling) or following replacement of the last S/G manway (as was the case during the period of 12/12/93 at 0400 until the PZR PORVs were operable) the NC level reading (0"-400" scale) would be driven offscale high. (40 psig x 2.31 Ft/psi x 12 in./ft. = 1110"). However, similar effects are expected for the previous wet leg arrangement and the new dry leg arrangement while aligned to the pressurizer. This is expected because of the transient effects caused by the pressurizer flooding phenomena, which results in slugs of water being driven up the PZR surge line while steam is

pressurizing the hot leg area and subcooled water is not actually available to the ND pump suction. This dynamic effect results in the appearance of a higher level (higher head) in the hot leg than is actually there. The only difference in expected response of the reference leg arrangements is that eventually when the NC system pressurizes above saturation pressure, wet and dry reference legs aligned to the pressurizer may return on scale as the pressurizer is filling.

2.5.6 Industry Practices Inadequate for Use at Catawba

Engineering has studied the practices in use at other Westinghouse and Combustion Engineering nuclear stations. Three such practices evaluated and judged to be inadequate for use at Catawba are:

- The dependence on a pressurizer opening up to and including the 16" pressurizer manway to act as an atmospheric vent path to preclude S/G nozzle dam failure,
- The dependence on the lifting, or "burping" of the reactor vessel head to act as a means of precluding S/G nozzle dam failure,
- The dependence on openings in the reactor vessel upper internals to act as a vent path during high decay heat when all S/G nozzle dams are in place and the refueling cavity is raised to 23 feet.

The performance of both the pressurizer and vessel flange vent paths has been analyzed by Engineering and found to be unconservative and therefore suspect because their adequacy has not been proven through computer transient (dynamic) analysis. Our design studies have concluded that for the credible range of operator response following the postulated loss of DHR, including that of a lack of response or an incorrect response, as well as the desired response as proceduralized, the peak pressures reached may dislodge a S/G nozzle dam and lead to subsequent core uncovery and damage. One discovery from the transient analysis results was that the failure of a hot leg nozzle dam or manway diaphragm can result in a more severe (greater fraction of) core uncovery than the failure of a cold leg nozzle dam or manway diaphragm. This result is reasonable due to the additional backpressure imposed on the steam exiting the core through the S/G tubes for the cold leg case.

The use of the RV Flange path brings up more complications in the Loss of ND Abnormal Procedure response. It becomes necessary to throttle the injection or gravity flow to preclude subsequent additional pressure increase leading to nozzle dam failure. Use of the larger S/G manway as a vent does not present this problem. While such an analysis may qualify Catawba to place the vessel head prior to the completion of S/G activities including the removal of any nozzle dams, this does not translate into a clear benefit over leaving the last S/G hot leg manway open as a vent path. The flange vent has been recommended for use only after refueling, when the decay heat is low. While the larger internals areas at Catawba may provide more favorable results at decay heat time as short as 5 days, there would be very little margin in our S/G nozzle dams, currently rated for 13 psig operating pressure, 20 psig hydrotest with 0 gpm leakage, and an ultimate pressure capability of 65 psig, analysis.

Catawba Engineering and Nuclear Safety Analysis feel there is a great deal of analytical uncertainty as to whether steam or water will be vented if the RV Flange vent is being used. There is no way to procedurally assure the water level considering the timing of operator response following the loss of ND. Excessive ND flow is not that unlikely, considering the manual gravity flow pathways and lack of a means of positive control over the head and flow when these are utilized. Even with the pressurizer safety valves removed, the S/G nozzle dams will see the pressure increase due to pressurizer flooding given a surge line layout off the side (Catawba layout) or off the top of the hot leg (a common layout at other utilities). The dynamic pressure across the surge line may be more complicated at Catawba due to the side-entry surge line.

Examining the issue of core cooling following loss of DHR with the upper internals in place best estimate analysis indicates that adequate vent area may exist to preclude core uncovery and damage following a loss of DHR during both high and low decay heat modes. However, there is insufficient conservatism in the high decay heat case considering the potentially serious consequences. The low decay heat case does contain sufficient conservatism and industry literature (NUREG/CR-5820) supports successful core cooling with 23 feet of water in the refueling cavity with upper internals in place following refueling (typically 40 days decay and approximately 1/3 of the core replaced with new fuel).

2.6 Operator Response to Loss of Residual Heat Removal System (ND)

In the event of a loss of Residual He Removal the Control Room Operators would take actions as described in pr dure AP/1/A/5500/19, Loss of Residual Heat Removal System. This proce covers loss of an ND Train With NC Pressure Boundary Intact, Leak In an D System, and Loss of an ND Train With the NC System Open to Containment.

Below is a summary of actions the Operators would take in the event of a Loss of ND.

1. Stop any malfunctioning pump

2. Secure Vacuum operation if in progress, and vent ND pump(s)

3. If loss of ND is due to fire damage, initiate action to repair cables needed for recovery

4. Restore NC Level to ensure adequate suction for ND pumps via Refueling Water Storage Tank (FWST) and Charging Pump (NV)

5. Ensure adequate support system operation for ND (Component Cooling Water and Nuclear Service Water)

6. Attempt to place other train of ND in service, if available

7. If NC system is intact:
   a) Establish heat removal using S/G if available
   b) If S/G not available:
      - Initiate Containment Closure
      - Evacuate Containment
   c) Establish Feed and Bleed of the NC system by any or all of the following to maintain Core Exit T/Cs less than 200 degrees F
      - FWST via NV Pumps/Cold Leg Injection flow path
      - FWST via NI Pumps/Cold Leg Injection flow path
      - NC PORVs would be opened to establish the Bleed path

   If NC system is open to Containment:
   a) Initiate Containment Closure and Evacuate Containment
   b) Ensure core is covered by either:
      - FWST via NV Pumps/Normal charging line
        OR
      - FWST via other forced injection flow path, i.e. NV Pump(s) injection flow path, NI Pump(s) injection flow path
        OR
      - FWST via large assured gravity flow path, ND Hot or Cold Leg injection path

   Level would be maintained at or above NC system overflow level

8. Flow would be controlled to maintain temperature stable below 190 degrees F

The procedure provides curves to alert the operator to time to core boiling and core uncovery. There is also a curve of required flow rate to match decay heat versus time after shutdown. The actions required by this procedure are not complicated and most are performed from the Control Room.

2.7 Residual Heat Removal Pump IWP Requirements

PT/1/A/4200/10A, Residual Heat Removal Pump 1A Performance Test, is the procedure used to satisfy the requirements of ASME Section XI, Subsection IWP/IWV of the ASME Boiler and Pressure Vessel Code with regard to the measurement of pump flow, differential pressure, bearing temperature and vibration, and various check valve strokes for pumps and valves within the ND system. This procedure was revised on October 12, 1992 to make changes concerning vibration instrumentation, units of measure, and vibration points recorded per Relief Request, Docket Numbers 50-413 and 50-414. This change allowed the use of velocity vibration monitoring. Previous testing used displacement readings on the lower bearing for IWP. Since IWP does not specify acceptance criteria for this type of monitoring, the acceptance criteria tables from OM-6 were incorporated into the IWP procedures. The basis for the Relief Request is that experience had shown that measuring vibration as required by IWP is not the most effective way to determine the mechanical condition of a pump. In order to better determine the mechanical condition of pumps, multiple vibration velocity measurements should be obtained/evaluated and supplemented, when necessary, with acceleration/displacement measurements and spectral analysis. In order to facilitate this testing, digital vibration instrumentation is used. IWP does not provide guidance/requirements for performing velocity vibration testing. In lieu of the vibration requirements of IWP-3100 and IWP-3300, peak vibration velocity is measured. In most cases, vibration velocity gives the best indication of pump mechanical condition. In lieu of the vibration ranges specified in ASME Section XI IWP, the following ranges were incorporated from OM-6 into the IWP program.

Acceptable Range	:	Vibration is less than or equal to $2.5V_r$
Alert Range	:	Vibration is greater than $2.5V_r$ but less than or equal to $6V_r$; OR greater than 0.325 inches per second (ips) but less than or equal to 0.700 ips.
Required Action Range	:	Vibration is greater than $6V_r$ or 0.700 ips.

The vibration acceptance criteria specified in the IWP test procedure for ND pump 1A is as follows:

Acceptable Range	:	Vibration is less than or equal to 0.325 ips. No action is necessary; pump is operable.

Alert Range	:	Vibration is greater than 0.325 ips but less than or equal to 0.700 ips. Pump is operable but test frequency is increased until the cause of the deviation is determined and corrected.
Required Action Range	:	Vibration is greater than 0.700 ips. Pump is inoperable.

The corrective actions listed above for the Alert and Required Action Ranges are as specified in the IWP program. In the Alert Range, the IWP program states that correction shall be either replacement or repair, or shall be an analysis to demonstrate that the condition does not impair pump operability and that the pump will still fulfill its function. A new set of reference values shall be established after such analysis.

