VALUE IMPACT ANALYSIS OF POTENTIAL PLANT ENHANCEMENTS FOR WATTS BAR NUCLEAR PLANT

FINAL REPORT

Prepared for

Tennessee Valley Authority

Prepared by

ERIN® Engineering and Research, Inc.
2175 N. California Blvd. Suite 625
Walnut Creek, CA 94596
(510) 943-7077

June 30, 1994

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LIST OF ACRONYMS

AFW	Auxiliary Feedwater
APB	Accident Progress Bin
ARF	Air Return Fan
BMT	Basemat Melt-through
CCP	Centrifugal Charging Pump
CCS	Component Cooling Water System
CD	Core Damage
CDC	Core Debris Control
CDF	Core Damage Frequency
CF	Containment Failure
CFR	Code of Federal Regulations
CIS	Containment Inerting System
DCH	Direct Containment Heating
EDG	Emergency Diesel Generator
ERCW	Essential Raw Cooling Water
FCMR	Fractional Contribution to Mean Risk
FCV	Filtered Containment Venting
FSAR	Final Safety Analysis Report
GPM	Gallons per Minute
HPME	High Pressure Core Melt Ejection
HVAC	Heating, Ventilation, and Air Conditioning
IPE	Individual Plant Examination
ISLOCA	Interfacing Systems Loss of Coolant Accident
LOCA	Loss of Coolant Accident
MAAP	Modular Accident Analysis Program
MOV	Motor-Operated Valve
NRC	Nuclear Regulatory Commission
PRA	Probabilistic Risk Assessment
PORV	Power-Operated Relief Valve
QA	Quality Assurance
RCP	Reactor Coolant Pump
RCS	Reactor Coolant System
RHR	Residual Heat Removal
RWST	Refueling Water Storage Tank
SAMDA	Severe Accident Mitigation Design Alternative
SBO	Station Blackout
SER	Safety Evaluation Report
SGTR	Steam Generator Tube Rupture
SI	Safety Injection
SQN	Sequoyah Nuclear Plant
TVA	Tennessee Valley Authority
VB	Vessel Breach
WBN	Watts Bar Nuclear Plant

EXECUTIVE SUMMARY

As part of an ongoing effort to utilize and apply the Individual Plant Examination (IPE) for the Watts Bar Nuclear Plant (WBN), Tennessee Valley Authority (TVA) undertook an effort to identify potential cost effective plant enhancements. This effort involved the systematic review of the IPE results and insights as well as reviews of related industry and NRC reports on severe accident design improvements. This effort, based on an updated version of the WBN IPE, is described in this report. The purpose of this executive summary is to provide a brief overview of the methods utilized and results of the value impact analyses performed.

Methodology

The overall approach to the identification and evaluation of potential plant enhancements is shown in Figure 1. The process involved the seven steps described below:

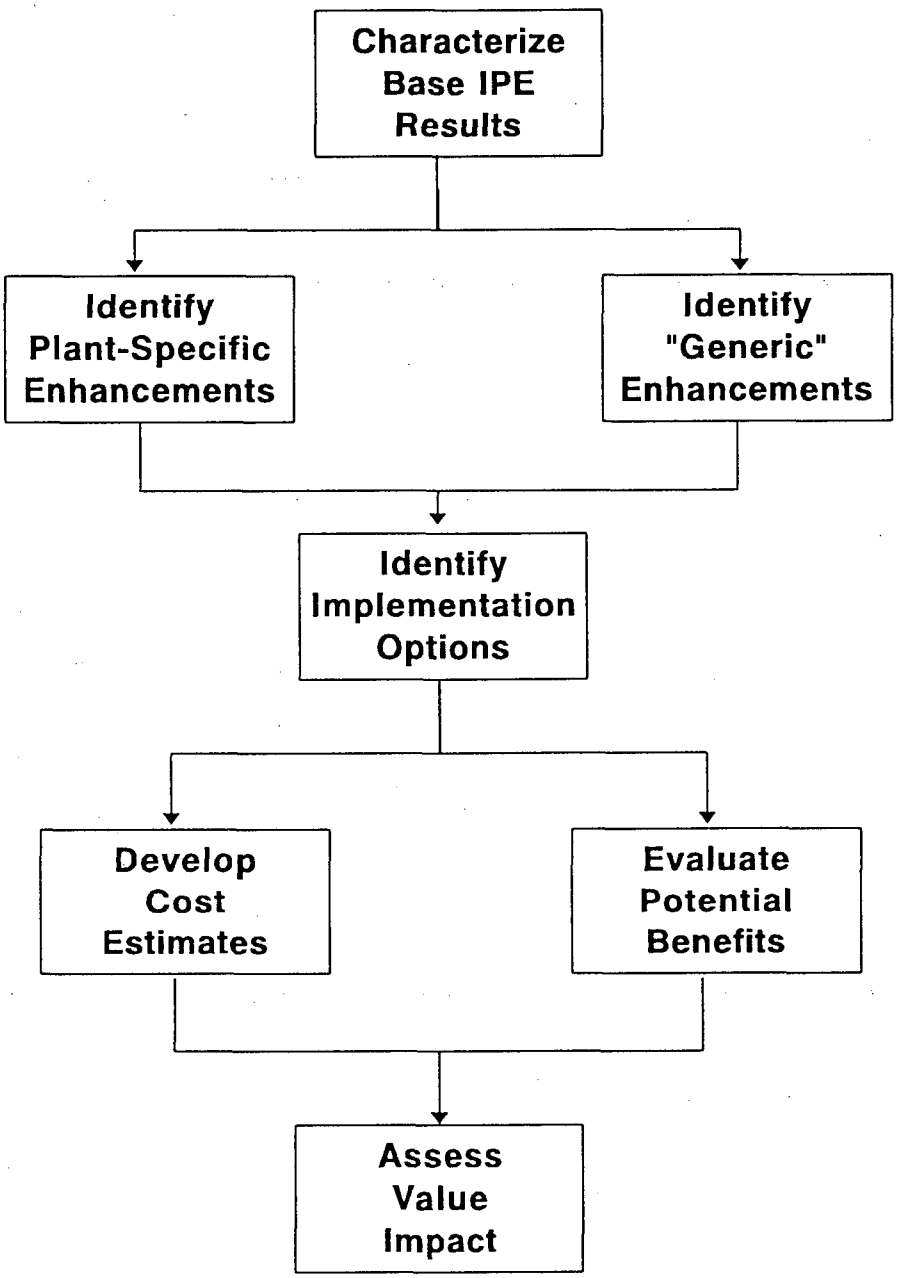
Step 1: Characterize Base IPE Results - This step involved the review of the IPE results to identify the major plant design features, procedures and functional failures which were contributors to core damage and containment failure.

Step 2: Identify Plant-Specific Enhancements - This step involved the detailed, systematic review of the IPE results to identify specific plant features which were important to risk and features which could be added to the plant design or procedures to reduce risk in light of the overall characterization of the IPE performed in Step 1. This involved the review of all split fractions and dominant sequences from the Level 1 and 2 PRA.

Step 3: Identify "Generic" Enhancements - This step involved the investigation of enhancements which were already present at other plants or had been considered as potentially cost-effective enhancements in other industry or NRC studies in light of the overall characterization of the IPE performed in Step 1. Sources reviewed include other ice condenser IPEs, NUREG-1150, Supplement 2 to Generic Letter 88-20, severe accident mitigation design alternative (SAMDA) submittals by other plants, among others.

Figure 1

PROCESS FOR IDENTIFICATION & EVALUATION OF POTENTIAL PLANT ENHANCEMENTS



Step 4: Identify Implementation Options - This step involved the definition of specific plant enhancement options of WBN, given the overall results of the IPE and the variety of potential enhancements identified from the plant specific and generic reviews. The purpose of the step was to provide sufficient definition to the enhancement to allow cost estimation and modeling of the benefit.

Step 5: Develop Cost Estimate - This step involved the development of order of magnitude cost estimates for the various implementation options identified in Step 4. In cases where specific details of the WBN design were involved, these estimates were developed specifically by TVA for WBN. In other cases where the enhancement was general in nature, previous cost estimates (industry or NRC) were used as representative.

Step 6: Evaluate Potential Benefits - This step involved the utilization of the WBN IPE model and results to evaluate the potential risk reduction associated with each implementation option. The benefit was expressed in terms of averted off-site dose to the public (e.g., person-rem) as well as other less quantitative effects.

Step 7: Assess Value Impact - This step involved the comparison of the cost and benefits to determine whether the enhancement was potentially cost beneficial. Any enhancement which had a cost to benefit ratio of less than $1000 per person-rem was considered cost beneficial.

Characterization of Base IPE Results

The IPE for Watts Bar Unit 1 was originally submitted to the NRC in September of 1993 based on a freeze date of December 1992. At that time, a number of design and procedural items were still unresolved. Based on the changes made between the original IPE freeze date and plant startup, an update was performed of the IPE which was intended to reflect the design and operation of the plant at the time of plant startup. As a result of this update, the mean point estimate CDF for Watts Bar was found to be 8.0×10^{-5} per reactor-year. Based on a review of the updated Level 1 PRA results and its contributors, no vulnerabilities were identified. The updated CDF is roughly a factor of four lower than the original IPE value of 3.3×10^{-4} per reactor year.

The following table provides a comparison of the IPE results submitted to the NRC for each of the ice condenser plants. In terms of overall CDF, Table 1 shows that Watts Bar Unit 1 falls within the range of values reported for other plants.

Table 1 Comparison of Ice Condenser IPE Level 1 Results

Ice Condenser Plant	Mean CDF (per reactor-year)
Sequoyah 1,2	1.7×10^{-4}
Watts Bar 1	8.0×10^{-5}
DC Cook 1,2	6.3×10^{-5}
Catawba 1,2	4.3×10^{-5}

The importance of initiating events was examined by determining the contributions of core damage sequences grouped by initiating event. The ranked results are shown in Figure 1 for eight major initiating event categories.

The general class of LOCAs accounts for approximately 30% of the total CDF. This class includes the following specific initiating events: small isolable LOCAs, small non-isolable LOCAs, medium LOCAs, large LOCAs, and excessive LOCAs (e.g., reactor pressure vessel failure). Sequences involving transient-induced LOCAs (e.g., stuck-open pressurizer PORV in response to a loss of main feedwater initiator) are included with the transient initiating event category. These events are primarily characterized by failure of the emergency core cooling systems (ECCS) in recirculation. These failures are due to either operator errors in aligning for recirculation or hardware failures in the recirculation systems.

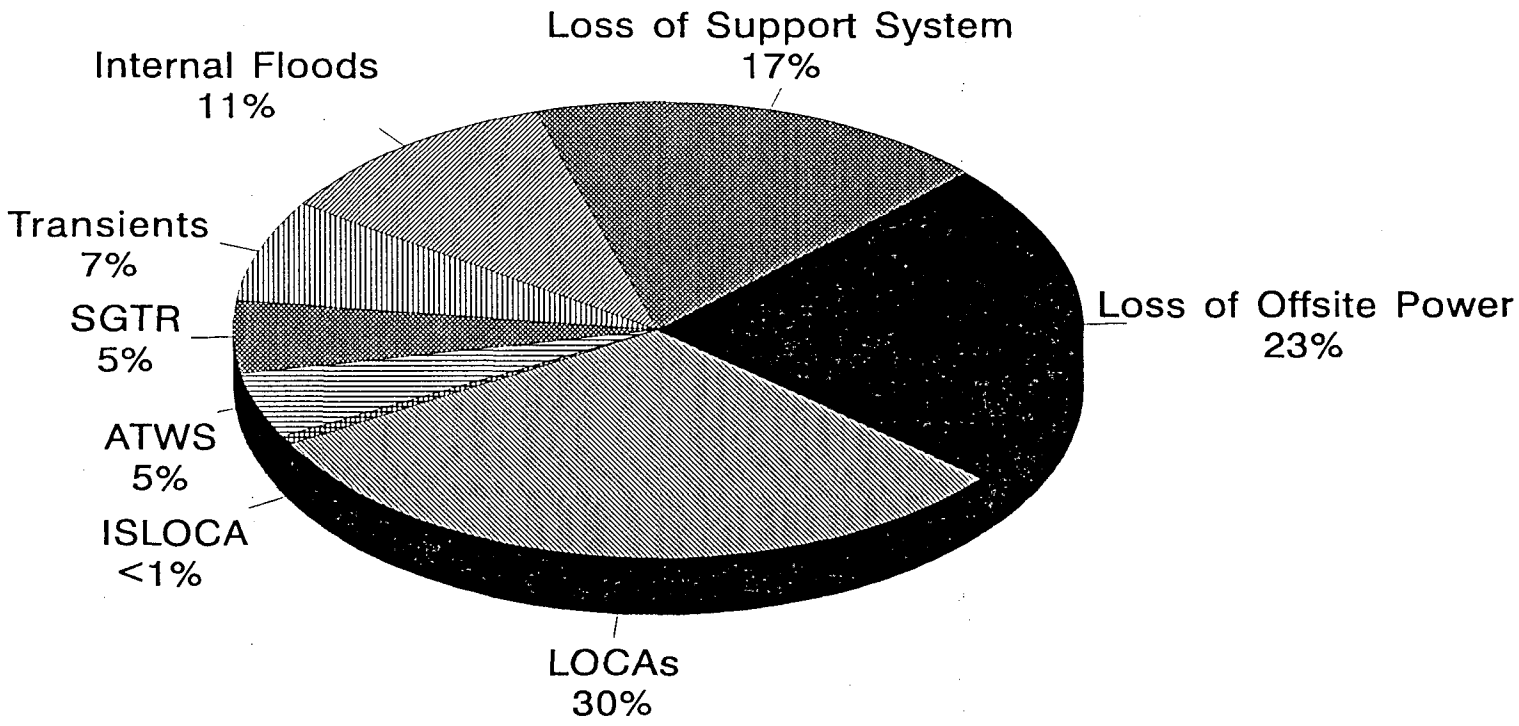
LOSP is the next largest contributor to the overall CDF. These sequences contribute roughly 23% to the total CDF. The predominant contributor to LOSP core damage sequences are unit blackout sequences with failure to recover power before core damage.

The general class of support system faults accounts for approximately 18% of the total CDF. Included in this grouping are system and system train failures involving electrical power boards, CCS, and essential raw cooling water (ERCW).

Internal floods make up about 11%. The most important sources of internal floods are associated with a rupture or major flow diversion in one ERCW train combined with failure of the other train. Many of these sequences are effectively a total loss of ERCW. ERCW is an important support system since it provides the ultimate heat sink for reactor coolant pump (RCP) seal cooling and ECCS pump cooling. Thus, a complete loss of ERCW results in an RCP seal LOCA with inadequate coolant makeup capability.

Figure 2

CORE DAMAGE FREQUENCY CONTRIBUTORS BY INITIATING EVENT GROUP



Total Mean CDF = 8.0×10^{-5}/yr

Transient events contribute approximately 7% to the total CDF. These events are generally characterized by subsequent support system failures which lead to a sufficient number of failures in frontline systems to lead to loss of core cooling.

SGTR events contribute roughly 5% to the total CDF. The SGTR event sequences are characterized by failure to adequately control reactor coolant inventory due to operator errors and hardware failures.

Sequences without reactor trip (ATWS) contribute approximately 5%. Such sequences may lead to core damage if the initial reactor coolant system (RCS) pressure transient is not mitigated or emergency boration is not accomplished in a timely manner.

Interfacing system LOCAs make up only a very small part of the total CDF (much less than 1%). However, should they lead to core damage, these initiators are significant because of their potential for a large release path to bypass the containment.

Section 2 contains a detailed discussion of the top sequences. A listing of the top 100 core damage sequences is provided in Appendix A.

SUMMARY OF LEVEL 2 PRA RESULTS

The WBN IPE includes a Level 2 PRA model. This model evaluates the response of the WBN containment to the challenges posed by a severe accident. A reasonable treatment of this continuum is to use a representative set of discrete release categories that span the spectrum from relatively large, early releases to ones which are much smaller, occur later, and/or over a long time period.

A more detailed definition of the Watts Bar release categories is given in Section 2. Table 2 represents a summary of these release categories in terms of general release category groups and percentage of the CDF.

Table 2. Definition and Results for General Release Category Groups

General Release Category Group	Description	Percentage of CDF Analyses*
I	Large, Early Containment Failures and Large Bypasses	2.4
II	Small, Early Containment Failures and Small Bypasses	10.1
III	Late Releases and Long-Term Releases	21.5
IV	Long-Term, Contained Releases (Containment Intact)	66.0

* Group frequency divided by CDF.

The overall contributors to containment failure are shown in Figure 3. This figure shows that nearly two thirds (65%) of the severe accident sequences end up with the containment intact. The largest contributor (12%) to containment failure is late hydrogen burns which result in a late, large failure of containment. The next largest contributor is late overpressurization failures (8%). These are largely due to events without containment heat removal and generally result in a late small failure of the containment. Containment bypasses represent the next largest contributor (8%). Most of these sequences were discussed above as large early releases. Basemat failures represent only 4% of the containment endstates. These failures are due to conditions where the core debris is inadequately cooled and core concrete interaction continues long enough for the containment basemat to be breached.

An important benchmark for a Level 2 PRA is the frequency of large, early releases. For this IPE, the frequency of large, early releases is the sum of Release Category Group I plus that fraction (0.73) or Release Category Group II that is associated with SGTR initiating events with a stuck-open secondary side relief valve. The Watts Bar frequency of large, early release is approximately 10% of the CDF, or 7.8×10^{-6} per reactor year. This frequency is low and is dominated by containment bypass results from SGTR, which accounts for approximately 5.9×10^{-6} per reactor year.

Table 3 lists the major contributors to large, early release. Included in this table is the type of event and the percentage contribution for each event.

Table 3. Major Contributors to Large, Early Release Frequency for Internal Events

Type of Event	Percent Contributions to Large, Early Release*
SGTRs (with bypass to the environment)	76
Containment Failure due to Direct Impingement	15
α-Mode Failure of Vessel/Containment	6
HPME/Hydrogen Burns at Vessel Breach	3
Hydrogen Burns/DDT before and after Vessel Breach	<1
Interfacing System LOCAs	<1

* Sum of Release Category Group I and SGTR Bypasses from Group II.

SGTR sequences contribute about 76% to the frequency of large, early releases. Containment failure due to direct impingement of debris in the containment cylinder wall in the seal table room is the second largest contributor. Steam explosions, caused by

DOMINANT CONTAINMENT FAILURE MODES

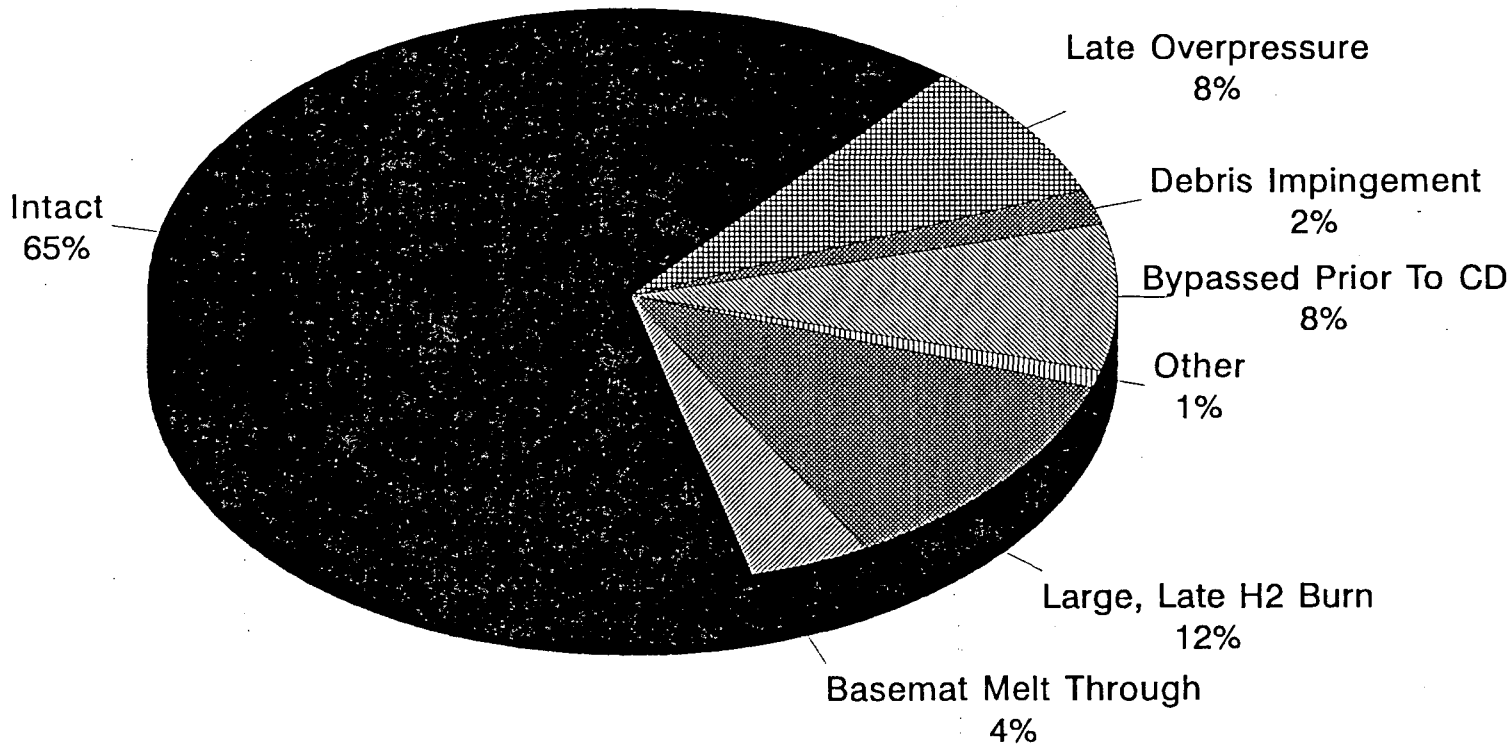


Figure 3

the interaction of hot fuel with water (i.e., alpha mode) is the third largest contributor. Overpressurization of the containment from hydrogen burns, detonations, and high pressure ejection of molten fuel when the pressure vessel fails contribute less than 4% to the frequency of large, early releases. Less than 1% of the large, early release is caused by interfacing systems LOCA.

Potential Enhancements Identified For Evaluation

Based upon a review of the base IPE results, the following six general categories of enhancements were identified:

- Improve Availability of ECCS Recirculation - This category of enhancements addresses the largest functional contributor to core damage, LOCAs with loss of ECCS recirculation.

- Improve Availability of AC Power - This category of enhancements addresses the second largest contributor, loss of offsite power. These enhancements specifically identify methods for providing alternate sources of AC power.

- Improve Ability To Cope With Loss of AC Power & Station Blackout -This category of enhancements is aimed at improving the plants ability to withstand extended losses of AC power by extending the time to core damage to allow more time for recovery of systems or AC power.

- Improve Ability To Cope With Loss of RCP Seal Cooling - This category of enhancements addresses the third largest contributor to core damage, event sequences involving loss of RCP seal cooling.

- Improve Containment Performance - This category of enhancements addresses the key WBN features impacting containment performance in a severe accident as identified in the Level 2 portion of the PRA.

- Miscellaneous - This category of enhancements addresses other items which were identified in the systematic review of the IPE, but do not belong in one of the categories identified above.

A detailed review of the WBN results and contributors combined with a review of generic industry sources yielded a total of twenty-eight implementation options for the six categories. These specific enhancements are listed in Table 4. For the purposes of identification, each category is identified with a roman numeral (I through VI) and each enhancement within each category is numbered. For example, one of the options for

Table 4

SUMMARY OF POTENTIAL ENHANCEMENTS CONSIDERED IN VALUE IMPACT ANALYSIS

ENHANCEMENT CATEGORY	IMPLEMENTATION OPTION
I - Improve Availability of ECCS Recirculation	1. Procedure Change To Stop One Train of Sprays 2. Install Containment Spray Throttle Valves 3. Redesign To Delay Containment Spray Actuation 4. Install Automatic High Pressure Recirculation
II - Improve Availability of AC Power	1. Procedure Change To Facilitate Cross-tie of 500kV and 161kV AC Power 2. Accelerate Availability of Fifth Emergency Diesel Generator 3. Procedure Change & Fifth Diesel
III - Improve Ability To Cope With Loss of AC Power & Station Blackout	1. Procedure Change To Utilize Existing Spare 6900V/480V Transformers 2. Install Improved RCP Seals 3. Install Independent RCP Seal Cooling System 4. Install Accumulators For Turbine Driven AFW Pump Flow Control Valves 5. Provide DC Load Shed Analysis & Procedure 6. Provide Portable Battery Charger 7. Install AC Independent Coolant Injection System
IV - Improve Ability To Cope With Loss of RCP Seal Cooling	1. Install Improved RCP Seals 2. Install Independent RCP Seal Cooling System (w/o new EDG) 3. Modify Charging Pump Cooling From CCS To ERCW
V - Improve Containment Performance	1. Install Deliberate Ignition System 2. Install Reactor Cavity Flooding System 3. Install Filtered Containment Venting System 4. Install Core Retention Device 5. Install Containment Inerting System 6. Install Additional Containment Bypass Instrumentation 7. Install Reactor Depressurization System 8. Install Independent Containment Spray System 9. Install AC Independent Air Return Fan Power Supplies
VI - Miscellaneous	1. Install MG Set Trip Breakers In Control Room (ATWS) 2. Improve Procedures To Provide Temporary HVAC During Loss of Room Cooling

improving the availability of AC power (Category II) is the acceleration of the schedule to provide the fifth diesel generator at WBN. This enhancement is the second option in category II and is numbered II.2. The following provides a brief summary of the twenty-eight enhancements evaluated and the anticipated benefits of each.

Category I - Improve Availability of ECCS Recirculation

This category of enhancements is intended to address the dominant contributor to the WBN IPE core damage frequency. Approximately 30% of the core damage frequency is contributed by LOCA events. Most of the LOCA core damage event sequences involve failure of ECCS recirculation. For example, 17% of the total CDF is contributed by Small LOCAs with failure of the ECCS recirculation alignment.

The Watts Bar ice condenser design results in actuation of containment spray for nearly all LOCA events, including small LOCAs. The realignment of the low pressure portion of the ECCS recirculation system is accomplished automatically. However, the high pressure realignment is performed manually. When the automatic realignment of low pressure ECCS is complete, the containment spray pumps continue to remove 4000 gpm per pump from the RWST until they are manually realigned. This allows only a limited period of time (~20 minutes) for the operators to perform the manual realignment and respond to any system problems encountered. The IPE identified that roughly 75% of the high pressure recirculation failures were due to common cause failures of motor operated valves (MOVs) in the ECCS systems. The other 25% was due to operator errors. The following implementation options were identified to address this contributor to risk.

I.1 - Procedure Change To Stop One Train of Sprays

This enhancement involves a change to the WBN emergency operating procedures (EOPs) to direct the stopping of one of the containment spray pumps in the event of a LOCA before recirculation is required. This would reduce the rate of RWST depletion and substantially increase the time for operator actions following a small LOCA. This additional time would manifest itself in a reduction in operator error rates and provide adequate time for local operator recovery actions to manually open MOVs which failed to realign.

I.2 - Install Containment Spray Throttle Valves

This enhancement involves a design change to the containment spray system to provide valves to allow throttling of containment spray flow and procedures to support their use. This enhancement would result in additional time for operator recovery actions and would further reduce the susceptibility of the plant to ECCS recirculation failures.

I.3 - Redesign To Delay Containment Spray Actuation

This enhancement involves the reanalysis and redesign of the containment spray actuation system. The current WBN design basis requires the spray system to function in the manner modeled in the IPE. However, with additional engineering analysis it is likely that the actuation of containment spray could be precluded in small LOCA events, thereby significantly extending the time before RWST depletion. This additional time would likely be sufficient to allow plant cooldown without ECCS recirculation.

I.4 - Install Automatic High Pressure Recirculation

This enhancement would automate the alignment of ECCS recirculation to the high pressure charging and safety injection pumps. Provision of this enhancement would essentially eliminate the human errors in realignment.

Category II - Improve Availability of AC Power

The second largest contributor to the WBN core damage frequency (~23%) is loss of offsite power (161kV). Roughly 21% is due to station blackout events. This category of enhancement is intended to improve the availability of AC power by providing access to alternate, diverse AC power sources not currently credited in the IPE.

II.1 - Procedure Change To Facilitate Cross-tie of 500kV and 161kV AC Power

The 6.9kV Shutdown Boards at Watts Bar Unit 1 are provided offsite power from the 161kV grid. Another, independent 500kV grid is connected to the WBN site, but is not currently allowed to be tied to the Unit 1 shutdown boards. A physical connection is possible, via bus cross-ties at Unit 2, but the current plant procedures do not support this crosstie. This enhancement would provide procedures and training on the crosstie of the 500kV grid to the Unit 1 shutdown boards.

II.2 - Accelerate Availability of Fifth Emergency Diesel Generator

The WBN emergency AC power system design provides a fifth emergency diesel generator (EDG) which can be connected to any of the four 6.9kV shutdown boards. The purpose of the fifth EDG is to provide operational flexibility by providing a installed spare for EDGs which are removed from service. When completed, the fifth EDG will provide a means for ensuring all four shutdown boards are supported by an operable EDG, even while one is

under going maintenance. Currently, the startup schedule for WBN Unit 1 does not support the provision of the fifth EDG at the time of plant startup. It is intended to be made available after Unit 1 startup, but due to the large number of outstanding design changes which would be required to make the EDG available, its availability is being deferred. This enhancement evaluates the benefit of the fifth EDG and considers whether the cost associated with accelerating the schedule is commensurate with the benefit.

II.3 - Procedure Change & Fifth Diesel

This enhancement is a combination of II.1 and II.2. It involves the provision of both the procedure for the crosstie of the 500kV grid to the Unit 1 shutdown boards and the fifth EDG.

Category III - Improve Ability To Cope With Loss of AC Power & Station Blackout

This category involves those enhancements which improve the ability of the plant to cope with an extended loss of offsite power or station blackout. While the Category II enhancements involved restoration of AC power, this category involves items which would make coping with loss of AC power less likely to lead to core damage and/or containment failure.

III.1 - Procedure Change To Utilize Existing Spare 6900V/480V Transformers

WBN Unit 1 has two additional spare 6900V/480V transformers which can be aligned to provide power to the 480V shutdown boards and MOV boards in the event one of the normal transformers fail. In the review of dominant split fractions from the IPE, it was identified that a procedure could be developed to assist plant operators in making the necessary bus/transformer alignments.

III.2 - Install Improved RCP Seals

One of the dominant contributors to the WBN core damage frequency (~21%) is station blackout. Many of the station blackout sequences involve overheating and failure of the RCP O-rings seals and depletion of primary system inventory prior to restoration of AC power for makeup. Westinghouse has recently begun to provide an improved RCP O-ring material which is made of elastomers which can withstand higher temperatures and have a higher likelihood of remaining intact under conditions such as station blackout. The expert elicitation performed as part of NUREG-1150 identified that seal with the improved O-rings would be roughly four times less likely to cause significant reactor coolant loss.

III.3 - Install Independent RCP Seal Cooling System

Another alternative to ensuring that the RCP seals remain intact and that the RCS inventory is sufficient to support secondary heat removal is to provide an alternative, AC independent RCP seal cooling system. At least two other Westinghouse plants have such a system. This enhancement involves the provision of a non-safety grade, independently powered (separate small EDG), independently cooled (non-CCS/ERCW) seal injection pump which could be manually actuated by the plant operators.

III.4 - Install Accumulators For Turbine Driven AFW Pump Flow Control Valves

Another contributor to loss of offsite power event sequences is loss of the turbine driven AFW pump due to loss of control air to the flow control valves to the steam generators. These valves are normally provided control air by the essential control air system which is EDG backed, but introduces additional dependencies for the AFW system. In the current design, if control air is lost, the plant operators must perform a local manual action to align nitrogen bottles to the AFW flow control valves and steam generator PORVs. This enhancement considers providing control air accumulators for the turbine driven AFW flow control valves, the motor driven AFW pressure control valves and the steam generator PORVs.

III.5 - Provide DC Load Shed Analysis & Procedure

The WBN DC power system is supported by four 125V vital batteries. In response to the Station Blackout Rule (10 CFR 50.63), it was determined that these batteries were sufficient as designed to cope for at least four hours under station blackout conditions. This enhancement involves the development of engineering analyses and procedures which would extend battery life by shedding unnecessary DC loads under station blackout conditions. The benefit of this enhancement is that it would allow operation of the turbine driven AFW pump for a longer period of time and would facilitate restoration of offsite power after 4 hours by ensuring availability of breaker control power.

III.6 - Provide Portable Battery Charger

This enhancement would provide a portable, diesel driven battery charger which would assure DC power would be available under station blackout conditions. The benefit of this enhancement is similar to item III.5, except the battery life could be extended essentially indefinitely.

III.7 - Install AC Independent Coolant Injection System

This enhancement would provide an AC independent coolant injection system which could be used under station blackout conditions (as well as others) to provide feed and bleed cooling of the RCS. The system evaluated included an independent emergency diesel generator, a pump and associated controls necessary to provide adequate makeup to the RCS.

Category IV - Improve Ability To Cope With Loss of RCP Seal Cooling

The third largest contributor to the WBN Unit 1 core damage frequency involves event sequences with loss of RCP seal cooling (non-station blackout). These sequences are characterized by simultaneous loss of RCP thermal barrier cooling and loss of seal injection. This category of enhancements includes items which would either improve RCP seal performance under such conditions or prevent failure of the seals altogether.

IV.1 - Install Improved RCP Seals

As described in enhancement III.2, Westinghouse has recently developed an improved O-ring for RCP seals which has a much lower likelihood of failure under loss of cooling conditions. However, such a modification would still require the plant operators to trip the RCPs before significant overheating of the seal occurred. The current RCP seals are assumed to lead to a small LOCA under loss of cooling conditions. This results in actuation of ECCS and containment spray and a need to initiate high pressure recirculation. However, many of the systems required to support RCP seal cooling (i.e., CCS, ERCW and charging) are used in high pressure recirculation. Improved seals could prevent containment spray actuation and allow a normal plant cooldown using AFW. The quantification of benefit of this enhancement includes both station blackout and non-station blackout events such as loss of CCS or loss of ERCW.

IV.2 - Install Independent RCP Seal Cooling System (w/o new EDG)

This enhancement is essentially identical to enhancement III.3. except it does not include one of the significant cost elements, the emergency diesel generator. Therefore, the quantified benefit of this enhancement includes only non-station blackout seal LOCAs.

IV.3 - Modify Charging Pump Cooling From CCS To ERCW

One of the key contributors to loss of RCP seal cooling is event sequences involving loss of CCS. The CCS system provides thermal barrier cooling to the RCPs and is the primary cooling medium for the centrifugal charging pumps (CCP) which provide seal injection. Consequently, when CCS is lost, RCP seal cooling is lost. One of the CCPs (1A-A) currently has the capability to be cooled by ERCW. This enhancement involves the provision of ERCW cooling to the other CCP.

Category V - Improve Containment Performance

As discussed in above, the WBN Level 2 PRA identified several containment failure mechanisms as primary contributors to release from containment. These mechanisms include late hydrogen burns, late overpressurization and basemat melt through. Additionally, containment bypass, although not strictly a containment issue, was identified as a key contributor.