The IWP test procedure is performed quarterly. Vibration data is obtained with the pump running in the miniflow condition. Miniflow was chosen because this is the only condition possible to run the pump during plant operation.

2.8 Lead Shielding Program

Catawba Site Directive 3.8.12, Installation of Temporary Shielding and Scaffolding, was developed to prevent unreviewed safety questions concerning the seismic validity of safety related equipment due to the installation of temporary shielding or scaffolding. The process for installing and removing temporary shielding is as follows:

1. Radiation Protection (RP) identifies shielding needs and initiates a work order for installation.

2. RP completes Section A of shielding request form and attaches to work order.

3. Work order is forwarded to Civil Engineering (CIV) for evaluation.

4. CIV contacts Operations (OPS) for operability requirements.

5. CIV performs calculations as required and completes Section B of shielding request indicating if travel stops are required for spring hangers, how much lead is allowed to be installed, if the system is operable, and any additional requirements.

6. CIV logs request in logbook and forwards work order to the Work Control Planning Group to be reviewed by OPS representatives for scheduling and PCMC determinations.

7. Work order is reviewed by OPS SRO.

8. Shielding is installed.

9. Upon removal of shielding, OPS and CIV are contacted.

10. CIV signs removal in logbook.

2.9 Residual Heat Removal Motor Rebuild Description

Work on motor for replacement of ND pump 1A was begun in June of 93. This motor was previously in the 2B location. The motor was disassembled and inspected. In the disassembly of the motor, the upper bearing assembly was inspected before removal. This inspection included measuring the depth of installation of the upper bearing assembly locking nut with T-square. This measurement was saved and the position of the nut was match marked. The rotor was moved from the work area in the Auxiliary Building to the hot machine shop. The lower bearing housing and the bearings were removed and the rotor was placed in v-blocks to assure the shaft was straight. The shaft was found to be straight within .002". The upper bearing runner and the upper shaft were measured for proper clearance and the runner was found to be out of tolerance. This indicated a loose fit of the upper bearing runner which could be caused by previously improper installation of the upper bearing nut. A new upper bearing runner was located.

The rotor was then moved to the Outside Maintenance Facility (OMF) where the rotor was balanced. The rotor with the pump impeller was balanced as an assembly. The rotor was returned to the work area for assembly. The lower bearings and bearing housing were installed. The bearing housing was a new one from the warehouse and the oil drain hole (that is not used by Westinghouse) was plugged. The rotor was then installed in the stator. The upper shaft and bearing runner were measured again for proper fit and were found to be within tolerance and were assembled. At this time the Total Indicated Runout (TIR) of the shaft was checked and found to be approximately .04" (limit of .002"). The upthrust was also checked and found out of tolerance. The rotor was removed and the lower bearing locking nut was tightened. The rotor was installed and the TIR had been reduced. The upthrust was checked and found to be within the limit of .002" but the TIR on the shaft was still slightly out.

In this same evolution the upper nut was checked to assure it was installed tight in the upper bearing assembly. Problems with the upper bearing nut shaft threads were encountered. The threads were cleaned up to the point that a new nut would easily go onto the shaft. The use of the new nut and a new bearing runner made the match marks and measurements made earlier of less value or non-existent. The thermocouples and stator were then electrically tested and found acceptable.

Westinghouse was contacted about the high runouts on the Shaft TIR. Westinghouse advised the crew to mark the high spots on the shaft and strike the shaft with a raw hide hammer on the high spot to relieve surface stresses in the shaft. This was done and all TIRs came into the required limits. Assembly was completed and motor was turned over to Mechanical Maintenance for pump installation.

2.10 Description of Vibration Measurements Taken on ND Pump 1A

Vibration measurements obtained by Mechanical Maintenance Vibration Crew and by Component Engineering Vibration Engineer were taken at six points on the motor.

[V3] - at elevation of lower motor bearing - parallel to discharge (for this pump: North - South direction)

[H3] - at elevation of lower motor bearing - perpendicular to discharge (East - West direction)

[A3] - at elevation of lower motor bearing - in the axial direction (vertical)

Physically these measurements are on prepared magnetic mounts (ferritic stainless steel disks) epoxied on the upper flange of the motor support. The motor lower end bell bolts directly to this flange.

[V4] - at the elevation of upper motor bearing - (North - South)

[H4] - at the elevation of upper motor bearing - (East - West)

[A4] - at the elevation of upper motor bearing - (axial)

Physically, as with the lower measurements, magnetic disks are used. The disks are epoxied to the "hard" case of the motor where the upper end bell is mounted.

Both upper and lower locations respond rigidly with gross motor motion well above running speed. Additionally, we had been successful in identifying Bearing Defect Frequencies on the 2A pump at the beginning of the Spring '93 outage (just prior to replacing that assembly). Historical records also show successful identification of a lower bearing defect on the 1B pump in 1988, by a sum and difference frequency (an indication in the spectra was identified as the Ball Pass Frequency on the Inner race minus Running Speed; roughly: (255 hz - 30 hz) = 225 hz).

Each measurement involves collection of:

- overall velocity value - 2 hz. to 1000 hz. bandwidth, scaled as 0-peak, derived from RMS (root-mean-square) processing in that bandwidth.

- five frequency bands

- one acceleration band including data from 1000 hz to 20000 hz

- a 400 line spectra from 0 - 1000 hz.

Additionally, each "gathering" of data includes logging the Pump Suction and Pump Discharge pressures from local gauges, and recording both bearing temperatures and flow value, available via the Operator Aid Computer.

The data logger has the functionality of a single channel spectrum analyzer. During some of the data collection additional data was collected. This included acceleration spectra and spectra with different bandwidth and with increased resolution (more lines, or values over the given frequency band). Also the number of averages was increased for some of the acceleration measurements to allow for a characterization of information in the noise floor. We have a preprocessor/demodulator attachment to the data collector. This was used during collection of some of the data and on taped data playback. The use of the demodulator has proved to be an effective tool for identifying first indications of rotating defects. It looks at high frequency data and determines essentially, at what rate or frequency is the high frequency energy occurring, or restated, what lower frequencies are modulating the high frequency carriers.

On 12/2 and on 12/8 (hammer test) and on 12/14 (with proximity probes and optical phase reference) data was tape recorded on a DAT format, 8 channel recorder. The same style accelerometers as are used in the monitoring program and as are used in IWP tests were used when tape recording.

The hammer testing referred to includes response from these accelerometers and a force signal from the instrumented excitation hammer. In this testing the ratio of the output response (typically acceleration) to input force (a short duration spike) is developed as a function of frequency by two channel Fourier Transform techniques. These output/input functions are measured for combinations of degrees of freedom (measurement points on the structure) sufficient to map out the relative shape of the response of the structure in the various dynamic modes captured.

Throughout the narrative, for brevity, overall velocity values are referred to for points [V4] and [H4] only. The magnitude of these measurements sufficiently describes the response of the pump/motor structure at its most sensitive or responsive location.

3.0 TIME LINE

The following section provides a chronological sequence of activities related to the ND pump 1A vibration problem and subsequent inoperability.

Note: The following vibration values are in velocity (inches/sec). Data was taken primarily at six points; however, the two points at the most responsive location (upper motor bearing) will be used. Both points are in the horizontal plane; V4 is in the north-south direction; H4 is in the east-west direction. For a detailed description of all vibration points monitored, see Section 2.10.

11/13/93 SAT — 0200 — Residual Heat Removal (ND) Train A entered into Technical Specification Action Item Log (TSAIL) to begin planned work per the original outage schedule
- Refueling Canal level at 23 feet
- Plant in No Mode (Defueled)

11/24/93 WED — Lead blankets and spring hanger stops placed on ND piping prior to ND pump 1A replacement for exposure control

11/30/93 TUE — 1820 — Replacement work complete on ND pump
- ND pump run for first time

Vibration data taken:

Time	**1820**
Flow (gpm)	**500 (miniflow)**
V4	**0.296**
H4	**0.353**

12/01/93 WED — 0800 — Pump running during ECCS Flow Balance testing

Vibration data taken:

Time	**0800**
Flow	**Varying**
V4	**0.596**
H4	**0.596**

Vibration Engineer (Vib Eng) concluded:
- Vibration was higher than expected (expected to be less than 0.2)
- Additional testing planned

12/02/93 THU	0030	ND pump 1A IWP test performed

Vibration data taken:

Time	**0030**
Flow (gpm)	**500**
V4	**0.423**
H4	**0.388**

Vibration is in the IWP program Alert Range (0.325-0.7)

0130 ND pump run for additional vibration data

Vibration data taken:

Time	**0130**	**0145**	**0155**	**0205**	**0230**	**0245**
Flow (gpm)	**500**	**960**	**1588**	**2100**	**2500**	**3450**
V4	**0.496**	**0.480**	**0.539**	**0.593**	**0.583**	**0.611**
H4	**0.545**	**0.561**	**0.547**	**0.512**	**0.634**	**0.692**

Vib Eng concluded:
- Data stable at 3450 gpm
- No Bearing Defect Frequencies (BDF) were found for any flow rate
- Vibration increased with flow

PM Vib Eng discussed data with IWP System Engineer. Noted that results at IWP flow (miniflow) were not approaching the 0.7 IWP program limit.