V.1 - Install Deliberate Ignition System

This enhancement would provide a system to promote ignition of combustible gases generated within the containment during severe accident scenarios. This enhancement will reduce the vulnerability to SBO and other scenarios in which significant amounts of hydrogen are generated.

V.2 - Install Reactor Cavity Flooding System

This enhancement would provide a method to flood the reactor cavity region of the containment. The design of the reactor cavity in ice-condenser containments is such that the introduction of large quantities of water into the reactor cavity region and lower compartment can essentially preclude the possibility of direct contact of postulated ex-core hot debris with the containment liner and has potentially mitigating effects on corium-concrete interaction and direct containment heating. This enhancement will provide a means to inject a large quantity of water (on the order of the equivalent of two RWSTs) into the lower compartment and reactor cavity, and a capability of replenishing the water during boil-off.

V.3 - Install Filtered Containment Venting System

This enhancement would provide the capability to vent the containment through a vent path routed to an external filter. The filtered containment vent (FCV) would mitigate challenges to containment from long-term over-pressure and hydrogen burns by reducing the baseline containment pressure.

V.4 - Install Core Retention Device

This enhancement would provide a core debris control (CDC) system to prevent the direct impingement of core debris onto the primary containment steel shell during a high pressure core melt ejection (HPME) event. The CDC system would prevent the molten core material from contacting the containment shell by providing a barrier between the seal table and the containment shell in the seal table room. This enhancement will reduce the vulnerability of prompt containment failure for scenarios in which HPME may occur.

V.5 - Install Containment Inerting System

This enhancement would provide a containment inerting system (CIS) which would assure an inerted containment atmosphere to prevent the combustion of hydrogen and carbon monoxide produced during core damage scenarios. This enhancement will reduce the vulnerability of containment failure for scenarios in which the combustion of flammable gases may threaten containment integrity.

V.6 - Install Additional Containment Bypass Instrumentation

This enhancement involves the installation of pressure-monitoring instrumentation (permanent pressure sensors) between the first two pressure isolation valves on the low-pressure injection lines, RHR suction lines, and high-pressure injection lines. The additional instrumentation would improve the ability to detect valve leakage or open valves, and would decrease the frequency of Interfacing Systems Loss of Coolant Accident (ISLOCA). This enhancement will reduce the vulnerability to ISLOCA scenarios.

V.7 - Install Reactor Depressurization System

This enhancement would provide the capability to rapidly depressurize the reactor coolant system (RCS), thus allowing injection utilizing low-pressure systems. This would reduce the threat of direct containment heating (DCH) and induced failures of steam generator tubes and RCS piping in the event of low-pressure injection systems not being available. RCM depressurization could be

achieved by a system specially designed to manually depressurize the RCS or by actuation of existing pressurizer power-operated relief valves (PORVs), reactor vessel head vent valves, and secondary system valves.

V.8 - Install Independent Containment Spray System

This enhancement would provide an independent containment spray system. The spray system would cool the core debris and provide containment heat removal thus preventing over-temperature and long-term over-pressure by steam. This enhancement will reduce the vulnerability to SBO and other scenarios where steam overpressure and/or quench of core debris ex-vessel is important.

V.9 - Install AC Independent Air Return Fan Power Supplies

The containment system at Watts Bar includes two ARF each having 100% capacity. The design function of each ARF is to create forced recirculation from the upper containment to the lower containment which ultimately forces the air back up through the ice condenser again. This function serves to maximize the pressure suppression capabilities of the ice condenser, and promote mixing within the containment regions to prevent the accumulation of detonable concentrations of hydrogen within the containment. This enhancement will provide the ARF functions for accident scenarios in which normal operation is not possible, e.g., Station Blackout.

Category VI - Miscellaneous Enhancements

As part of the detailed review of the dominant contributors to core damage and containment failure, several other potential enhancements were identified.

VI.1 - Install MG Set Trip Breakers In Control Room (ATWS)

This enhancement would provide trip breakers for the MG sets in the WBN control room. In the current design, if an ATWS were to occur, the plant operators would be instructed to trip the MG sets which would require an immediate action outside the control room. This enhancement would simplify that action and decrease the risk of an ATWS event.

VI.2 - Improve Procedures To Provide Temporary HVAC During Loss of Room Cooling

Many rooms which contain ECCS, electrical and other key support equipment require room cooling to ensure availability of components. This enhancement involves the development of procedures to cope with loss of a room cooler by providing a temporary means of room cooling. Loss of an existing room cooler could lead to overheating of equipment and subsequent failure. However, depending upon the component, conditions and configuration failure could be delayed significantly (i.e., an hour or more). Thus, time could be available for plant operators to provide a temporary means of room cooling until the normal cooling could be restored.

Value Impact Analysis

The assessment of value impact requires the quantification of the benefit (i.e., value) and the costs (i.e., impact). The approach utilized in this assessment involves the quantification of benefits using the Level 2 PRA developed for the WBN Unit 1 IPE combined with site specific dose conversion factors to quantify the averted dose to the public which might be yielded by the proposed enhancement. The benefit assessments were generally biased in a conservative manner. That is, they were developed in a manner which identifies the maximum (or bounding) potential benefit. Specific descriptions of how the benefit of each enhancement was quantified are provided in Section 4.

The quantification of the cost of each enhancement was developed either from a site specific estimate or, for the major modifications, from industry and NRC data. In general, the site specific cost estimates are biased low in order to minimize the cost-benefit ratio. In addition, efforts were made to identify simple methods for accomplishing the site specific enhancements in order to minimize costs. Specific descriptions of how the cost estimates for each enhancement were quantified are provided in Section 4.

The results of the value impact analysis are presented in Table 5 in terms of the cost of the enhancement option (in 1994 dollars), the maximum benefit calculated (in person-rem over the life of the plant) and the cost benefit ratio (in $ per person-rem). It is generally accepted that cost to benefit ratios which are less than $1000 per person-rem should be considered cost-effective, unless unquantifiable factors indicate a strong reason to not perform the enhancement. Cost to benefit ratios in excess of $1000 per person-rem are generally considered non-cost beneficial.

Only two enhancements were identified as potentially cost beneficial: (1) the procedure change to stop one train of containment sprays and (2) the procedure change to facilitate

cross-tie of 500kV and 161kV AC power. Both of these enhancements are low cost and directly address dominant contributors to the WBN core damage risk profile. All of the other enhancement identified exceed the $1000 per person-rem criteria by more than a factor of 2 to 3, thus indicating that they are not cost beneficial. Many of the enhancements have cost to benefit ratios in excess of $10,000 per person-rem.

Conclusions

A comprehensive, systematic effort to identify potentially cost beneficial plant enhancement for Watts Bar Unit 1 has been completed. As a result, two potential plant enhancements are recommended for implementation. The first involves development of appropriate procedural guidance for incorporation into plant emergency operating procedures which would direct plant operators to place one train of containment spray in standby prior to establishing high pressure recirculation. This enhancement addresses the largest contributor to core damage, small LOCA with failure of ECCS recirculation, by providing additional time for operator actions to align high pressure recirculation and response to hardware failures.

The second enhancement involves the development of a plant procedure which would facilitate the cross-tie of 500kV offsite power to the 6.9kV shutdown boards at Unit 1. This procedure would provide an additional, diverse source of offsite power in the event of loss of the normal 161kV offsite power supply to the shutdown boards. This enhancement addresses the second largest contributor to core damage risk: station blackout.

All other potential enhancements were found to be non-cost beneficial.

TABLE 5

SUMMARY OF VALUE IMPACT RESULTS

ENHANCEMENT CATEGORY	IMPLEMENTATION OPTION	COST ($)	MAXIMUM RISK REDUCTION[1] (person-rem)	COST-BENEFIT RATIO ($/person-rem)
I - Improve Availability of ECCS Recirculation	1. Procedure Change To Stop One Train of Sprays	$25,200	34.2	**$737**
	2. Install Containment Spray Throttle Valves	>$200,000[2]	34.2	> $5,848
	3. Redesign To Delay Containment Spray Actuation	$406,470	34.2	$11,885
	4. Install Automatic High Pressure Recirculation	$2.1M	< 34.2	> $61,403
II - Improve Availability of AC Power	1. Procedure Change To Facilitate Cross-tie of 500kV and 161kV AC Power	$25,200	43.6	**$578**
	2. Accelerate Availability of Fifth Emergency Diesel Generator	$538,200	64.1	$8,396
	3. Procedure Change & Fifth Diesel	$563,400	70.6	$7,980
III - Improve Ability To Cope With Loss of AC Power & Station Blackout	1. Procedure Change To Utilize Existing Spare 6900V/480V Transformers	$25,200	5.2	$4,846
	2. Install Improved RCP Seals	$160,000	43.0	$3,721
	3. Install Independent RCP Seal Cooling System	$3.5M	52.3	$66,922
	4. Install Accumulators For Turbine Driven AFW Pump Flow Control Valves	$324,600	52.4	$6,195
	5. Provide DC Load Shed Analysis & Procedure	$113,200	43.0	$2,633
	6. Provide Portable Battery Charger	$131,800	43.0	$3,065
	7. Install AC Independent Coolant Injection System	$3.5M	65.0	$53,846
IV - Improve Ability To Cope With Loss of RCP Seal Cooling	1. Install Improved RCP Seals	$160,000	43.0	$3,721
	2. Install Independent RCP Seal Cooling System (w/o new EDG)	$2.16M	43.5	$49,655
	3. Modify Charging Pump Cooling From CCS To ERCW	$295,200	43.5	$6,786

TABLE 5

SUMMARY OF VALUE IMPACT RESULTS

ENHANCEMENT CATEGORY	IMPLEMENTATION OPTION	COST ($)	MAXIMUM RISK REDUCTION[1] (person-rem)	COST-BENEFIT RATIO ($/person-rem)
V - Improve Containment Performance	1. Install Deliberate Ignition System	$6.1M	21.4	$285,047
	2. Install Reactor Cavity Flooding System	$8.75M	65.0	$133,800
	3. Install Filtered Containment Venting System	$20.0M	65.0	$307,700
	4. Install Core Retention Device	$44.5M	61.6	$722,400
	5. Install Containment Inerting System	$10.9M	21.4	$509,300
	6. Install Additional Containment Bypass Instrumentation	$2.3M	0.8	$2,875,000
	7. Install Reactor Depressurization System	$4.6M	18.0	$255,600
	8. Install Independent Containment Spray System	$5.8M	61.7	$94,000
	9. Install AC Independent Air Return Fan Power Supplies	$1.0M	21.4	$46,700
VI - Miscellaneous	1. Install MG Set Trip Breakers In Control Room (ATWS)	$140,500	9.4	$14,947
	2. Improve Procedures To Provide Temporary HVAC During Loss of Room Cooling	$25,200	0.5	$50,400

NOTES:

(1) Based on 40 year plant life.

(2) No specific cost estimate developed for these enhancements. However, due to the nature of the design changes involved a reasonable lower bound cost estimate of $200,000 was assumed.

Section 1

INTRODUCTION

This report describes the effort undertaken to identify and evaluate potential enhancements of the Watts Bar Nuclear Plant (WBN). This evaluation is based in large part on the results and insights of the WBN Unit 1 Individual Plant Examination (IPE), but also accounts for other generic insights identified in other NRC and industry studies of severe accidents. The enhancement identification process was performed in a systematic manner in order to ensure that potential enhancements and different implementation options were not overlooked. The process consisted of:

- A systematic review and evaluation of the IPE results to determine plant enhancements that had a potential for reducing risk. All systems and functions currently modeled in the IPE were reviewed.

- A review of relevant published reports to identify "generic" enhancements which would address the dominant contributors of the WBN IPE.

- A value-impact analysis of those enhancements that were predicted to yield a substantial decrease in risk.

The report is divided into three major sections and is supported by three appendices. Section 2 provides an overview of the WBN IPE results, describes the dominant contributors to core damage and containment failure and establishes the major functional contributors to risk. Appendix A provides a listing of the top 100 core damage sequences from the IPE. Section 3 provides a description of the methodology and assumptions used in the identification and evaluation of potential enhancements. Appendix B provides discussion of each of the IPE model elements reviewed and the insights gleaned during the systematic review process. Appendix C provides a description of the approach taken to converting the Level 2 PRA results to population dose estimates required for the value impact analysis. Section 4 identifies the potential enhancements evaluated and provides a summary of the value impact analyses performed. Section 5 provides a summary of the results and conclusions.

Section 2
RESULTS CHARACTERIZATION

2.1 BACKGROUND

To provide a suitable basis and background for evaluation of potential enhancements, this section documents the work performed by the Tennessee Valley Authority (TVA) to update the Watts Bar Nuclear Plant Unit 1 Individual Plant Examination (IPE) (see Reference 20). The update consists of a revision of the Level 1 and Level 2 probabilistic risk assessment (PRA) based on the current plant design and operation. The original IPE submittal, made in September 1992, was based on the plant design, procedures and training in place in late 1991. Since that time numerous plant design changes, procedures upgrades, and training enhancements have been made in preparation for plant startup. The update reflects the anticipated plant configuration at commercial operation.

The major findings of the updated Watts Bar Level 1 PRA are presented in this section. These findings include the results of the Level 1 CDF quantification, identification of the principal contributors to core damage risk, and engineering insights into plant and operational features of Watts Bar that have been found to be important to safety as a result of the update.

2.2 RESULTS OF CORE DAMAGE FREQUENCY

Based on the updated design and operating understanding of the plant which reflects the plant at the time of plant startup, the mean point estimate CDF for Watts Bar was found to be 8.0×10^{-5} per reactor-year. Based on a review of the updated Level 1 PRA results and its contributors, no vulnerabilities were identified. The results for CDF were developed in terms of a mean point estimate, as required in NUREG-1335 (Reference 28).

The updated CDF is roughly a factor of four lower than the original IPE value of 3.3×10^{-4} per reactor year. The major changes to the plant model which resulted in this reduction are summarized in Reference 20.

The following table provides a comparison of the IPE results submitted to the NRC for each of the ice condenser plants. In terms of overall CDF, Table 2-1 shows that Watts Bar Unit 1 falls within the range of values reported for other plants.

Table 2-1
Comparison of Ice Condenser IPE Level 1 Results

Ice Condenser Plant	Mean CDF (per reactor-year)
Sequoyah 1,2 (Reference 29)	1.7×10^{-4}
Watts Bar 1 (Updated)	8.0×10^{-5}
DC Cook 1,2 (Reference 30)	6.3×10^{-5}
Catawba 1,2 (Reference 31)	4.3×10^{-5}

In order to better understand the results of a Level 1 PRA model, it is best to evaluate the contributors to overall CDF from several different perspectives. The following subsections describe the contributors in the following terms:

- Initiating Event Groups (Section 2.1.1)
- Dominant Sequences (Section 2.1.2)
- Top Events (2.1.3)
- Key Human Actions (Section 2.1.4)
- Key Plant Hardware Characteristics (Section 2.1.5)
- Key Plant Damage States (Section 2.1.6)

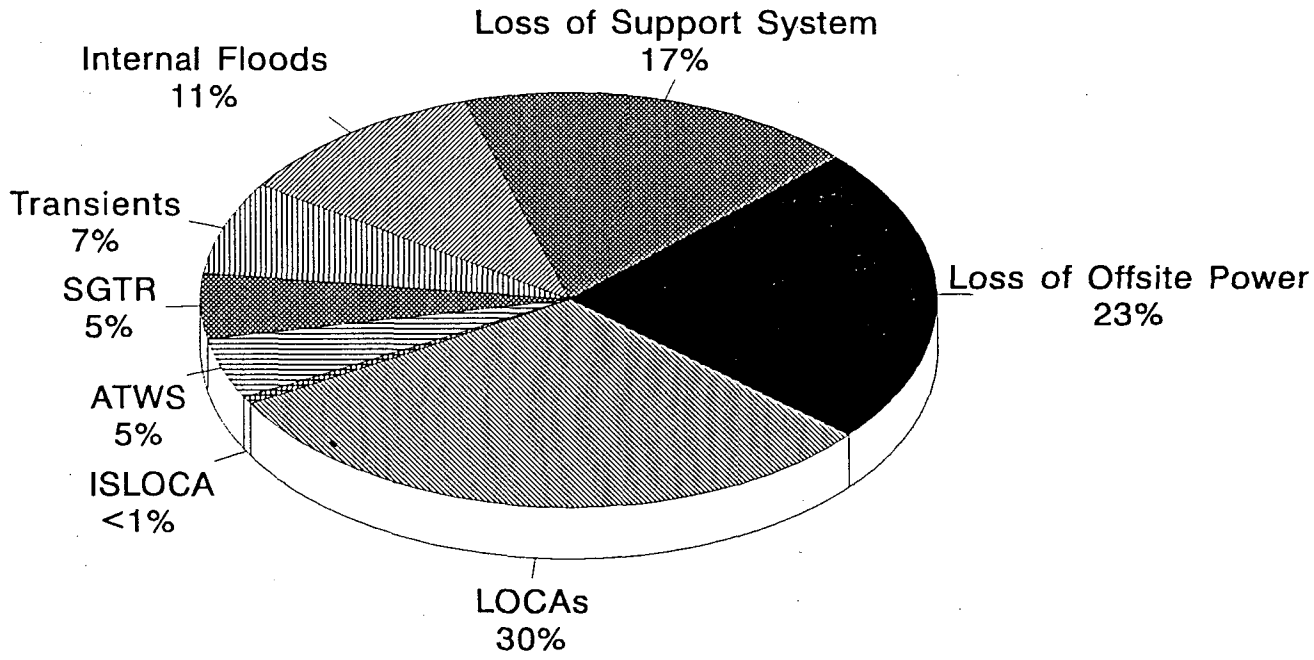
2.2.1 Initiating Event Groups

The importance of initiating events was examined by determining the contributions of core damage sequences grouped by initiating event. Consistent with the original IPE, the ranked results are shown in Figure 2-1 and Table 2-2 for eight major initiating event categories.

The general class of LOCAs accounts for approximately 30% of the total CDF. This class includes the following specific initiating events: small isolable LOCAs, small non-isolable LOCAs, medium LOCAs, large LOCAs, and excessive LOCAs (e.g., reactor pressure vessel failure). Sequences involving transient-induced LOCAs (e.g., stuck-open pressurizer PORV in response to a loss of main feedwater initiator) are included with the transient initiating event category. These events are primarily characterized by failure of the emergency core cooling systems (ECCS) in recirculation. These failures are due to either operator errors in aligning for recirculation or hardware failures in the recirculation systems.

Figure 2-1

CORE DAMAGE FREQUENCY CONTRIBUTORS BY INITIATING EVENT GROUP



Total Mean CDF = 8.0×10^{-5}/yr

TABLE 2-2

SUMMARY OF DOMINANT INITIATING EVENT CONTRIBUTIONS TO CORE DAMAGE FREQUENCY

INITIATING EVENT	FREQUENCY	NON-ATWS SEQUENCES		ATWS SEQUENCES		ALL SEQUENCES	
		CDF	%	CDF	%	TOTAL CDF	%
LOCAs						**2.29E-05**	**30.0%**
Small Non-Isolable LOCA (SLOCAN)	5.83E-03	1.71E-05	22.5%	3.08E-09	<0.1%		
Large LOCA (LLOCA)	2.03E-04	2.32E-06	3.0%				
Medium LOCA (MLOCA)	4.65E-04	1.79E-06	2.3%				
Small Isolable LOCA (SLOCAI)	2.30E-02	1.40E-06	1.8%	2.03E-08	<0.1%		
Excessive LOCA (ELOCA)	2.66E-07	2.66E-07	0.3%				
Loss of Offsite Power						**1.79E-05**	**23.5%**
Loss of Offsite Power (LOSP)	3.64E-02	1.78E-05	23.3%	1.21E-07	0.2%		
Steam Generator Tube Rupture						**3.88E-06**	**5.1%**
Steam Generator Tube Rupture (SGTR)	2.84E-02	3.84E-06	5.0%	3.52E-08	0.0%		
Internal Floods						**8.58E-06**	**11.3%**
Flood In ERCW Strainer Room 'A' (FLPH1A)	2.33E-03	4.04E-06	4.8%				
Flood In ERCW Strainer Room 'B' (FLPH1B)	2.33E-03	4.48E-06	5.4%				
Flood In Turbine Building (FLTB)	2.00E-02	5.27E-08	0.1%				
RWST Flood In Auxiliary Bldg. (FLAB3R)	3.20E-03	7.10E-09	<0.1%				
ERCW Flood In Auxiliary Bldg. (FLAB2)	4.20E-06	1.07E-09	<0.1%				
CST Flood In Auxiliary Bldg. (FLAB3C)	2.80E-05	9.75E-10	<0.1%				

TABLE 2-2
SUMMARY OF DOMINANT INITIATING EVENT CONTRIBUTIONS TO CORE DAMAGE FREQUENCY
(continued)

INITIATING EVENT	FREQUENCY	NON-ATWS SEQUENCES		ATWS SEQUENCES		ALL SEQUENCES	
		CDF	%	CDF	%	TOTAL CDF	%
Loss of Support Systems						**1.40E-05**	**18.4%**
Loss of 6.9kV Shutdown Board 1A-A (LASD)	3.03E-03	2.58E-06	3.4%	5.05E-08	0.1%		
Loss of 6.9kV Shutdown Board 1B-B (LBSD)	3.04E-03	6.06E-06	8.0%	1.75E-09	<0.1%		
Loss of All ERCW (ERCWTL)	1.63E-06	1.63E-06	2.0%				
Loss of Train 'A' Component Cooling (CCSA)	4.13E-03	1.08E-06	1.8%				
Loss of Vital Battery Board I (LVBB1)	5.97E-03	4.53E-07	0.6%	1.15E-07	0.2%		
Loss of Vital Battery Board II (LVBB2)	5.79E-03	4.35E-07	0.6%	1.12E-07	0.1%		
Loss of All Component Cooling (CCSTL)	1.30E-05	3.45E-07	0.5%				
Loss of Support Systems (Continued)							
Loss of 1-I Vital AC Instrument Board (LDAAC)	1.19E-01	2.71E-07	0.4%	4.74E-08	0.1%		
Loss of 1-II Vital AC Instrument Board (LDBAC)	1.19E-01	2.93E-07	0.4%	4.81E-08	0.1%		
Loss of 1-III Vital AC Instrument Board (LDCAC)	1.16E-01	1.68E-07	0.2%	3.04E-08	<0.1%		
Loss of 1-IV Vital AC Instrument Board (LDDAC)	1.15E-01	1.01E-07	0.1%	2.94E-08	<0.1%		
Loss of Train 'A' ERCW (ERCWA)	7.02E-05	1.07E-07	0.1%				
Loss of Train 'B' ERCW (ERCWB)	7.12E-05	1.21E-07	0.2%				

TABLE 2-2
SUMMARY OF DOMINANT INITIATING EVENT CONTRIBUTIONS TO CORE DAMAGE FREQUENCY
(continued)

INITIATING EVENT	FREQUENCY	NON-ATWS SEQUENCES		ATWS SEQUENCES		ALL SEQUENCES	
		CDF	%	CDF	%	TOTAL CDF	%
Transients						**8.86E-06**	**11.6%**
Partial Loss of Main Feedwater (PLMFW)	1.13E+00	1.27E-06	1.7%	1.86E-06	2.4%		
Turbine Trip (TTIE)	1.07E+00	1.19E-06	1.6%	3.45E-07	0.5%		
Reactor Trip (RTIE)	1.35E+00	1.53E-06	2.0%				
Excessive Main Feedwater (EXMFW)	1.68E-01	4.04E-07	0.5%	2.41E-07	0.3%		
Total Loss of Main Feedwater (TLMFW)	1.62E-01	3.92E-07	0.5%	2.29E-07	0.3%		
Loss of Primary Flow (LRCP)	1.76E-01	4.26E-07	0.6%	4.52E-08	0.1%		
Loss of Condenser Vacuum (LOCV)	1.18E-01	2.83E-07	0.4%	1.57E-07	0.2%		
Inadvertent Safety Injection (ISI)	2.99E-02	1.90E-07	0.2%	3.68E-08	<0.1%		
Inadvertent Closure of All MSIVs (IMSIV)	1.93E-02	5.09E-08	0.1%	3.08E-08	<0.1%		
Inadvertent Closure of One MSIVs (MSIV)	8.66E-02	7.40E-08	0.1%	2.22E-08	<0.1%		
Steam Line Break Outside Containment (SLBOC)	6.04E-03	3.32E-08	0.1%	3.18E-09	<0.1%		
Steam Line Break Inside Containment (SLBIC)	4.65E-04	1.71E-08	<0.1%				
Inad. Opening of Main Steam Relief Valve (MSVO)	4.19E-03	2.22E-08	<0.1%	2.21E-09	<0.1%		
Core Power Excursion (CPEX)	2.68E-02	1.58E-08	<0.1%				
Interfacing Systems LOCA						**4.99E-08**	**0.1%**
Interfacing System LOCA In RHR Suction (VS)	7.20E-06	4.68E-08	0.1%				
Interfacing System LOCA In RHR Injection (VI)	4.00E-06	3.10E-09	<0.1%				

LOSP is the next largest contributor to the overall CDF. These sequences contribute roughly 23% to the total CDF. The predominant contributor to LOSP core damage sequences are unit blackout sequences with failure to recover power before core damage.

The general class of support system faults accounts for approximately 18% of the total CDF. Included in this grouping are system and system train failures involving electrical power boards, CCS, and essential raw cooling water (ERCW).

Internal floods make up about 11%. The most important sources of internal floods are associated with a rupture or major flow diversion in one ERCW train combined with failure of the other train. Many of these sequences are effectively a total loss of ERCW. ERCW is an important support system since it provides the ultimate heat sink for reactor coolant pump (RCP) seal cooling and ECCS pump cooling. Thus, a complete loss of ERCW results in an RCP seal LOCA with inadequate coolant makeup capability.

The transient events contribute approximately 7% to the total CDF. These events are generally characterized by subsequent support system failures which lead to a sufficient number of failures in frontline systems to lead to loss of core cooling.

SGTR events contribute roughly 5% to the total CDF. The SGTR event sequences are characterized by failure to adequately control reactor coolant inventory due to operator errors and hardware failures.

Sequences without reactor trip (ATWS) contribute approximately 5%. Such sequences may lead to core damage if the initial reactor coolant system (RCS) pressure transient is not mitigated or emergency boration is not accomplished in a timely manner.

Interfacing system LOCAs make up only a very small part of the total CDF (much less than 1%). However, should they lead to core damage, these initiators are significant because of their potential for a large release path to bypass the containment.

Table 2-3 provides a summary of some of the dominant accident sequence types contributing to the overall CDF.

Table 2-3 Accident Sequence Types Contributing to Core Damage		
Accident Sequence Type	**Frequency per Reactor-Year**	**Percent of Total CDF**
Small LOCA With Failure of Recirculation	**1.4×10^{-05}**	**~17**
Small LOCA With Hardware Failures Causing Failure of High Pressure Recirculation	1.0×10^{-05}	~12%
Small LOCA With Operator Failure To Align High Pressure Recirculation	3.5×10^{-06}	~4%
Station Blackout	**1.7×10^{-05}**	**~21%**
Long Term SBO With Failure To Recover Power Before Core Damage	1.3×10^{-05}	~16%
Short Term SBO (i.e., with failure of the turbine driven AFW pump) With Failure To Recover Power Before Core Damage	4.3×10^{-06}	~5%
Loss of All ERCW	**2.5×10^{-06}**	**~3%**
Pipe Break or Significant Flow Diversion In An ERCW Strainer Room (Train 'A' or 'B') With Independent Failure of Other Train Leading To Failure of RCP Seals and Failure of ECCS	2.3×10^{-07}	~1%
Loss of All ERCW As Initiating Event Leading To Failure of RCP Seals and Failure of ECCS	2.3×10^{-06}	~3%

2.2.2 Analysis of Individual Sequences

No single core damage sequence was found to dominate the total frequency of core damage. In fact, the largest individual core damage sequence contributes only 3.8×10^{-6} per reactor year to the total CDF (<5% of the total CDF). As is typical with linked event tree PRAs, a large number of sequences make up the total CDF. Table 2-4 provides information on the distribution of core damage sequences across the frequency range.

Table 2-4
Breakdown of Core Damage Sequences in Each Frequency Range

Frequency Range (events per year)	Number of Sequences	Percentage of CDF
$> 10^{-5}$	0	-
10^{-6} to 10^{-5}	9	30%
10^{-7} to 10^{-6}	95	33%
10^{-8} to 10^{-7}	603	21%
10^{-9} to 10^{-8}	3154	11%
$< 10^{-8}$	Very Large Number	3%

Review of individual sequences can provide additional insight. However, since so many sequences are involved, it is easier to understand and characterize the results in terms of groups of sequences having similar characteristics or similar functional failures. Table A-1 provides a listing of the top 100 sequences generated by RISKMAN. This table provides a description of the initiating event and random failures (i.e., those plant/system failures caused by the combination of initiating event and random failures), the plant damage state (or end state) the sequence was assigned, the CDF associated with the sequence and the percentage contribution of the sequence to the total CDF. These top 100 sequences constitute about 62% of the total CDF and range in value from 3.8×10^{-6} per reactor-year to 1.2×10^{-7} per reactor-year. The following discussion provides a summary of the dominant functional event sequence groups which are represented in the top 100 sequences listed in Table A-1 and provides a cross-reference to the individual event sequences in each group.

- **Small LOCA Initiating Events with Failure at Recirculation or Loss of Recirculation Cooling**. Core damage from these sequences occurs when the shift to high-pressure recirculation is required during a small LOCA initiating event. The ice-condenser containment design results in a need for containment spray actuation from all but the smallest of LOCA initiators. Containment spray actuation

empties the refueling water storage (RWST) in less than one hour with a resulting need for realignment of the injection systems for long term recirculation from the containment sump through the low pressure injection pumps (the RHR pumps) to the high pressure injection pumps (safety injection and charging) and to the RCS loops. The low pressure to high pressure crossover valves are paralleled so that either RHR pump can supply any high pressure injection pump. One RHR pump and one high pressure injection pump operating in the recirculation mode is all that is necessary for success. A portion of the switchover to sump recirculation is automatic, opening the containment sump isolation valves and closure of the RHR pumps suction from the RWST. The opening of the low pressure to high pressure crossover valves from the RHR pumps to the high pressure pumps is manual and is covered by plant Emergency Operating Procedure (EOP), ES-1.3.

Failure of the alignment can be caused by failure of the low pressure to high pressure crossover valves to open, combinations of failure of one RHR pump train or sump switchover train and the other crossover path, failure of both RHR pump trains or both sump switchover trains, failure of the high pressure pump trains, or failure of operator action. Failure of the high pressure recirculation top event, RR, with all support available is 1.6×10^{-3}. The operator error frequency assigned to this action with all support available is 5.3×10^{-4} (HARR1). The dominant cause of failure of the RR top event with all support available is common cause failure of the crossover MOVs to open. Because of the limited time available to complete the switchover prior to RWST emptying, the IPE assumes that operator action to manually open the failed closed MOVs is not taken.

During the short injection phase of LOCA response, the IPE assumes that the RHR pumps must operate in the mini-flow mode for small and medium LOCAs. This mode requires that the MOV in the RHR recirculation path open. Failure of the RHR pump mini-flow valve to open results in pump failure in a short period of time. Operator action to make-up to the RWST following early failure of the RHR pumps is included in top event MU. Because of the limited time available for makeup to be established, this operator action has a failure frequency of 4.4×10^{-1}.

Part of the realignment for sump recirculation requires the initiation of CCS to the RHR heat exchangers. Failure of the alignment of CCS to the RHR heat exchangers or combination of failure of CCS and RHR pump trains will result in failure of the injection pumps in the recirculation mode due to the high temperature of the containment sump water. No credit is taken for the heat removal capacity of the containment spray heat exchangers which are cooled by the ERCW system. In the Level 2 analysis, this sequence class was evaluated using the Modular Accident Analysis Program (MAAP) (Reference 33) thermal-hydraulic analysis program. Given a successful cooldown by the operators, MAAP shows that core

damage would not occur due to failure of high pressure recirculation, provided that the RHR pumps operate for low pressure recirculation from the sump. The accumulator inventory keeps the core covered while the RCS cools down and depressurizes sufficiently for low pressure recirculation. These sequences are assumed to be arrested within the vessel for the Level 2 analysis.

In the top 100 sequences, sequences 1, 3, 5, 31, 32, 38, 39, 45, 46, 49, 53, 55, 59, 60, 63, 65, 69, 75, and 85 represent the effects of the failures described above.

- **LOSP and Loss of AC Power to Vital Buses**. Sequences caused by LOSP and failure to restore power to the vital AC buses are usually referred to as "Station Blackout (SBO)" sequences. Four 6.9kV vital shutdown boards are provided for the two Watts Bar units, two for Unit 1 loads and two for the Unit 2 loads. Because several of the necessary support systems at Watts Bar Unit 1 are shared between the two units, all four 6.9kV shutdown boards are included in the Watts Bar model. For the purposes of the IPE, SBO events are defined as loss of power on a minimum of two Unit 1 6.9kV shutdown boards, 1A-A and 1B-B.

  The support system model includes a top event, OGR1, that models the likelihood of power restoration within one hour of the LOSP initiating event. A power recovery event tree is included in the Watts Bar IPE to account for the likelihood of power recovery after one hour but prior to core damage for various SBO sequences. SBO events usually are a result of the LOSP initiating event and failures of the emergency diesel generators (EDGs) and failure to restore power to the shutdown buses prior to core damage.

  With no power at the vital shutdown boards, a RCP seal LOCA can eventually develop and worsen until each pump seal is leaking at up to 480 gpm. However, the likelihood of core damage is affected by a number of factors:

  - Availability of the AC-Independent Turbine Driven AFW Pump
  - Operator action to depressurize the steam generators to reduce RCS pressure and temperature and limit the challenge to RCP seals
  - The combination of EDG failures which lead to the SBO condition (i.e., failure to start or failure during 24 hours of operation)
  - The size of the RCP seal LOCA assumed. (The IPE used a plant-specific adaptation of the NUREG-1150 expert panels probabilistic model).

Each of these factors is accounted for in the assessment of the amount of time available for AC power recovery.

Sequences involving failure of the turbine driven AFW pump will eventually result in no decay heat removal from the RCS. Water remaining in the steam generators after the plant trip will be relieved through the steam generator PORVs until all inventory is exhausted. At this point, the RCS temperature will increase, RCS pressure will increase due to the increasing pressurizer level, eventually lifting the pressurizer PORVs. Operation of the pressurizer PORVs will continue until the RCS inventory loss uncovers the core and core damage occurs. The IPE assumes that core damage will occur within two hours under SBO conditions with no AFW turbine driven pump.

Loss of power is dominated by failure of the EDGS, represented by top events GA and GB for Unit 1 and GC and GD for Unit 2. Failure of the 6.9kv supply breakers to open and/or close to effect bus stripping and to the allow EDGs to supply power is the next most likely failure. These failures are modeled by top events AA and BA for Unit 1 and AB and BB for Unit 2. Loss of ERCW to the EDGs results in rapid (less than 5 minutes assumed in the IPE) failure of the EDGs. Loss of ERCW is modeled by top events AE and BE which represent the Train A and Train B ERCW supply.

In the top 100 sequences, sequences 9, 11, 12, 13, 15, 21, 22, 23, 25, 33, 36, 41, 50, 51, 54, 66, 67, 76, 77, 78, 79, 80, 83, 86, 88, 90, 91, 93, 96, and 98 represent the effects of the failures described above. The primary differences among the sequences are the timing of core damage (turbine driven AFW pump operating or failed), and the combinations of EDG, 6.9kV shutdown board and diesel support system failures which affect the likelihood of recovery prior to core damage.

- **Internal Floods Leading to Core Damage**. The internal floods included in the Watts Bar IPE result in a Unit trip and failure of one or more of the systems necessary to mitigate the consequences of the flood. Pipe break or significant diversion in ERCW supply header 1A-A, FLPH1A, and supply header 1B-B, FLPH1B, are the dominant floods in the IPE. The flood location assumed for FLPH1A and FLPH1B is the ERCW strainer room for the affected supply header. The flood results in loss of one of the two ERCW supply headers to Unit 1 at Watts Bar. Any failure that affects the other ERCW supply header or components cooled by that header result in core damage because of the loss of long term plant heat removal.

Sequences 6, 7, 17, 19, 27, 35, 71, 84, 87, 92 and 94 in the top 100 sequences include the flood initiators FLPH1A and FLPH1B and failures of opposite train equipment.

- **Steam Generator Tube Rupture.** SGTR sequences appear in most IPE dominant sequence lists because the SGTR event response requires a higher level of operator involvement in the sequence than is typical for most initiators. Failure of the operators to depressurize the RCS is assumed to result in loss of all RWST inventory through the broken tube to the environment through the steam generator PORVs or safety valves. Loss of the RWST results in failure of the high pressure injection pumps and loss of RCS make-up, eventual core uncovery and core damage. The plant EOPs provide several alternative paths for RCS depressurization with and without steam generator cooling and/or high pressure injection. Makeup to the RWST will allow continued operation of the high pressure injection pumps while RCS depressurization continues.

  Top event MU models the operator action to refill the RWST during a SGTR event, the frequency of operator failure under normal conditions is 2.5×10^{-2} (HAMU1). Top event DS models the operator actions to isolate the leaking steam generator and depressurize the RCS to stop the leak and mitigate the SGTR. The frequency of operator failure for this top under normal conditions is 3.1×10^{-3} (HADS2). Top event SL models the operator actions and plant equipment necessary to isolate the affected steam generator, the top event frequency of failure under normal conditions is 5.1×10^{-2} to which the operator contribution is 1.7×10^{-3}.

  Sequences 8, 47, 56, and 100 of the top 100 sequences represent typical SGTR sequences.

- **Support System Initiators, Loss of ERCW.** Three initiators model the contribution to core damage from failure of the ERCW system at Watts Bar. ERCWTL reflects the likelihood of failure of the entire ERCW system. ERCWA and ERCWB represents the failure of ERCW Header 1A-A and ERCW header 1B-B at Watts Bar Unit 1, respectively. Eight ERCW pumps are provided to supply cooling to essential and non-essential plant equipment at Watts Bar Units 1 and 2. Four pumps supply the A headers at Units 1 and 2 and four pumps supply the B headers at Units 1 and 2. ERCW provides cooling for the CCS heat exchangers, the EDGs, the containment spray heat exchangers, and various other essential and non-essential plant equipment. Loss of ERCW Header 1A-A requires operator action cross-tie the loads normally supplied by this header to ERCW header 2B-B, failure to cross-tie, or loss of header 1B-B results in loss of cooling to Train A essential equipment. Loss of ERCW header 1B-B requires operator action to cross-tie the loads normally supplied by this header to ERCW header 2A-A,

including cooling water to the A Train CCS heat exchanger. Failure to cross-tie, or loss of header 2A-A results in loss of cooling to Train B essential equipment. The models for the ERCW header failure initiating events assumes the other ERCW header is available unless failed by support system failure (e.g. loss of power). This is to avoid double counting with the total loss of ERCW initiator (ERCWTL). Loss of the ERCW system is assumed to result in core damage due to the loss of the heat sink. Sequence 9 of the top 100 sequences represent loss of the ERCW system.

- **Support System Initiators, Loss of CCS**. Initiating events CCSTL and CCSA represent failure of the CCS (CCSTL) or failure of Train A of the CCS (CCSA). The CCS provides cooling for essential and non-essential equipment and Watts Bar Units 1 and 2. Five pumps and three heat exchangers are provided for the CCS. Two pumps and one heat exchanger supply the Unit 1 Train A loads which includes Train A ECCS pump seal and oil coolers, Train A RHR heat Exchanger, the RCP motor bearing oil coolers, and the RCP thermal barrier cooling booster pumps. One pump and heat exchanger supplies the Train B loads at Units 1 and 2, which includes the Train B ECCS pump seal and oil coolers and the Train B RHR heat exchanger. The remaining CCS pumps and heat exchanger supply the Unit 2 Train A CCS loads. Loss of CCS Train A (CCSA) will require operator action to restore header flow or to trip the RCPs within ten minutes (minimum). If charging pump 1A is operating, operator action to start the Train B charging pump, if available, and align backup ERCW to the charging pump oil coolers is required. Failure to trip the RCPs within 10 minutes is assumed to result in an RCP seal LOCA. Failure to restore cooling to the A charging pump within 10 minutes, if operating, is assumed to result in pump failure. Loss of the entire CCS (CCSTL) results in similar required operator actions, however the Train B charging pump is assumed to unrecoverable. The operator action to trip the RCPs is included in top event SE in the plant model.

  Sequences 20, 61 and 70 are the CCS initiator related sequences in the top 100 sequences. Sequences 20 and 61 represent the timing questions associated with aligning ERCW to the operating centrifugal charging pump (CCP) (assumed to be 1A-A). Sequence 70 models CCSA with failure to trip the RCPs prior to pump seal damage and failure to complete the necessary switchover to containment sump recirculation under single train conditions.

- **Support System Initiators, Loss of a Single 6.9kV Shutdown Board**. Initiating events LASD and LBSD model the loss of 6.9kV Shutdown Board 1A-A and 1B-B respectively. Loss of a single shutdown board is assumed to result in a plant trip and fails one train of equipment necessary to respond to the trip. LOSP is not guaranteed as a result of these initiators which allows the other unit shutdown

board to remain energized from its normal source of power. Sequences which lead to core damage as a result of these initiators usually have failure of power in the opposite train from causes other than LOSP (e.g. 480V shutdown board failures A1, A2, B1, B2). The progression to core damage is similar to that described for the LOSP sequences previously. Sequences 26, 28, 29, 40, 42, 43, 44 and 74 of the top 100 sequences include failures of 6.9kV shutdown boards A or B and additional support system failures in the other train.

Additional sequences relating to loss of power at a single shutdown board and failure to realign ERCW to the 1A-A CCP are important due to the plant configuration and operating procedures. If, cooling is lost to CCP 1A-A, either directly through loss of CCS Train A or indirectly through loss of cooling to CCS Train A heat exchanger, the operators are directed to start CCP 1B-B, if available, secure CCP 1A-A, and align ERCW to CCP 1A-A. This ensures continued flow to the RCP seals through the seal injection system. If CCP 1B-B is not available, the operators will not secure CCP 1A-A while aligning ERCW to the pump. Human error HCCSR4, was developed to reflect the likelihood of successfully completing this action prior to CCP 1A-A failure due to loss of oil cooling. Sequences 48, 62, and 82 model these functional failures.

- **Large LOCA Initiator**. The design basis large LOCA event is the basis for the IPE model of the Large LOCA initiator (LLOCA). This LOCA requires: Successful injection by at least one low pressure injection train (RHR pumps), top events RA and RB; injection by three of four accumulators (three of three on intact RCS loops), top event LCL; successful switchover to containment sump recirculation, top events RR, RVA and RVB; and alignment to RCS hot leg recirculation at approximately 18 hours, top event RH. Successful operation of the high pressure injection pumps is assumed to be insufficient to prevent core damage.

  Sequences 10, 14 and 81 are included in the top 100 sequences and model LLOCA core damage sequences.

- **Excessive LOCA Initiator**. The beyond design basis large LOCA event is included in the IPE for completeness. Core damage is guaranteed as a result of this event. One sequence, 52, is included in the top 100 sequences.

- **Medium LOCA Initiator**. The medium LOCA (MLOCA) is the upper range of the FSAR small LOCA category. This size reflects the need for successful high pressure injection but only low pressure recirculation. This category of LOCA requires: Successful injection by at least one low pressure injection train (RHR pumps), top events RA and RB; injection by two of four high pressure injection pumps, top events S1, S2, VA and VB; injection by two of four accumulators (two

of three on intact RCS loops), top event CL; successful switchover to containment sump recirculation, top events RR, RVA and RVB; and long term operation of RHR in sump recirculation, are required for successful mitigation of a Medium LOCA.

Sequences 16, 37, and 58 are included in the top 100 sequences and model MLOCA core damage sequences.

- **Small LOCA Initiators with Failure of Actuation**. Given the stress associated with any LOCA event, failure of the actuation system and failure of the operator to respond in a short period of time (less than 10 minutes) to start or restart equipment is included in the top 100 sequences, only sequences 73 and 89 reflects this condition.

- **Other Plant Initiators, General Transients**. Plant response to a general transient initiating event depends somewhat on the type of initiator, however, some functions are always required: Reactivity control - successful reactor trip, or operator action to insert control rods or emergency borate and successful response to the pressure challenge; core decay heat removal - usually through the operation of the main condenser bypass valves or the steam generator PORVs, with feedwater from AFW; with a failure of steam generator cooling, operator initiation of feed and bleed, starting the safety injection pumps and opening at least one of two pressurizer PORVS can successfully remove core decay heat; and maintenance of RCP seal integrity requires successful operation of the thermal barrier cooling or seal injection from the coolant charging system. Other functions may be necessary depending on the specific initiator.

  Sequences 24, 30, 34, 64, 68, and 95 represent typical core damage sequences resulting from a general transient initiator.

- **Other Plant Initiators, Anticipated Transients without Scram**. Anticipated Transients without Scram (ATWS) challenge RCS integrity, reactivity control, core heat removal, etc. ATWS events start with a requirement for reactor scram actuation, but because of function failures, the reactor trip is not completed. Westinghouse, in WCAP-11993 (Reference 34) has analyzed the plant response to a failure scram when required. Failure to scram, modeled by top event RT, is dominated by common cause failure of the reactor trip breakers to open given a scram signal is present. Operator action to manual insert control rods, top event MR, operator action to emergency borate, including manual trip of the control rod drive motor-generator sets (MGs), top event EB, reactor power level less than 40%, top event PL, AMSAC mitigation actuation, top event AM, primary pressure relief, top event SR, main feedwater (MFW) availability, top event FW, and AFW availability, top events, MA, MB, TP, and AF, all affect plant response to an ATWS

event. If power level is greater than 40%, MFW is unavailable, and the primary relief function fails, core damage is assumed to occur. Sequence 18 represents this type of core damage sequence initiated by a partial loss of MFW. Failure of the operator actions or equipment modeled in top event EB are assumed to lead to core damage due to loss of coolant inventory. Sequence 72 represents scram failure with failure of emergency boration action. Sequences 97 and 98 represent failures of the reactor trip function after a loss of MFW initiating event with power level greater than 40% and failure of one of two motor driven AFW pumps. The model assumes that core damage results from the resulting high RCS pressure.

2.2.3 Top Event Importances

Another perspective of the underlying contributors to risk can be gained by evaluating various importance measures of the individual event tree branch point probabilities, or split fractions, that are evaluated in this study. One importance measure often used is computed by determining the percentage contribution to the total CDF made by all sequences grouped by common failed split fractions. This is in contrast to the look at individual sequences in the previous section.

The accident sequence model contains two types of split fractions: guaranteed failure (GF) split fractions, whose failure frequency is set to equal 1.0 because of functional dependencies on other equipment or operator actions that has already failed in the same accident sequence, and nonguaranteed failure (NGF) split fractions; i.e., those whose split fraction values are other than 1.0.

All of the split fractions for a particular top event can be grouped into one of these two categories. The importance rankings for these groups of split fractions are evaluated separately because the evaluation of each group has different risk management implications. The importance of the highest ranked top events for each group of split fractions is described below.

The risk contribution from guaranteed failed split fractions results from the dependencies between systems and between multiple operator actions; i.e., if the first event fails, the second is then guaranteed to occur. The risk contribution of guaranteed failed split fractions is not associated with the reliability characteristics of the associated system. To reduce or eliminate the importance of these split fractions, it is necessary to attack the dependencies of the important system on the other systems whose failure triggered the guaranteed value.

The most important guaranteed failed split fractions are summarized in Table 2-5.

The first five split fractions in Table 2-5 represent switches used in the event trees to reflect pre-existing conditions at a particular point in the event tree and do not present any single system.

The highest ranking guaranteed failed function in REC. REC models operator actions to recover failed sequences prior to core damage. The only sequences currently recovered in the Watts Bar IPE using top event REC are the LOSP sequences where offsite power can be recovered prior to core damage.

The highest ranked system top event for the importance of guaranteed failed split fractions is Top Event SE. Top Event SE represents the challenge to the integrity of the RCP seals. This Top Event is guaranteed to be failed for any SBO event or non-isolable LOCA initiator. As LOSP initiated SBO sequences and SLOCA sequences contribute 55% to the CDF, it is not surprising that this guaranteed failure should be so important. The next most important guaranteed failed top event split fraction is Top Event TB. This top event models the RCP thermal barrier cooling system. This top event also reflects the importance of LOSP generated SBO sequences and the SLOCA sequences which result in loss of thermal barrier cooling due to the phase B isolation signal.

The importance evaluation of the non-guaranteed failure split fractions is summarized in Table 2-6. For these split fractions, it is possible to change the CDF by changing the reliability characteristics of the associated system. For this group of split fractions, five different importance measures are used:

> Fraction Importance: The fraction of the CDF which is due to events sequences containing the split fraction.
>
> Fussel-Vesely Importance: The fraction of the CDF which would be eliminated if this failure were eliminated (i.e., guaranteed success).
>
> Birnbaum Importance: The ratio of the difference between the CDF with the split fraction assumed failed and assumed successful to the base CDF.
>
> Achievement Worth: The ratio of the CDF with the split fraction assumed failed (i.e., set equation to 1.0) to the base CDF.
>
> Reduction Worth: The ratio of the CDF with the split fraction assumed successful (i.e., set equal to 0.0) to the base CDF.

Each of the measures is presented in Table 2-6, along with the split fraction values used in the event tree quantification and the frequency of all core damage sequences that involve failure of the split fraction.

TABLE 2-5
Guaranteed Failed Split Fractions Sorted by Importance (RISKMAN Generated)

MODEL Name: WBN-UPDATE
Split Fraction Importance
Sorted by Fraction Importance

	SF Name	Fraction Importance	Fussel-Vesely Importance	Birnbaum Importance	Achievement Worth	Reduction Worth	Frequency
1	MELTF	1.0000E+00	n/a	n/a	1.0000E+00	n/a	7.6176E-05
2	INTPRF	9.3888E-01	n/a	n/a	1.0000E+00	n/a	7.1520E-05
3	RHRSF	9.1196E-01	n/a	n/a	1.0000E+00	n/a	6.9469E-05
4	MELTIF	9.0058E-01	n/a	n/a	1.0000E+00	n/a	6.8603E-05
5	IYAF	9.0037E-01	n/a	n/a	1.0000E+00	n/a	6.8587E-05
6	RECF	8.3568E-01	n/a	n/a	1.0000E+00	n/a	6.3659E-05
7	SEF	7.6049E-01	n/a	n/a	1.0000E+00	n/a	5.7931E-05
8	TBF	7.4943E-01	n/a	n/a	1.0000E+00	n/a	5.7089E-05
9	RRF	6.8208E-01	n/a	n/a	1.0000E+00	n/a	5.1958E-05
10	CMF	6.6760E-01	n/a	n/a	1.0000E+00	n/a	5.0855E-05
11	CSBF	6.5684E-01	n/a	n/a	1.0000E+00	n/a	5.0035E-05
12	CSRF	6.4245E-01	n/a	n/a	1.0000E+00	n/a	4.8939E-05
13	CSAF	6.4217E-01	n/a	n/a	1.0000E+00	n/a	4.8918E-05
14	CHF	6.3350E-01	n/a	n/a	1.0000E+00	n/a	4.8257E-05
15	DPF	6.3063E-01	n/a	n/a	1.0000E+00	n/a	4.8039E-05
16	CSIF	6.2331E-01	n/a	n/a	1.0000E+00	n/a	4.7481E-05
17	CAVF	6.1706E-01	n/a	n/a	1.0000E+00	n/a	4.7005E-05
18	RBF	6.0918E-01	n/a	n/a	1.0000E+00	n/a	4.6405E-05
19	S2F	6.0918E-01	n/a	n/a	1.0000E+00	n/a	4.6405E-05
20	VBF	6.0110E-01	n/a	n/a	1.0000E+00	n/a	4.5789E-05
21	S1F	5.9588E-01	n/a	n/a	1.0000E+00	n/a	4.5392E-05
22	RAF	5.9588E-01	n/a	n/a	1.0000E+00	n/a	4.5392E-05
23	SIF	5.7777E-01	n/a	n/a	1.0000E+00	n/a	4.4012E-05
24	VCF	5.7759E-01	n/a	n/a	1.0000E+00	n/a	4.3998E-05
25	DSF	5.7561E-01	n/a	n/a	1.0000E+00	n/a	4.3848E-05
26	VAF	5.4797E-01	n/a	n/a	1.0000E+00	n/a	4.1742E-05
27	MUF	4.3208E-01	n/a	n/a	1.0000E+00	n/a	3.2914E-05
28	MBF	4.1474E-01	n/a	n/a	1.0000E+00	n/a	3.1593E-05
29	MAF	4.0759E-01	n/a	n/a	1.0000E+00	n/a	3.1049E-05
30	MSF	3.5645E-01	n/a	n/a	1.0000E+00	n/a	2.7153E-05
31	B1LF	3.5247E-01	n/a	n/a	1.0000E+00	n/a	2.6850E-05
32	RVBF	3.5140E-01	n/a	n/a	1.0000E+00	n/a	2.6768E-05
33	VT1BF	3.4209E-01	n/a	n/a	1.0000E+00	n/a	2.6059E-05
34	PDF	3.2107E-01	n/a	n/a	1.0000E+00	n/a	2.4458E-05
35	ACF	3.1192E-01	n/a	n/a	1.0000E+00	n/a	2.3761E-05
36	A1LF	2.8387E-01	n/a	n/a	1.0000E+00	n/a	2.1624E-05
37	RVAF	2.8320E-01	n/a	n/a	1.0000E+00	n/a	2.1573E-05
38	B2LF	2.8111E-01	n/a	n/a	1.0000E+00	n/a	2.1414E-05
39	BALF	2.8056E-01	n/a	n/a	1.0000E+00	n/a	2.1372E-05

Table 2-5 (continued)

40	RQF	2.7456E-01	n/a	n/a	1.0000E+00	n/a	2.0915E-05
41	VINV1F	2.7070E-01	n/a	n/a	1.0000E+00	n/a	2.0621E-05
42	B1F	2.7021E-01	n/a	n/a	1.0000E+00	n/a	2.0584E-05
43	B2F	2.7021E-01	n/a	n/a	1.0000E+00	n/a	2.0584E-05
44	CCSRF	2.6559E-01	n/a	n/a	1.0000E+00	n/a	2.0232E-05
45	VT1AF	2.6510E-01	n/a	n/a	1.0000E+00	n/a	2.0194E-05
46	DGF	2.6510E-01	n/a	n/a	1.0000E+00	n/a	2.0194E-05
47	CCPRF	2.4918E-01	n/a	n/a	1.0000E+00	n/a	1.8982E-05
48	A2LF	2.4477E-01	n/a	n/a	1.0000E+00	n/a	1.8646E-05
49	AALF	2.4382E-01	n/a	n/a	1.0000E+00	n/a	1.8573E-05
50	CTMUF	2.3659E-01	n/a	n/a	1.0000E+00	n/a	1.8022E-05
51	OGF	2.3508E-01	n/a	n/a	1.0000E+00	n/a	1.7907E-05
52	BAF	2.3190E-01	n/a	n/a	1.0000E+00	n/a	1.7665E-05
53	A2F	2.2506E-01	n/a	n/a	1.0000E+00	n/a	1.7144E-05
54	A1F	2.2506E-01	n/a	n/a	1.0000E+00	n/a	1.7144E-05
55	ARF	2.1652E-01	n/a	n/a	1.0000E+00	n/a	1.6494E-05
56	PAF	2.0611E-01	n/a	n/a	1.0000E+00	n/a	1.5701E-05
57	UB1CF	2.0456E-01	n/a	n/a	1.0000E+00	n/a	1.5583E-05
58	UB1AF	2.0456E-01	n/a	n/a	1.0000E+00	n/a	1.5583E-05
59	UB1DF	2.0434E-01	n/a	n/a	1.0000E+00	n/a	1.5566E-05
60	UB1BF	2.0434E-01	n/a	n/a	1.0000E+00	n/a	1.5566E-05
61	HHF	2.0420E-01	n/a	n/a	1.0000E+00	n/a	1.5555E-05
62	A3F	2.0260E-01	n/a	n/a	1.0000E+00	n/a	1.5433E-05
63	B3F	2.0260E-01	n/a	n/a	1.0000E+00	n/a	1.5433E-05
64	AAF	1.8755E-01	n/a	n/a	1.0000E+00	n/a	1.4287E-05
65	DEF	1.7565E-01	n/a	n/a	1.0000E+00	n/a	1.3380E-05
66	FEF	1.6681E-01	n/a	n/a	1.0000E+00	n/a	1.2707E-05
67	BCF	1.6611E-01	n/a	n/a	1.0000E+00	n/a	1.2654E-05
68	PBF	1.6326E-01	n/a	n/a	1.0000E+00	n/a	1.2436E-05
69	CEF	1.6089E-01	n/a	n/a	1.0000E+00	n/a	1.2256E-05
70	EEF	1.6088E-01	n/a	n/a	1.0000E+00	n/a	1.2255E-05
71	PRF	1.5659E-01	n/a	n/a	1.0000E+00	n/a	1.1928E-05
72	PEF	1.4719E-01	n/a	n/a	1.0000E+00	n/a	1.1212E-05
73	BEF	1.4290E-01	n/a	n/a	1.0000E+00	n/a	1.0886E-05
74	AEF	1.3788E-01	n/a	n/a	1.0000E+00	n/a	1.0503E-05
75	SGCLGF	1.0880E-01	n/a	n/a	1.0000E+00	n/a	8.2879E-06
76	B2U2LF	9.8835E-02	n/a	n/a	1.0000E+00	n/a	7.5289E-06
77	B1U2LF	9.7067E-02	n/a	n/a	1.0000E+00	n/a	7.3942E-06
78	BBLF	9.6909E-02	n/a	n/a	1.0000E+00	n/a	7.3821E-06
79	MFF	9.6144E-02	n/a	n/a	1.0000E+00	n/a	7.3239E-06
80	A2U2LF	9.5747E-02	n/a	n/a	1.0000E+00	n/a	7.2936E-06
81	A1U2LF	9.5593E-02	n/a	n/a	1.0000E+00	n/a	7.2819E-06
82	ABLF	9.5451E-02	n/a	n/a	1.0000E+00	n/a	7.2711E-06
83	VINV2F	8.8490E-02	n/a	n/a	1.0000E+00	n/a	6.7408E-06

Table 2-5 (continued)

84	VT2BF	8.6722E-02	n/a	n/a	1.0000E+00	n/a	6.6061E-06
85	B1U2F	8.6564E-02	n/a	n/a	1.0000E+00	n/a	6.5941E-06
86	B2U2F	8.6564E-02	n/a	n/a	1.0000E+00	n/a	6.5941E-06
87	DHF	7.6810E-02	n/a	n/a	1.0000E+00	n/a	5.8511E-06
88	VT2AF	7.6810E-02	n/a	n/a	1.0000E+00	n/a	5.8511E-06
89	A1U2F	7.6668E-02	n/a	n/a	1.0000E+00	n/a	5.8403E-06
90	A2U2F	7.6668E-02	n/a	n/a	1.0000E+00	n/a	5.8403E-06
91	BBF	6.8067E-02	n/a	n/a	1.0000E+00	n/a	5.1851E-06
92	CDF	6.3179E-02	n/a	n/a	1.0000E+00	n/a	4.8127E-06
93	V1F	6.2289E-02	n/a	n/a	1.0000E+00	n/a	4.7449E-06
94	V1RF	6.2289E-02	n/a	n/a	1.0000E+00	n/a	4.7449E-06
95	V2F	6.1526E-02	n/a	n/a	1.0000E+00	n/a	4.6868E-06
96	V2RF	6.1526E-02	n/a	n/a	1.0000E+00	n/a	4.6868E-06
97	ABF	5.8780E-02	n/a	n/a	1.0000E+00	n/a	4.4776E-06
98	RDF	5.1877E-02	n/a	n/a	1.0000E+00	n/a	3.9518E-06
99	OTF	5.1606E-02	n/a	n/a	1.0000E+00	n/a	3.9311E-06
100	MELTBF	4.8726E-02	n/a	n/a	1.0000E+00	n/a	3.7118E-06

Table 2-6
Non-Guaranteed Failed Split Fractions Sorted by Importance (RISKMAN Generated)

MODEL Name: WBN-UPDATE
Split Fraction Importance
Sorted by Fraction Importance

.....	SF Name...	Fraction... Importance	Fussel-Vesely.. Importance	Birnbaum.. Importance	Achievement. Worth	Reduction.. Worth	SF Value.....	Frequency
1.	OGR11	2.0260E-01	1.9097E-01	7.4890E-01	1.5579E+00	8.0903E-01	2.5500E-01	1.5433E-05
2.	GA1	1.4925E-01	1.4187E-01	1.0947E+00	1.9528E+00	8.5813E-01	1.2960E-01	1.1369E-05
3.	MU2	1.3408E-01	6.2189E-02	1.4057E-01	1.0784E+00	9.3781E-01	4.4240E-01	1.0214E-05
4.	RR1	1.2880E-01	1.2880E-01	7.9913E+01	8.0784E+01	8.7120E-01	1.6117E-03	9.8115E-06
5.	GB2	1.1937E-01	1.1336E-01	6.2803E-01	1.5147E+00	8.8664E-01	1.8050E-01	9.0932E-06
6.	CCPR2	1.1932E-01	1.0318E-01	2.0492E-01	1.1017E+00	8.9682E-01	5.0350E-01	9.0891E-06
7.	TPR1	8.8156E-02	5.6796E-02	7.0309E-02	1.0135E+00	9.4320E-01	8.0780E-01	6.7153E-06
8.	AC2	8.4003E-02	8.3873E-02	3.0689E+01	3.1605E+01	9.1613E-01	2.7330E-03	6.3990E-06
9.	B11	7.1880E-02	7.1665E-02	2.1919E+02	2.2012E+02	9.2833E-01	3.2695E-04	5.4755E-06
10.	RA2	7.1284E-02	6.6293E-02	3.7258E+00	4.6595E+00	9.3371E-01	1.7793E-02	5.4301E-06
11.	REC1	5.8352E-02	5.8352E-02	1.5519E+00	2.4936E+00	9.4165E-01	3.7600E-02	4.4451E-06
12.	TP1	5.3004E-02	1.7725E-02	2.8305E-01	1.2653E+00	9.8228E-01	6.2620E-02	4.0376E-06
13.	RB6	4.9202E-02	4.7595E-02	5.8737E-01	1.5398E+00	9.5241E-01	8.1030E-02	3.7480E-06
14.	PL1	4.2768E-02	3.4306E-02	5.1822E-02	1.0175E+00	9.6569E-01	6.6200E-01	3.2579E-06
15.	TP3	4.2493E-02	2.5403E-02	3.5404E-01	1.3286E+00	9.7460E-01	7.1750E-02	3.2370E-06
16.	MU3	4.2416E-02	4.2332E-02	1.3225E+00	2.2801E+00	9.5767E-01	3.2010E-02	3.2311E-06
17.	RT1	4.0245E-02	4.0230E-02	1.2359E+03	1.2368E+03	9.5977E-01	3.2552E-05	3.0657E-06
18.	A11	4.0038E-02	3.9798E-02	1.2183E+02	1.2279E+02	9.6020E-01	3.2668E-04	3.0499E-06
19.	REC3	3.9830E-02	3.9830E-02	4.4099E-01	1.4012E+00	9.6017E-01	9.0320E-02	3.0341E-06
20.	DE3	3.7809E-02	3.7789E-02	3.0524E+01	3.1486E+01	9.6221E-01	1.2380E-03	2.8802E-06
21.	GC3	3.6558E-02	5.9188E-03	2.1825E-02	1.0159E+00	9.9408E-01	2.7120E-01	2.7848E-06
22.	CE3	3.6436E-02	3.6407E-02	3.0466E+01	3.1430E+01	9.6359E-01	1.1950E-03	2.7755E-06
23.	REC2	3.4869E-02	3.4869E-02	9.2737E-01	1.8925E+00	9.6513E-01	3.7600E-02	2.6562E-06
24.	AA2	3.4468E-02	3.4434E-02	4.9710E+01	5.0676E+01	9.6557E-01	6.9270E-04	2.6257E-06
25.	DS8	3.3388E-02	3.3387E-02	1.1379E+01	1.2346E+01	9.6661E-01	2.9340E-03	2.5433E-06
26.	BA4	3.1373E-02	3.1031E-02	2.8184E-01	1.2508E+00	9.6897E-01	1.1010E-01	2.3899E-06
27.	GD3	2.8058E-02	6.7972E-03	2.9773E-02	1.0230E+00	9.9320E-01	2.2830E-01	2.1374E-06
28.	GB1	2.6487E-02	2.3372E-02	1.9158E-01	1.1682E+00	9.7663E-01	1.2200E-01	2.0177E-06
29.	RR5	2.3816E-02	2.3815E-02	2.4256E+00	3.4018E+00	9.7618E-01	9.8184E-03	1.8142E-06
30.	RR4	2.2961E-02	2.2960E-02	2.3192E+00	3.2963E+00	9.7704E-01	9.9000E-03	1.7491E-06
31.	RVA1	2.2117E-02	1.5529E-02	1.6406E+00	2.6251E+00	9.8447E-01	9.4653E-03	1.6848E-06
32.	CI4	2.1907E-02	-1.9778E-03	-1.7090E-02	9.8489E-01	1.0020E+00	1.1573E-01	1.6688E-06
33.	TB2	2.1163E-02	2.0833E-02	4.4006E-01	1.4192E+00	9.7917E-01	4.7340E-02	1.6121E-06
34.	ZA1	1.9461E-02	1.4111E-02	1.6488E+00	2.6347E+00	9.8589E-01	8.5584E-03	1.4825E-06
35.	DE1	1.8914E-02	1.8788E-02	1.0642E+02	1.0740E+02	9.8121E-01	1.7654E-04	1.4408E-06
36.	RB4	1.8246E-02	1.4395E-02	8.6454E-01	1.8501E+00	9.8561E-01	1.6650E-02	1.3899E-06
37.	GC2	1.8046E-02	1.1275E-02	7.0251E-02	1.0590E+00	9.8872E-01	1.6050E-01	1.3747E-06
38.	OS3	1.7906E-02	1.7881E-02	8.2060E+00	9.1881E+00	9.8212E-01	2.1790E-03	1.3640E-06
39.	GD4	1.7901E-02	6.2438E-03	1.6150E-02	1.0099E+00	9.9376E-01	3.8660E-01	1.3636E-06
40.	AC9	1.7736E-02	1.7216E-02	1.2886E+00	2.2714E+00	9.8278E-01	1.3360E-02	1.3511E-06
41.	BC1	1.7092E-02	1.5591E-02	4.2297E+00	5.2141E+00	9.8441E-01	3.6860E-03	1.3020E-06
42.	REC5	1.7050E-02	1.7050E-02	2.6344E-01	1.2464E+00	9.8295E-01	6.4720E-02	1.2988E-06
43.	AB6	1.6939E-02	2.6214E-04	4.8806E-04	1.0002E+00	9.9974E-01	5.3710E-01	1.2903E-06
44.	CTMU1	1.6081E-02	-2.8283E-03	-1.1451E-01	8.8832E-01	1.0028E+00	2.4699E-02	1.2250E-06
45.	CCPR1	1.5984E-02	1.5478E-02	9.2629E-01	1.9108E+00	9.8452E-01	1.6710E-02	1.2176E-06
46.	RVB1	1.5693E-02	1.0911E-02	1.2149E+00	2.2040E+00	9.8909E-01	8.9810E-03	1.1955E-06
47.	SR1	1.4815E-02	1.4669E-02	4.2311E-01	1.4084E+00	9.8533E-01	3.4669E-02	1.1285E-06
48.	VA1	1.4315E-02	1.1840E-02	1.8211E+00	2.8092E+00	9.8816E-01	6.5020E-03	1.0905E-06
49.	BB14	1.4207E-02	1.1272E-03	1.3586E-03	1.0002E+00	9.9887E-01	8.2970E-01	1.0822E-06
50.	ZB6	1.3992E-02	1.3757E-02	1.9920E-01	1.1854E+00	9.8624E-01	6.9060E-02	1.0659E-06
51.	RH1	1.3950E-02	1.3853E-02	2.5043E+00	3.4904E+00	9.8615E-01	5.5318E-03	1.0626E-06
52.	AE5	1.2939E-02	1.2911E-02	1.8547E+00	2.8418E+00	9.8709E-01	6.9614E-03	9.8567E-07
53.	GD2	1.2685E-02	8.5381E-03	5.7885E-02	1.0493E+00	9.9146E-01	1.4750E-01	9.6629E-07

Table 2-6
Non-Guaranteed Failed Split Fractions Sorted by Importance (RISKMAN Generated)
(continued)