Discussed data with Component Engineering (CE) Manager. Vib Eng and CE Manager conclude pump is reliable/operable. Decision made to contact vendor (Ingersoll-Dresser) for review of data.

12/05/93 SUN 1622 Entered Mode 6, Refueling

- Refueling Canal level at 23 feet
- Equipment available per Shutdown Risk Management program (exceeds Tech Spec requirements):
  1 D/G, 2 offsite power supplies, 1 ND Train, 1 Charging pump (NV Train)
- ND Train B operable; ND Train A remains in TSAIL for outage work but is available for operation

12/06/93 MON PM Meeting was held to discuss status of the ND pump
- Meeting attended by System Engineering (SE) Manager, Component Engineers (CE), Vib Eng, IWP System Engineer, and Operations (OPS) Staff Engineers

- Discussed IWP Code and applicability of 0.7 IWP program limit at other than IWP flow (miniflow); Vib Eng left meeting with the understanding that the 0.7 limit applied only at IWP flow (miniflow) and was subject to Engineering evaluation at other flows
- Evaluations by Vib Eng, Pump Eng and IWP System Eng concluded that pump was capable of meeting all requirements for operability. SE Manager prompted discussion of long term reliability of pump which led to decision to take additional vibration data to demonstrate repeatability.

12/07/93 TUE — AM **Vibration data taken:**

Time	**1000**	**1040**	**1300**	**1345**
Flow (gpm)	**500**	**500**	**3300**	**3300**
V4	**0.389**	**0.420**	**0.443**	**0.523**
H4	**0.389**	**0.360**	**0.343**	**0.606**

Vib Eng concluded:
- No Bearing Defects Frequencies observed
- No other observations in data review different from previous runs
- Pump sounded smooth at higher flows; audible bearing noise consistent with other pumps with acceptable vibration
- Pump considered reliable

PM — Vib Eng conducted additional review of data that was tape recorded during the 12/2/93, 0130 pump run
- Review indicated a resonance type response indicative of a system/structure response, which is not specific to the motor installed
- Station Vib Eng discussed data with Duke Power (DPC) Generation Services (GSD) Vibration Engineer. His experiences indicate that similar vertical pumps have operated in resonance condition for long periods of time
- Station Vib Eng discussed data with DPC Nuclear Services Vib Eng. Possibility of insufficient venting suggested, however, pump running smoothly at high flows contradicted this

12/8/93 WED — AM Hammer test performed on pump for additional system/structure response information to assist in diagnosis
- Results compared to hammer test performed on 1/7/93 (different motor but same location)
- Lead blankets noticed on suction piping; action initiated to remove

Vib Eng concluded:
- Resonance is a factor
- Results similar to previous hammer test
- Increase in east-west (H4) mobility at running speed noted

1300 Response received from Ingersoll-Dresser; continued operation not endorsed due to specific concern stated with mechanical failure of bearings and seal

Vib Eng concluded:
- Based on AM hammer test information, load analysis of bearings is well below dynamic load ratings indicating that mechanical failure of bearings not likely
- No evidence of rub which would indicate a seal problem
- No indicators of distress present in data review or observations
- Historical performance of Unit 2 pumps under previous IWP requirements indicated that this level of running speed vibration could be sustained without degraded pump performance

1400 Meeting held to discuss status of ND pump
- Meeting attended by SE, CE, OPS Staff Eng, Mechanical Maintenance, Radiation Protection, Work Control personnel
- Vendor response shared with attendees
- Pump was considered operable based on evaluations by Vib Eng, Pump Eng, and IWP System Eng
- Decision made to replace pump after ESF testing (available window prior to Mode 4) to eliminate need for monthly testing
- Action initiated to have Civil Engineering start efforts for restraint design in the event that the replacement motor exhibits resonant vibration

PM Lead shielding removed

12/9/93 THU 0550 Upper Internals installed (ND Train B operable per Tech Specs; ND Train A available as required per Shutdown Risk Management program)
- Refueling canal level at 23 ft.

1500 ND pump 1A declared operable and removed from TSAIL
- All outage work request paperwork completed on ND pump

PM Westinghouse rep contacted, vibration data discussed
- Rep indicated that other utilities have run these pumps with similar vibration levels. No immediate concern expressed.
- Rep suggested obtaining proximity probe data targeting the shaft above the seal
- Vib Eng initiates action to contract Westinghouse to assist in diagnosis of vibration problem

12/10/93 FRI	1215	**Vibration data taken:** **Time 1215 1245** **Flow (gpm) 3300 3300** **V4 0.422 0.439** **H4 0.267 0.261** Vib Eng concluded: - Removal of lead blankets may have been cause of improved vibration data due to resonance response. - Pump is operable
	1353	Refueling Canal draindown started; canal level less than 23 feet. This condition requires 2 operable ND pumps per Tech Specs
	1744	Draindown secured at Reactor Coolant (NC) System level of 23% (just below Vessel flange) - Equipment available per Shutdown Risk Management program: 2 D/Gs, 2 offsite power supplies, 2 ND Trains, 1 NV train, 2 gravity flow paths. An additional Safety Injection (NI) Train was available but not required - S/Gs A,C,D secondary side filled
12/11/93 SAT	0315	NC drained to 8.5% (two inches above top of Hot Leg piping)
	0445	S/G 1B Hot Leg nozzle dam removed for NC system vent path
	0548	Reactor Vessel Head set in place
	0700	NC pump 1A and 1D seal work started
	AM	Vib Eng discussed improved 12/10 data with Component Engineering Manager; subsequent discussions with IWP System Eng concludes that additional testing desired to demonstrate repeatability.
12/12/93 SUN	0400	S/G 1B primary manway installed; all manways in place
	1300	**Vibration data taken:** **Time 1300 1330** **Flow (gpm) 3300 3300** **V4 0.626 0.607** **H4 0.785 0.785** Additional data taken in the Bearing Defect Frequency range.

		Vib Eng concludes pump is operable due to: - Loading through bearings is significantly less than the dynamic load rating for bearings - No change in Bearing Defect Frequencies - There are no frequency indicators of a rub - Understanding that 0.7 IWP program limit does not apply at 3300 gpm - Confidence that pump would be within 0.7 IWP program limit at IWP flow (miniflow) - System/structure resonance remains a factor
	PM	Vib Eng, SE Supervisor, and NRC Resident discuss latest test results. Items discussed include: - Vibration readings that exceed 0.7 were not at IWP flow (miniflow) - Confidence that vibration at IWP flow would be less than 0.7
	PM	Vib Eng established testing frequency twice per day starting the following morning
12/13/93 MON	AM	Vib Eng discussed 12/12 data with the CE Manager. The Westinghouse contact on 12/9 was also discussed; decision made to pursue getting the Westinghouse rep onsite.

Vibration data taken:

Time	**0730**	**0800**
Flow (gpm)	**3300**	**3300**
V4	**0.646**	**0.642**
H4	**0.817**	**0.857**

Vib Eng concluded:
- Vibration increase noted (at running speed only)
- Data review results unchanged regarding evidence of distress
- Vibration levels remain in range that Unit 2 pumps had run
- Pump is operable

1323	Unit 1 entered Mode 5, Cold Shutdown (NC level remains at 8.5%)
PM	Spring hanger stops removed
1530	**Vibration data taken:**

Time	**1530**
Flow (gpm)	**3300**
V4	**0.643**
H4	**0.834**

Vib Eng concluded:
- Data is essentially unchanged
- No evidence of distress in data review
- Magnitude remains dominated by running speed response

12/14/93 TUE 0900 **Vibration data taken:**

Time	**0900**
Flow (gpm)	**3300**
V4	**0.676**
H4	**0.927**

AM Vib Eng informed SE Manager, CE Manager, IWP System Eng, and SE Supervisor of the latest data results; meeting scheduled to discuss pump status

12/14/93 TUE 1230 Meeting was held to discuss latest data. Attendance included the Station Manager, Engineering Manager, SE Manager, CE Manager, OPS Superintendent, Vib Eng, and IWP System Eng. The conclusion reached was that the pump should be declared inoperable. The basis for this conclusion was:
- Definite upward trend exists
- Decision made to declare pump inoperable due to excessive vibration

1330 **Vibration data taken:**

Time	**1330**
Flow (gpm)	**3300**
V4	**0.692**
H4	**0.986**

1400 ND pump 1A declared inoperable and entered in TSAIL by OPS

PM Meetings held to determine proper course of action. The following options were discussed:
1) remain at Reduced Inventory and repair pump
2) proceed with NC system atmospheric Fill and Vent in parallel with ND pump repair
3) perform NC vacuum Fill and Vent in parallel with ND pump repair
4) return to midloop to establish large vent path via S/G manway