.....	SF Name...	Fraction... Importance	Fussel-Vesely.. Importance	Birnbaum.. Importance	Achievement. Worth	Reduction.. Worth	SF Value.....	Frequency
54.	MU1	1.2397E-02	9.6622E-03	2.1910E-02	1.0122E+00	9.9034E-01	4.4100E-01	9.4436E-07
55.	CE1	1.2332E-02	1.2204E-02	6.8727E+01	6.9715E+01	9.8780E-01	1.7757E-04	9.3944E-07
56.	REC4	1.1502E-02	1.1502E-02	3.0591E-01	1.2944E+00	9.8850E-01	3.7600E-02	8.7619E-07
57.	MDE1	1.1191E-02	6.8511E-03	1.3855E+00	2.3786E+00	9.9315E-01	4.9450E-03	8.5248E-07
58.	DC3	1.1069E-02	1.0943E-02	1.9625E+01	2.0614E+01	9.8906E-01	5.5760E-04	8.4318E-07
59.	DS6	1.1012E-02	-1.1264E-03	-1.6550E-02	9.8458E-01	1.0011E+00	6.8062E-02	8.3888E-07
60.	BC2	1.0501E-02	1.0320E-02	2.7967E+00	3.7864E+00	9.8968E-01	3.6900E-03	7.9989E-07
61.	EB1	1.0349E-02	1.0051E-02	1.1279E+00	2.1178E+00	9.8995E-01	8.9113E-03	7.8836E-07
62.	LCL1	1.0172E-02	1.0079E-02	2.5490E+00	3.5389E+00	9.8992E-01	3.9540E-03	7.7487E-07
63.	RA1	9.5029E-03	8.8528E-03	6.5138E-01	1.6425E+00	9.9115E-01	1.3591E-02	7.2390E-07
64.	AFR1	9.1730E-03	5.2177E-03	9.8262E-02	1.0930E+00	9.9478E-01	5.3100E-02	6.9876E-07
65.	ZA5	9.0240E-03	6.6918E-03	8.3262E-01	1.8259E+00	9.9331E-01	8.0370E-03	6.8742E-07
66.	BE41	8.7797E-03	8.7669E-03	1.2776E+00	2.2688E+00	9.9123E-01	6.8620E-03	6.6880E-07
67.	RVB3	8.3121E-03	3.7308E-03	6.1554E-02	1.0578E+00	9.9627E-01	6.0610E-02	6.3318E-07
68.	OS2	8.2135E-03	8.0983E-03	2.5474E-01	1.2466E+00	9.9190E-01	3.1790E-02	6.2567E-07
69.	SED	7.9889E-03	7.9888E-03	1.4725E+00	2.4645E+00	9.9201E-01	5.4253E-03	6.0856E-07
70.	ZB10	7.0287E-03	6.8923E-03	1.0568E-01	1.0988E+00	9.9311E-01	6.5220E-02	5.3542E-07
71.	RB3	6.9220E-03	6.7812E-03	1.1044E-01	1.1037E+00	9.9322E-01	6.1400E-02	5.2729E-07
72.	SL1	6.6536E-03	6.0738E-03	4.2707E-01	1.4210E+00	9.9393E-01	1.4222E-02	5.0684E-07
73.	DS4	6.2368E-03	6.1440E-03	2.2282E-01	1.2167E+00	9.9386E-01	2.7574E-02	4.7509E-07
74.	GD1	6.0583E-03	4.1997E-03	3.7297E-02	1.0331E+00	9.9580E-01	1.1260E-01	4.6150E-07
75.	CSA1	5.9919E-03	-1.2166E-03	-6.0486E-02	9.4073E-01	1.0012E+00	2.0113E-02	4.5644E-07
76.	AC1	5.9697E-03	5.9344E-03	7.1063E+01	7.2057E+01	9.9407E-01	8.3510E-05	4.5475E-07
77.	AE1	5.9072E-03	5.9060E-03	1.3907E+03	1.3917E+03	9.9409E-01	4.2467E-06	4.4999E-07
78.	OF1	5.6291E-03	5.6284E-03	1.4039E-01	1.1348E+00	9.9437E-01	4.0090E-02	4.2880E-07
79.	TB4	5.6153E-03	3.9359E-03	8.4170E-02	1.0802E+00	9.9606E-01	4.6761E-02	4.2775E-07
80.	PD4	5.4507E-03	-3.1627E-04	-7.8073E-03	9.9251E-01	1.0003E+00	4.0510E-02	4.1521E-07
81.	S11	5.1581E-03	7.2540E-04	6.5909E-02	1.0652E+00	9.9927E-01	1.1006E-02	3.9292E-07
82.	MA3	5.1229E-03	1.6540E-03	2.1686E-01	1.2152E+00	9.9835E-01	7.6270E-03	3.9025E-07
83.	BA1	5.0021E-03	4.9841E-03	1.8773E+02	1.8872E+02	9.9502E-01	2.6550E-05	3.8104E-07
84.	BE3	4.8360E-03	3.7917E-03	2.8466E-01	1.2809E+00	9.9621E-01	1.3320E-02	3.6839E-07
85.	CSB1	4.7921E-03	-1.3215E-03	-6.8827E-02	9.3249E-01	1.0013E+00	1.9200E-02	3.6504E-07
86.	BE2	4.5387E-03	4.5164E-03	2.3499E-01	1.2305E+00	9.9548E-01	1.9220E-02	3.4574E-07
87.	MB9	4.4443E-03	1.7863E-03	2.5074E-01	1.2490E+00	9.9821E-01	7.1240E-03	3.3855E-07
88.	AC4	4.3687E-03	4.1626E-03	2.6180E-01	1.2576E+00	9.9584E-01	1.5900E-02	3.3279E-07
89.	OB1	4.2185E-03	3.8788E-03	3.5644E-01	1.3526E+00	9.9612E-01	1.0882E-02	3.2135E-07
90.	PA1	4.1522E-03	2.2193E-03	7.2499E-01	1.7228E+00	9.9778E-01	3.0612E-03	3.1630E-07
91.	DS2	4.1004E-03	4.1004E-03	4.8988E-01	1.4858E+00	9.9590E-01	8.3702E-03	3.1235E-07
92.	RF1	4.0827E-03	4.0650E-03	7.9690E+00	8.9649E+00	9.9594E-01	5.1010E-04	3.1100E-07
93.	PD1	4.0740E-03	3.5517E-03	3.1997E+00	4.1962E+00	9.9645E-01	1.1100E-03	3.1034E-07
94.	SEH	4.0650E-03	4.0493E-03	7.4325E-01	1.7392E+00	9.9595E-01	5.4481E-03	3.0966E-07

The highest ranked non-guaranteed failure split fraction to importance (i.e. by percentage contribution to the total CDF) is split fraction is split fraction OGR11 at 20%. This split fraction models the likelihood of power recovery by one hour after a LOSP initiating event. The third, sixth, eleventh, thirteenth, seventeenth, and eighteenth ranked split fractions also are related to the LOSP initiating event, which reflects the overall importance of any of the system top event split fractions that affect the quantification of the LOSP sequences.

The second most important non-guaranteed failure split fraction is CCPR2 (13%). This split fraction models the operator actions necessary to align ERCW to operating CCP 1A-A when the support necessary for CCP 1B-B is unavailable. The plant abnormal procedure for loss of component cooling, AOI-15, directs the operators to start CCP 1B-B on loss of the component cooling to CCP 1A-A, if 1A-A is running. This allows the operators to go to the charging pump room and align ERCW to CCP 1A-A to restore oil cooling and thereby maintain seal injection to the RCPs. If support is unavailable for CCP 1B-B, the operators are directed to not secure CCP 1A-A in order to maintain seal injection flow to the RCPs. This gives the operators approximately 10 minutes to align ERCW to a running CCP prior to CCP failure on loss of oil cooling. The value for CCPR2 (0.5) reflects the time available and the constraints on operator action under this condition. The tenth ranked top event split fraction, B11, models the 480V shutdown board support for CCP 1B-B and is also related to this procedure.

The fourth most important non-guaranteed failure split fraction, MU2 (12%), models the operator actions to refill the RWST during a SLOCA initiating event. All LOCAs at Watts Bar are assumed to result in containment spray actuation in the IPE. When spray is actuated, the RWST will empty in less than one hour, forcing a shift to containment sump recirculation. The completion of the switch to containment sump recirculation requires operator action to open the low pressure pumps to high pressure pumps crossover MOVs. Failure of the parallel MOVs to open is assumed to be non-recoverable because of the short time available prior to RWST depletion. RWST refill is assumed to be the only viable source of continued make-up to the RCS during a LOCA event. The short time available to start the refill operation results in an operator error likelihood for the MU2 split fraction of approximately 0.5. The fifth, ninth and fifteenth most important non-guaranteed failed split fractions also indicate the importance of the SLOCA initiating events and the timing of containment spray actuation.

The seventh, fourteenth, and nineteenth ranked split fractions are related to the turbine driven AFW pump. TPR1, the seventh ranked sequence, models the operator actions to restart the turbine driven AFW pump after a start failure. The fourteenth and nineteenth ranked are separate split fractions associated with the turbine driven AFW pump under differing boundary conditions. The turbine driven AFW pump is the only water source available for steam generator inventory control and reactor decay heat removal during the

LOSP generated SBO sequences. Failure of this water source reduces the time available to restore offsite power prior to core damage during these sequences.

The twelfth ranked split fraction is MU3 which models the operator actions necessary to refill the RWST to maintain a source of continued RCS make-up during a SGTR initiating event. This split fraction reflects the higher possibility for operator error during the SGTR.

The split fractions associated with reactor trip, RT1, etc., have a split fraction importance value of approximately 5% which reflects the importance of the function while the achievement worth of $1.5 \times 10^{+3}$ reflects the high reliability of the system.

2.2.4 Important Operator Actions

The determination of contributions from sequences grouped by the occurrence of specific operator actions and system failure modes is termed an importance analysis. The importance measure used here is the reduction of the total CDF that could be achieved if the operators never failed the specific action. Table 2-7 summarizes the important operator action failures that contribute 1% or more to the total CDF.

Table 2-7
Important Operator Actions

Operator Action	Contribution To CDF
1. Align ERCW to CCP 1A-A, 1B-B Unavailable	13%
2. Makeup to RWST after LOCA/Loss of Recirculation	12%
3. Align HP Recirculation/Auto Switchover Successful	11%
4. Start Turbine-Driven AFW Pump/Control or Start Signal Failure	8%
5. Makeup to RWST/LOCA with Loss of Recirculation and Spray	5%
6. Manually Start AFW - Reactor Trip with No Safety Injection (SI)	3%
7. Identify and Isolate Ruptured Steam Generator	2%
8. Cooldown and Depressurize RCS/SGTR - Isolation Failed	2%
9. Refill CST During Non-LOCA Events	2%
10. Align and Start Alternate Cooling to CCP	1%
11. Transfer to Hot Leg Recirculation - LOCA > 2" Diameter	1%
12. Restore MFW/No AFW - No SI	1%
13. Makeup to RWST after SGTR	1%

The operator actions to recover electric power are not included in Table 2-7 because they are a complex function of the time available and the specific equipment failures involved. For comparison purposes, about 20% of the CDF involves failure to recover electric power in a SBO before core damage. The following table summarizes the contributions of various offsite power recovery failures:

Table 2-8
Contribution of Offsite Power Recovery

Recovery Scenario	Contribution To CDF
Total Contribution of Loss of Offsite Power Events	**23%**
1. Long Term SBO, AFW Successfully Operates To Battery Depletion, With Failure To Recover AC Power Before Core Damage	~ 16%
2. Short Term SBO With Failure of AFW and Failure To Recover AC Power Before Core Damage	~ 5%
3. LOSP with AC Power Recovered Successfully, But Other Failures Lead To Core Damage	~ 1%
4. LOSP with At Least One EDG Available At Unit 1 With Other Failures Leading To A Need To Recover AC Power Before Core Damage	~ 1%
5. SBO With AC Power Recovered Successfully, But Other Failures Lead To Core Damage	~ 1%

2.2.5 Important Plant Hardware Characteristics

An importance analysis of plant system and component failure modes to the total CDF was also performed. As above, the importance is measured in terms of the reduction of the total CDF that could be achieved if the hardware never failed. Only hardware failures involving the system itself are considered in Table 2-9.

Here, importance means the percentage of the CDF involving failure of part or all of the indicated system. These importance measures are not strictly additive because multiple system failures may occur in the same sequence. The importance rankings account for failures within the systems that lead to a plant trip, or failures that limit the capability of the plant to mitigate the cause of a plant trip. Consequential failures resulting from dependencies on other plant systems (e.g., the loss of ECCS due to failure of 480V Shutdown Boards) are not included in this importance ranking. In addition, the failures of key operator actions are not included in Table 2-9 totals.

Table 2-9
Important Component and System Failures

Component/System	Contribution To CDF
Recirculation Alignment	18%
EDG 1A-A	14%
EDG 1B-B	14%
CCS Train A	12%
RHR Pump Train 'A'	7%
RHR Pump Train 'B'	7%
480V Shutdown Board 1B1-B	7%
ERCW Supply Header 1B-B	6%
ERCW Supply Header 1A-A	5%
Reactor Trip Breakers	5%
Turbine Driven AFW Pump	4%
480V Shutdown Board 1A1-A	4%
6.9kV Shutdown Board 1B-B	4%
6.9kV Shutdown Board 1B-B	4%

2.2.6 Plant Damage States

One output from the Level 1 event sequence model is a description of the PDS (e.g., RCS pressure, containment isolation, etc.) at the time of core damage. This PDS strongly influences the performance of the containment and magnitude of fission product release that are assessed in the Level 2 analysis, as described in Section 2.2.

Table 2-10 provides the frequencies of different PDSs associated with core damage. These results only account for the impact on containment integrity of the accident sequence up to the time of core damage. As examples, the Level 1 analysis considers failures to isolate containment penetrations, containment bypass from SGTR, and preexisting leaks. The results cited in Table 2-10 do not account for challenges to containment from severe accident phenomena; e.g., hydrogen burns, concrete degradation, which are analyzed in Level 2.

As shown in Table 2-10, over 89% of core damage events would be associated with an intact containment, and approximately 10% would be associated with small and large violations of containment integrity. Core damage sequences accompanied by a loss of containment integrity generally lead to greater fission product releases.

Table 2-10
Core Damage Frequency Breakdown for Watts Bar by Major Plant Damage State Group

Containment State	Frequency per Reactor-Year	CDF (percent)
Isolated and Not Bypassed	7.22×10^{-5}	89.8
Not Isolated or Bypassed – Small Leak	3.94×10^{-6}	4.9
Small Bypass	3.89×10^{-6}	4.8
Not Isolated or Bypassed – Large Leak	2.99×10^{-7}	0.4
Total	**8.0×10^{-5}**	**99.9**

Specific plant damage states comprising the top 99% of the CDF are described in Table 2-11.

2.2.7 Key Plant Damage States and Representative Sequences

As shown in Table 2-11, the Level 1 model identified 21 PDSs with a frequency of **4×10^{-8}** or greater per reactor-year. For Level 2 analysis, these PDSs are condensed into a reduced set of key plant damage states (KPDS). This condensation process is described in this section and is based on the IPE reporting criteria established by the NRC in Appendix 2 of Generic Letter No. 88-20 (Reference 24). The process takes advantage of the known frequency and the relative severity or consequence potential for each PDS.

In Section 2.2.2.5 of NUREG-1335 (Reference 28), it is stated that "all accident sequences (represented now by PDSs or bins) that meet the screening criteria should be represented by CETs according to standard practice." Thus, the approach used in this submittal is believed to be in full compliance with the IPE intent.

Because the PDSs represent "functional accident sequences," the KPDSs (each of which requires a detailed Level 2 analysis) are selected on the basis of the PDS frequencies in comparison to the IPE reporting criteria.

Table 2-11
Dominant Plant Damage States

Rank	PDS Name	RCS Pressure	Containment Heat Removal	Containment Integrity	Annual Frequency	Percent of Total CDF
1	ENI	High	No	Isolated and Not Bypassed	3.65E-05	45.42%
2	FCI	High	CSI and CSR	Isolated and Not Bypassed	2.24E-05	27.91%
3	GNI	High	No	Isolated and Not Bypassed	4.69E-06	5.83%
4	BCI	Low	CSI and CSR	Isolated and Not Bypassed	4.10E-06	5.09%
5	EIB	High	RHR Only	Small Bypass	3.35E-06	4.17%
6	ENS	High	No	Not Isolated, Small	2.13E-06	2.65%
7	GNS	High	No	Not Isolated, Small	1.67E-06	2.08%
8	HCI	High	CSI and CSR	Isolated and Not Bypassed	1.36E-06	1.69%
9	HGI	High	CSI Only	Isolated and Not Bypassed	1.09E-06	1.36%
10	DCI	Medium	CSI and CSR	Isolated and Not Bypassed	7.20E-07	0.90%
11	FNI	High	No	Isolated and Not Bypassed	5.92E-07	0.74%
12	ENB	High	No	Small Bypass	4.66E-07	0.58%
13	FGI	High	CSI Only	Isolated and Not Bypassed	4.28E-07	0.53%
14	GTL	High	No	Not Isolated, Large	1.77E-07	0.22%
15	HNI	High	No	Isolated and Not Bypassed	1.08E-07	0.13%
16	FCS	High	CSI and CSR	Not Isolated, Small	9.11E-08	0.11%
17	ETL	High	No	Not Isolated, Large	8.99E-08	0.11%
18	EGI	High	CSI Only	Isolated and Not Bypassed	7.55E-08	0.09%
19	FCB	High	CSI and CSR	Small Bypass	6.70E-08	0.08%
20	AGI	Low	CSI Only	Isolated and Not Bypassed	5.31E-08	0.07%
21	ATV	Low	No	Large Bypass, V	4.99E-08	0.06%
				Total	8.03E-05	99.8%

NOTE: Exponential notation is indicated in abbreviated form; e.g., 3.65E-05 = 3.65×10^{-05}

On the basis of the Level 2 functional sequence, the following 9 KPDSs were identified for Watts Bar:

KPDS	PDS Frequency per Reactor-Year	KPDS Frequency per Reactor-Year	Subsumed PDSs
ENI (HANNI)	3.7×10^{-5}	3.7×10^{-5}	
FCI (HAYCI)	2.2×10^{-5}	2.2×10^{-5}	
GNI (HXNNI)	4.7×10^{-6}	4.7×10^{-6}	
BCI (LNYCI)	4.1×10^{-6}	4.1×10^{-6}	
ENS (HANNS)	2.1×10^{-6}	2.1×10^{-6}	
EIB (HANIB)	3.4×10^{-6}	5.4×10^{-6}	GNS,FCB,FCS,KTL,ETL,FNS,GTL
HGI (HXYGI)	1.1×10^{-6}	1.1×10^{-6}	
ENB (HANNB)	4.7×10^{-7}	4.7×10^{-7}	
HCI (HXYCI)	1.4×10^{-6}	1.4×10^{-6}	

In addition to these 9 KPDSs, the V-sequence PDS [ATV (LNNTV)] is also given visibility in the Level 2 analysis, but its frequency (5.0×10^{-8} per reactor year) is extremely low and is not likely to be a significant contributor to risk. The KPDSs, as well as other PDSs whose frequency was subsumed into the KPDS frequency, are identified in Table 2-23 as being "analyzed" in Level 2. As indicated in Table 2-23, more than 97% of the core damage frequency (CDF) has been addressed in Level 2, although some PDSs (i.e., functional sequences) with frequencies less than 1.0×10^{-6} per reactor-year were addressed by subsuming the PDS frequency into KPDS EIB (HANIB). Preliminary Modular Accident Analysis Program (MAAP) analysis of the representative sequence [SGTR with a stuck-open steam generator relief valve faulted outside of containment] for EIB indicated a very significant source term. PDS FCB (HAYCB) was rebinned to EIB since it also represented an SGTR bypass, and its frequency was much lower than that of EIB. No specific guidance is given in Generic Letter No. 88-20 regarding screening criteria for sequences involving containment isolation failures. There are two Watts Bar PDSs (KTL and ETL) involving large (e.g., purge lines) containment isolation failures for functional sequences involving containment bypass. The combined frequency of these two PDSs was subsumed into KPDS EIB. There are three PDSs (GNS, FCS, and FNS) involving small isolation failures with frequencies between 1×10^{-7} and 1×10^{-6} per reactor-year. The combined frequency of these three PDSs was also rebinned to EIB. The net effect of subsuming all of these PDSs into EIB was to increase its frequency by approximately 59% to 5.4×10^{-6} per reactor-year.

2.2.8 Selection of Representative Accident Sequences for Severe Accident Analysis

This section defines the accident sequences that were selected to represent the KPDSs.

2.2.8.1 Key PDS ENI (HANNI)

The highest frequency sequence to PDS ENI is initiated by a total loss of all ERCW. Since ERCW provides the ultimate heat sink for many safety systems, numerous systems are unavailable in this sequence. In particular, CCS and the charging pumps are unavailable. The operators trip the reactor and the RCPs in response to the loss of CCS. However, the loss of all seal cooling leads to an eventual seal LOCA. AFW operates successfully, and the operators depressurize the steam generators to cool down the RCS shortly after the seal LOCA develops. Core damage occurs due to the loss of all high pressure injection. The RHR and containment spray pumps are assumed to operate in the injection mode while taking suction from the RWST inventory. However, the RHR and containment spray pumps are unavailable during recirculation due to the loss of ERCW and CCS cooling.

The air return fans operate successfully, and the hydrogen ignitors are energized. The containment isolates automatically.

A second sequence is initiated by a loss of train A of 6.9kV shutdown power. An independent failure of a specific train B 480V shutdown board also occurs. The loss of these two support system trains leads to the loss of CCS train A and of both CCPs for RCP seal injection. A seal LOCA eventually develops. The safety injection pumps are also unavailable. Core damage results from the loss of all high pressure injection. The RHR and containment spray pump trains are also unavailable due to the loss of these two support trains.

The B train air return fan operates successfully, but the hydrogen ignitors in this sequence cannot be energized due to the power failures. The containment isolates automatically.

A third sequence assigned to PDS ENI is initiated by a loss of offsite power that is not recovered within the first hour. The EDGs also fail to provide shutdown power as a backup. The loss of all seal cooling leads to an eventual seal LOCA without high pressure injection. Electric power is not restored prior to core damage. Turbine-driven AFW is available, and the operators initiate steam generator depressurization to limit the rate of seal leakage.

In this sequence, both the air return fans and the hydrogen ignitors are unavailable due to the loss of all AC power. The containment isolates automatically.

2.2.8.2 Key PDS FCI (HAYCI)

The highest ranked sequence to PDS FCI is initiated by a small LOCA, which is assumed to occur at the seals of one RCP. The plant trips, and a safety injection signal is

generated. Both the charging pumps and the safety injection pumps actuate to provide RCS inventory control at high pressure. Containment spray pumps come on in response to a Phase B condition. Later, automatic swapover of RHR suction to the containment sump is successful, but the operators fail to align for high pressure recirculation; i.e., the discharge of the RHR pumps is not aligned to the suction of the charging or safety injection pumps.

AFW is successful, and the operators are assumed to depressurize the steam generator in accordance with procedures at about 15 minutes after plant trip. Both RHR pumps and both spray pumps are assumed to be available for recirculation from the sump.

The air return fans operate, and the hydrogen ignitors are energized. The containment isolates successfully.

A second sequence was evaluated for this PDS. It is also initiated by a small LOCA, which is assumed to occur at the seals of one RCP. The plant trips, and a safety injection signal is generated. Both the charging pumps and the safety injection pumps actuate to provide RCS inventory control at high pressure.

Containment spray pumps actuate in response to a Phase B condition. However, the RHR pumps both fail to operate. In addition, the operators fail to provide makeup to the RWST via the containment spray system.

AFW is successful, and the operators are assumed to depressurize the steam generator in accordance with procedures at about 15 minutes after plant trip. Both spray pumps are available for recirculation from the sump.

2.2.8.3. Key PDS GNI (HXNNI)

The highest frequency sequence to PDS GNI is initiated by a loss of offsite power, which is not recovered within the first hour. The backup diesel generator for train A shutdown power also fails. Train B of the ERCW pumps then also fails independently to provide adequate flow. As a result of these support train failures, all high pressure pumps are unavailable. However, the operators successfully cross-tie the train A ERCW to the 1B-B EDG. The turbine-driven AFW pump also fails, which shortens the time available for recovery of electric power. The loss of all seal cooling leads to a small LOCA. Electric power is not recovered prior to core damage.

RHR and containment spray are unavailable for both injection and recirculation. In this sequence, power is still available for the air return fans and for the hydrogen ignitors. The containment successfully isolates.

A second sequence assigned to PDS GNI is initiated by a loss of offsite power, which is not recovered within the first hour. Both Unit 1 EDGs also fail to provide shutdown power as a backup. The turbine-driven AFW pump fails independently, and attempts to start the pump locally also fail. The loss of all seal cooling leads to an eventual seal LOCA without high pressure injection. Electric power is not restored prior to core damage. Both MFW and AFW are unavailable, and the operators initiate steam generator depressurization to limit the rate of seal leakage.

In this sequence, both the air return fans and the hydrogen ignitors are unavailable due to the loss of all AC power. The containment isolates successfully; i.e., the operators locally isolate the seal return line.

2.2.8.4 Key PDS BCI (LNYCI)

The highest ranked sequence to PDS BCI is initiated by a medium LOCA; i.e., a LOCA big enough to depressurize the RCS without secondary heat removal, or greater than the equivalent of a 2-inch-diameter hole. The high-pressure injection pumps (i.e., charging pumps and safety injection pumps) provide RCS inventory control initially, and the containment spray pumps actuate to limit containment pressure. AFW is available. In accordance with procedures, the operators depressurize the steam generators, beginning at about 15 minutes. The automatic swapover for sump recirculation operates successfully, but the operators fail to align for high pressure recirculation. Low pressure injection is not possible at the initial time of swapover to the containment sump.

Both RHR and containment spray pumps are available in the injection and recirculation modes.

The air return fans are available, and the hydrogen ignitors are energized. The containment isolates automatically.

2.2.8.5 Key PDS ENS (HANNS)

The highest frequency sequence assigned to PDS ENS is initiated by a loss of offsite power that is not recovered in the first hour. Both Unit 1 EDGs also fail to provide shutdown power as a backup. The turbine-driven AFW pump operates to provide secondary heat removal. The operators initiate steam generator depressurization to limit the rate of seal leakage. The loss of all seal cooling leads to an eventual seal LOCA without high pressure injection. Electric power is not restored prior to core damage.

In this sequence, both the air return fans and the hydrogen ignitors are unavailable due to the loss of all AC power. The operators fail to locally isolate the containment by not closing the seal return line.

Other sequences with some shutdown power available assigned to this PDS are similar, but the status of the air return fans and hydrogen ignitors is different. Therefore, this same station blackout sequence was evaluated three more times to reflect the different possible states of these containment systems. Cases with both the air return fans and hydrogen ignitors operable, and with just one or the other of them operable were evaluated.

2.2.8.6 Key PDS EIB (HANIB)

The highest frequency sequence to PDS EIB is initiated by a SGTR. A safety injection signal successfully actuates the CCPs and safety injection pumps for RCS inventory control. The ruptured steam generator is initially isolated, and AFW is available. However, the operators fail to initiate RCS cooldown by depressurizing the intact steam generators. As a consequence, the ruptured steam generator overfills due to the flow of RCS through the broken tube. The safety valves on the ruptured steam generator open and then fail to reclose after passing water (faulted steam generation outside containment). Leakage continues from the ruptured steam generator, with the RCS still at pressure.

Assuming that AFW to the ruptured steam generator is isolated automatically or by the operator per procedure, over a long period of time, the RWST is depleted by the CCPs. In this sequence, the operators then fail to make up borated water to the RWST for continued high pressure injection. Recirculation from the containment sump is unavailable because the lost inventory is outside containment.

The air return fans are available, and the hydrogen ignitors are energized. The containment isolates automatically.

2.2.8.7 Key PDS HGI (HXYGI)

The representative sequence assigned to PDS HGI is initiated by a loss of offsite power that is not recovered in the first hour. The onsite Unit 1 EDG for train B fails. An independent failure of the train A EDG on Unit 2 also occurs. These support system train failures together with an independent failure of the turbine-driven AFW pump results in the loss of all AFW on Unit 1. The operators successfully initiate feed and bleed cooling using the train A charging and safety injection pumps. However, since only one shutdown board is available on each train, there is insufficient ERCW flow on both trains for recirculation from the sump. Sump recirculation is therefore unavailable. Electric power is not restored prior to core damage.

In this sequence, the A train air return fan and the hydrogen ignitors are available. The containment is manually isolated.

2.2.8.8 Key PDS ENB (HANNB)

The highest frequency sequence to PDS ENB is initiated by a SGTR. Vital Battery Board I of 125V DC control power fails independently. A safety injection signal successfully actuates the train B charging pump and the train B safety injection pump for RCS inventory control. The ruptured steam generator fails to isolate due to the loss of DC control power train A. AFW is available, but the operators fail to initiate RCS cooldown by depressurizing the intact steam generators. Makeup to the RWST is also unavailable due to the same DC control power loss. Core damage results from the eventual loss of RCS inventory out the ruptured and faulted steam generator to the environment.

Containment spray and recirculation from the containment sump are unavailable due to the loss of inventory out the break.

The B train air return fan is available, and the hydrogen ignitors are energized. The containment is bypassed via the ruptured and faulted steam generator.

2.2.8.9 Key PDS HCI (HXYCI)

The highest ranked sequence to PDS HCI is initiated by a partial loss of main feedwater from greater than 40% power. The reactor fails to trip, both automatically and manually. Main feedwater is assumed to be isolated in response to the initiating event. The turbine-driven AFW pump fails independently. The motor-driven AFW pumps both operate, but at least one of the valves to the four steam generators fails to open. Therefore, there is insufficient secondary heat removal to avoid overpressure of the RCS. The reactor vessel fails, which is assumed to result in core damage. Containment spray and recirculation from the containment sump are available after core damage. The air return fans are available, and the hydrogen ignitors are energized. The containment isolates automatically.

2.3 RESULTS FOR RELEASE FREQUENCY

The purpose of Level 2 portion of the IPE is to assess the frequency of fission product releases into the environment (release category frequencies). These results are based on the integration of the Level 1 ("front-end" or "plant") model in which the responses of the plant systems and operators are addressed, and the "back-end" model whose containment event tree defines the outcome of the core damage scenarios in terms of the timing of the containment response and the magnitude of the release of radioactive material (referred to as source terms). The extension of the front-end analysis to include back-end analyses is called a Level 2 analysis.

There is a continuum of possible releases that could result from a core damage event. A reasonable treatment of this continuum is to use a representative set of discrete release categories that span the spectrum from relatively large, early releases to ones which are much smaller, occur later, and/or over a long time period. A detailed definition of the Watts Bar release categories is given in Reference 20. Table 2-12 represents a summary of these release categories in terms of general release category groups and percentage of the CDF.

Table 2-12
Definition and Results for General Release Category Groups

General Release Category Group	Description	Percentage of CDF Analyses*
I	Large, Early Containment Failures and Large Bypasses**	2.4
II	Small, Early Containment Failures and Small Bypasses**	10.1
III	Late Releases and Long-Term Releases	21.5
IV	Long-Term, Contained Releases (containment intact following vessel breach)	66.0

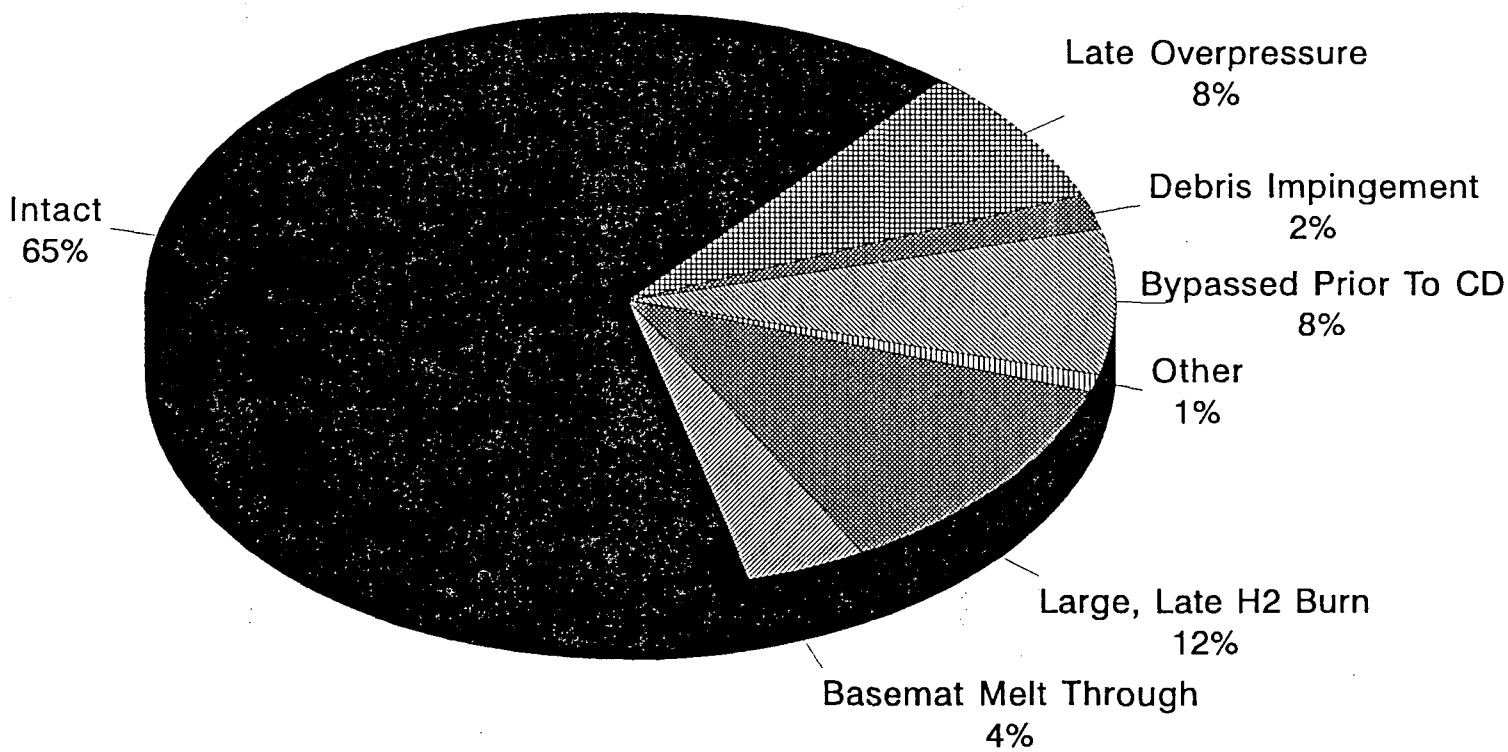
* Group frequency divided by CDF.
** The term "bypass" refers to the consideration when a release path from the RCS bypasses the containment and releases directly to the environment or into the auxiliary building, [e.g., faulted SGTR].

The overall contributors to containment failure are shown in Figure 2-2. This figure shows that nearly two thirds (65%) of the severe accident sequences end up with the containment intact. The largest contributor (12%) to containment failure is late hydrogen burns which result in a late, large failure of containment. The next largest contributor is late overpressurization failures (8%). These are largely due to events without containment heat removal and generally result in a late small failure of the containment. Containment bypasses represent the next largest contributor (8%). Most of these sequences were discussed above as large early releases. Basemat failures represent only 4% of the containment endstates. These failures are due to conditions where the core debris is inadequately cooled and core concrete interaction continues long enough for the containment basemat to be breached.

Early fatality risk is dominated by General Release Group I and certain bypasses from Group II. As indicated in Table 2-12, the frequency of Category I releases for Watts Bar is estimated to be 2.4% of the core damage frequency, or 1.9×10^{-6} per reactor year.

Figure 2-2

DOMINANT CONTAINMENT FAILURE MODES



Release Category Group II is dominated by sequences involving and SGTR or other initiator followed by a stuck-open secondary relief valve. While such events involve a bypass of relatively small flow area, the associated source term can be relatively large. As indicated in Table 2-12, the frequency of Release Group II is 10.1% of the total CDF or 8.0×10^{-6} per reactor year. SGTR events account for 73% of the Group II frequency and are considered to be a large, early release.

Release Category Group III involves sequences leading to degraded containment performance, but which do not contribute significantly to early health risk. The releases associated with Release Category IV should be comparable to those from unmitigated design bases accidents.