Conclusion reached:
- Perform NC atmospheric Fill and Vent in parallel with ND pump repair
- Remove pump from service but keep it available (i.e. not tagged out) until replacement pump ready for swapout
- Continue to take data to assist in diagnosis of problem

- Immediate action initiated to prepare for repair of spare ND pump to comply with Tech Specs
- Station Manager, Engineering Manager, and OPS Superintendent discuss recovery plan and Tech Spec compliance with NRC Resident

1530 **Vibration data taken:**

Time	**1530**
Flow (gpm)	**3300**
V4	**0.697**
H4	**1.049**

1900 Work in progress to repair spare for ND pump 1A

12/15/93 WED 0800 NC pump 1D seal is water tight

0900 ND pump 1A tagged and ready for replacement

1700 NC pump 1A seal is water tight

1905 NC system atmospheric Fill and Vent in progress; NC level at 26% (Reduced Inventory exited) and increasing

12/16/93 THU 0600 NC level at 85% (near top of Pressurizer)

12/17/93 FRI 0347 NC system filled and vented; S/Gs available for heat removal
- loops filled condition met; only one ND Train required per Tech Specs
- exited Tech Spec Action for loss of ND pump

0600 ND pump 1A replacement complete; pump filled and vented

1400 ND pump 1A IWP post-maintenance testing performed

Vibration data taken:

Time	**1400**
Flow (gpm)	**500 (miniflow)**
V4	**0.288**
H4	**0.175**

- Bearing Stabilization completed

1530 Additional vibration testing on ND pump 1A

Vibration data taken:

Time	**1530**	**1550**	**1605**	**1750**
Flow (gpm)	**3200**	**3900**	**2000**	**4000**
V4	**0.308**	**0.324**	**0.355**	**0.412**
H4	**0.211**	**0.156**	**0.219**	**0.193**

1800 All post-maintenance testing on ND pump 1A complete
- Head curve and flow verification performed

12/18/93 SAT 1610 ND pump 1A declared operable and removed from TSAIL

4.0 CONCLUSION

Risk Conclusion

The relative risk of core damage during this period of inoperability did not significantly increase. The core damage frequency during this period with two operable ND pumps is estimated to be 8E-09, and increases to an estimate of 4E-08 with only one ND pump operable. The Shutdown Risk Management program requires safety equipment available beyond that required by Technical Specifications. Two Trains of NV, two Trains of NI, and an operable ND Train (1B) were available, any one of which is capable of removing core decay heat. There was no interruption of core cooling, all Technical Specification Action requirements were met, and the health and safety of the public were not affected.

Vibration Analysis Conclusions

The technical analyses made by the Vib Eng were reviewed. Also, an independent review of the vibration data was performed by another qualified Vibration Engineer. The vibration analysis techniques were determined to be sound and appropriate. Analysis of the data for this period did not show any indications of imminent pump failure. This was confirmed by the independent data review.

The vibration analysis by the Vib Eng from 11/30 until 12/14 determined that the pump exhibited no indicators of pump distress and remained operable and reliable. The basis of his determinations were:

1. Vibration levels remained essentially constant from 11/30 to 12/13.
2. Pump was run as much as possible to demonstrate continued reliability.
3. No Bearing Defect Frequencies indicated.
4. With configuration of the pump/motor being a vertical cantilever arrangement unrestrained at the top, higher vibration is expected at the top location. The magnitude of vibration seen was not excessive, given this arrangement.
5. Resonance of the system/structure results in amplification of the vibration. The force transmitted from the shaft to the housing is significantly less to produce a higher level of vibration of a pump in resonance.
6. Previous history of Unit 2 pumps support that operating at similar magnitudes can be sustained without degraded pump performance.
7. Discussions with other DPC vibration personnel indicated that similar pumps can operate reliably in resonant condition in this range of magnitudes.
8. Discussion with Westinghouse indicated other utilities have successfully run at similar vibration levels.

9. Flexibility to use Engineering judgment to determine pump operability and reliability at flows outside of IWP test conditions.
10. Bearing temperatures remained normal.
11. Pump sounded smooth, similar to other pumps with normal vibration.
12. Bearing loads were well below dynamic load rating for the bearings.

The 12/14 data indicated to the Vib Eng that an unacceptable trend existed and that the pump should be declared inoperable.

An independent review of the vibration data from 11/30/93 to 12/14/93 was performed. The review was performed by a vibration engineer in the DPC Generation Services Department. This independent review concluded that the mechanical condition of the pump, prior to 12/14/93 was acceptable for continued operation, even though vibration levels had trended up overall. This review confirmed the conclusions by the Station Vib Eng.

Motor Vibration Analysis

The cause of the excessive ND pump 1A motor vibration was a loose upper bearing runner, apparently due to improper installation.

The nut was installed with a wrench as tight as could be achieved and then further tightened using a punch and a hammer. Westinghouse has fabricated an upper bearing assembly press to ease the installation of the nut and to help assure its proper installation. There is no mention in the Technical Manual of the use of this tool and Catawba engineers were not aware of this practice until the motor was taken to Westinghouse for evaluation. An unloaded run of the motor before installation in the plant would have shown the excessive vibration and would have required correction before use. The station is completing installation of a motor test stand to allow pre-installation testing of this type motor assembly.

Corrective actions to assure the upper bearing runner is tight and correctly assembled and vibration detected prior to installation, are:

- A press similar to the one used by Westinghouse has been obtained for use in future rebuilds.
- Improved methods for taking measurements with the rotor in the disassembled state will assure the upper bearing runner is installed properly. The procedure will be modified to ensure these measurements are used in the reassembly section of the procedure.
- A motor test stand will be completed to allow pre-installation testing of this type motor assembly.

Additionally, to inform the industry of this potential problem, a Nuclear Network message will be issued.

Current ND Pump 1A Status

The currently installed ND pump 1A configuration was last disassembled in 1983. It has been in service since that time with satisfactory performance indicators. The current configuration exhibits some amplifications of vibration due to system/structure resonance. The magnitude of vibration is satisfactory and the pump is reliable and operable. Options are being evaluated to determine if improvements can be accomplished to reduce the system/structure resonance.

IWP/OM-6 Requirements/Applicability

Catawba was recently granted a Relief Request for IWP program testing to allow the use of velocity vibration monitoring rather than displacement vibration monitoring as specified in IWP. As a result, OM-6 vibration acceptance criteria are used while ASME Section XI IWP paragraph requirements are used. Upon review, it is evident that there was not a consistent understanding of which requirements from each document (IWP/OM-6) apply when vibration monitoring is performed. Throughout this period, it was generally thought that the 0.7 limit in the IWP test procedure applied only at IWP flow (miniflow) and that vibration results above the limits at higher flows were subject to Engineering evaluation. The IWP Code allows Engineering evaluation when vibration results are in the Required Action range; OM-6 does not. The following corrective actions will ensure a consistent understanding of the IWP program requirements:

- Define the IWP program vibration monitoring requirements and include in Site Directive 3.1.14, Operability Determination
- Review the hard limits of the IWP program with appropriate personnel involved with rotating equipment, including management
- Revise Position Specific Training Guidelines to include specific IWP program training to personnel involved with rotating equipment (this will ensure that future personnel in these positions are aware of requirements)

Operability Process

From 11/30 to 12/14 evaluations were being made each time data was taken to determine if ND pump 1A was operable/reliable.

On 12/12 vibration results exceeded the 0.7 IWP program limit for the first time. At this point, the Vib Eng concluded the pump was operable due to the technical reasons listed earlier and his understanding that the 0.7 limit was not a hard limit for higher flows.

The formal operability process was not properly entered upon exceeding the .7 IWP program limit on 12/12. This process would have ensured formal management involvement in this decision making process and ensured interface with Operations.

The vibration data collected by the Vib Eng was included in his vibration oversight responsibilities and was not required by a formal program. Data was taken on 10 occasions between 11/30 and 12/14. The practice of collecting data not formally required, without having a trigger to enter the formal operability process, could delay or prevent initiation of the operability process. A review will be conducted to determine the appropriate process to use when collecting informal data.

The operability process and related management expectations have been reviewed with Component and System Engineers. For long term corrective action, the following items concerning operability determinations will be incorporated into continuing training for Engineering personnel:

- the proper use of the operability process
- when to enter and proceed through the operability process

Benefits of using the process:

- ensures appropriate management involvement
- ensures involvement of Operations management

Management Involvement

Throughout this time period, management was pursuing resolution of the ND pump vibration and was involved in the decision making process, focusing on the technical operability and reliability of the pump. The decision to defer pump replacement was based on the current operability of the pump and the data not showing any predication of imminent pump failure. A decision to replace the pump during the early portion of this review, when a window existed to replace the pump, would have provided additional assurance consistent with a conservative approach to operation and therefore would have been a better alternative than continued evaluation. The need to consider plant conditions and associated risk when evaluating degraded components/systems will be emphasized to management and engineers. In addition, a management signoff will be required prior to Reduced Inventory to ensure an overview of the status of key components/systems.

Lead Shielding Process

During the hammer test performed on 12/8, the technicians and Vib Eng noted that lead blankets were installed on the suction piping of the pump and initiated action to have them removed. Further investigation revealed that spring hanger stops were installed on several adjacent hangers which remained in place until 12/13. Due to the apparent breakdown associated with the control of lead shielding/spring hanger stop removal, a Problem Investigation Process (PIP) investigation report was generated (1-C93-1117). The subsequent operability evaluation associated with this report is complete and indicates that ND was operable with the spring hanger stops installed (the lead blankets were removed prior to the pump being declared operable on 12/9). This issue will be resolved and corrective action taken via PIP 1-C93-1117.

Analysis of Options Considered Upon Pump Inoperability

On 12/14 ND pump 1A was declared inoperable due to unacceptable vibration levels. The NC system was at Reduced Inventory (NC level 8.5%) with the system intact (all primary manways installed). There was no interruption of decay heat removal and no increase in NC system temperature. The appropriate Technical Specification Action was entered when the pump was declared inoperable. Meetings were held by Station, Engineering, and Operations management and included other key personnel to evaluate the situation and advise the best course of action to maximize plant safety while removing and replacing the inoperable ND pump.

Options considered:

1. Remain at Reduced Inventory until ND pump is replaced

2. Proceed with NC atmospheric Fill & Vent in parallel with ND pump replacement

3. Perform NC vacuum Fill & Vent (requires return to midloop) in parallel with ND pump replacement

4. Return to NC midloop to open a large vent path via the S/G hot leg manway until ND pump 1A is replaced

Note: The Shutdown Risk Management program requires that two trains of ND be operable in order to drain down to midloop.

The following discussion is based on Design Studies (including both steady state boiloff and transient analyses) which have been performed by Engineering over the past four years. The results and conclusions of these studies have been incorporated into Operating and Abnormal procedures, as well as the Shutdown Risk Management program, which specifies systems required during all phases of outages. Outage schedules are developed and conducted in accordance with this program.

Experience Based Assumptions:

- ND pump removal and replacement would require 72 hours from start to finish
- NC atmospheric Fill & Vent would require from 32 to 60 hours
- NC vacuum Fill & Vent would require from 9 to 12 hours

Discussion of Options:

1. Remain at Reduced Inventory until ND pump is replaced

   If the NC system were allowed to remain at the same Reduced Inventory level for the time of the ND pump 1A replacement, the time-to-boiling would remain at approximately 45 minutes. With no primary level in the steam generator, natural circulation cooling would not be available. With the NC system intact and able to pressurize during a loss of DHR event, the gravity fill option for Station Blackout (Loss of all AC) would be limited, but is possible by filling and venting air and water out the 3" alternate head vent prior to core boiling. At core boiling, the 3" vent would become choked by steam flow and the NC system would pressurize and stop gravity feed. Although the gravity fill option would be available but limited, both trains of ECCS were available for forced injection. Time to reach NC Loops Filled condition (S/G considered available for heat removal per Tech Specs) is estimated to be 84 hours.

2. Proceed with NC atmospheric Fill & Vent in parallel with ND pump replacement

   If NC Fill & Vent was performed in parallel with ND pump replacement, NC inventory would be continuously increasing, resulting in an improvement in the time-to-uncovery from approximately 45 minutes to over 5 hours. The quantity of water on the secondary side of all four S/Gs would serve to further increase the time-to-boiling. Although the gravity fill option for Station Blackout would continue to be available but limited during the increasing level, both trains of ECCS were available for forced injection. Time to reach NC Loops Filled condition is estimated to be 60 hours.

3. Perform NC Vacuum Fill and Vent in parallel with ND pump replacement

   Midloop level is required to draw the air from the S/G tubes and out of the NC system via the vacuum pump skid attached to the pressurizer relief tailpipe. During the vacuum process, the time-to-boiling is gradually reduced from 45 minutes to a few minutes as maximum allowable vacuum is reached. The use of vacuum fill and vent is desirable from a chemistry, time, and labor standpoint. The associated entry to midloop is normally considered risk acceptable due to its short duration, controlling procedures, and benefits attained. With one ND pump inoperable and considered unavailable, this was not an acceptable risk. In addition, the Shutdown Risk Management program does not allow entry to midloop with only one ND train operable. The time to reach Loops Filled condition is estimated to be 12 hours.

4. Return to NC midloop level to open a large vent path via the S/G Hot Leg manway until ND pump 1A is replaced

   This option would have also required a return to NC midloop level to remove the S/G manway to act as an atmospheric vent path in support of the gravity flow option for core cooling (fill and spill) assuming a Station Blackout event. Again, the time-to-boiling would remain at approximately 45 minutes for the entire 72 hours estimated for ND pump replacement. Since midloop operation is recognized to be the main contributor to loss of DHR events, it was recognized in the Shutdown Risk Management program that a backup train of ND should always be held in reserve to restart core cooling via the ND system following recovery of suction conditions. Thus this option was not considered advisable for this situation. A Probabilistic Risk Assessment confirmed that the probability for a loss of DHR during the entire 72 hours of exposure to both NC level and ND flow-related contributors exceeds by at least a factor of 50 the probability of loss of DHR due to Station Blackout. Although the risk decreases with the establishment of gravity feed, the risk of a loss of ND far exceeds this benefit. The time estimated to establish a backup ND train is 72 hours. An additional 12 hours would be required to achieve the Loops Filled condition via the Vacuum Fill process.

Conclusion:

The management team chose Option 2 because it provided an increase in time to core boiling resulting from increasing NC level and the availability of both ECCS Trains and D/Gs should a loss of ND occur. The option to lower NC level and remove a S/G manway was eliminated due to the increased probability of losing the operable ND pump due to loss of suction. Subsequent review of each option and associated risks indicate that this choice was appropriate. Analytical modeling by Probabilistic Risk Assessment personnel (using ORAM methodology) has confirmed that the probability for a Station Blackout is sufficiently remote that the decision not to return to a large S/G manway vent path was proper given the other alternatives available. Profiles of Core Damage Frequency versus Time, for the period 12/10 to 12/18 are provided in the Safety Evaluation section of this report.

5.0 CORRECTIVE ACTIONS

5.1 Subsequent

1. The motor assembly for ND pump 1A was replaced.

2. The motor assembly removed from ND pump 1A was sent to Westinghouse for analysis of vibration problem.

3. The operability determination process and related management expectations have been reviewed with Component and System Engineers.

4. Problem Investigation Process report 1-C93-1117 was generated to address the proper control of lead shielding and spring hanger stops.

5. An upper bearing assembly press has been obtained for use in future rebuilds of this type motor assembly.

5.2 Planned

1. Define the IWP program vibration monitoring requirements and include in Site Directive 3.1.14, Operability Determination.

2. Review the hard limits of the IWP program with appropriate personnel involved with rotating equipment, including management.

3. Revise Position Specific Training Guidelines to include specific IWP program training to personnel involved with rotating equipment (this will ensure that future personnel in these positions are aware of requirements).

4. The requirements on the proper use of the operability determination process and when to enter the process will be incorporated into continuing training for Engineering personnel.

5. The need to consider plant conditions and associated risk when evaluating degraded components/systems will be emphasized to management and engineers.

6. A management signoff prior to Reduced Inventory will be added to station procedures to require management review of the status of key components/systems prior to entering the risk period.

7. Maintenance procedures will be revised to include an improved method for taking measurements when reassembling the upper bearing runner.

8. A motor test stand will be set up to assist in pre-installation testing of this type motor assembly.

9. Evaluate options for reducing amplification due to resonance for the current ND pump 1A.

10. A review will be conducted to determine the appropriate process to use when collecting informal data.

6.0 SAFETY EVALUATION

The relative risk of core damage during this period of inoperability did not significantly increase. The core damage frequency during this period with two operable ND pumps is estimated to be 8E-09, and increases to an estimate of 4E-08 with only one ND pump operable. Two Trains of NV, two Trains of NI, and the operable ND Train were available for forced injection, any one of which is capable of removing core decay heat. There was no interruption of core cooling and no increase in NC temperature.