The important benchmark for a Level 2 PRA is the frequency of large, early releases. For this IPE, the frequency of large, early releases is the sum of Release Category Group I plus that fraction (0.73) or Release Category Group II that is associated with SGTR initiating events with a stuck-open secondary side relief valve. The Watts Bar frequency of large, early release is approximately 10% of the CDF, or 7.8×10^{-6} per reactor year. This frequency is low and is dominated by containment bypass results from SGTR, which accounts for approximately 5.9×10^{-6} per reactor year.

2.3.1 Contributors to Release Category Groups

Table 2-13 summarizes the assignment of individual release categories into these general release category groups.

2.3.1.1 Release Category Group I – Large, Early Containment Failure and Large Containment Bypass

Table 2-14 lists those individual sequences whose frequencies are greater than 1×10^{-10} per reactor-year and that contribute to Release Category Group I. Table 2-15 summarizes the frequency contribution of the key plant damage state (KPDS) to Group I. As shown in Table 2-15, three KPDSs dominated by sequences involving loss of ERCW or loss of

offsite power (GNIYA, ENIYA, and GNIYN) account for approximately 74% of the group frequency while the Interfacing Systems LOCAs (KPDS ATV) contributes only approximately 2.7% of the group frequency.

2.3.1.2 Release Category Group II – Small, Early Containment Failure and Small Containment Bypass

Table 2-16 lists those individual sequences whose frequencies are greater than 1.0×10^{-10} per reactor-year and contribute to Release Category Group II.

Table 2-13 (Page 1 of 2)
Summary of Release Category Frequency (per reactor-year) and General Grouping

Release Category	Release Category Frequency	General Grouping			
		I	II	III	IV
		Large, Early Containment Failure and Bypass	Small, Early Containment Failure and Bypass	Late Releases and Long-Term Releases	Long-Term, Contained Releases
R01IF	8.78E-08	8.78E-08			
R22	8.12E-06				8.12E-06
R20	8.05E-06		8.05E-06		
R09I	7.50E-07			7.50E-07	
R11UI	6.89E-09			6.89E-09	
R11I	6.88E-06			6.88E-06	
R01	6.05E-08	6.05E-08			
R03I	5.64E-08	5.64E-08			
R03UI	5.55E-11	5.55E-11			
R19	4.99E-08	4.99E-08			
R01UIF	4.82E-09	4.82E-09			
R01I	3.70E-08	3.70E-08			
R17U	2.97E-06			2.97E-06	
R09UI	2.90E-07			2.90E-07	
R04UIF	2.52E-08	2.52E-08			
R17LU	2.49E-06			2.49E-06	
R03IF	2.39E-07	2.39E-07			
R03	2.36E-08	2.36E-08			
R17L	2.30E-06			2.30E-06	
R01UI	2.03E-09	2.03E-09			
R04	1.33E-07	1.33E-07			
R03UIF	1.32E-10	1.32E-10			

Note: Exponential notation is indicated in abbreviated form; e.g., 1.7-4 = 1.7×10^{-4}.

Table 2-13 (Page 2 of 2)
Summary of Release Category Frequency (per reactor-year) and General Grouping

Release Category	Release Category Frequency	General Grouping			
		I	II	III	IV
		Large, Early Containment Failure and Bypass	Small, Early Containment Failure and Bypass	Late Releases and Long-Term Releases	Long-Term, Contained Releases
R01DI	1.15E-06	1.15E-06			
R11IF	1.04E-06			1.04E-06	
R21	4.36E-05				4.36E-05
R18	0.00E+00	0.00E+00			
R07SLUIF	0.00E+00		0.00E+00		
R07SLUI	0.00E+00		0.00E+00		
R05SLUIF	0.00E+00		0.00E+00		
R05SLUI	0.00E+00		0.00E+00		
R05SLIF	0.00E+00		0.00E+00		
R05SLI	0.00E+00		0.00E+00		
R04IF	0.00E+00	0.00E+00			
R03SUIF	0.00E+00	0.00E+00			
R03SUI	0.00E+00	0.00E+00			
R03SIF	0.00E+00	0.00E+00			
R03SI	0.00E+00	0.00E+00			
R02IF	0.00E+00	0.00E+00			
R01SUIF	0.00E+00	0.00E+00			
R01SUI	0.00E+00	0.00E+00			
R01SIF	0.00E+00	0.00E+00			
R01SI	0.00E+00	0.00E+00			
Total	7.83E-05	1.87E-06	8.05E-06	1.67E-05	5.16E-05
Fraction of Frequency Analyzed		0.02	0.10	0.21	0.66

Note: Exponential notation is indicated in abbreviated form; e.g., 1.7-4 = 1.7×10^{-4}.

Table 2-14
Individual Sequences Contributing to Release Category Group I

MODEL Name: WBCET1
Sequences For Group: GRPI Sorted By Frequency
Total Frequency of Sequences = 1.8724E-06

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Rank	Index	Initiator	Frequency	Failed and Multi-State Split Fractions
1	5	GNIYA	3.1242E-07	/CVC*SPB*HOB*RPP*MEH*DII
2	14	GNIYA	2.7398E-07	/CVC*SPB*HOB*RPR*MES*DIH
3	3	ENIYA	2.2827E-07	/CVC*SPB*HOB*RPW*C2A*L2A*SOB
4	5	GNIYN	1.3156E-07	/CVC*SPB*HOB*RPP*MEH*DII
5	9	GNIYA	1.2797E-07	/CVC*SPB*HOB*RPQ*MEH*DIH
6	4	FCI	1.2206E-07	/CVB*HOB*ICEB*RPW*C2A*L2A*SOB
7	14	GNIYN	1.1538E-07	/CVC*SPB*HOB*RPR*MES*DIH
8	6	HGI	9.1970E-08	/CVC*LSO*HOB*ICEB*RPT*MEH*DII
9	15	GNIYA	6.4026E-08	/CVC*SPB*HOB*RPR*MES*C2S*L2S*SOB
10	12	HGI	5.9760E-08	/CVC*LSO*HOB*ICEB*RPU*MEH*C2O*L2O*SOB
11	2	ENIYN	5.5517E-08	/CVC*SPB*RPW*C2A*L2A*SOB
12	9	GNIYN	5.3890E-08	/CVC*SPB*HOB*RPQ*MEH*DIH
13	1	ATV	4.9930E-08	/BYV*LBV
14	11	HGI	4.6294E-08	/CVC*LSO*HOB*ICEB*RPU*MEH*DIH
15	15	GNIYN	2.6962E-08	/CVC*SPB*HOB*RPR*MES*C2S*L2S*SOB
16	4	BCI	2.5228E-08	/CVA*HOB*RPW*C2A*L2A*DBCN*SOB
17	10	GNIYA	2.3733E-08	/CVC*SPB*HOB*RPQ*MEH*C2P*L2P*SOB
18	7	HGI	1.9920E-08	/CVC*LSO*HOB*ICEB*RPT*MEH*C2L*L2L*SOB
19	3	HCI	1.0844E-08	/CVC*HOB*ICEB*RPW*C2A*L2A*SOB
20	10	GNIYN	9.9941E-09	/CVC*SPB*HOB*RPQ*MEH*C2P*L2P*SOB
21	2	ENIYB	8.3616E-09	/CVC*SPB*RPW*C2A*L2A*SOB
22	12	GNIYA	4.8192E-09	/CVC*SPB*HOB*RPR*X2F*DBCN*HEB*CET*LET*SOB
23	2	HGI	2.1830E-09	/CVC*LSO*HOB*ICEB*RPS*C2A*L2A*SOB
24	6	GNIYA	2.0604E-09	/CVC*SPB*HOB*RPP*MEH*C2M*L2M*SOB
25	12	GNIYN	2.0294E-09	/CVC*SPB*HOB*RPR*X2F*DBCN*HEB*CET*LET*SOB
26	4	HGI	1.4735E-09	/CVC*LSO*HOB*ICEB*RPT*C2EV*L2EV*SOB
27	6	GNIYN	8.6765E-10	/CVC*SPB*HOB*RPP*MEH*C2M*L2M*SOB
28	9	HGI	7.3676E-10	/CVC*LSO*HOB*ICEB*RPU*C2EV*L2EV*SOB
29	2	GNIYA	1.3189E-10	/CVC*SPB*HOB*RPO*C2A*L2A*DBCN*SOB
30	2	GNIYN	5.5540E-11	/CVC*SPB*HOB*RPO*C2A*L2A*DBCN*SOB

Table 2-15
KPDS Contributions to Release Category Group I

MODEL Name: WBCET1
Initiator Contributions to End State Group : GRPI
Total Frequency for the End State Group = 1.8724E-06

13:46:27 11 MAR 1994

Initiator.....	Frequency.....	Unaccounted....
GNIYA	8.0913E-07	0.0000E+00
GNIYN	3.4074E-07	0.0000E+00
ENIYA	2.2827E-07	0.0000E+00
HGI	2.2234E-07	0.0000E+00
FCI	1.2206E-07	0.0000E+00
ENIYN	5.5517E-08	0.0000E+00
ATV	4.9930E-08	0.0000E+00
BCI	2.5228E-08	0.0000E+00
HCI	1.0844E-08	0.0000E+00
ENIYB	8.3616E-09	0.0000E+00
LNIYC	0.0000E+00	0.0000E+00
ENSYC	0.0000E+00	0.0000E+00
ENSYB	0.0000E+00	0.0000E+00
FNI	0.0000E+00	0.0000E+00
ENB	0.0000E+00	0.0000E+00
FGI	0.0000E+00	0.0000E+00
KNSYC	0.0000E+00	0.0000E+00
LCI	0.0000E+00	0.0000E+00
EIB	0.0000E+00	0.0000E+00
KNSYA	0.0000E+00	0.0000E+00
ENSYN	0.0000E+00	0.0000E+00
LNIYA	0.0000E+00	0.0000E+00
EGI	0.0000E+00	0.0000E+00
KNI	0.0000E+00	0.0000E+00
ENSYA	0.0000E+00	0.0000E+00
HNI	0.0000E+00	0.0000E+00

Table 2-16
Individual Sequences Contributing to Release Category Group II

MODEL Name: WBCET1
Sequences For Group: GRPII Sorted By Frequency
Total Frequency of Sequences = 8.0487E-06

13:42:25 11 MAR 1994

Rank	Index	Initiator	Frequency	Failed and Multi-State Split Fractions
1	1	EIB	5.4495E-06	/BYB
2	1	ENSYN	1.3120E-06	/BYB
3	1	ENSYA	4.9619E-07	/BYB
4	1	ENB	4.6574E-07	/BYB
5	1	ENSYC	1.6830E-07	/BYB
6	1	ENSYB	1.5697E-07	/BYB

Table 2-17 summarizes the frequency contribution of the key plant damage states to Group II. As indicated by this table, the two KPDSs associated with SGTR (EIB and ENB) account for approximately 73% of the frequency of this group. Approximately 27% of this group's frequency results from KPDS ENS which is dominated by sequences involving loss of offsite power and associated containment isolation failures resulting in a small containment bypass via the reactor coolant pump (RCP) seal return lines.

2.3.1.3 Release Category Group III – Late Containment Failure and Group IV Long-term Contained Releases

Table 2-18 lists those individual sequences whose frequencies are greater than 1×10^{-10} per reactor-year and that contribute to Release Category Group III. Table 2-19 summarizes the frequency contribution of KPDSs to Group III. As indicated in Table 2-19, the dominant KPDS contributor to the frequency of this group is KPDS ENIYN in which the dominant sequence involves a loss of train A of 6.9kV shutdown power. Basemat melt-through makes a minor contribution to this group.

Table 2-20 lists those individual sequences whose frequencies are greater than 1×10^{-10} per reactor-year and that contribute to Release Category Group IV. It should be noted that sequences involving containment failures at times greater than 48 hours were also binned to this group. The importance of these sequences is discussed in the next section. Table 2-21 summarizes the frequency contributions of KPDSs to Group IV.

Late burns were predicted for most of the KPDSs. In nearly all cases, these burns were predicted to occur at a relatively low concentration of hydrogen. In some cases, the oxygen content was eventually depleted to less than 5%, prohibiting additional burns.

Supplement No. 3 to U.S. Nuclear Regulatory Commission Generic Letter No. 88-20 (Reference 24) requests that "licensees with ice condenser containments are expected to evaluate the vulnerability to interruption of power to the hydrogen ignitors as part of the IPE." Of primary concern is the restoration of power during station blackouts.

Only 14% (1.1×10^{-5} per reactor-year) of the core damage frequency involves KPDS which have failure of the ignitor system. The dominant KPDS contributors associated with ignitor unavailabilityare ENIYN, ENIYB, GNIYN, and ENSYN* which are represented by sequences loss of offsite power, loss of Train A shutdown power, or total loss of ERCW.

*Plant damage state ENS is represented by a sequence involving a small bypass prior to core damage. Thus, the frequency associated with ENS is binned to Release Category Group II.

Table 2-17
KPDS Contributions to Release Category Group II

MODEL Name: WBCET1
Initiator Contributions to End State Group : GRPII
Total Frequency for the End State Group = 8.0487E-06

13:38:28 11 MAR 1994

Initiator.....	Frequency.....	Unaccounted....
EIB	5.4495E-06	0.0000E+00
ENSYN	1.3120E-06	0.0000E+00
ENSYA	4.9619E-07	0.0000E+00
ENB	4.6574E-07	0.0000E+00
ENSYC	1.6830E-07	0.0000E+00
ENSYB	1.5697E-07	0.0000E+00
EGI	0.0000E+00	0.0000E+00
ENIYB	0.0000E+00	0.0000E+00
KNI	0.0000E+00	0.0000E+00
HCI	0.0000E+00	0.0000E+00
FNI	0.0000E+00	0.0000E+00
LNIYC	0.0000E+00	0.0000E+00
FGI	0.0000E+00	0.0000E+00
KNSYC	0.0000E+00	0.0000E+00
ENIYA	0.0000E+00	0.0000E+00
GNIYN	0.0000E+00	0.0000E+00
LCI	0.0000E+00	0.0000E+00
LNIYA	0.0000E+00	0.0000E+00
FCI	0.0000E+00	0.0000E+00
HGI	0.0000E+00	0.0000E+00
HNI	0.0000E+00	0.0000E+00
GNIYA	0.0000E+00	0.0000E+00
ATV	0.0000E+00	0.0000E+00
NIYN	0.0000E+00	0.0000E+00
KNSYA	0.0000E+00	0.0000E+00
BCI	0.0000E+00	0.0000E+00

Table 2-18
Individual Sequences Contributing to Release Category Group III

MODEL Name: WBCET1
Sequences For Group: GPIII Sorted By Frequency
Total Frequency of Sequences = 1.6731E-05

13:41:39 11 MAR 1994

Rank	Index	Initiator	Frequency	Failed and Multi-State Split Fractions
1	1	ENIYN	6.8841E-06	/CVC*SPB*RPW*X2F*HEB*XEF*CLA*LLA
2	2	BCI	2.9718E-06	/CVA*HOB*RPW*DBCN*HEB*BIU
3	1	ENIYB	1.0368E-06	/CVC*SPB*RPW*X2F*HEB*XEF*CLA*LLA
4	4	GNIYA	9.7325E-07	/CVC*SPB*HOB*RPP*MEH*X2F*HEB*XEF*XLTF*CLTL*LLTG
5	3	FCI	7.5679E-07	/CVB*HOB*ICEB*RPW*X2S*HEB*XEF*XLTF*CLT1*LLT1
6	13	GNIYA	5.5125E-07	/CVC*SPB*HOB*RPR*MES*X2F*HEB*XEF*XLTF*CLTL*LLTG
7	3	GNIYA	4.7628E-07	/CVC*SPB*HOB*RPP*X2F*DBCN*HEB*XEF*XLTF*CLTL*LLTG
8	2	ENIYA	4.5289E-07	/CVC*SPB*HOB*RPW*X2F*HEB*XEF*XLTF*CLTD*LLTD
9	4	GNIYN	4.0985E-07	/CVC*SPB*HOB*RPP*MEH*X2F*HEB*XEF*CLA*LLA
10	5	HGI	2.8651E-07	/CVC*LSO*HOB*ICEB*RPT*MEH*X2C*HEB*XEF*XLTF*CLTL*LLTG
11	1	HGI	2.7069E-07	/CVC*LSO*HOB*ICEB*RPS*X2C*HEB*XEF*XLTF*CLTL*LLTG
12	8	GNIYA	2.5748E-07	/CVC*SPB*HOB*RPQ*MEH*X2F*HEB*XEF*XLTF*CLTL*LLTG
13	13	GNIYN	2.3214E-07	/CVC*SPB*HOB*RPR*MES*X2F*HEB*XEF*CLA*LLA
14	3	GNIYN	2.0057E-07	/CVC*SPB*HOB*RPP*X2F*DBCN*HEB*XEF*CLA*LLA
15	3	BCI	1.5641E-07	/CVA*HOB*RPW*X2S*DBCN*HEB*XEF*XLTF*CLT1*LLT1
16	7	GNIYA	1.5134E-07	/CVC*SPB*HOB*RPQ*X2F*DBCN*HEB*XEF*XLTF*CLTL*LLTG
17	3	HGI	1.4588E-07	/CVC*LSO*HOB*ICEB*RPT*X2C*HEB*XEF*XLTF*CLTL*LLTG
18	8	GNIYN	1.0843E-07	/CVC*SPB*HOB*RPQ*MEH*X2F*HEB*XEF*CLA*LLA
19	10	HGI	9.3145E-08	/CVC*LSO*HOB*ICEB*RPU*MEH*X2C*HEB*XEF*XLTF*CLTL*LLTG
20	8	HGI	7.2939E-08	/CVC*LSO*HOB*ICEB*RPU*X2C*HEB*XEF*XLTF*CLTL*LLTG
21	2	HCI	6.7233E-08	/CVC*HOB*ICEB*RPW*X2S*HEB*XEF*XLTF*CLT1*LLT1
22	7	GNIYN	6.3732E-08	/CVC*SPB*HOB*RPQ*X2F*DBCN*HEB*XEF*CLA*LLA
23	11	GNIYA	6.2114E-08	/CVC*SPB*HOB*RPR*X2F*DBCN*HEB*XEF*XLTF*CLTL*LLTG
24	11	GNIYN	2.6157E-08	/CVC*SPB*HOB*RPR*X2F*DBCN*HEB*XEF*CLA*LLA
25	1	GNIYA	1.6354E-08	/CVC*SPB*HOB*RPO*X2F*DBCN*HEB*XEF*XLTF*CLTL*LLTG
26	1	GNIYN	6.8870E-09	/CVC*SPB*HOB*RPO*X2F*DBCN*HEB*XEF*CLA*LLA

Table 2-19
KPDS Contributions to Release Category Group III

MODEL Name: WBCET1
Initiator Contributions to End State Group : GRPIII
Total Frequency for the End State Group =

13:38:28 11 MAR 1994

Initiator.....	Frequency.....	Unaccounted....
FNI	0.00E+00	0.00E+00
ENIYN	6.88E-06	0.00E+00
GNIYA	2.49E-06	0.00E+00
BCI	3.13E-06	0.00E+00
ENIYB	1.04E-06	0.00E+00
FCI	7.57E-07	0.00E+00
HGI	8.69E-07	0.00E+00
GNIYN	1.04E-06	0.00E+00
EGI	0.00E+00	0.00E+00
HNI	0.00E+00	0.00E+00
KNI	0.00E+00	0.00E+00
FGI	0.00E+00	0.00E+00
ENIYA	1.53E-07	0.00E+00
LNIYC	0.00E+00	0.00E+00
LCI	0.00E+00	0.00E+00
HCI	6.72E-08	0.00E+00

Table 2-20
Individual Sequences Contributing to Release Category Group IV

MODEL Name: WBCET1
Sequences For Group: GPIV Sorted By Frequency
Total Frequency of Sequences = 5.1631E-05

13:41:07 11 MAR 1994

Rank	Index	Initiator	Frequency	Failed and Multi-State Split Fractions
1	1	ENIYA	2.7853E-05	/CVC*SPB*HOB*RPW*X2F*HEB*XEF*XLTF
2	2	FCI	1.4379E-05	/CVB*HOB*ICEB*RPW*HEB
3	1	FCI	7.1802E-06	/
4	1	HCI	1.2774E-06	/CVC*HOB*ICEB*RPW*HEB
5	1	BCI	9.4194E-07	/

Table 2-21
KPDS Contributions to Release Category Group IV

MODEL Name: WBCET1
Initiator Contributions to End State Group : GPIV
Total Frequency for the End State Group = 5.1631E-05

13:34:40 11 MAR 1994

Initiator.....	Frequency.....	Unaccounted....
ENIYA	2.7853E-05	0.0000E+00
FCI	2.1559E-05	0.0000E+00
HCI	1.2774E-06	0.0000E+00
BCI	9.4194E-07	0.0000E+00
LNIYC	0.0000E+00	0.0000E+00
ENSYB	0.0000E+00	0.0000E+00
EGI	0.0000E+00	0.0000E+00
ENIYB	0.0000E+00	0.0000E+00
KNI	0.0000E+00	0.0000E+00
ENB	0.0000E+00	0.0000E+00
FNI	0.0000E+00	0.0000E+00
ENSYC	0.0000E+00	0.0000E+00
FGI	0.0000E+00	0.0000E+00
KNSYC	0.0000E+00	0.0000E+00
ENSYA	0.0000E+00	0.0000E+00
LNIYA	0.0000E+00	0.0000E+00
GNIYN	0.0000E+00	0.0000E+00
ENIYN	0.0000E+00	0.0000E+00
HGI	0.0000E+00	0.0000E+00
LCI	0.0000E+00	0.0000E+00
HNI	0.0000E+00	0.0000E+00
GNIYA	0.0000E+00	0.0000E+00
ENSYN	0.0000E+00	0.0000E+00
KNSYA	0.0000E+00	0.0000E+00
EIB	0.0000E+00	0.0000E+00
ATV	0.0000E+00	0.0000E+00

Following the recovery of AC power, the operators are instructed to start the containment spray pumps if containment pressure is above the phase B condition and to determine the volumetric concentration of hydrogen. If this concentration exceeds 6 percent, the ignitors are not energized. If large concentrations of hydrogen are present, there are other sources of ignition which could trigger a hydrogen burn. Since these ignition sources may be of a random nature, an ignition could occur at any time following recovery of AC power. To demonstrate that Watts Bar has no specific vulnerability to ignitor unavailability, it was conservatively assumed that all of the CDF associated with KPDSs with the ignitors unavailable would result in containment failure at some time.

2.3.2 Containment Event Tree Split Fraction Importance

2.3.2.1 Release Category Group I

The importance evaluation of the split fractions contributing to Release Category Group I is shown in Table 2-22. Five importance measures are summarized: (1) the percentage contribution with that split fraction failed (fraction importance); (2) the Fussel-Vesely importance; (3) the Birnbaum importance; (4) the factor increase in the group frequency when the split fraction is arbitrarily assigned a failure frequency of 1.0 (risk achievement worth); (5) the factor decrease in the group frequency when the split fraction is arbitrarily assigned a failure frequency of 0.0 (risk reduction worth).

Because the frequency of large, early containment failures and bypasses is extremely low (1.9×10^{-6} per reactor-year) and the fraction of CDF that results in low pressure at the time of vessel breach is high, it is not surprising that α-mode failure [at low reactor coolant system (RCS) pressure] of the reactor vessel and containment emerges (split fraction C2A or L2A) as a dominant contributor to the Group I frequency, contributing to approximately 24% of the group frequency. This estimate is based on using the NUREG/CR-4551 (Reference 10) mean value of 0.008 for the associated split fraction.

Also shown in Table 2-22 is the contribution to large, early containment failures due to direct impingement of debris on the containment wall due to seal table failure following high pressure melt ejection. This contribution (the sum of split fractions DII and DIH) amounts to approximately 62% of the frequency of Group I, or 1.2×10^{-6} per reactor-year.

DDT prior to vessel breach (split fraction C1T) and shortly after vessel breach (split fraction CET) contributes to only 0.4% of the Group I frequency despite the rather conservative treatment used in this study (see Section 4.8 of the original IPE report).

The importance of split fractions associated with high pressure melt ejection (HPME) (the sum of split fractions C2L, C2S, C2P, C2J, C2M, and C2O) indicate that containment

Table 2-22
CET Split Fraction Importance to Release Category Group I

MODEL Name: WBCET1
Split Fraction Importance for Group : GRPI
Sorted by Fraction Importance
Group Frequency = 1.8724E-06
13:27:29 11 MAR 1994

...SF	Name....	Fraction..... Importance	Fussel-Vesely... Importance	Birnbaum.... Importance	Achievement... Worth	Reduction... Worth	SF Value.....	Frequency
1.	HOB	9.3922E-01					1.0000E+00	1.7586E-06
2.	CVC	8.9467E-01	2.8623E-01	1.1779E+00			1.0000E+00	1.6752E-06
3.	SPB	7.7014E-01			1.0000E+00		1.0000E+00	1.4420E-06
4.	MEH	4.7021E-01	-3.5930E-02	-6.7159E-02		5.3298E-01	7.3000E-01	8.8044E-07
5.	SOB	3.5731E-01					1.0000E+00	6.6904E-07
6.	DIH	3.2979E-01			1.8917E+00	6.7021E-01	3.3200E-01	6.1750E-07
7.	DII	2.8623E-01			1.0000E+00	7.1377E-01	2.4300E-01	5.3595E-07
8.	RPR	2.6019E-01			1.0023E+00	8.4608E-01	2.9000E-01	4.8719E-07
9.	MES	2.5653E-01	1.5392E-01	5.3075E-01	1.0198E+00	7.9206E-01	9.3000E-01	4.8034E-07
10.	C2A	2.4175E-01			1.1169E+00	7.5825E-01	8.0000E-03	4.5266E-07
11.	L2A	2.4175E-01			1.0000E+00		1.0000E+00	4.5266E-07
12.	RPW	2.4048E-01			1.0000E+00		1.0000E+00	4.5028E-07
13.	RPP	2.3868E-01	0.0000E+00	0.0000E+00	1.4470E+00	1.0359E+00	5.3500E-01	4.4691E-07
14.	ICEB	1.8972E-01					1.0000E+00	3.5524E-07
15.	LSO	1.1874E-01	9.9596E-05	1.9919E-02	1.1727E+00		1.0000E+00	2.2234E-07
16.	RPQ	1.1514E-01	3.8022E-02	1.5209E-01	1.3768E+00	9.0844E-01	1.7000E-01	2.1559E-07
17.	CVB	6.5190E-02	3.2979E-01	9.9334E-01	1.0000E+00	9.3481E-01	6.8000E-01	1.2206E-07
18.	RPT	6.0544E-02			1.1141E+00	1.0000E+00	5.0000E-01	1.1336E-07
19.	RPU	5.7033E-02			7.5952E-01	9.6198E-01	2.5000E-01	1.0679E-07
20.	L2S	4.8594E-02			1.0000E+00		1.0000E+00	9.0989E-08
21.	C2S	4.8594E-02			1.0471E+00	9.6754E-01	7.2000E-02	9.0989E-08
22.	L2O	3.1916E-02			1.0000E+00		1.0000E+00	5.9760E-08
23.	C2O	3.1916E-02	1.3473E-02	1.7498E-02	1.1954E+00	9.7868E-01	3.0000E-01	5.9760E-08
24.	BYV	2.6666E-02	1.1804E-03	1.1804E-01			1.0000E+00	4.9930E-08
25.	LBV	2.6666E-02	4.6702E-01	6.3976E-01	1.0000E+00		1.0000E+00	4.9930E-08
26.	C2P	1.8012E-02	6.5190E-02	9.5867E-02	1.4184E+00	9.8797E-01	5.8000E-02	3.3727E-08
27.	L2P	1.8012E-02			1.0000E+00		1.0000E+00	3.3727E-08
28.	DBCN	1.7231E-02			1.6636E+00		1.0000E+00	3.2264E-08
29.	CVA	1.3473E-02			1.0307E+00	9.8653E-01	7.7000E-01	2.5228E-08
30.	C2L	1.0639E-02	1.2032E-02	2.0745E-01	1.7387E+00	9.9195E-01	5.0000E-02	1.9920E-08
31.	L2L	1.0639E-02			1.0000E+00		1.0000E+00	1.9920E-08
32.	HEB	3.6576E-03					1.0000E+00	6.8486E-09
33.	CET	3.6576E-03			1.0040E+00	9.9634E-01	7.2000E-02	6.8486E-09
34.	LET	3.6576E-03					1.0000E+00	6.8486E-09
35.	X2F	3.6576E-03					1.0000E+00	6.8486E-09
36.	C2M	1.5638E-03	3.2461E-02	4.5085E-01		9.9882E-01	1.6000E-03	2.9280E-09
37.	L2M	1.5638E-03			1.0000E+00		1.0000E+00	2.9280E-09
38.	L2EV	1.1804E-03			1.0000E+00		1.0000E+00	2.2103E-09
39.	C2EV	1.1804E-03	2.1320E-02	7.1066E-02	1.1530E+00	9.9882E-01	1.0000E-02	2.2103E-09
40.	RPS	1.1659E-03			1.0000E+00	9.9922E-01	2.5000E-01	2.1830E-09
41.	RPO	1.0010E-04	7.7725E-04	3.1090E-03	9.6877E-01	9.9990E-01	5.0000E-03	1.8743E-10
42.	SPA	0.0000E+00			1.0000E+00	1.0000E+00	0.0000E+00	0.0000E+00
43.	BYA	0.0000E+00	2.4175E-01	3.0219E+01	1.0000E+00	1.0000E+00	0.0000E+00	0.0000E+00
44.	DBCC	0.0000E+00			1.0000E+00	1.0000E+00	0.0000E+00	0.0000E+00
45.	C2NF	0.0000E+00	3.6576E-03	5.0800E-02	1.0497E+00	1.0000E+00	0.0000E+00	0.0000E+00
46.	HON	0.0000E+00			1.0000E+00	1.0000E+00	0.0000E+00	0.0000E+00
47.	C1B	0.0000E+00	8.0534E-03	1.6107E-01		1.0000E+00	0.0000E+00	0.0000E+00
48.	C1D	0.0000E+00	1.1838E-03	7.3985E-01	3.0977E+01	1.0000E+00	0.0000E+00	0.0000E+00
49.	MEL	0.0000E+00	9.1555E-02	5.3856E-01	1.0157E+00	1.0000E+00	0.0000E+00	0.0000E+00
50.	LSL	0.0000E+00	2.0794E-01	2.2359E-01	1.0000E+00	1.0000E+00	0.0000E+00	0.0000E+00
51.	ISL	0.0000E+00			1.0000E+00	1.0000E+00	0.0000E+00	0.0000E+00
52.	ICEA	0.0000E+00			1.0000E+00	1.0000E+00	0.0000E+00	0.0000E+00
53.	IPL	0.0000E+00				1.0000E+00	0.0000E+00	0.0000E+00

failures due to HPME amount to approximately 11% of the Release Category Group I frequency.

2.3.2.2 Release Category Group II

Table 2-23 summarizes the importance of specific CET split fractions to the frequency of Release Category Group II. As indicated by the importance of split fraction BYB (SGTR initiating events), bypass scenarios dominate the Group II frequency.

2.3.2.3 Release Category Groups III

Table 2-24 summarizes the importance of specific CET split fractions to the frequency of Release Category Group III. This group contains sequences in which containment failure is predicted to occur within 48 hours of the initiating event. Split fractions CLTF and CLTL representing long-term containment overpressurization, appear in 20% of the Group III frequency. Containment failure due to long-term overpressurization is not expected to occur within 24 hours for GNIYA, HNI, FNI, and FGI, which are involved in a large fraction of the long-term overpressurization failures. Split fraction XLTF appears in 29% of the Group III frequency, indicating that failure of long-term containment heat removal is involved in the Group III frequency. Basemat melt-through (as indicated by split fraction BIU) makes less than a 18% contribution to the Group III frequency.

The importance of the assumption regarding ignitor unavailability is illustrated by the contribution of split fraction CLA, which is 54% of the Group III frequency.

2.3.2.4 Release Category Group IV

Table 2-25 summarizes the importance of specific CET split fractions to the frequency of Release Category Group IV. This group contains sequences with long-term containment intact as well as sequences in which containment failure is very likely but not within 48 hours. This differentiation is facilitated by examining the split fraction contribution to the frequency of the group. Those sequences that contain split fraction XLTF (no long term containment heat removal) will eventually go to containment failure if no recovery takes place within 48 hours. These sequences account for approximately 54% of the frequency of this group. The remaining sequences in this group represent either "recovered in-vessel" or long-term containment heat removal.

2.4 OVERALL CHARACTERIZATION

Based on the results and insights from the WBN IPE the following functional areas are identified for consideration as candidates for evaluation in the value impact analysis:

- Improve Availability of ECCS Recirculation

- Improve Availability of AC Power
- Improve Capability to Cope With Loss of AC Power/Station Blackout
- Improve Ability to Cope With Loss of RCP Seal Cooling
- Improve Containment Performance

In addition, other items may be identified from the detailed review of the IPE results which have the potential to decrease core damage for some dominant contributors.