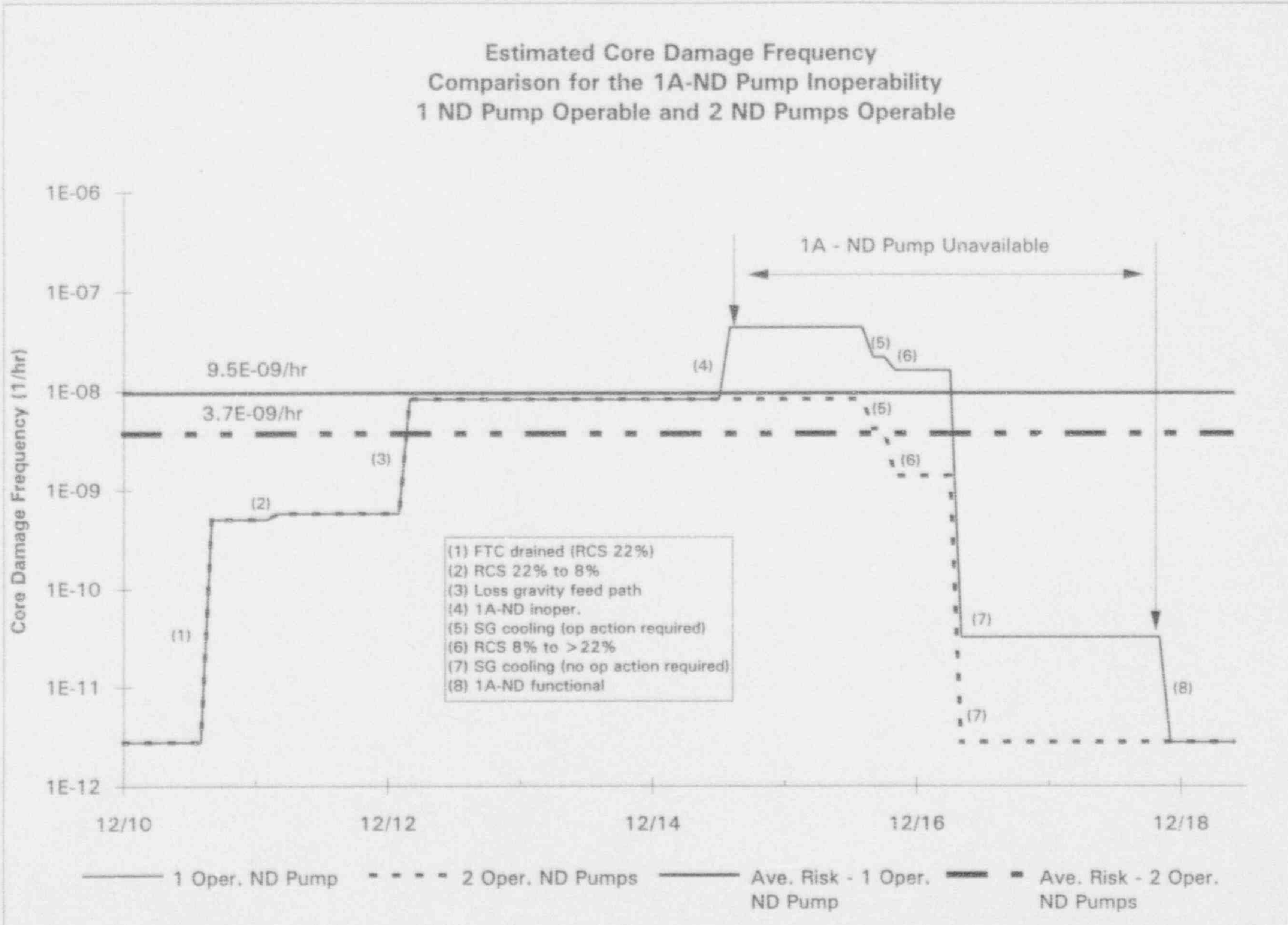
Three Figures are provided showing the Risk versus Time profile for the period of the outage from 12/10 to 12/18. Annotated notes on each Figure explain the rationale for the changes in risk along the time lines.

- Figure 1: "Estimated Core Damage Frequency Comparison for the 1A ND Pump Inoperability, 1 ND Pump Operable and 2 ND Pumps Operable"
- Figure 2: "Estimated Core Damage Frequency Comparison for the 1A ND Pump Inoperability, Large Vent path (S/G Manway) Available During Inoperability"
- Figure 3: "Estimated Core Damage Frequency Comparison for the 1A ND Pump Inoperability, Large Vent Path (S/G Manway) Available until Vacuum Refill"

The analysis indicates that the option chosen for the ND pump inoperability did not significantly increase the core damage frequency. Also the analysis indicates that if other options had been chosen, they would not have significantly improved the core damage frequency over the option chosen. This can be attributed to the low decay heat that existed during the pump inoperability and the availability of several alternative decay heat removal methods (feed and bleed cooling, reflux cooling, etc.). Conservatively, no credit was taken for gravity flooding the core for the Station Blackout following closure of the last S/G manway, even though the 3" alternative head vent does allow limited gravity fill and spill capability. Because the current PRA model assumes equal credit for reflux cooling or natural circulation, no credit is taken for the additional inventory added by the fill and vent process.

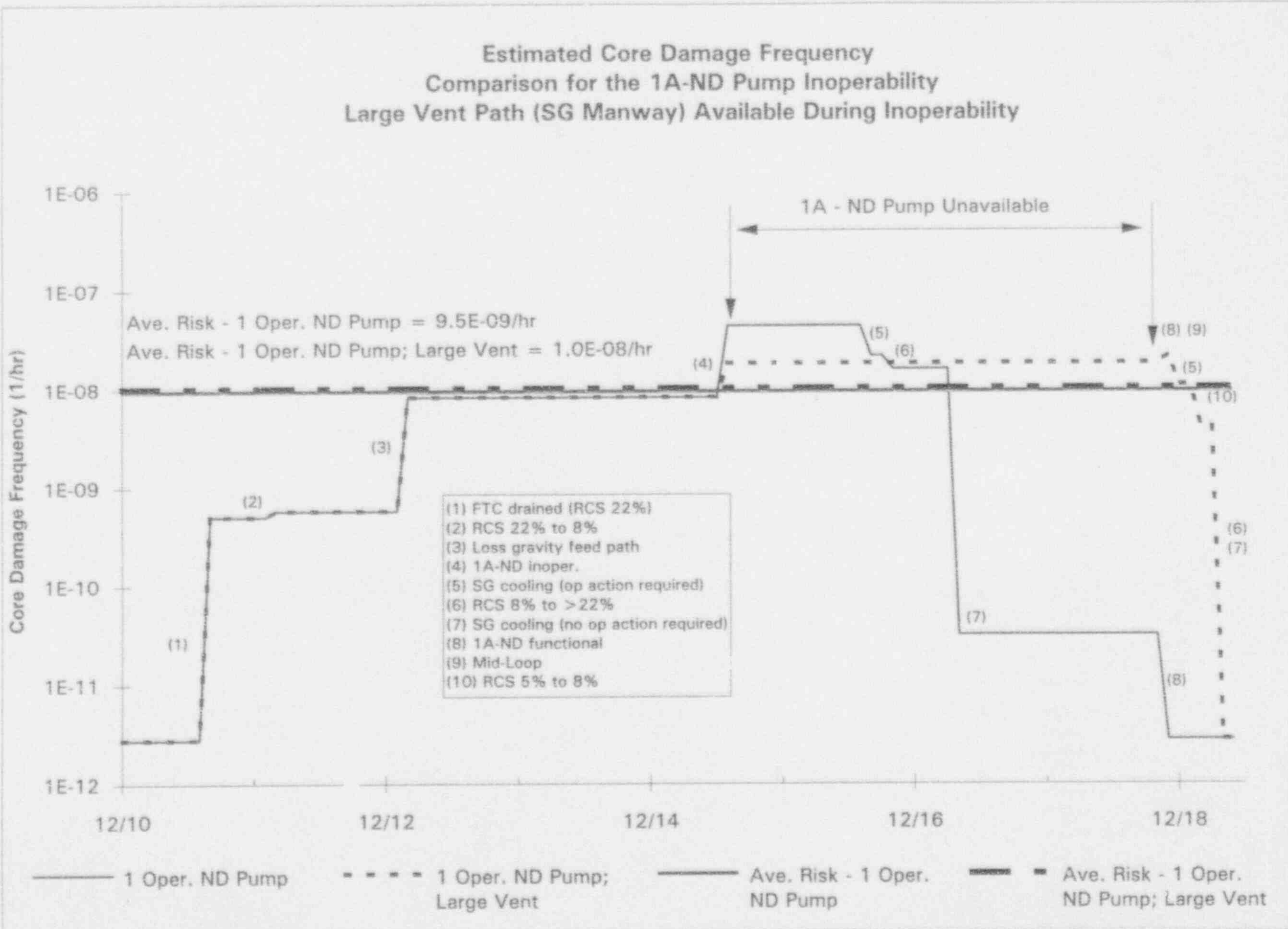
The health and safety of the public were not affected.

Figure 1



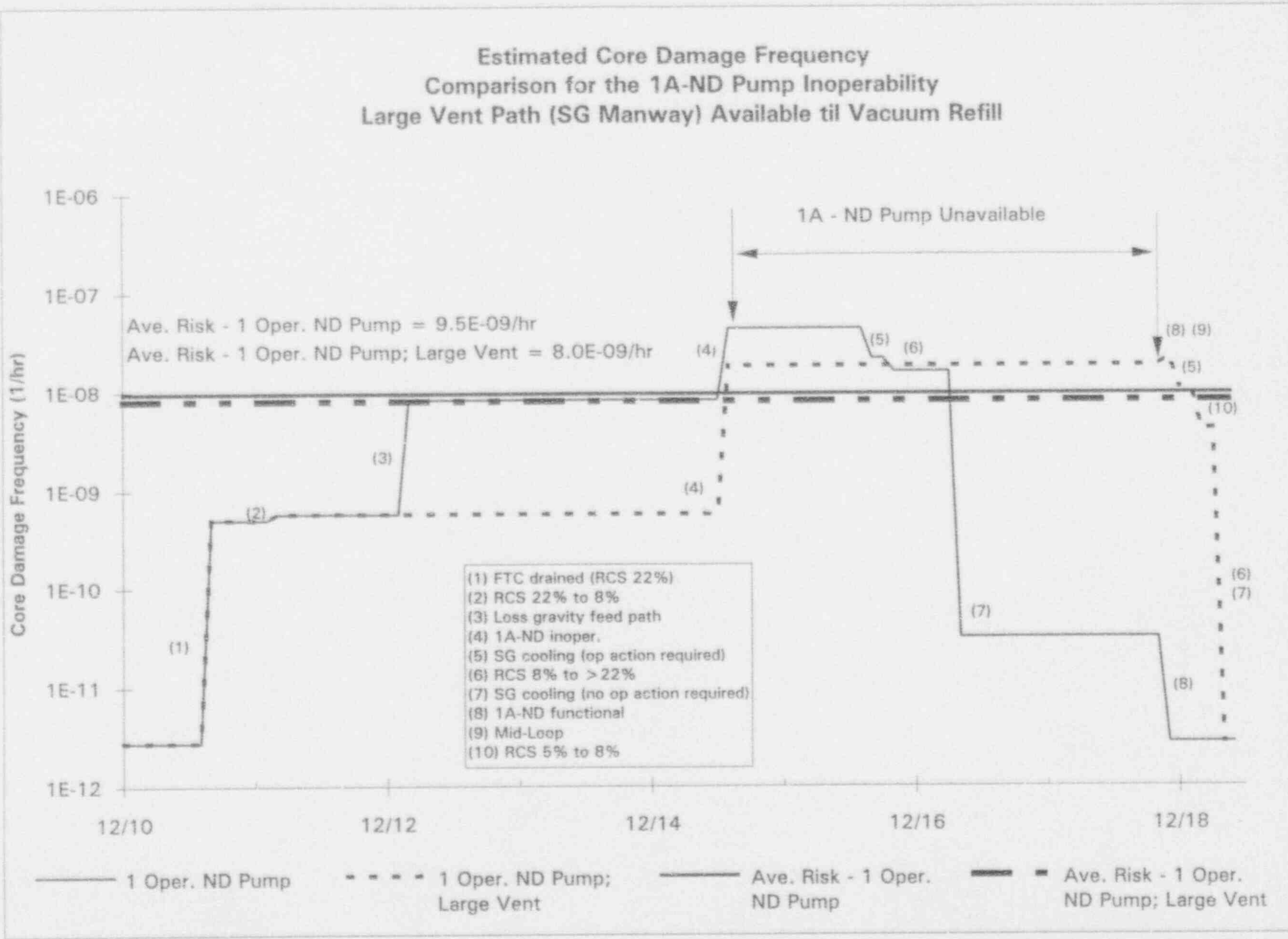
Estimated Core Damage Frequency
Comparison for the 1A-ND Pump Inoperability
1 ND Pump Operable and 2 ND Pumps Operable
1A - ND Pump Unavailable
9.5E-09/hr
3.7E-09/hr
Core Damage Frequency (1/hr)
1E-06
1E-07
1E-08
1E-09
1E-10
1E-11
1E-12
12/10
12/12
12/14
12/16
12/18
(1) FTC drained (RCS 22%)
(2) RCS 22% to 8%
(3) Loss gravity feed path
(4) 1A-ND inoper.
(5) SG cooling (op action required)
(6) RCS 8% to >22%
(7) SG cooling (no op action required)
(8) 1A-ND functional
1 Oper. ND Pump
2 Oper. ND Pumps
Ave. Risk - 1 Oper. ND Pump
Ave. Risk - 2 Oper. ND Pumps

Figure 2



Estimated Core Damage Frequency
Comparison for the 1A-ND Pump Inoperability
Large Vent Path (SG Manway) Available During Inoperability
1A - ND Pump Unavailable
Ave. Risk - 1 Oper. ND Pump = 9.5E-09/hr
Ave. Risk - 1 Oper. ND Pump; Large Vent = 1.0E-08/hr
Core Damage Frequency (1/hr)
1E-06
1E-07
1E-08
1E-09
1E-10
1E-11
1E-12
12/10
12/12
12/14
12/16
12/18
(1) FTC drained (RCS 22%)
(2) RCS 22% to 8%
(3) Loss gravity feed path
(4) 1A-ND inoper.
(5) SG cooling (op action required)
(6) RCS 8% to >22%
(7) SG cooling (no op action required)
(8) 1A-ND functional
(9) Mid-Loop
(10) RCS 5% to 8%
1 Oper. ND Pump
1 Oper. ND Pump; Large Vent
Ave. Risk - 1 Oper. ND Pump
Ave. Risk - 1 Oper. ND Pump; Large Vent

Figure 3



Estimated Core Damage Frequency
Comparison for the 1A-ND Pump Inoperability
Large Vent Path (SG Manway) Available til Vacuum Refill
1A - ND Pump Unavailable
Ave. Risk - 1 Oper. ND Pump = 9.5E-09/hr
Ave. Risk - 1 Oper. ND Pump; Large Vent = 8.0E-09/hr
Core Damage Frequency (1/hr)
1E-06
1E-07
1E-08
1E-09
1E-10
1E-11
1E-12
12/10
12/12
12/14
12/16
12/18
(1) FTC drained (RCS 22%)
(2) RCS 22% to 8%
(3) Loss gravity feed path
(4) 1A-ND inoper.
(5) SG cooling (op action required)
(6) RCS 8% to >22%
(7) SG cooling (no op action required)
(8) 1A-ND functional
(9) Mid-Loop
(10) RCS 5% to 8%
1 Oper. ND Pump
1 Oper. ND Pump; Large Vent
Ave. Risk - 1 Oper. ND Pump
Ave. Risk - 1 Oper. ND Pump; Large Vent

7.0 ENCLOSURE

7.1 NC/ND System Configuration Figures

PERCENT/ELEVATION TABULATION

WIDE RANGE LEVEL (NCLT5200 & 6450)

PERCENT	ELEVATION	PERCENT	ELEVATION	PERCENT	ELEVATION	PERCENT	ELEVATION
0%	566'-0"	25.5%	574'-6"	51%	583'-0"	76.5%	591'-6"
.5%	566'-2"	26%	574'-8"	51.5%	583'-2"	77%	591'-8"
1%	566'-4"	26.5%	574'-10"	52%	583'-4"	77.5%	591'-10"
1.5%	566'-6"	27%	575'-0"	52.5%	583'-6"	78%	592'-0"
2%	566'-8"	27.5%	575'-2"	53%	583'-8"	78.5%	592'-2"
2.5%	566'-10"	28%	575'-4"	53.5%	583'-10"	79%	592'-4"
3%	567'-0"	28.5%	575'-6"	54%	584'-0"	79.5%	592'-6"
3.5%	567'-2"	29%	575'-8"	54.5%	584'-2"	80%	592'-8"
4%	567'-4"	29.5%	575'-10"	55%	584'-4"	80.5%	592'-10"
4.5%	567'-6"	30%	576'-0"	55.5%	584'-6"	81%	593'-0"
5%	567'-8"	30.5%	576'-2"	56%	584'-8"	81.5%	593'-2"
5.5%	567'-10"	31%	576'-4"	56.5%	584'-10"	82%	593'-4"
6%	568'-0"	31.5%	576'-6"	57%	585'-0"	82.5%	593'-6"
6.5%	568'-2"	32%	576'-8"	57.5%	585'-2"	83%	593'-8"
7%	568'-4"	32.5%	576'-10"	58%	585'-4"	83.5%	593'-10"
7.5%	568'-6"	33%	577'-0"	58.5%	585'-6"	84%	594'-0"
8%	568'-8"	33.5%	577'-2"	59%	585'-8"	84.5%	594'-2"
8.5%	568'-10"	34%	577'-4"	59.5%	585'-10"	85%	594'-4"
9%	569'-0"	34.5%	577'-6"	60%	586'-0"	85.5%	594'-6"
9.5%	569'-2"	35%	577'-8"	60.5%	586'-2"	86%	594'-8"
10%	569'-4"	35.5%	577'-10"	61%	586'-4"	86.5%	594'-10"
10.5%	569'-6"	36%	578'-0"	61.5%	586'-6"	87%	595'-0"
11%	569'-8"	36.5%	578'-2"	62%	586'-8"	87.5%	595'-2"
11.5%	569'-10"	37%	578'-4"	62.5%	586'-[illegible]	88%	595'-4"
12%	570'-0"	37.5%	578'-6"	63%	587'-[illegible]	88.5%	595'-6"
12.5%	570'-2"	38%	578'-8"	63.5%	587'-[illegible]	89%	[illegible]'-8"
13%	570'-4"	38.5%	578'-10"	64%	587'-4"	89.5%	595'-10"
13.5%	570'-6"	39%	579'-0"	64.5%	587'-6"	90%	596'-0"
14%	570'-8"	39.5%	579'-2"	65%	587'-8"	90.5%	596'-2"
14.5%	570'-10"	40%	579'-4"	65.5%	587'-10"	91%	596'-4"
15%	571'-0"	40.5%	579'-6"	66%	588'-0"	91.5%	596'-6"
15.5%	571'-2"	41%	579'-8"	66.5%	588'-2"	92%	596'-8"
16%	571'-4"	41.5%	579'-10"	67%	588'-4"	92.5%	596'-10"
16.5%	571'-6"	42%	580'-0"	67.5%	588'-6"	93%	597'-0"
17%	571'-8"	42.5%	580'-2"	68%	588'-8"	93.5%	597'-2"
17.5%	571'-10"	43%	580'-4"	68.5%	588'-10"	94%	597'-4"
18%	572'-0"	43.5%	580'-6"	69%	589'-0"	94.5%	597'-6"
18.5%	572'-2"	44%	580'-8"	69.5%	589'-2"	95%	597'-8"
19%	572'-4"	44.5%	580'-10"	70%	589'-4"	95.5%	597'-10"
19.5%	572'-6"	45%	581'-0"	70.5%	589'-6"	96%	598'-0"
20%	572'-8"	45.5%	581'-2"	71%	589'-8"	96.5%	598'-2"
20.5%	572'-10"	46%	581'-4"	71.5%	589'-10"	97%	598'-4"
21%	573'-0"	46.5%	581'-6"	72%	590'-0"	97.5%	598'-6"
21.5%	573'-2"	47%	581'-8"	72.5%	590'-2"	98%	598'-8"
22%	573'-4"	47.5%	581'-10"	73%	590'-4"	98.5%	598'-10"
22.5%	573'-6"	48%	582'-0"	73.5%	590'-6"	99%	599'-0"
23%	573'-8"	48.5%	582'-2"	74%	590'-8"	99.5%	599'-2"
23.5%	573'-10"	49%	582'-4"	74.5%	590'-10"	100%	599'-4"
24%	574'-0"	49.5%	582'-6"	75%	591'-0"		
24.5%	574'-2"	50%	582'-8"	75.5%	591'-2"		
25%	574'-4"	50.5%	582'-10"	76%	591'-4"		