Table 2-23
CET Split Fraction Importance to Release Category Group II

MODEL Name: WBCET1
Split Fraction Importance for Group : GRPII
Sorted by Fraction Importance
Group Frequency = 8.0487E-06

13:26:55 11 MAR 1994

...SF	Name....	Fraction..... Importance	Fussel-Vesely... Importance	Birnbaum.... Importance	Achievement... Worth	Reduction... Worth	SF Value.....	Frequency
1.	BYB	1.0000E+00			1.0000E+00	1.0000E+00	1.0000E+00	8.0487E-06
2.	LBB	0.0000E+00					0.0000E+00	0.0000E+00

Table 2-24
CET Split Fraction Importance to Release Category Group III

MODEL Name: WBCET1
Split Fraction Importance for Group : GPIII
Sorted by Fraction Importance
Group Frequency = 1.6731E-05
13:26:09 11 MAR 1994

...SF	Name....	Fraction..... Importance	Fussel-Vesely... Importance	Birnbaum.... Importance	Achievement... Worth	Reduction... Worth	SF Value.....	Frequency
1.	HEB	1.0000E+00			1.0000E+00	1.0000E+00	1.0000E+00	1.6731E-05
2.	XEF	8.2238E-01			1.0000E+00	1.0000E+00	1.0000E+00	1.3759E-05
3.	CVC	7.6780E-01	-3.2033E-02	-1.3182E-01	1.0000E+00	1.0000E+00	1.0000E+00	1.2846E-05
4.	RPW	7.3672E-01			2.6328E-01	1.0000E+00	1.0000E+00	1.2326E-05
5.	X2F	7.1183E-01			1.0000E+00	9.5075E-01	1.0000E+00	1.1910E-05
6.	SPB	7.1183E-01			1.0000E+00		1.0000E+00	1.1910E-05
7.	LLA	5.3605E-01			1.0000E+00		1.0000E+00	8.9687E-06
8.	CLA	5.3605E-01			1.0000E+00	1.0000E+00	1.0000E+00	8.9687E-06
9.	HOB	5.2657E-01			1.0000E+00	1.0000E+00	1.0000E+00	8.8101E-06
10.	XLTF	2.8633E-01			1.0000E+00	1.0000E+00	1.0000E+00	4.7906E-06
11.	DBCN	2.4695E-01			1.0000E+00	1.0369E+00	1.0000E+00	4.1317E-06
12.	CLTL	2.0066E-01			1.0000E+00	8.1303E-01	1.0000E+00	3.3572E-06
13.	LLTG	2.0066E-01			1.0000E+00	1.0000E+00	1.0000E+00	3.3572E-06
14.	CVA	1.8697E-01			1.0558E+00	9.5477E-01	7.7000E-01	3.1282E-06
15.	BIU	1.7762E-01	-6.0829E-03	-7.6037E-01	1.0000E+00	1.0000E+00	1.0000E+00	2.9718E-06
16.	MEH	1.2723E-01	-1.8534E-02	-3.4644E-02	9.8067E-01	1.0000E+00	7.3000E-01	2.1287E-06
17.	RPP	1.2312E-01	0.0000E+00	0.0000E+00	9.8389E-01	9.7239E-01	5.3500E-01	2.0599E-06
18.	ICEB	1.0120E-01			1.0000E+00	1.0000E+00	1.0000E+00	1.6932E-06
19.	LLT1	5.8600E-02			1.0000E+00		1.0000E+00	9.8043E-07
20.	X2S	5.8600E-02			1.9358E+00		5.0000E-02	9.8043E-07
21.	CLT1	5.8600E-02	4.5233E-02	6.6518E-02	1.0000E+00	9.7293E-01	1.0000E+00	9.8043E-07
22.	RPR	5.2099E-02			1.0755E+00	9.8921E-01	2.9000E-01	8.7166E-07
23.	X2C	5.1949E-02			1.0000E+00		1.0000E+00	8.6916E-07
24.	LSO	5.1949E-02	1.3821E-03	2.7642E-01	1.0000E+00	1.0523E+00	1.0000E+00	8.6916E-07
25.	MES	4.6823E-02	3.0819E-02	1.0627E-01	9.9825E-01	9.9862E-01	9.3000E-01	7.8339E-07
26.	CVB	4.5233E-02	-3.6908E-02	-1.1117E-01	1.0213E+00		6.8000E-01	7.5679E-07
27.	RPQ	3.4725E-02	6.6178E-03	2.6471E-02	1.1348E+00	9.6918E-01	1.7000E-01	5.8098E-07
28.	LLTD	2.7069E-02	-5.2266E-02	-7.1597E-02	1.0000E+00		1.0000E+00	4.5289E-07
29.	CLTD	2.7069E-02			2.6647E+00		1.6000E-02	4.5289E-07
30.	RPT	2.5843E-02			1.0000E+00	9.9338E-01	5.0000E-01	4.3239E-07
31.	RPS	1.6179E-02			1.0324E+00	1.0000E+00	2.5000E-01	2.7069E-07
32.	RPU	9.9267E-03			1.0199E+00		2.5000E-01	1.6608E-07
33.	RPO	1.3891E-03	1.0786E-02	4.3144E-02	1.2750E+00	1.0185E+00	5.0000E-03	2.3241E-08
34.	XLTI	0.0000E+00					0.0000E+00	0.0000E+00
35.	BYA	0.0000E+00	-1.3211E-04	-1.3211E-02		1.0000E+00	0.0000E+00	0.0000E+00
36.	C1D	0.0000E+00	-1.3248E-04	-8.2799E-02		1.0061E+00	0.0000E+00	0.0000E+00
37.	C2A	0.0000E+00			2.4571E-01	1.0001E+00	8.0000E-03	0.0000E+00
38.	SPA	0.0000E+00	4.9251E-02	9.8502E-01			0.0000E+00	0.0000E+00
39.	XEI	0.0000E+00					0.0000E+00	0.0000E+00
40.	C1B	0.0000E+00	-9.0128E-04	-1.8026E-02		1.0000E+00	0.0000E+00	0.0000E+00
41.	C2EV	0.0000E+00	-2.3859E-03	-7.9532E-03	9.8692E-01	1.0009E+00	1.0000E-02	0.0000E+00
42.	CLN	0.0000E+00	1.8697E-01	2.4282E-01			0.0000E+00	0.0000E+00
43.	C2P	0.0000E+00			9.7813E-01	1.0036E+00	5.8000E-02	0.0000E+00
44.	DIH	0.0000E+00			9.2574E-01	1.0320E+00	3.3200E-01	0.0000E+00
45.	DBCC	0.0000E+00					0.0000E+00	0.0000E+00
46.	DII	0.0000E+00			9.0021E-01		2.4300E-01	0.0000E+00
47.	C2O	0.0000E+00	-4.0934E-04	-5.6852E-03	9.9443E-01	1.0013E+00	3.0000E-01	0.0000E+00
48.	CET	0.0000E+00	2.7069E-02	1.6918E+00	9.9472E-01		7.2000E-02	0.0000E+00
49.	C2S	0.0000E+00			9.5318E-01	1.0000E+00	7.2000E-02	0.0000E+00
50.	CEB	0.0000E+00				1.0004E+00	0.0000E+00	0.0000E+00
51.	MEL	0.0000E+00	2.7613E-02	1.6243E-01		1.0233E+00	0.0000E+00	0.0000E+00
52.	C2M	0.0000E+00	-3.6328E-03	-5.0455E-02	9.1733E-01	1.0000E+00	1.6000E-03	0.0000E+00
53.	C2L	0.0000E+00	-1.3466E-03	-2.3217E-02	9.8288E-01	1.0001E+00	5.0000E-02	0.0000E+00
54.	ISL	0.0000E+00					0.0000E+00	0.0000E+00
55.	LSL	0.0000E+00	-2.3271E-02	-2.5023E-02			0.0000E+00	0.0000E+00
56.	HON	0.0000E+00					0.0000E+00	0.0000E+00
57.	C2NF	0.0000E+00				1.0024E+00	0.0000E+00	0.0000E+00
58.	IPL	0.0000E+00				1.0000E+00	0.0000E+00	0.0000E+00
59.	ICEA	0.0000E+00					0.0000E+00	0.0000E+00

Table 2-25
CET Split Fraction Importance to Release Category Group IV

MODEL Name: WBCET1
Split Fraction Importance for Group : GPIV
Sorted by Fraction Importance
Group Frequency = 5.1631E-05

13:25:23 11 MAR 1994

...SF	Name....	Fraction..... Importance	Fussel-Vesely... Importance	Birnbaum.... Importance	Achievement... Worth	Reduction... Worth	SF Value.....	Frequency
1.	RPW	8.4269E-01			1.0000E+00		1.0000E+00	4.3509E-05
2.	HOB	8.4269E-01					1.0000E+00	4.3509E-05
3.	HEB	8.4269E-01			1.0000E+00		1.0000E+00	4.3509E-05
4.	CVC	5.6420E-01			1.0000E+00		1.0000E+00	2.9130E-05
5.	X2F	5.3946E-01			1.0000E+00		1.0000E+00	2.7853E-05
6.	SPB	5.3946E-01	-1.5960E-02	-3.1919E-01	6.9677E-01		1.0000E+00	2.7853E-05
7.	XLTF	5.3946E-01					1.0000E+00	2.7853E-05
8.	XEF	5.3946E-01			1.0000E+00		1.0000E+00	2.7853E-05
9.	ICEB	3.0323E-01					1.0000E+00	1.5656E-05
10.	CVB	2.7849E-01				1.0170E+00	6.8000E-01	1.4379E-05
11.	SPA	0.0000E+00			1.0000E+00	1.0000E+00	0.0000E+00	0.0000E+00
12.	MEL	0.0000E+00				1.0000E+00	0.0000E+00	0.0000E+00
13.	LSL	0.0000E+00			1.5731E-01	1.0000E+00	0.0000E+00	0.0000E+00
14.	XLTI	0.0000E+00				1.0000E+00	0.0000E+00	0.0000E+00
15.	X2S	0.0000E+00				1.0160E+00	5.0000E-02	0.0000E+00
16.	XEI	0.0000E+00				1.0000E+00	0.0000E+00	0.0000E+00
17.	BYA	0.0000E+00	-6.7959E-03	-8.4949E-01	1.5731E-01	1.0000E+00	0.0000E+00	0.0000E+00
18.	CLN	0.0000E+00	-6.1076E-02	-7.9320E-02	9.8176E-01	1.0000E+00	0.0000E+00	0.0000E+00
19.	CEB	0.0000E+00	-8.7716E-03	-5.4823E-01	4.6054E-01	1.0000E+00	0.0000E+00	0.0000E+00
20.	CLTD	0.0000E+00	-1.7022E-02	-2.5032E-02	9.9199E-01	1.0088E+00	1.6000E-02	0.0000E+00
21.	C1D	0.0000E+00				1.0000E+00	0.0000E+00	0.0000E+00
22.	C2A	0.0000E+00				1.0068E+00	8.0000E-03	0.0000E+00
23.	ISL	0.0000E+00				1.0000E+00	0.0000E+00	0.0000E+00
24.	IPL	0.0000E+00				1.0000E+00	0.0000E+00	0.0000E+00
25.	ICEA	0.0000E+00				1.0000E+00	0.0000E+00	0.0000E+00
26.	CVA	0.0000E+00			1.0000E+00	1.0611E+00	7.7000E-01	0.0000E+00
27.	DBCC	0.0000E+00			1.0000E+00	1.0000E+00	0.0000E+00	0.0000E+00

Section 3

ANALYSIS METHODOLOGY

The overall methodology used in identifying and evaluating potential enhancements is shown in Figure 3-1. The first step of the process involves the characterization of the base IPE results. Section 2 provides a summary of these results. Based on the overall results of the IPE, the following functional improvements were identified for investigation:

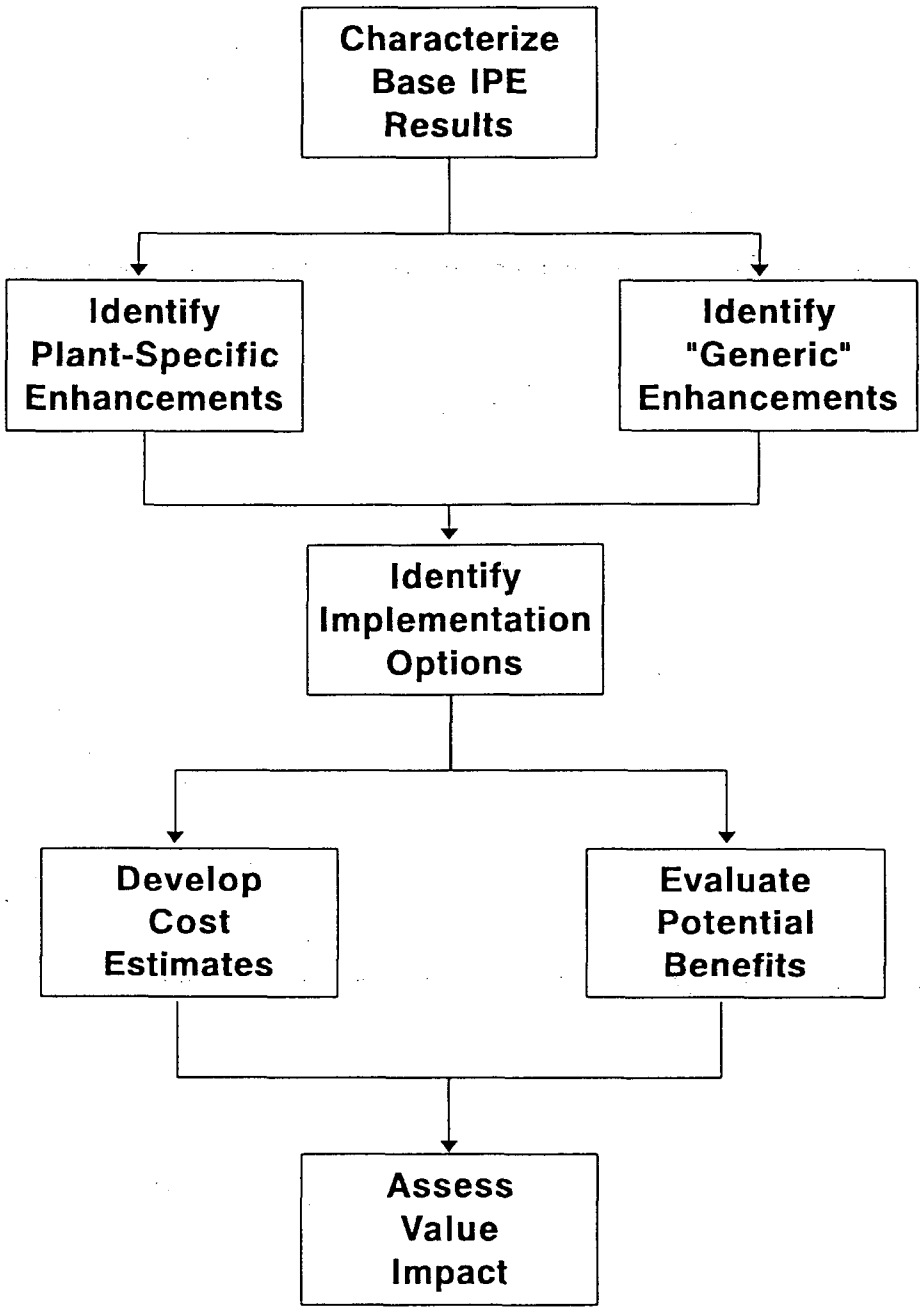
- Improve Availability of ECCS Recirculation
- Improve Availability of AC Power
- Improve Capability to Cope With Loss of AC Power/Station Blackout
- Improve Ability to Cope With Loss of RCP Seal Cooling
- Improve Containment Performance

These functional improvement categories are too broad to allow the assessment of cost or benefit. It is therefore necessary to identify specific options for implementation. Potential options for implementation were derived based on a detailed review of the IPE and other "generic" sources. The detailed review of the IPE involved the review of the PRA model outputs (i.e., dominant sequences, importance listings, etc.) and considerations of potential procedural or design improvements which could address a dominant contributor. In addition to reviewing the details of the WBN IPE, the overall insights of the IPE were used in evaluating the potential benefit of "generic" or non-plant specific enhancement identified by the NRC or industry in other relevant studies. These studies included IPEs from other similar plants, NRC generic letters, NUREG-1150 and licensing submittals related to severe accident mitigation design alternatives. Based on the review of the plant specific details and the generic implementation options, a list of candidate implementation options was developed.

The second phase of the evaluation process involved the assessment of costs and benefits associated with each implementation option. The design options for each candidate enhancement were reviewed to determine if plant specific features required a detailed cost analysis. In cases where low cost options could be identified, plant specific cost estimates were developed. In some cases where the modifications were significant, other utility or NRC estimates for implementation costs were used. The benefits associated with each enhancement were assessed using the WBN Level 2 PRA model. Each enhancement was reviewed and evaluated to determine how its implementation could be reflected in the IPE. In all cases, the analysis approach used was defined to

Figure 3-1

PROCESS FOR IDENTIFICATION & EVALUATION OF POTENTIAL PLANT ENHANCEMENTS



estimate the maximum benefit achievable, if the enhancement were implemented. As such, the benefit estimates are intended to bound the potential benefit and may overstate the actual improvement. With the costs and benefits identified, an assessment of the value impact associated with the enhancement can be made. This evaluation was made based on a comparison of the averted offsite dose (person-rem) to the cost to determine if the cost exceeded $1000 per person-rem. Enhancement options which had a cost of less than $1000 per person-rem were considered cost beneficial.

3.1 IDENTIFICATION OF POTENTIAL ENHANCEMENTS

3.1.1 Identification of "Generic" Enhancements

Based on the five identified functional enhancement categories, a review was undertaken of published reports, such as NUREG reports, EPRI reports, other IPE reports, and previously published TVA reports. Specifically, the review included the following:

- Generic Letter 88-20, Supplement 2
- NUREG/CR-5589
- Limerick Generating Station SAMDA Analysis
- Commanche Peak SAMDA Analysis
- Watts Bar SAMDA Analysis
- NUREG-1150
- DC Cook IPE
- Catawba IPE
- Sequoyah IPE

Table 3-1 provides a summary of the conclusions regarding the items contained in NRC Generic Letter 88-20, Supplement 2. Table 3-2 provides a summary of the items identified from NUREG/CR-5589, other SAMDA analyses and NUREG-1150.

A review of the other ice condenser IPEs identified three potential enhancements based on plant specific features present at other plants. A review of the DC Cook IPE identified the potential for cross-tying AC power busses to another switchyard (and grid) as an option for providing AC power in the event of a loss of offsite power. This enhancement is applicable to Watts Bar because of the presence of two separate grids, a 161kV and a 500 kV. The Catawba IPE identified a potential enhancement related to an independent RCP seal cooling system. The Catawba plant has such a system which is relied upon to mitigate loss of RCP seal cooling events, including station blackout. Finally, a review of the Sequoyah IPE identified a design difference between Sequoyah and Watts Bar related to the cooling medium for the charging pumps. At Watts Bar, the charging pumps are cooled by the component cooling system (CCS) and one can be cross-tied to essential

raw cooling water (ERCW). This means that in the event of a loss of CCS, an operator action is required to align ERCW to ensure continued charging and RCP seal cooling. At Sequoyah, the charging pumps are cooled by ERCW at all times. Therefore, a candidate enhancement option involves the redesign of the charging pump cooling to utilize ERCW rather than CCS.

3.1.2 Identification of Plant Specific Enhancements

The task in the identification process involved a detailed and systematic review of the review of the Watts Bar IPE and results. The first step involved a review and evaluation of the insights and potential plant improvements identified in the IPE. Table 3-3 provides a summary of the potential plant improvements identified in the updated IPE report.

The next step involved a detailed review of each top event and split fraction in the IPE to determine whether specific enhancement could address key contributors. This involved the review of each of the top events in the Watts Bar IPE against two screening criteria and those top events that fell below both sets of criteria were dropped from further consideration. The review criteria were:

- Risk Reduction Worth greater than 0.99
- Top Event Importance less than 0.01

A Risk Reduction Worth greater than 0.99 indicates that the maximum change in core damage frequency that can be expected from a potential enhancement will be less than 1%. A top event importance less than 0.01 indicates that a particular top event appears in sequences with a total core damage frequency of less than 1%. Table 3-4 presents a summary of the top events contained in the Watts Bar IPE and the results of the initial screen. Those top events screened out as a result of the risk reduction or top event importance values are indicated by comments under the "No" column for the "Consider Enhancement" group. All other top events were evaluated in the detailed Enhancement Analysis Sheets indicated and presented in Appendix B. In order to facilitate the review and analysis of the Enhancement Analysis Sheets, the sheets are separated into functions as follows:

Support Systems - AC Power, AC Instrument, DC Power, Actuation, ERCW, CCS, Ventilation, Air, CST, RWST

Reactivity Control - Reactor Trip, Rod Insertion, Boration, Power Level, etc.

Decay Heat Removal - Secondary and Primary, etc.

RCS Make-up - High Pressure and Low Pressure, RCP Seals, etc.

Containment Functions - Spray, Hydrogen Control, Air Return Fans, etc.

An example Enhancement Analysis Sheet is presented in Table 3-5. These sheets identify the top event, the function of the top event, boundary conditions and dependencies that affect the top event, the importance measures for the top event, the effect of the top event on other functions, the enhancements considered, and the classification of the enhancements. The classification is based on a "High", Medium", and "Low" rating. A "High" classification indicates the potential for core damage frequency reduction is greater than 10%. A "Medium" classification indicates the potential for a change in core damage frequency is between 1 and 10%. A "Low" classification indicates that the potential benefit is less than a 1% change in core damage frequency. The Enhancement Analysis Sheets for the Generic Letter 88-20 enhancements, the IPE identified enhancements, and the NUREG/CR-5589 enhancements are similar to the enhancement analysis sheets for the IPE top events.

Table 3-1
Candidate IPE Enhancement Items
(Generic Letter 88-20, Supplement 2)

Item #	Description	Implemented
I	Conserving and Replenishing Limited Resources:	
I.a	Refill RWST with borated water, or CST with condensate. Assure adequate supply of boron on site	Yes, in IPE (CTMU, MU)
I.b	Throttle CS to conserve water for core injection	No, Sheet 1
I.c	Conserve battery capacity by shedding non-essential loads.	Yes (procedures)
I.d	Use portable battery chargers or other power sources to recharge batteries.	No, Sheet 2
I.e	Enable emergency replenishment of gas supply, or otherwise ensure operability of air-operated components.	No, Sheet 3
I.f	Enable early detection, isolation, or otherwise mitigate the effects of an interfacing systems LOCA.	Yes (procedures)

Table 3-1
Candidate IPE Enhancement Items
(Generic Letter 88-20, Supplement 2)

Item #	Description	Implemented
II.	Using Systems and Components in Innovative Applications:	
II.a	Strategies to enable emergency use of available pumps to accomplish safety functions.	
	Use diesel-fire systems for injection to the containment sprays, or the Steam Generators	No, Sheet 4
	Use charging pumps for core injection	NA (in Model)
	Use alternate injection when RCP seal cooling lost	No
	Enable emergency crosstie of service water and component cooling water to feedwater.	No - Little Benefit
	Use condensate or startup pumps for feedwater injection.	Yes, Sheet 5
II.b	Strategies to enable emergency connection of available ac power sources to meet critical safety needs:	
	Enable emergency crosstie of ac power between two units	No, Sheet 6
II.c	Strategies to enable emergency connection of injection systems to alternate water sources:	
	Ensure appropriate recirculation switchover and cope with the failure to switchover in LOCAs.	No, Sheet 7
	Enable emergency connection of service water or feedwater systems to rivers, etc.	Yes, automatic switchover, AFW suction
II.d	Strategies for Reactivity Control:	
	Ensure abundant supply of borated makeup for long-term accident control.	Yes, Sheet 72
III.	Defeating Interlocks and Component Protective Trips in Emergencies:	Not Important, Already in Design
	Reopen MSIVs and TBVs to regain condenser as a heat sink.	
	Enable emergency bypass of protective trips for diesel generators and injection pumps	

No - Not in IPE
NA - Not Applicable to WBN
Yes - Already Modeled in IPE
Sheet "n - Further discussion on indicated Enhancement Sheet

Table 3-2
Candidate Enhancement Items From
NUREG/CR-5589, SAMDA Analyses and NUREG-1150

Item #	Description	Status
1.	Additional Diesel Generator	IPE.5, Sheet 20
2.	Additional Battery Capacity	IPE.5, Sheet 21
3.	Alternate Means of Core Injection	Sheet 22
4.	Improved Availability of Recirculation Mode	Sheet 23
5.	Additional Instrumentation for Bypass Sequences	Sheet 24
6.	Deliberate Ignition System (Improved System)	Sheet 25
7.	Reactor Depressurization System	Sheet 26
8.	Independent Containment Spray System	Sheet 27
9.	Reactor Cavity Flooding System	Sheet 28
10.	Filtered Containment Vent	Sheet 29
11.	Enhancement of Air Return Fans (Backup Power, etc.)	Sheet 30
12.	Core Debris Control	Sheet 31
13.	Containment Inerting Capability	Sheet 32
14.	ERCW Cross-Connection to Centrifugal Charging Pumps and Increased Lube Oil Storage Capacity	IPE.4, Sheet 33
15.	Independent RCP Seal Injection System	IPE.4, Sheet 34
16.	Delay of Containment Spray Actuation	Sheet 35

Table 3-3
Candidate IPE Enhancement Items
(IPE Update Report, Dec. 16, 1993)

Item #	Description	Status
1.	Reactor Subcriticality:	
	Simplify MG Set Breaker Operation	Sheet 8
2.	Core Cooling:	
	Utilize Containment Spray Pumps for ECCS Recirculation	Sheet 9
	Enhance Procedures Related to Refill of RWST	88-20, I.a
3.	Heat Removal:	
	Alternate Power to Motor Driven MFW Pump	Sheet 10
	Change TDAFW Pump Flow Control Valves to Fail Open	Sheet 11
4.	Mechanical Support Systems:	
	Automatic Reactor Trip/RCP Trip on High RCP Motor Bearing Temperature	Sheet 12
	Alternate Cooling (Firewater) and Power to PDP	Sheet 13
	HVAC Procedures	Sheet 14
	Fire Water Cooling to CCPs	88-20, II.a, Sheet 15
	Install New RCP Seals	88-20, II.a, Sheet 16
5.	Electrical Support Systems:	
	Fifth Emergency Diesel Generator	88-20, II.b, Sheet 17
	Cross-tie Capability from Unit 2 to Unit 1 6.9kV Shutdown Boards	88-20, II.b, Sheet 18
	Dedicated Connection Capability from Watts Bar Hydro Plant to 6.9kV Shutdown Boards	Already Exists
	Fifth Battery Bus	Sheet 19

Table 3-4
Top Event Importance Measures

Top	Frequency F(x)	Top Importance (Total)	Fraction Importance (GF)	%	Fraction Importance (Non-GF)	%	Risk Achievement Worth	Risk Reduction Worth	Delta CDF	Consider Enhancement Yes	Consider Enhancement No	Remarks
OGR1	1.5433E-05	2.0260E-01	0.0000E+00	0.00%	2.0260E-01	100.00%	1.5579E+00	8.0903E-01	1.54E-05	Sheet 38		Analysis Sheet 5
RR	6.5771E-05	8.6341E-01	6.8208E-01	79.00%	1.8133E-01	21.00%	8.7899E+01	8.1872E-01	1.46E-05	Sheet 94		Analysis Sheet 1
REC	7.6127E-05	9.9936E-01	8.3568E-01	83.62%	1.6367E-01	16.38%	4.3702E+00	8.3633E-01	1.32E-05	Sheet 36		Analysis Sheet 4
GA	1.1658E-05	1.5304E-01	3.7844E-03	2.47%	1.4925E-01	97.52%	1.9528E+00	8.5813E-01	1.14E-05	Sheet 39		Analysis Sheet 7
GB	1.1604E-05	1.5233E-01	3.8796E-03	2.55%	1.4845E-01	97.45%	1.6997E+00	8.6077E-01	1.12E-05	Sheet 39		Analysis Sheet 7
CCPR	2.9288E-05	3.8448E-01	2.4918E-01	64.81%	1.3530E-01	35.19%	2.0125E+00	8.8134E-01	9.54E-06	Sheet 57		Analysis Sheet 14
AC	3.2765E-05	4.3013E-01	3.1192E-01	72.52%	1.1821E-01	27.48%	1.1091E+02	8.8303E-01	9.40E-06	Sheet 56		Analysis Sheet 14
MU	4.7317E-05	6.2115E-01	4.3208E-01	69.56%	1.8907E-01	30.44%	2.3716E+00	8.8572E-01	9.19E-06	Sheet 69		Analysis Sheet 1
RA	5.1546E-05	6.7666E-01	5.9588E-01	88.06%	8.0787E-02	11.94%	5.3020E+00	9.2486E-01	6.04E-06	Sheet 92		Analysis Sheet 6
RB	5.2524E-05	6.8950E-01	6.0918E-01	88.35%	8.0327E-02	11.65%	2.8073E+00	9.2618E-01	5.94E-06	Sheet 92		Analysis Sheet 6
B1	2.6059E-05	3.4209E-01	2.7021E-01	78.99%	7.1880E-02	21.01%	2.2012E+02	9.2833E-01	5.76E-06	Sheet 43		Analysis Sheet 10
TPR	9.7108E-06	1.2748E-01	3.9322E-02	30.85%	8.8156E-02	69.15%	1.0135E+00	9.4320E-01	4.57E-06		Sheet 76	Data
DE	1.7711E-05	2.3251E-01	1.7565E-01	75.55%	5.6851E-02	24.45%	1.3856E+02	9.4330E-01	4.56E-06	Sheet 53		Analysis Sheet 11
CE	1.5981E-05	2.0979E-01	1.6089E-01	76.69%	4.8898E-02	23.31%	1.0081E+02	9.5127E-01	3.92E-06	Sheet 53		Analysis Sheet 11
RT	3.5870E-06	4.7088E-02	0.0000E+00	0.00%	4.7088E-02	100.00%	1.4865E+03	9.5296E-01	3.78E-06	Sheet 71		Analysis Sheet 13
TP	1.0279E-05	1.3494E-01	3.9322E-02	29.14%	9.5617E-02	70.86%	1.5426E+00	9.5698E-01	3.46E-06	Sheet 75		Analysis Sheet 5, 9
DS	4.8038E-05	6.3062E-01	5.7561E-01	91.28%	5.5001E-02	8.72%	1.3050E+01	9.5723E-01	3.44E-06	Sheet 85		Analysis Sheet 9
A1	2.0194E-05	2.6510E-01	2.2506E-01	84.90%	4.0038E-02	15.10%	1.2279E+02	9.6020E-01	3.20E-06	Sheet 43		Analysis Sheet 10
BA	2.0584E-05	2.7021E-01	2.3190E-01	85.82%	3.8317E-02	14.18%	1.9197E+02	9.6208E-01	3.05E-06		Sheet 41	Data
AA	1.7144E-05	2.2506E-01	1.8755E-01	83.33%	3.7512E-02	16.67%	1.6460E+02	9.6255E-01	3.01E-06		Sheet 41	Data
PL	3.2579E-06	4.2768E-02	0.0000E+00	0.00%	4.2768E-02	100.00%	1.0175E+00	9.6569E-01	2.76E-06		Sheet 73	WCAP-11993
BC	1.5216E-05	1.9975E-01	1.6611E-01	83.16%	3.3644E-02	16.84%	8.2582E+00	9.6983E-01	2.43E-06	Sheet 56		Analysis Sheet 14
OS	2.0187E-06	2.6501E-02	0.0000E+00	0.00%	2.6501E-02	100.00%	9.4437E+00	9.7367E-01	2.12E-06	Sheet 50		
GD	5.1851E-06	6.8067E-02	1.6677E-03	2.45%	6.6399E-02	97.55%	1.1181E+00	9.7371E-01	2.11E-06	Sheet 39		Analysis Sheet 7
TB	5.9129E-05	7.7621E-01	7.4943E-01	96.55%	2.6779E-02	3.45%	1.3743E+00	9.7523E-01	1.99E-06	Sheet 59		Analysis Sheet 14
BE	1.2707E-05	1.6681E-01	1.4290E-01	85.67%	2.3907E-02	14.33%	7.2060E+01	9.7781E-01	1.78E-06	Sheet 52	Sheet 52	Data
AE	1.2255E-05	1.6088E-01	1.3788E-01	85.70%	2.2991E-02	14.29%	1.4270E+03	9.7802E-01	1.77E-06	Sheet 52	Sheet 52	Data
ZB	2.6394E-06	3.4648E-02	5.1507E-03	14.87%	2.9498E-02	85.14%	1.3162E+00	9.7852E-01	1.73E-06	Sheet 51		Model
ZA	2.6231E-06	3.4435E-02	5.0801E-03	14.75%	2.9354E-02	85.24%	3.4970E+00	9.7886E-01	1.70E-06	Sheet 51		Model
RVB	2.8865E-05	3.7892E-01	3.5140E-01	92.74%	2.7517E-02	7.26%	2.6120E+00	9.8201E-01	1.45E-06		Sheet 93	Data
SR	2.5640E-06	3.3658E-02	1.6084E-02	47.79%	1.7575E-02	52.22%	1.4112E+00	9.8257E-01	1.40E-06		Sheet 74	WCAP-11993
GC	4.4776E-06	5.8780E-02	1.3699E-03	2.33%	5.7410E-02	97.67%	1.0670E+00	9.8379E-01	1.30E-06	Sheet 39		Analysis Sheet 7
RVA	2.3258E-05	3.0532E-01	2.8320E-01	92.76%	2.2117E-02	7.24%	2.6251E+00	9.8447E-01	1.25E-06		Sheet 93	Data
RH	1.7087E-06	2.2431E-02	7.5826E-03	33.80%	1.4848E-02	66.19%	3.5531E+00	9.8526E-01	1.19E-06		Sheet 98	Data
VA	4.2888E-05	5.6302E-01	5.4797E-01	97.33%	1.5050E-02	2.67%	2.8858E+00	9.8755E-01	1.00E-06	Sheet 88		Analysis Sheet 6
SE	5.8859E-05	7.7267E-01	7.6049E-01	98.42%	1.2182E-02	1.58%	3.2077E+00	9.8783E-01	9.78E-07	Sheet 60		Analysis Sheet 14
EB	8.6738E-07	1.1387E-02	0.0000E+00	0.00%	1.1387E-02	100.00%	2.2292E+00	9.8891E-01	8.92E-07	Sheet 72		Analysis Sheet 13
DC	8.4318E-07	1.1069E-02	0.0000E+00	0.00%	1.1069E-02	100.00%	1.9851E+01	9.8906E-01	8.80E-07	Sheet 48		Analysis Sheet 5
LCL	7.7632E-07	1.0191E-02	0.0000E+00	0.00%	1.0191E-02	100.00%	3.5405E+00	9.8990E-01	8.12E-07		Sheet 95	Success Criteria
MB	3.2639E-05	4.2846E-01	4.1474E-01	96.80%	1.3726E-02	3.20%	1.7567E+00	9.9040E-01	7.72E-07	Sheet 77		Analysis Sheet 9

Table 3-4 (continued)