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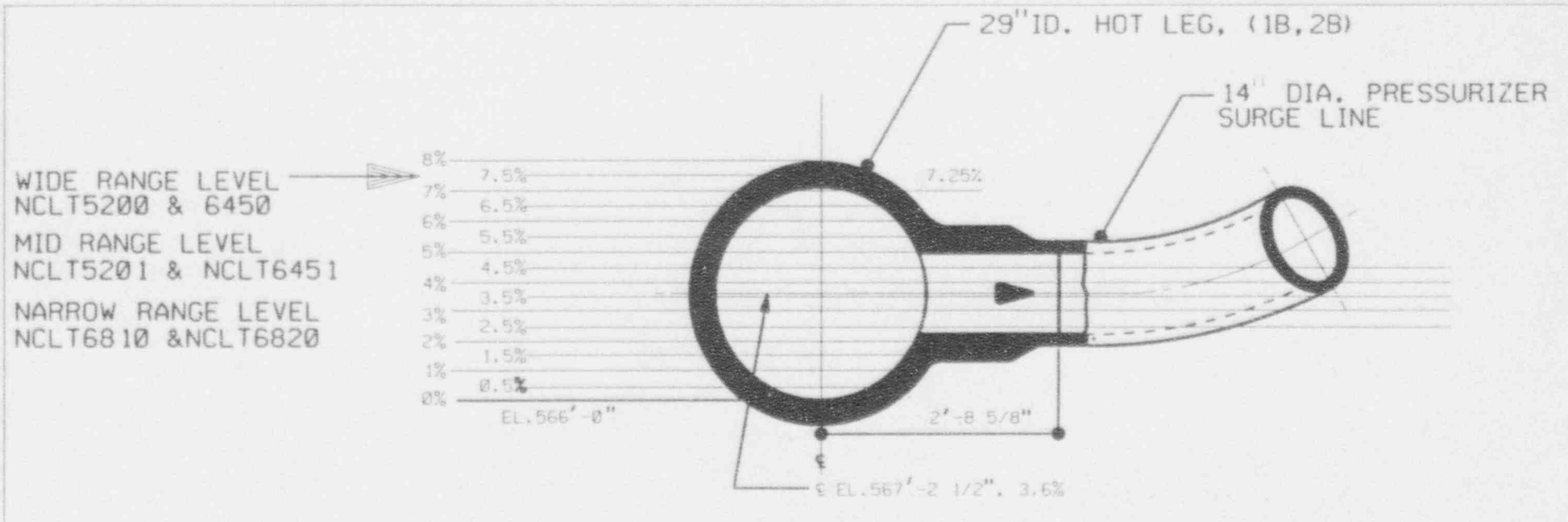

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SCALE: 3/4" = 1'-0"

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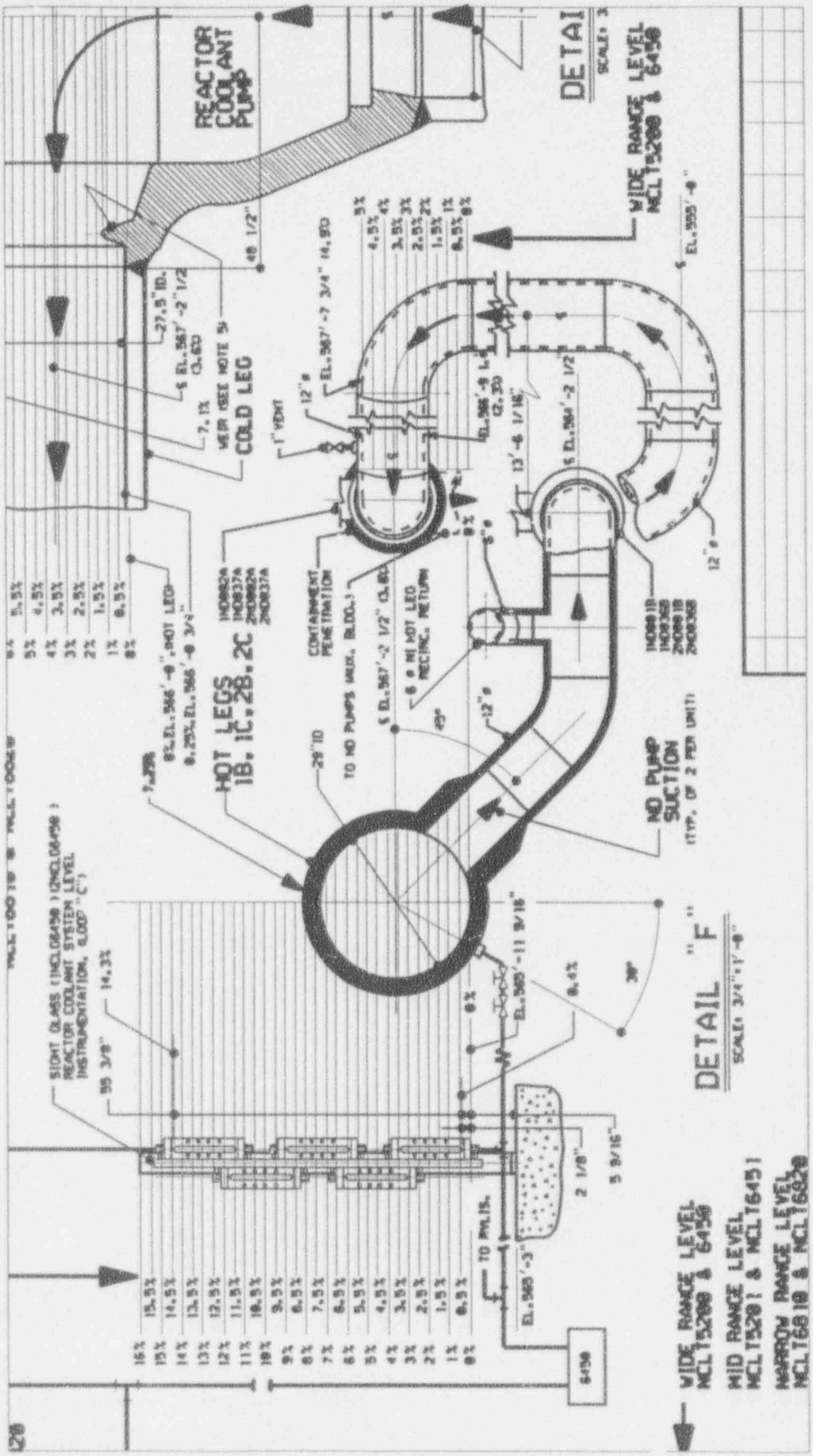

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