Top	Frequency F(x)	Top Importance (Total)	Fraction Importance (GF)	%	Fraction Importance (Non-GF)	%	Risk Achievement Worth	Risk Reduction Worth	Delta CDF	Consider Enhancement Yes	Consider Enhancement No	Remarks
AF	1.0955E-06	1.4381E-02	3.0393E-04	2.11%	1.4077E-02	97.89%	5.4236E+01	9.9310E-01	5.55E-07	Sheet 78		Analysis Sheet 9
MDE	8.5248E-07	1.1191E-02	0.0000E+00	0.00%	1.1191E-02	100.00%	2.3786E+00	9.9315E-01	5.51E-07	Sheet 54		Analysis Sheet 11
PR	1.2446E-05	1.6338E-01	1.5659E-01	95.84%	6.7890E-03	4.16%	8.4521E+00	9.9328E-01	5.40E-07		Sheet 83	
MA	3.1879E-05	4.1849E-01	4.0759E-01	97.40%	1.0906E-02	2.61%	1.7602E+00	9.9337E-01	5.33E-07	Sheet 77		Analysis Sheet 9
OF	4.9668E-07	6.5201E-03	0.0000E+00	0.00%	6.5201E-03	100.00%	1.1461E+00	9.9378E-01	5.00E-07		LF	
SL	8.3927E-07	1.1017E-02	4.0904E-03	37.13%	6.9271E-03	62.88%	1.4079E+00	9.9413E-01	4.72E-07		Sheet 96	
OB	4.6880E-07	6.1542E-03	2.7660E-04	4.49%	5.8776E-03	95.51%	1.4476E+00	9.9474E-01	4.23E-07		Sheet 84	
RF	3.1619E-07	4.1508E-03	0.0000E+00	0.00%	4.1508E-03	100.00%	8.9626E+00	9.9592E-01	3.28E-07		LF	
PB	1.3099E-05	1.7196E-01	1.6326E-01	94.94%	8.7058E-03	5.06%	1.5725E+00	9.9637E-01	2.92E-07	Sheet 65		Analysis Sheet 9
MF	7.6092E-06	9.9889E-02	9.6144E-02	96.25%	3.7456E-03	3.75%	1.1403E+00	9.9656E-01	2.77E-07		Sheet 82	Analysis Sheet 2
PA	1.6312E-05	2.1414E-01	2.0611E-01	96.25%	8.0247E-03	3.75%	1.7630E+00	9.9667E-01	2.68E-07	Sheet 65		Analysis Sheet 9
DB	8.1624E-07	1.0715E-02	7.1801E-03	67.01%	3.5351E-03	32.99%	3.8704E+01	9.9679E-01	2.58E-07		Sheet 48	
PD	2.5268E-05	3.3171E-01	3.2107E-01	96.79%	1.0634E-02	3.21%	4.1696E+00	9.9695E-01	2.45E-07	Sheet 66		Analysis Sheet 9
FB	2.9553E-07	3.8796E-03	0.0000E+00	0.00%	3.8796E-03	100.00%	1.5345E+00	9.9710E-01	2.33E-07		LF	
FA	2.8828E-07	3.7844E-03	0.0000E+00	0.00%	3.7844E-03	100.00%	1.6078E+00	9.9715E-01	2.29E-07		LF	
RD	4.1407E-06	5.4356E-02	5.1877E-02	95.44%	2.4796E-03	4.56%	1.2054E+00	9.9752E-01	1.99E-07		Sheet 97	
S2	4.6908E-05	6.1579E-01	6.0918E-01	98.93%	6.6128E-03	1.07%	1.0956E+00	9.9753E-01	1.99E-07	Sheet 90		Analysis Sheet 6
EE	1.2435E-05	1.6324E-01	1.6088E-01	98.55%	2.3690E-03	1.45%	1.3461E+01	9.9778E-01	1.78E-07	Sheet 53		Analysis Sheet 11
DA	7.5511E-07	9.9126E-03	7.4667E-03	75.33%	2.4459E-03	24.67%	2.8063E+01	9.9781E-01	1.76E-07		Sheet 48	
BB	6.5941E-06	8.6564E-02	6.8067E-02	78.63%	1.8497E-02	21.37%	4.5540E+00	9.9781E-01	1.76E-07		Sheet 41	Data
CCSR	2.0399E-05	2.6778E-01	2.6559E-01	99.18%	2.1877E-03	0.82%	2.3017E+00	9.9793E-01	1.66E-07	Sheet 58		Analysis Sheet 14
B2U2	6.7408E-06	8.8490E-02	8.6564E-02	97.82%	1.9256E-03	2.18%	7.1900E+00	9.9832E-01	1.35E-07	Sheet 43		Analysis Sheet 10
OG	1.8022E-05	2.3659E-01	2.3508E-01	99.36%	1.5055E-03	0.64%	1.5328E+01	9.9857E-01	1.15E-07		Sheet 37	
DD	1.1108E-07	1.4581E-03	0.0000E+00	0.00%	1.4581E-03	100.00%	2.6226E+00	9.9867E-01	1.07E-07		Sheet 48	
MR	2.5134E-07	3.2995E-03	1.5912E-03	48.23%	1.7082E-03	51.77%	1.1422E+00	9.9869E-01	1.05E-07		LF	
VB	4.6048E-05	6.0449E-01	6.0110E-01	99.44%	3.3925E-03	0.56%	1.1782E+00	9.9894E-01	8.52E-08	Sheet 88		Analysis Sheet 6
VS	7.0724E-07	9.2843E-03	7.9729E-03	85.88%	1.3115E-03	14.13%	1.7044E+00	9.9899E-01	8.12E-08		Sheet 87	
AB	5.8402E-06	7.6668E-02	5.8780E-02	76.67%	1.7888E-02	23.33%	3.0866E+00	9.9919E-01	6.51E-08		Sheet 41	Data
FD	1.2704E-07	1.6677E-03	0.0000E+00	0.00%	1.6677E-03	100.00%	1.0357E+00	9.9922E-01	6.27E-08		LF	
S1	4.5784E-05	6.0103E-01	5.9588E-01	99.14%	5.1581E-03	0.86%	1.0652E+00	9.9927E-01	5.87E-08	Sheet 90		Analysis Sheet 6
A2	1.7214E-05	2.2598E-01	2.2506E-01	99.59%	9.1786E-04	0.41%	3.4899E+00	9.9930E-01	5.63E-08	Sheet 43		Analysis Sheet 10
RL	5.5720E-08	7.3147E-04	0.0000E+00	0.00%	7.3147E-04	100.00%	3.3771E+01	9.9932E-01	5.47E-08		LF	
CD	5.0416E-06	6.6184E-02	6.3179E-02	95.46%	3.0051E-03	4.54%	1.0793E+00	9.9936E-01	5.15E-08		Sheet 80	Analysis Sheet 2
VS8	4.0315E-08	5.2924E-04	0.0000E+00	0.00%	5.2924E-04	100.00%	1.0088E+00	9.9947E-01	4.26E-08		LF	
VSA	4.0315E-08	5.2924E-04	0.0000E+00	0.00%	5.2924E-04	100.00%	1.0047E+00	9.9947E-01	4.26E-08		LF	
CH	4.8590E-05	6.3786E-01	6.3350E-01	99.32%	4.3623E-03	0.68%	9.8305E-01	9.9953E-01	3.78E-08		Sheet 100	
VNV2R	3.9333E-08	5.1635E-04	0.0000E+00	0.00%	5.1635E-04	100.00%	1.1538E+00	9.9967E-01	2.65E-08		LF	
B2	2.0621E-05	2.7070E-01	2.7021E-01	99.82%	4.8900E-04	0.18%	2.0672E+00	9.9971E-01	2.33E-08	Sheet 43		Analysis Sheet 10
FC	1.0435E-07	1.3699E-03	0.0000E+00	0.00%	1.3699E-03	100.00%	9.7087E-01	9.9972E-01	2.25E-08		LF	
AM	2.5398E-08	3.3342E-04	4.9579E-05	14.87%	2.8384E-04	85.13%	1.2462E+00	9.9975E-01	2.01E-08		LF	
RW	2.1647E-08	2.8417E-04	9.3269E-05	32.82%	1.9090E-04	67.18%	3.1041E+02	9.9981E-01	1.53E-08		Sheet 68	

Table 3-4 (continued)

Top	Frequency F(x)	Top Importance (Total)	Fraction Importance (GF)	%	Fraction Importance (Non-GF)	%	Risk Achievement Worth	Risk Reduction Worth	Delta CDF	Consider Enhancement Yes	Consider Enhancement No	Remarks
VF	8.6713E-09	1.1383E-04	0.0000E+00	0.00%	1.1383E-04	100.00%	1.0990E+00	9.9990E-01	8.04E-09		LF	
FE	1.2723E-05	1.6701E-01	1.6681E-01	99.88%	2.0757E-04	0.12%	1.3369E+00	9.9991E-01	7.24E-09	Sheet 53		Analysis Sheet 11
VS1	5.8034E-09	7.6184E-05	0.0000E+00	0.00%	7.6184E-05	100.00%	1.0895E+00	9.9992E-01	6.43E-09		LF	
CL	3.3234E-09	4.3628E-05	0.0000E+00	0.00%	4.3628E-05	100.00%	5.8220E+00	9.9996E-01	3.22E-09		LF	
A2U2	5.8628E-06	7.6964E-02	7.6668E-02	99.62%	2.9607E-04	0.38%	1.1468E+00	9.9996E-01	3.22E-09	Sheet 43		Analysis Sheet 10
IP	5.9726E-08	7.8405E-04	6.9062E-04	88.08%	9.3428E-05	11.92%	1.0468E+00	9.9996E-01	3.22E-09		LF	
SI	4.4044E-05	5.7819E-01	5.7777E-01	99.93%	4.1951E-04	0.07%	1.0423E+00	9.9996E-01	3.22E-09		Sheet 91	
VI8	2.9757E-09	3.9064E-05	0.0000E+00	0.00%	3.9064E-05	100.00%	1.0007E+00	9.9996E-01	3.22E-09		LF	
VI9	2.9757E-09	3.9064E-05	0.0000E+00	0.00%	3.9064E-05	100.00%	1.0004E+00	9.9996E-01	3.22E-09		LF	
VI7	2.9757E-09	3.9064E-05	0.0000E+00	0.00%	3.9064E-05	100.00%	1.0002E+00	9.9996E-01	3.22E-09		LF	
VS4	5.8034E-09	7.6184E-05	7.6184E-05	100.00%	0.0000E+00	0.00%	1.0000E+00				LF	
B1L	2.6850E-05	3.5247E-01	3.5247E-01	100.00%	0.0000E+00	0.00%	1.0000E+00	1.0000E+00			X	Sheet 44
BAL	2.1372E-05	2.8056E-01	2.8056E-01	100.00%	0.0000E+00	0.00%	1.0000E+00	1.0000E+00			X	Sheet 42
A2L	1.8646E-05	2.4477E-01	2.4477E-01	100.00%	0.0000E+00	0.00%	1.0000E+00	1.0000E+00			X	Sheet 44
AAL	1.8573E-05	2.4382E-01	2.4382E-01	100.00%	0.0000E+00	0.00%	1.0000E+00	1.0000E+00			X	Sheet 42
BBL	7.3822E-06	9.6909E-02	9.6909E-02	100.00%	0.0000E+00	0.00%	1.0000E+00	1.0000E+00			X	Sheet 42
A1L	2.1624E-05	2.8387E-01	2.8387E-01	100.00%	0.0000E+00	0.00%	1.0000E+00	1.0000E+00			X	Sheet 44
B2L	2.1414E-05	2.8111E-01	2.8111E-01	100.00%	0.0000E+00	0.00%	1.0000E+00	1.0000E+00			X	Sheet 44
VS9	2.8221E-08	3.7047E-04	0.0000E+00	0.00%	3.7047E-04	100.00%	1.0000E+00	1.0000E+00			LF	
ABL	7.2711E-06	9.5451E-02	9.5451E-02	100.00%	0.0000E+00	0.00%	1.0000E+00	1.0000E+00			X	Sheet 42
DH	5.8511E-06	7.6810E-02	7.6810E-02	100.00%	0.0000E+00	0.00%	1.0000E+00	1.0000E+00			X	Not Called by Any Top
B2U2L	7.5288E-06	9.8835E-02	9.8835E-02	100.00%	0.0000E+00	0.00%	1.0000E+00	1.0000E+00			X	Sheet 44
A2U2L	7.2936E-06	9.5747E-02	9.5747E-02	100.00%	0.0000E+00	0.00%	1.0000E+00	1.0000E+00			X	Sheet 44
B1U2L	7.3942E-06	9.7067E-02	9.7067E-02	100.00%	0.0000E+00	0.00%	1.0000E+00	1.0000E+00			X	Sheet 44
A1U2L	7.2819E-06	9.5593E-02	9.5593E-02	100.00%	0.0000E+00	0.00%	1.0000E+00	1.0000E+00			X	Sheet 44
V2R	4.6868E-06	6.1526E-02	6.1526E-02	100.00%	0.0000E+00	0.00%	9.9997E-01	1.0000E+00			Sheet 62	BC
FW	2.3953E-06	3.1444E-02	3.1408E-02	99.89%	3.6376E-05	0.12%	9.9985E-01	1.0000E+00			Sheet 81	
V1R	4.7449E-06	6.2289E-02	6.2289E-02	100.00%	0.0000E+00	0.00%	9.9960E-01	1.0000E+00			Sheet 62	BC
RI	4.4691E-09	5.8667E-05	0.0000E+00	0.00%	5.8667E-05	100.00%	8.7123E-01	1.0000E+00			LF	
PE	1.1212E-05	1.4719E-01	1.4719E-01	100.00%	0.0000E+00	0.00%	1.4784E-01	1.0000E+00			Sheet 67	Analysis Sheet 9
V2	4.6889E-06	6.1554E-02	6.1526E-02	99.95%	2.8289E-05	0.05%	1.4309E-01	1.0000E+00			Sheet 61	Recovered by V2R
DSLR	2.1640E-06	2.8408E-02	2.6490E-02	93.25%	1.9188E-03	6.75%	9.9656E-01	1.0001E+00			Sheet 55	
VT2AR	5.0495E-09	6.6287E-05	0.0000E+00	0.00%	6.6287E-05	100.00%	9.5443E-01	1.0001E+00			LF	
VT2BR	6.2507E-09	8.2055E-05	0.0000E+00	0.00%	8.2055E-05	100.00%	9.5118E-01	1.0001E+00			LF	
DCAC	3.0046E-07	3.9443E-03	3.3393E-03	84.66%	6.0491E-04	15.34%	8.7087E-01	1.0001E+00			LF	
B1U2	6.6062E-06	8.6722E-02	8.6564E-02	99.82%	1.5795E-04	0.18%	5.6759E-01	1.0001E+00		Sheet 43		Analysis Sheet 10
A1U2	5.8511E-06	7.6810E-02	7.6668E-02	99.82%	1.4260E-04	0.19%	5.2976E-01	1.0001E+00		Sheet 43		Analysis Sheet 10
MS	2.7153E-05	3.5645E-01	3.5645E-01	100.00%	0.0000E+00	0.00%	4.1536E-01	1.0001E+00			Sheet 79	
VINV1	2.0621E-05	2.7070E-01	2.7070E-01	100.00%	0.0000E+00	0.00%	2.7134E-01	1.0001E+00			Sheet 64	Recovered by VNV1R
VC	4.4025E-05	5.7794E-01	5.7759E-01	99.94%	3.5350E-04	0.06%	1.0188E+00	1.0002E+00			Sheet 89	
RS	8.2538E-07	1.0835E-02	1.0611E-02	97.93%	2.2427E-04	2.07%	9.5430E-01	1.0002E+00			Sheet 103	

Table 3-4 (continued)

Top	Frequency F(x)	Top Importance (Total)	Fraction Importance (GF)	%	Fraction Importance (Non-GF)	%	Risk Achievement Worth	Risk Reduction Worth	Delta CDF	Consider Enhancement Yes	Consider Enhancement No	Remarks
VNV1R	2.8228E-08	3.7056E-04	0.0000E+00	0.00%	3.7056E-04	100.00%	9.1166E-01	1.0002E+00			LF	
OT	3.9462E-06	5.1804E-02	5.1606E-02	99.62%	1.9743E-04	0.38%	8.5993E-01	1.0002E+00			Sheet 104	
DBAC	3.9236E-07	5.1507E-03	4.6086E-03	89.48%	5.4211E-04	10.52%	7.6506E-01	1.0002E+00			LF	
DAAC	3.8698E-07	5.0801E-03	4.5689E-03	89.94%	5.1121E-04	10.06%	7.3521E-01	1.0002E+00			LF	
VT1B	2.6063E-05	3.4214E-01	3.4209E-01	99.99%	4.5835E-05	0.01%	4.8381E-01	1.0002E+00			Sheet 63	Recovered by VT1BR
VT1A	2.0199E-05	2.6516E-01	2.6510E-01	99.98%	6.3823E-05	0.02%	4.4598E-01	1.0002E+00			Sheet 63	Recovered by VT1AR
DG	2.0199E-05	2.6516E-01	2.6510E-01	99.98%	6.1182E-05	0.02%	4.3376E-01	1.0002E+00			Sheet 47	
VT2B	6.6097E-06	8.6769E-02	8.6722E-02	99.95%	4.6885E-05	0.05%	2.1977E-01	1.0002E+00			Sheet 63	Recovered by VT2BR
VT1AR	1.8525E-08	2.4319E-04	0.0000E+00	0.00%	2.4319E-04	100.00%	8.5131E-01	1.0003E+00			LF	
A3	1.5440E-05	2.0269E-01	2.0260E-01	99.96%	9.0053E-05	0.04%	4.0444E-01	1.0003E+00			Sheet 46	
B3	1.5440E-05	2.0269E-01	2.0260E-01	99.96%	8.9815E-05	0.04%	4.0386E-01	1.0003E+00			Sheet 46	
VT2A	5.8534E-06	7.6840E-02	7.6810E-02	99.96%	3.0076E-05	0.04%	1.7003E-01	1.0003E+00			Sheet 63	Recovered by VT2AR
V1	4.7751E-06	6.2685E-02	6.2289E-02	99.37%	3.9624E-04	0.63%	1.5445E-01	1.0003E+00			Sheet 61	Recovered by V1R
PI	2.8906E-07	3.7946E-03	0.0000E+00	0.00%	3.7946E-03	100.00%	1.4330E+00	1.0004E+00			LF	
VT1BR	2.4576E-08	3.2262E-04	0.0000E+00	0.00%	3.2262E-04	100.00%	8.1757E-01	1.0004E+00			LF	
DP	4.8185E-05	6.3254E-01	6.3063E-01	99.70%	1.9112E-03	0.30%	9.6045E-01	1.0005E+00			Sheet 86	
DDAC	1.8741E-07	2.4602E-03	2.2534E-03	91.59%	2.0675E-04	8.40%	2.9817E-01	1.0005E+00			LF	
VINV2	6.8229E-06	8.9568E-02	8.8490E-02	98.80%	1.0781E-03	1.20%	1.8989E-01	1.0006E+00			Sheet 64	Recovered by VNV2R
SU	3.4946E-07	4.5875E-03	0.0000E+00	0.00%	4.5875E-03	100.00%	6.8302E+01	1.0008E+00			LF	
D1	1.7101E-07	2.2450E-03	0.0000E+00	0.00%	2.2450E-03	100.00%	7.0545E-01	1.0009E+00			LF	
AR	1.6549E-05	2.1725E-01	2.1652E-01	99.66%	7.2836E-04	0.34%	3.9264E-01	1.0009E+00			Sheet 102	Level II
D2	1.5029E-07	1.9729E-03	0.0000E+00	0.00%	1.9729E-03	100.00%	6.3444E-01	1.0011E+00			LF	
UB1D	1.5627E-05	2.0514E-01	2.0434E-01	99.61%	8.0102E-04	0.39%	5.5802E-01	1.0011E+00			X	Not Called by Any Top
CSA	4.9375E-05	6.4817E-01	6.4217E-01	99.07%	5.9919E-03	0.92%	9.4073E-01	1.0012E+00		Sheet 99		Analysis Sheet 6
HH	1.5643E-05	2.0535E-01	2.0420E-01	99.44%	1.1451E-03	0.56%	6.0169E-01	1.0012E+00			Sheet 101	Level II
UB1C	1.5644E-05	2.0536E-01	2.0456E-01	99.61%	8.0093E-04	0.39%	5.4430E-01	1.0012E+00			X	Not Called by Any Top
UB1B	1.5627E-05	2.0514E-01	2.0434E-01	99.61%	8.0119E-04	0.39%	5.2805E-01	1.0013E+00			X	Not Called by Any Top
UB1A	1.5644E-05	2.0536E-01	2.0456E-01	99.61%	8.0109E-04	0.39%	4.9337E-01	1.0014E+00			X	Not Called by Any Top
CP	2.3009E-07	3.0206E-03	0.0000E+00	0.00%	3.0206E-03	100.00%	3.8096E-01	1.0014E+00			LF	Level II
CSB	5.0444E-05	6.6220E-01	6.5684E-01	99.19%	5.3608E-03	0.81%	9.2656E-01	1.0015E+00		Sheet 99		Analysis Sheet 6
CTMU	1.9247E-05	2.5267E-01	2.3659E-01	93.64%	1.6081E-02	6.36%	8.8832E-01	1.0028E+00			Sheet 70	
CI	3.7975E-06	4.9852E-02	2.5150E-02	50.45%	2.4702E-02	49.55%	6.7815E-01	1.0039E+00			Sheet 105	Level II

BC - Boundary Condition Dominates Failures
LF - Screened due to Low Frequency
X - Not Used in Model
M - Mapping

Enhancement Analysis Sheet
(Example)

Table 3-5

Source: RISKMAN Results

Description: Top Event REC

Discussion:

1. Top Event REC models the probability of recovering possible core damage sequences prior to actual damage and the probability of recovery of sequences leading to core damage prior to vessel failure. Currently, only LOSP sequences are recovered in the Watts Bar IPE.
2. REC depends on the off-site power grid arrangement, the frequency of loss of off-site power, and the line recovery history at the site, if available.
3. The Watts Bar Station Black-out Report identifies the characteristics, etc. of WBN.
4. The top event importance factors for REC are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
REC	0.99936	0.83568 (83.6%)	.16367 (16.4%)	4.3702	.83633

5. Guaranteed failed sequences are dominated by lack of recovery quantification for all initiators except LOSP.

Enhancements:

1. New off-site power recovery distributions will be prepared using information from the FSAR and the Station Black-out Report for WBN.
2. The new recovery split fractions will only affect sequences with a probabilistic importance of 0.16367 (maximum change in core damage frequency 8.04E-05 * (1-.83633), or 1.3E-05 per reactor year).

Classification: Medium

Maximum change in recovery split fraction less than 10% based on a review of newer data, maximum change in core damage frequency is 0.1 * 1.3E-05 or 1.3E-06 per reactor year.

Analysis sheet 4 presents the results of cross-tie of 500kV power between the units.

Sheet 1 of xxx

3.2 VALUE-IMPACT ANALYSIS METHODOLOGY

3.2.1 Method For Determining Costs

Cost estimates for the candidate potential plant enhancements were developed by utilizing applicable cost estimates published in industry documents, by soliciting applicable cost estimates from other TVA plants and other Licensees, and by performing Watts Bar-specific scoping estimates, when necessary. Specific references to the cost estimate sources are provided in the individual write-ups on the potential plant enhancements assessments. The cost estimates taken from historic industry documents have been escalated, when appropriate, to 1993 dollars. The escalation factors used in this analysis were based on the Consumer Price Index of all commodities as published by the U.S. Bureau of Labor Statistics (Reference 16). This index is deemed to be a reasonable measure of general inflation and to provide an appropriate cost escalation index. The percent change of this price index for the years 1987 through 1993 and the calculated escalation factors are as follows:

Cost Escalation Factors

YEAR	% CHANGE (All Commodities)	Escalation Factor to 1993 Dollars
1987	3.2	1.29
1988	3.5	1.25
1989	4.7	1.21
1990	5.2	1.15
1991	3.1	1.09
1992	3.0[1]	1.06
1993	3.0[1]	1.03

For the plant-specific cost estimates, the following criteria were generally used for determining the cost:

- Expected plant life of 40 years.
- These estimates are order-of-magnitude. They are based on design concepts as identified by TVA.

[1] The current annual report from the Bureau of Labor Statistics only contains data through 1991; therefore, an increase of 3.0% has been assumed for the year 1992 and 1993.

- Pricing is based on 1994 cost.
- No overtime premiums for manual labor have been included.
- Unitized costs are based on percentages of work as they relate to Unit 1 and common space.
- Craft labor work-hours were priced at $21/hour based on current TVA construction experience.
- Engineering work-hours were priced at $53/hour based on current TVA engineering experience using contractors.
- Costs represent the total scope for one unit.
- Order-of-magnitude work hour estimates were based on input from Ebasco and TVA Projects using preliminary design concepts. Allowances were included based on engineering/estimating judgments for quantities for which preliminary design was not available.
- Material pricing is based on current TVA and Ebasco pricing information.
- Labor rates reflect recent nuclear construction experience.
- Distributable manual and non-manual labor costs are included as a percentage of direct labor cost.
- Engineering cost is based on individual estimates for each of the options studied.
- The preliminary cost estimates have used the two following items as basic assumptions:

    1) Environmental qualification of components added to the modification is not required unless failure of the equipment could have an adverse impact on other equipment.

    2) Structures, systems and components added by the modification will not be be safety related or seismic Category 1 unless they adversely impact the function of safety-related

equipment, structures or materials. Cases requiring seismic Category 1 treatment are so noted.

- No cost associated with the potential delay of unit start-up due the installation a potential plant enhancement has been included.

3.2.2 Method For Determining Benefits

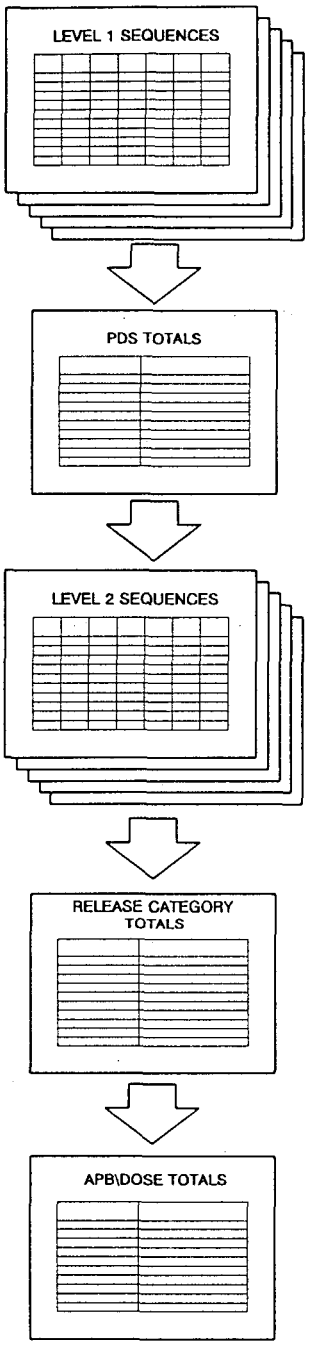
The overall process used in the assessment of the potential benefits of a proposed enhancement relied upon the WBN IPE model. The WBN IPE is a Level 2 PRA which considers all internally initiated events and internal floods. The end point of the IPE is the frequency of various release categories. These release categories identify, in general terms, the timing and magnitude of the fission product release. In order to perform a value impact analysis, it is necessary to quantify the potential offsite consequences (dose to public). This requires a Level 3 PRA type analysis. Rather than expand the WBN IPE to a full Level 3 analysis, a simplified approach was used to convert the release categories from the Level 2 PRA to average (mean) doses based on Level 3 PRA results for Sequoyah and a scaling to account for Watts Bar specific meteorology and demographics. The overall process used to calculate the potential benefit of an enhancement is shown in Figure 3-2.

The WBN IPE model is a very large, complex linked event tree PRA model which utilizes the RISKMAN software. Requantification of the entire model is very time consuming. Therefore, the quantification of benefits associated with enhancements was performed using a streamlined process which relied upon a series of spreadsheets derived from the RISKMAN model.

3.2.2.1 Level 1 PRA Spreadsheets

A spreadsheet model of the Watts Bar core damage sequences saved by RISKMAN was created to assist in the evaluation of the possible enhancements to Watts Bar. RISKMAN was run with a sequence save frequency of 1×10^{-9}. This allowed all plant damage sequences with a frequency greater than 1×10^{-9} to be written to a data file. The sum of the saved sequences was 7.62×10^{-5} or 95% of the RISKMAN calculated frequency of 8.04×10^{-5}. Three thousand eight hundred and fifty-five (3855) sequences were written to a file and imported into a spreadsheet model of the Watts Bar results. The Master Frequency File and the initiating event frequency files were also imported into the spreadsheet model.

Figure 3-2
PROCESS FOR CALCULATING POTENTIAL BENEFIT OF ENHANCEMENTS



LEVEL 1 PRA SPREADSHEETS

- Dominant RISKMAN Sequences
- Utilizes MFF
- Rapid Requantification
- Computes Sequence Frequency

PLANT DAMAGE STATE SPREADSHEET

- Totals Plant Damage State Frequencies
- Transfers Frequencies To Level 2

LEVEL 2 PRA SPREADSHEETS

- Translates PDS Results To Release Category Frequencies

RELEASE CATEGORY SPREADSHEETS

- Totals Accident Progression Bin Frequencies From Release Category Frequencies

VALUE IMPACT SPREADSHEET

- Computes New Dose To Public
- Calculates Change In Risk
- Calculates Averted Costs

The sequences were represented as algebraic expressions (the product of the initiating event frequency times the split fraction value(s)), and the sequences quantified using the equations representing the sequences, the master frequency file and the initiating event frequency file. A reduction process was performed to obtain a minimal sequence representation of the results, where a minimal sequence only contain those split fractions that determine core damage and plant damage state. Success terms were added to the sequence equations as appropriate. If the split fraction value was greater than 0.01, a success term equal to (1 - split fraction value) was included in the sequence equation. The reduced set of sequences was summed by initiating event, and the output sent to a summary file and compared to the RISKMAN results. The reduced model result, containing 1812 sequences, is 8.31×10^{-5} compared the RISKMAN result of 8.04×10^{-5}. The difference is due entirely to the incomplete assignment of success terms.

The spreadsheet model allows changes in split fraction values due to proposed enhancements to be quickly evaluated on a sequence basis and the change in core damage frequency calculated without relying on the RISKMAN code.

In addition to the split fraction information retained in the spreadsheet model, the plant damage state assignments were also retained. The sequence frequency by initiator and by plant damage state were sent to an PDS output file for use in determining the change in plant damage state frequency due to various enhancements considered in this analysis.

Table 3-6 represents an example of a sequence spreadsheet file. Table 3-7 presents the summary output file and Table 3-8 presents the plant damage state (PDS) spreadsheet.

3.2.2.2 Level 2/3 Spreadsheets

The Level 2/3 methodology utilized in the WBN IPE relied upon containment event trees to translate each plant damage state to release categories. This process results in a constant transfer function from each PDS to its respective release categories. Consequently, release category frequencies can be recomputed by simply ratioing the new frequency of the PDS with the old frequency. This approach, sometimes called a C-Matrix, is effective as long as no factors affecting containment are involved in the sensitivity study. In those cases, other means, either bounding assumptions or recomputation of the Level 2/3 model, are required to calculate the release frequencies.

The value-impact analyses in this report were performed using the WBN updated Level 1 results from Reference 20, the revised Level 1 spreadsheet results (described in Section 3.2), cost estimation techniques described in Reference 19, and the value-impact analysis methodology described in References 21 and 22. Calculations were performed using a set of three spreadsheets developed for this project. Examples of these three

spreadsheets are presented in Tables 3-9 through 11. These example spreadsheets provide results for the "base case" calculation showing estimated plant risk and value-impact values.

Table 3-9 shows the base case plant damage state (PDS) to key release category (KRC) transformation matrix. This transformation or "mapping" of frequencies is determined by the structure and split fraction values in the containment event tree. Since this event tree was not changed during the WBN IPE update, the transformation fractions remain the same as before. The PDS-KRC spreadsheet in Table 3-9 was tested against the actual updated Level 2 quantification (Reference 20) and found to be accurate to at least four decimal places.

The KRC to accident progression bin (APB) transformation matrix is shown in Table 3-10. This is a direct mapping matrix following the mapping rules described in Reference 10.

The APB to population dose (PD) spreadsheet presented in Table 3-11 applies the WBN population dose conversion factors described in Appendix C to the new APB frequencies and calculates averted population dose over the expected life of the plant, 40 years.

The dose conversion factors used by TVA for evaluating candidate potential plant enhancements at Watts Bar have been categorized into the same Summary Accident Progression Bins (APBs) used in the final NUREG-1150 report. The characteristics that were used to define an APB are based on the primary accident progression attributes that influence a source term, e.g., the timing and failure mode of the reactor pressure vessel and containment. The dose conversion data based on the Watts Bar-specific PRA results are shown in Table 3-12. Column 2 of this table shows the Summary APB Categories. Column 3 provides the frequency of the Watts Bar-specific events for each summary APB category. These event frequencies have been derived directly from the Watts Bar PRA by binning the Watts Bar PRA results, i.e., Release Categories, into the appropriate APB category. Column 4 shows the dose conversion factor for each APB. Column 5 shows the dose risk associated with each APB.

Table 3-6 EXAMPLE LEVEL 1 SEQUENCE SPREADSHEET MODEL

MODEL Name: WBN-ERIN LOSP
Sequences Sorted By Frequency
08 FEB 1994

			ATWS	1.41749E-07	BCI	ENI	ENS	ETL	FCI	FGI	FNI	GNI	GNS	GTL
Total			1.79076E-05	1.96533E-05	1.42E-07	1.22E-05	1.36E-06	1.28E-08	1.08E-08	1.59E-09	1.18E-08	4.34E-06	2.91E-07	4.04E-09
Rank	End State	Index	RM3 Frequency	Calculated Frequency	Initiator	Multi-State Split Fractions								
150	BCI	644	8.3686E-08	1.0234E-07	LOSP	RTB	PL1	SR4	OGR11N	TP1N				
528	BCI	650	1.8765E-08	1.9705E-08	LOSP	RTB	PL1	MA7	TP1N	OGR11N	MB28N	AFA3N		
529	BCI	649	1.8763E-08	1.9705E-08	LOSP	RTB	PL1	MB27	TP1N	OGR11N	MA7N	AFA3N		
4	ENI	619	3.6890E-06	3.8344E-06	LOSP	OGR11	GA1	GB2	REC1	GC3N	GD3N	TP3N	AF7N	
11	ENI	897	1.0669E-06	1.2304E-06	LOSP	OGR11	GA1	GB2	GC3	GD4	REC5	TP3N	AF7N	
12	ENI	416	1.0822E-06	1.1344E-06	LOSP	OGR11	GA1	GB2	GD3	REC2	GC3N	TP3N	AF7N	
13	ENI	232	1.0811E-06	1.1342E-06	LOSP	OGR11	GA1	GB2	GC3	REC2	GD4N	TP3N	AF7N	
15	ENI	360	7.1240E-07	7.6957E-07	LOSP	AA2	BA4	AB6	BB14	OGR11N	TP3N	AF7N		
22	ENI	266	6.2045E-07	5.6725E-07	LOSP	AA2	BA4	AB6N	OGR11N	BB7N	TP3N	AF7N	CI4N	
66	ENI	744	1.9406E-07	2.2753E-07	LOSP	OGR11	AE5	BE34	GA1N	GB1N	GC1N	GD1N	TP1N	AF7N
67	ENI	560	1.8531E-07	2.0115E-07	LOSP	OGR11	GA1	GD2	TB4	REC4	GB2N	GC2N	TP1N	
80	ENI	479	1.6672E-07	1.7305E-07	LOSP	OGR11	GB1	AE5	REC4	GA1N	GC2N	GD2N	TP1N	
83	ENI	839	1.5642E-07	1.7059E-07	LOSP	OGR11	GA1	BE41	REC4	GB2N	GC2N	GD2N	TP1N	
90	ENI	336	1.4762E-07	1.3967E-07	LOSP	AA2	BA4	BB7	OGR11N	AB6N	TP3N	AF7N	CI4N	
93	ENI	349	1.4430E-07	1.3967E-07	LOSP	AA2	BA4	AB6	OGR11N	BB14N	TP3N	AF7N	CI4N	
99	ENI	434	1.3147E-07	1.8894E-07	LOSP	OGR11	AA2	BA4	AB6	BB14	GA1N	GB1N	GC1N	GD1N
102	ENI	732	1.3401E-07	1.7941E-07	LOSP	OGR11	AE5	MDE1	GA1N	GB1N	GC1N	GD1N	TP1N	
104	ENI	819	1.1924E-07	1.6491E-07	LOSP	OGR11	AA2	BA4	AB6N	BB7N	TP3N	GA1N	GB1N	CI4N
107	ENI	189	1.0734E-07	1.3363E-07	LOSP	OGR11	GA1	FB1	REC1	TP1N	GC5N	GD6N		
108	ENI	44	1.0734E-07	1.3614E-07	LOSP	OGR11	FA1	GB3	REC1	TP1N	GC5N	GD6N		
121	ENI	250	8.9267E-08	9.6724E-08	LOSP	AA2	BE41	OGR11N	BA4N	TP1N	AF7N			
170	ENI	464	6.1331E-08	7.11E-08	LOSP	OGR11	GB1	AC3	CCPR2	REC4	GA1N	GC2N	GD2N	
171	ENI	655	5.7094E-08	6.5233E-08	LOSP	AC8	BC28	CCPR1	OGR11N					
198	ENI	73	6.2637E-08	5.9524E-08	LOSP	OGR11	GA1	GC2	GD3	TB4	REC2	GB2N	TP1N	
199	ENI	242	5.1742E-08	6.0775E-08	LOSP	A11	BE41	OGR11N						
265	ENI	507	3.6374E-08	4.224E-08	LOSP	OGR11	GB1	GD2	AC5	CCPR2	REC4	GA1N	GC2N	
271	ENI	8	3.5011E-08	4.3357E-08	LOSP	OGR11	FA1	FB2	FC3	FD4	REC5	TP3N	AF7N	
276	ENI	665	3.5514E-08	4.0657E-08	LOSP	DB3	AC3	CCPR2	OGR11N					
281	ENI	671	3.5208E-08	4.4843E-08	LOSP	BA3	AC3	CCPR2	OGR11N					
308	ENI	256	3.1432E-08	3.1617E-08	LOSP	AA2	BB6	TB4	OGR11N	TP3N	AF7N	CI4N		
334	ENI	653	2.6571E-08	3.0865E-08	LOSP	AC8	BC28	VA2	OGR11N					
339	ENI	425	2.6907E-08	4.0605E-08	LOSP	OGR11	AA2	BA4	BB7	AB6N	TP3N	CI4N	GA1N	GB1N
341	ENI	430	2.6782E-08	4.0605E-08	LOSP	OGR11	AA2	BA4	AB6	BB14N	TP3N	CI4N	GA1N	GB1N
356	ENI	307	2.4376E-08	2.6833E-08	LOSP	OGR11	DB3	AC5	CCPR2	GA1N	GB1N	GC1N	GD1N	TP1N
357	ENI	761	2.4238E-08	2.6682E-08	LOSP	OGR11	DD3	AC5	CCPR2	GA1N	GB1N	GC1N	GD1N	TP1N
408	ENI	510	2.1355E-08	2.694E-08	LOSP	OGR11	GB1	GD2	AE5	REC4	GA1N	GC2N	TP1N	AF7N
417	ENI	67	2.1007E-08	2.695E-08	LOSP	OGR11	GA1	GC2	BE85	REC4	GB2N	GD3N	TP1N	AF7N
439	ENI	573	1.9750E-08	2.2906E-08	LOSP	OGR11	GA1	GD2	AC3	REC4	GB2N	GC2N	TP1N	
445	ENI	669	1.8382E-08	2.3768E-08	LOSP	B11	AC3	CCPR2	OGR11N					

Table 3-7 SUMMARY SPREADSHEET

WATTS BAR MODIFIED DOMINANT SEQUENCE MODEL

Total CDF	7.6177E-05	(RM3 Summary)	DELTA	-9.03E-06
Sequences	8.5207E-05	Sum of RM3 Sequences	(Total-Calc)	-11.85%
Base Case	8.5207E-05	Delta 0		

Initiator	RM3 Sequence	Calculated	DELTA	%
LOSP	1.791E-05	1.965E-05	1.746E-06	9.75%
SLOCAN	1.711E-05	1.963E-05	2.520E-06	14.73%
LBSD	6.061E-06	6.426E-06	3.645E-07	6.01%
FLPH1B	4.481E-06	4.774E-06	2.929E-07	6.54%
FLPH1A	4.042E-06	4.134E-06	9.255E-08	2.29%
SGTR	3.880E-06	4.149E-06	2.687E-07	6.93%
PLMFW	3.121E-06	3.581E-06	4.597E-07	14.73%
LASD	2.629E-06	2.743E-06	1.140E-07	4.34%
LLOCA	2.322E-06	2.559E-06	2.378E-07	10.24%
MLOCA	1.786E-06	2.204E-06	4.181E-07	23.41%
ERCWTL	1.594E-06	2.382E-06	7.884E-07	49.47%
TTIE	1.536E-06	1.736E-06	2.000E-07	13.03%
RTIE	1.530E-06	1.707E-06	1.768E-07	11.56%
SLOCAI	1.417E-06	1.707E-06	2.906E-07	20.51%
CCSA	1.078E-06	1.174E-06	9.542E-08	8.85%
EXMFW	6.451E-07	7.758E-07	1.307E-07	20.27%
TLMFW	6.211E-07	7.335E-07	1.124E-07	18.10%
LVBB1	5.688E-07	6.702E-07	1.014E-07	17.83%
LVBB2	5.469E-07	6.204E-07	7.343E-08	13.43%
LRCP	4.713E-07	5.159E-07	4.461E-08	9.47%
LOCV	4.401E-07	5.226E-07	8.242E-08	18.73%
CCSTL	3.449E-07	3.769E-07	3.197E-08	9.27%
LDAAC	3.182E-07	3.771E-07	5.891E-08	18.51%
LDBAC	3.141E-07	3.655E-07	5.137E-08	16.35%
ELOCA	2.493E-07	2.675E-07	1.814E-08	7.27%
ISI	2.266E-07	2.712E-07	4.463E-08	19.70%
LDCAC	1.987E-07	2.422E-07	4.343E-08	21.85%
LDDAC	1.306E-07	1.596E-07	2.900E-08	22.20%
ERCWB	1.208E-07	1.423E-07	2.151E-08	17.81%
ERCWA	1.068E-07	1.210E-07	1.421E-08	13.30%
MSIV	9.628E-08	1.178E-07	2.150E-08	22.34%
IMSIV	8.167E-08	1.029E-07	2.123E-08	26.00%
FLTB	5.268E-08	6.362E-08	1.094E-08	20.77%
VS	4.612E-08	7.533E-08	2.921E-08	63.33%
SLBOC	3.640E-08	4.470E-08	8.306E-09	22.82%
MSVO	2.445E-08	2.976E-08	5.319E-09	21.76%
SLBIC	1.712E-08	2.145E-08	4.332E-09	25.30%
CPEX	1.580E-08	2.016E-08	4.358E-09	27.58%
FLAB3R	7.105E-09	8.618E-09	1.514E-09	21.30%
VI	2.976E-09	2.984E-09	8.300E-12	0.28%
FLAB2	1.072E-09	1.373E-09	3.014E-10	28.12%
FLAB3C	9.747E-10	9.747E-10	0.000E+00	0.00%

Table 3-7 (Continued)

ATWS Results

LOSP-A	1.417E-07
SLOCAN-A	4.356E-09
SGTR-A	4.594E-08
LASD-A	6.123E-08
PLMFW-A	2.164E-06
LBSD-A	2.488E-09
LDAAC-A	6.021E-08
SLOCAI-A	2.613E-08
TTIE-A	3.939E-07
EXMFW-A	3.094E-07
LVBB1-A	1.404E-07
TLMFW-A	2.867E-07
LRCP-A	5.651E-08
LOCV-A	1.993E-07
LVBB2-A	1.292E-07
LDBAC-A	2.524E-08
ISI-A	5.067E-08
LDCAC-A	3.734E-08
LDDAC-A	3.677E-08
IMSIV-A	4.143E-08
MSIV-A	2.78E-08
SLBOC-A	3.181E-09
MSVO-A	2.936E-09
	4.247E-06

Table 3-8 PDS SUMMARY SPREADSHEET

Total Frequency (RISKMAN) = 8.0402E-05
Calculated Frequency = 8.5207E-05
End State Totals for Group(s) MELT

End State	AGI	AGS	ANI	ANS	ARL	ATL	ATV	BCI	BCS	BEI
RM3 Frequency	5.31E-08	2.08E-10	2.06E-09	4.38E-09	6.35E-11	5.38E-10	4.99E-08	4.10E-06	1.79E-08	6.35E-09
Initiators	5.30E-08	0.00E+00	0.00E+00	4.97E-09	0.00E+00	0.00E+00	7.83E-08	4.49E-06	1.38E-08	4.47E-09
CCSA										
CCSTL										
CPEX										
ELOCA								2.66E-07	1.27E-09	
ERCWA										
ERCWB										
ERCWTL										
EXMFW								1.51E-08		
FLAB2										
FLAB3C										
FLAB3R										
FLPH1A										
FLPH1B										
FLTB										
IMSIV								1.88E-09		
ISI								2.71E-09		
LASD										
LBSD										
LDAAC										
LDBAC										
LDCAC										
LDDAC										
LLOCA	1.61E-08			4.97E-09				2.52E-06	9.01E-09	4.47E-09
LOCV								1.08E-08		
LOSP								1.42E-07		
LRCP										
LVBB1										
LVBB2										
MLOCA	3.69E-08							1.41E-06	3.57E-09	
MSIV										
MSVO										
PLMFW								1.09E-07		
RTIE										
SGTR								2.60E-09		
SLBIC										
SLBOC										
SLOCAI										
SLOCAN										
TLMFW								1.48E-08		
TTIE										
VI							2.98E-09			
VS							7.53E-08			

Table 3-8 (continued)

End State	BES	BGI	BGS	BII	BIS	BNI	BPL	CGI	CNI	CNS
RM3 Frequency	1.24E-11	1.80E-08	2.73E-11	2.62E-09	1.39E-12	3.75E-09	5.01E-09	4.14E-11	4.81E-09	1.01E-08
Initiators	0.00E+00	8.69E-09	0.00E+00	1.47E-09	0.00E+00	0.00E+00	1.59E-09	0.00E+00	0.00E+00	1.01E-08
CCSA										
CCSTL										
CPEX										
ELOCA										
ERCWA										
ERCWB										
ERCWTL										
EXMFW										
FLAB2										
FLAB3C										
FLAB3R										
FLPH1A										
FLPH1B										
FLTB										
IMSIV										
ISI										
LASD										
LBSD										
LDAAC										
LDBAC										
LDCAC										
LDDAC										
LLOCA		1.60E-09		1.47E-09			1.59E-09			
LOCV										
LOSP										
LRCP										
LVBB1										
LVBB2										
MLOCA		7.09E-09								1.01E-08
MSIV										
MSVO										
PLMFW										
RTIE										
SGTR										
SLBIC										
SLBOC										
SLOCAI										
SLOCAN										
TLMFW										
TTIE										
VI										
VS										

Table 3-8 (continued)

End State	CTL	DCI	DCS	DGI	DGS	DNI	DPL	EGB	EGI	EGS
RM3 Frequency	1.28E-09	7.20E-07	3.28E-09	6.35E-09	1.45E-11	2.27E-09	8.16E-10	1.27E-10	7.55E-08	1.18E-10
Initiators	1.32E-09	7.32E-07	1.85E-09	3.67E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.69E-08	0.00E+00
CCSA										
CCSTL										
CPEX										
ELOCA										
ERCWA										
ERCWB										
ERCWTL										
EXMFW										
FLAB2										
FLAB3C										
FLAB3R										
FLPH1A										
FLPH1B										
FLTB										
IMSIV										
ISI										
LASD										
LBSD										
LDAAC										
LDBAC										
LDCAC										
LDDAC										
LLOCA										
LOCV										
LOSP										
LRCP										
LVBB1										
LVBB2										
MLOCA	1.32E-09	7.32E-07	1.85E-09	3.67E-09						
MSIV										
MSVO										
PLMFW									7.94E-09	
RTIE										
SGTR										
SLBIC										
SLBOC										
SLOCAI										
SLOCAN									5.90E-08	
TLMFW										
TTIE										
VI										
VS										

Table 3-8 (continued)

End State	EIB	ENB	ENI	ENS	ETL	FCB	FCI	FCS	FEI	FGI
RM3 Frequency	3.35E-06	4.66E-07	3.65E-05	2.13E-06	8.99E-08	6.70E-08	2.24E-05	9.11E-08	4.27E-09	4.28E-07
Initiators	3.43E-06	4.58E-07	3.84E-05	2.24E-06	8.03E-08	6.56E-08	2.46E-05	8.37E-08	1.84E-09	4.53E-07
CCSA			8.73E-07	6.05E-09			2.19E-07			3.75E-08
CCSTL			3.08E-07							
CPEX			1.88E-08							
ELOCA										
ERCWA			1.21E-07							
ERCWB			1.29E-07							
ERCWTL			2.15E-06	1.02E-08	3.12E-09					
EXMFW			1.66E-07			2.00E-09	2.73E-07			
FLAB2			1.37E-09	0.00E+00	0.00E+00		0.00E+00			0.00E+00
FLAB3C										
FLAB3R			1.44E-09	0.00E+00	0.00E+00		0.00E+00			0.00E+00
FLPH1A			4.09E-06	2.19E-08	4.14E-09		0.00E+00			0.00E+00
FLPH1B			4.24E-06	2.14E-08	3.75E-09		7.08E-09			1.95E-08
FLTB			9.97E-09	0.00E+00	0.00E+00		2.01E-09			0.00E+00
IMSIV			9.71E-09				4.15E-08			
ISI			1.78E-07				4.46E-08			
LASD			2.33E-06	1.35E-07			1.18E-07			9.83E-09
LBSD			6.10E-06	1.69E-07	6.09E-09		5.73E-08			3.74E-08
LDAAC			1.15E-07	2.19E-09			7.00E-08			
LDBAC			1.19E-07	2.10E-09			5.59E-08			
LDCAC			1.05E-07				3.73E-08			
LDDAC			1.12E-07				3.68E-08			
LLOCA										
LOCV			1.14E-07				1.89E-07			
LOSP			1.22E-05	1.36E-06	1.28E-08		1.08E-08			1.59E-09
LRCP			1.77E-07				3.15E-07			3.78E-10
LVBB1			2.52E-09				3.79E-07			1.17E-08
LVBB2			3.60E-07				1.24E-07			2.73E-09
MLOCA										
MSIV			8.37E-08				2.78E-08			
MSVO			2.16E-08				2.94E-09			
PLMFW			1.18E-06	2.15E-08		2.22E-08	1.84E-06	3.76E-09	1.84E-09	3.23E-09
RTIE			1.42E-06	2.28E-08			2.11E-08			4.02E-09
SGTR	3.43E-06	4.58E-07	1.57E-07			3.94E-08	1.61E-08			
SLBIC				1.06E-08			1.09E-08			
SLBOC			3.30E-08				4.22E-09			
SLOCAI			1.94E-07	3.46E-07	3.92E-08		1.06E-06			2.40E-08
SLOCAN			4.64E-08	8.58E-08	1.12E-08		1.90E-05	7.99E-08		2.98E-07
TLMFW			1.58E-07			2.05E-09	2.52E-07			
TTIE			1.13E-06	1.95E-08			4.05E-07			3.20E-09
VI										
VS										

Table 3-8 (continued)

End State	FGS	FII	FNI	FNS	FPL	FTL	GGI	GNB	GNI	GNS
RM3 Frequency	2.60E-09	1.97E-09	5.92E-07	1.18E-09	2.34E-08	1.93E-10	2.76E-09	4.75E-10	4.69E-06	1.67E-06
Initiators	0.00E+00	0.00E+00	6.03E-07	0.00E+00	1.86E-08	0.00E+00	0.00E+00	0.00E+00	4.95E-06	1.69E-06
CCSA			3.83E-08							
CCSTL			6.91E-08							
CPEX										1.38E-09
ELOCA										
ERCWA										
ERCWB			5.07E-09						8.53E-09	
ERCWTL									2.22E-07	
EXMFW			2.11E-09							1.95E-07
FLAB2			0.00E+00						0.00E+00	0.00E+00
FLAB3C										
FLAB3R			1.45E-09						0.00E+00	0.00E+00
FLPH1A			1.34E-08						4.10E-09	0.00E+00
FLPH1B			2.06E-07						2.78E-07	0.00E+00
FLTB			0.00E+00						0.00E+00	2.28E-08
IMSIV										2.19E-08
ISI										3.84E-08
LASD									2.15E-08	3.46E-09
LBSD			4.22E-08						4.68E-09	
LDAAC			1.50E-09							1.69E-07
LDBAC			1.49E-09							1.67E-07
LDCAC			1.46E-09						1.95E-08	9.54E-09
LDDAC			1.44E-09							8.34E-09
LLOCA										
LOCV			1.48E-09							1.37E-07
LOSP			1.18E-08						4.34E-06	2.91E-07
LRCP			5.67E-09							1.44E-08
LVBB1			2.82E-08							6.79E-09
LVBB2			5.45E-09						1.02E-08	6.58E-09
MLOCA										
MSIV										6.31E-09
MSVO										5.18E-09
PLMFW			3.26E-08						1.32E-08	1.02E-07
RTIE			3.90E-08						2.00E-08	1.22E-07
SGTR										3.71E-08
SLBIC										
SLBOC										7.45E-09
SLOCAI			1.61E-08							2.76E-08
SLOCAN			4.67E-08		1.86E-08					6.30E-09
TLMFW			2.03E-09							1.88E-07
TTIE			3.07E-08						1.25E-08	9.71E-08
VI										
VS										

Table 3-8 (continued)

End State	GTL	HCB	HCI	HCS	HEI	HGI	HGS	HNI	HNS	HRL	INI
RM3 Frequency	1.77E-07	3.48E-09	1.36E-06	3.14E-09	1.24E-10	1.09E-06	7.34E-09	1.08E-07	2.12E-10	9.88E-10	6.83E-10
Initiators	1.62E-07	1.37E-09	1.23E-06	0.00E+00	0.00E+00	1.11E-06	7.87E-09	1.26E-07	0.00E+00	0.00E+00	0.00E+00
CCSA											
CCSTL											
CPEX											
ELOCA											
ERCWA											
ERCWB											
ERCWTL											
EXMFW	2.50E-08		9.72E-08								
FLAB2	0.00E+00							0.00E+00			
FLAB3C											
FLAB3R	0.00E+00							5.73E-09			
FLPH1A	0.00E+00							0.00E+00			
FLPH1B	0.00E+00							0.00E+00			
FLTB	2.98E-09							2.59E-08			
IMSIV	2.87E-09		2.50E-08								
ISI	4.20E-09		3.33E-09								
LASD			1.30E-07			3.59E-10		2.42E-10			
LBSD			5.95E-09					6.38E-09			
LDAAC	1.86E-08		1.45E-09								
LDBAC	1.84E-08		1.45E-09								
LDCAC			6.59E-08			3.50E-09					
LDDAC			1.40E-09								
LLOCA											
LOCV	1.75E-08		5.37E-08								
LOSP	4.04E-09		1.56E-07			1.10E-06	7.87E-09	3.16E-08			
LRCP			3.43E-09								
LVBB1			2.02E-07			1.23E-09		3.81E-08			
LVBB2			9.41E-08					1.76E-08			
MLOCA											
MSIV											
MSVO											
PLMFW	1.21E-08		2.24E-07			1.73E-09					
RTIE	1.45E-08		4.04E-08			2.06E-09					
SGTR	4.02E-09	1.37E-09									
SLBIC											
SLBOC											
SLOCAI	2.19E-09										
SLOCAN											
TLMFW	2.41E-08		9.46E-08								
TTIE	1.15E-08		2.54E-08			1.64E-09					
VI											
VS											

Table 3-9

WBN UPDATED IPE PLANT DAMAGE STATE/RELEASE CATEGORY TRANSFORMATION MATRIX (PDS-KRC Base Case 3/9/94)

LEVEL 1 OUTPUT KEY PLANT DAMAGE STATE (KPDS)	PDS FREQUENCY	LEVEL 2 INPUT KEY PLANT DAMAGE STATE (KPDS)	PDS FREQUENCY	KEY RELEASE CATEGORY FREQUENCY													
				RO1	RO1DI	RO1I	RO1IF	RO1SI	RO1SIF	RO1SUI	RO1SUIF	RO1UI	RO1UIF	RO2IF	RO3	RO3I	RO3IF
ATV	7.83E-08	ATV	7.83E-08														
BCI	1.19E-06	BCI	1.19E-06														
EOI	0.00E+00	EOI	0.00E+00														
EIB	5.52E-06	EIB	5.52E-06														
ENB	1.58E-07	ENB	1.58E-07														
ENI	3.81E-05	ENIYA	3.00E-05														2.10E-07
ENS	2.21E-06	ENIYB	1.10E-06														8.80E-09
FCI	2.16E-05	ENIYN	7.30E-06													5.81E-08	
FOI	0.00E+00	ENSYA	5.20E-07														
FNI	0.00E+00	ENSYB	1.65E-07														
GNI	1.95E-06	ENSYC	1.76E-07														
HCI	1.23E-06	ENSYN	1.37E-06														
HOI	1.11E-06	FCI	2.16E-05														
INI	0.00E+00	FOI	0.00E+00														0.00E+00
KNI	0.00E+00	FNI	0.00E+00														0.00E+00
KNS	0.00E+00	GNIYA	3.19E-06		7.55E-07		9.28E-08						5.10E-09				2.18E-09
LCI	0.00E+00	GNIYN	1.17E-06		3.18E-07	3.91E-08						2.15E-09				9.17E-10	
LNI	0.00E+00	HCI	1.23E-06														
OTHERS	0.00E+00	HOI	1.11E-06	6.13E-08	1.10E-07										2.39E-08		
		INI	0.00E+00		0.00E+00												0.00E+00
		KNI	0.00E+00		0.00E+00		0.00E+00						0.00E+00				0.00E+00
		KNSYA	0.00E+00		0.00E+00				0.00E+00		0.00E+00						
		KNSYC	0.00E+00		0.00E+00			0.00E+00		0.00E+00							
		LCI	0.00E+00		0.00E+00									0.00E+00			
		LNIYA	0.00E+00														
		LNIYC	0.00E+00		0.00E+00	0.00E+00									0.00E+00	0.00E+00	
		OTHERS	0.00E+00														
		KRC GROUP I		6.13E-08	1.21E-06	3.91E-08	9.28E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.15E-09	5.10E-09	0.00E+00	2.39E-08	5.93E-08	2.51E-07
		KRC GROUP II															
		KRC GROUP III															
		KRC GROUP IV															
		KRC SUBTOTAL		6.13E-08	1.21E-06	3.91E-08	9.28E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.15E-09	5.10E-09	0.00E+00	2.39E-08	5.93E-08	2.51E-07
		PDS TOTAL															

Table 3-9 (continued)

WBN UPDATED IPE PLANT DAMAGE STATE/RELEASE CATEGORY TRANSFORMATION MATRIX (PDS-KRC Base Case 3/9/94)

KEY RELEASE CATEGORY FREQUENCY

R03SI	R03SIF	R03SUI	R03SUIF	R03UI	R03UIF	R01	R01IF	R01UIF	R05SLI	R05SLIF	R05SLUI	R05SLUIF	R07SLUI	R07SLUIF	R09I	R09UI	R11I	R11IF
								2.77E-08										
					0.00E+00													
																		1.09E-06
																	7.21E-06	
						1.31E-07												
					1.39E-10													
				5.87E-11											7.93E-07	3.07E-07		
						9.80E-03												
					0.00E+00													
	0.00E+00		0.00E+00							0.00E+00		0.00E+00		0.00E+00				
0.00E+00		0.00E+00							0.00E+00		0.00E+00		0.00E+00					
							0.00E+00											
0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.87E-11	1.39E-10	1.11E-07	0.00E+00	2.77E-08										
									0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
															7.93E-07	3.07E-07	7.21E-06	1.09E-06
0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.87E-11	1.39E-10	1.11E-07	0.00E+00	2.77E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.93E-07	3.07E-07	7.21E-06	1.09E-06

Table 3-9 (continued)

WBN UPDATED IPE PLANT DAMAGE STATE/RELEASE CATEGORY TRANSFORMATION MATRIX (PDS-KRC Base Case 3/9/94)

KEY RELEASE CATEGORY FREQUENCY										SUBTOTAL	KEY RELEASE CATEGORY GROUP FREQUENCY			
R11U1	R17L	R17LU	R17U	R18	R19	R20	R21	R22	OTHERS		I	II	III	IV
					7.83E-08					7.83E-08	7.83E-08			
	1.72E-07		3.26E-06					1.03E-06		4.19E-06	2.77E-08		3.43E-06	1.03E-06
		0.00E+00	0.00E+00							0.00E+00	0.00E+00		0.00E+00	
						5.52E-06				5.52E-06		5.52E-06		
						4.58E-07				4.58E-07		4.58E-07		
	4.77E-07						2.93E-05			3.00E-05	2.40E-07		4.77E-07	2.93E-05
										1.10E-06	8.80E-09		1.09E-06	
										7.30E-06	5.84E-08		7.24E-06	
						5.20E-07				5.20E-07		5.20E-07		
						1.65E-07				1.65E-07		1.65E-07		
						1.76E-07				1.76E-07		1.76E-07		
						1.37E-06				1.37E-06		1.37E-06		
	8.30E-07						1.58E-05	7.87E-06		2.46E-05	1.31E-07		8.30E-07	2.36E-05
	0.00E+00						0.00E+00			0.00E+00	0.00E+00		0.00E+00	0.00E+00
	0.00E+00						0.00E+00			0.00E+00	0.00E+00		0.00E+00	0.00E+00
		2.63E-06								3.19E-06	8.55E-07		2.63E-06	
7.28E-09										1.47E-06	3.60E-07	7.28E-09	1.10E-06	
	6.08E-08						1.16E-06			1.23E-06	9.80E-09		6.08E-08	1.16E-06
	8.81E-07									1.11E-06	2.25E-07		8.81E-07	
	0.00E+00									0.00E+00	0.00E+00		0.00E+00	
		0.00E+00		0.00E+00						0.00E+00	0.00E+00		0.00E+00	
				0.00E+00						0.00E+00	0.00E+00	0.00E+00		
				0.00E+00						0.00E+00	0.00E+00	0.00E+00		
	0.00E+00			0.00E+00			0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00
								0.00E+00		0.00E+00				0.00E+00
	0.00E+00			0.00E+00						0.00E+00	0.00E+00		0.00E+00	
										0.00E+00				
				0.00E+00	7.83E-08									
7.28E-09						8.21E-06								
	2.42E-06	2.63E-06	3.26E-06											
							4.62E-05	8.91E-06						
7.28E-09	2.42E-06	2.63E-06	3.26E-06	0.00E+00	7.83E-08	8.21E-06	4.62E-05	8.91E-06	0.00E+00	8.31E-05	2.00E-06	8.22E-06	1.77E-05	5.51E-05
										8.31E-05				

Table 3-10

WBN KEY RELEASE CATEGORY/ACCIDENT PROGRESSION BIN
TRANSFORMATION MATRIX (KRC-APB BASE CASE 3/9/94)

KRC ID	KRC FREQ.	APB FREQUENCIES 1	2	3	4	5	6	7	8	9	10	SUBTOTAL
R01	6.13E-08			6.13E-08								6.13E-08
R01DI	1.21E-06			1.21E-06								1.21E-06
R01I	3.91E-08			3.91E-08								3.91E-08
R01IF	9.28E-08			9.28E-08								9.28E-08
R01SI	0.00E+00	0.00E+00										0.00E+00
R01SIF	0.00E+00	0.00E+00										0.00E+00
R01SUI	0.00E+00	0.00E+00										0.00E+00
R01SUIF	0.00E+00	0.00E+00										0.00E+00
R01UI	2.15E-09			2.15E-09								2.15E-09
R01UIF	5.10E-09			5.10E-09								5.10E-09
R02IF	0.00E+00			0.00E+00								0.00E+00
R03	2.39E-08				2.39E-08							2.39E-08
R03I	5.93E-08		5.93E-08									5.93E-08
R03IF	2.51E-07		2.51E-07									2.51E-07
R03SI	0.00E+00	0.00E+00										0.00E+00
R03SIF	0.00E+00	0.00E+00										0.00E+00
R03SUI	0.00E+00	0.00E+00										0.00E+00
R03SUIF	0.00E+00	0.00E+00										0.00E+00
R03UI	5.87E-11				5.87E-11							5.87E-11
R03UIF	1.39E-10				1.39E-10							1.39E-10
R04	1.44E-07		1.44E-07									1.44E-07
R04IF	0.00E+00				0.00E+00							0.00E+00
R04UIF	2.77E-08				2.77E-08							2.77E-08
R05SLI	0.00E+00	0.00E+00										0.00E+00
R05SLIF	0.00E+00	0.00E+00										0.00E+00
R05SLUI	0.00E+00	0.00E+00										0.00E+00
R05SLUIF	0.00E+00			0.00E+00								0.00E+00
R07SLUI	0.00E+00	0.00E+00										0.00E+00
R07SLUIF	0.00E+00	0.00E+00										0.00E+00
R09I	7.93E-07					7.93E-07						7.93E-07
R09UI	3.07E-07					3.07E-07						3.07E-07
R11I	7.24E-06					7.24E-06						7.24E-06
R11IF	1.09E-06					1.09E-06						1.09E-06
R11UI	7.28E-09					7.28E-09						7.28E-09
R17L	2.42E-06					2.42E-06						2.42E-06
R17LU	2.63E-06					2.63E-06						2.63E-06
R17U	3.26E-06						3.26E-06					3.26E-06
R18	0.00E+00							0.00E+00				0.00E+00
R19	7.83E-08							7.83E-08				7.83E-08
R20	8.21E-06							8.21E-06				8.21E-06
R21	4.62E-05								4.62E-05			4.62E-05
R22	8.91E-06										8.91E-06	8.91E-06
OTHERS	0.00E+00											0.00E+00
APB SUBTOTALS	8.31E-05	0.00E+00	4.54E-07	1.41E-06	5.18E-08	1.45E-05	3.26E-06	8.29E-06	4.62E-05	0.00E+00	8.91E-06	8.31E-05
TOTAL FREQUENCY												8.31E-05

Table 3-11

WBN VALUE-IMPACT ASSESSMENT MATRIX (BASE CASE APB-PD 3/9/94)

APB ID	BASE CASE APB FREQUENCY (EVENTS/RX-YR)	REVISED APB FREQUENCY (EVENTS/RX-YR)	BASE CASE POPULATION DOSE RATE (Man-REM/YR)	REVISED POPULATION DOSE RATE (Man-REM/YR)	BASE CASE POPULATION DOSE (Man-REM)	REVISED POPULATION DOSE (Man-REM)	AVERTED POPULATION DOSE (Man-REM)
1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	4.54E-07	4.54E-07	8.27E-02	8.27E-02	3.31E+00	3.31E+00	0.00E+00
3	1.41E-06	1.41E-06	4.51E-01	4.51E-01	1.80E+01	1.80E+01	0.00E+00
4	5.18E-08	5.18E-08	1.75E-02	1.75E-02	7.02E-01	7.02E-01	0.00E+00
5	1.45E-05	1.45E-05	9.95E-01	9.95E-01	3.98E+01	3.98E+01	0.00E+00
6	3.26E-06	3.26E-06	6.98E-02	6.98E-02	2.79E+00	2.79E+00	0.00E+00
7	8.29E-06	8.29E-06	3.38E+00	3.38E+00	1.35E+02	1.35E+02	0.00E+00
8	4.62E-05	4.62E-05	9.24E-03	9.24E-03	3.69E-01	3.69E-01	0.00E+00
9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	8.91E-06	8.91E-06	1.04E-03	1.04E-03	4.15E-02	4.15E-02	0.00E+00
TOTAL	8.31E-05	8.31E-05	5.01E+00	5.01E+00	2.00E+02	2.00E+02	0.00E+00

USER-PROVIDED DATA	
EXPECTED REMAINING PLANT LIFE (YEARS)	40

Table 3-12
Summary of Base Case Accident Progression Bins and 50-Mile Population Doses for Evaluating Candidate Potential Plant Enhancements

APB #	Summary APB Category	APB Frequency (/rx-yr)	Dose Conversion Factor (person-rem)	Dose Risk (person-rem/rx-yr)
1	VB, early CF (during CD)	No significant contributors	3.90E+5	N/A
2	VB, alpha, early CF (at VB)	4.54E-7	1.85E+5	8.27E-2
3	VB > 200 psi, early CF (at VB)	1.41E-6	3.18E+5	4.51E-1
4	VB < 200 psi, early CF (at VB)	5.18E-8	3.41E+5	1.75E-2
5	VB, late CF	1.45E-5	6.86E+4	9.95E-1
6	VB, BMT, very late CF	3.26E-6	2.14E+4	6.98E-2
7	Bypass	8.29E-6	4.07E+5	3.38E+00
8	VB, No CF	4.62E-5	1.98E+2	9.24E-3
9	No VB, early CF (during CD)	No significant contributors	2.41E+5	N/A
10	No VB	8.91E-6	1.43E+2	1.04E-3
TOTAL				5.00

Section 4

SUMMARY OF RESULTS

Based upon a review of the base IPE results, the following six general categories of enhancements were identified:

- Improve Availability of ECCS Recirculation - This category of enhancements addresses the largest functional contributor to core damage, LOCAs with loss of ECCS recirculation.

- Improve Availability of AC Power - This category of enhancements addresses the second largest contributor, loss of offsite power. These enhancements specifically identify methods for providing alternate sources of AC power.

- Improve Ability To Cope With Loss of AC Power & Station Blackout -This category of enhancements is aimed at improving the plants ability to withstand extended losses of AC power by extending the time to core damage to allow more time for recovery of systems or AC power.

- Improve Ability To Cope With Loss of RCP Seal Cooling - This category of enhancements addresses the third largest contributor to core damage, event sequences involving loss of RCP seal cooling.

- Improve Containment Performance - This category of enhancements addresses the key WBN features impacting containment performance in a severe accident as identified in the Level 2 portion of the PRA.

- Miscellaneous - This category of enhancements addresses other items which were identified in the systematic review of the IPE, but do not belong in one of the categories identified above.

A detailed review of the WBN results and contributors combined with a review of generic industry sources yielded a total of twenty-eight implementation options for the six categories. These specific enhancements are listed in Table 4-1. For the purposes of identification, each category is identified with a roman numeral (I through VI) and each enhancement within each category is numbered. For example, one of the options for improving the availability of AC power (Category II) is the acceleration of the schedule to provide the fifth diesel generator at WBN. This enhancement is the second option in

Table 4-1

SUMMARY OF POTENTIAL ENHANCEMENTS CONSIDERED IN VALUE IMPACT ANALYSIS

ENHANCEMENT CATEGORY	IMPLEMENTATION OPTION
I - Improve Availability of ECCS Recirculation	1. Procedure Change To Stop One Train of Sprays 2. Install Containment Spray Throttle Valves 3. Redesign To Delay Containment Spray Actuation 4. Install Automatic High Pressure Recirculation
II - Improve Availability of AC Power	1. Procedure Change To Facilitate Cross-tie of 500kV and 161kV AC Power 2. Accelerate Availability of Fifth Emergency Diesel Generator 3. Procedure Change & Fifth Diesel
III - Improve Ability To Cope With Loss of AC Power & Station Blackout	1. Procedure Change To Utilize Existing Spare 6900V/480V Transformers 2. Install Improved RCP Seals 3. Install Independent RCP Seal Cooling System 4. Install Accumulators For Turbine Driven AFW Pump Flow Control Valves 5. Provide DC Load Shed Analysis & Procedure 6. Provide Portable Battery Charger 7. Install AC Independent Coolant Injection System
IV - Improve Ability To Cope With Loss of RCP Seal Cooling	1. Install Improved RCP Seals 2. Install Independent RCP Seal Cooling System (w/o new EDG) 3. Modify Charging Pump Cooling From CCS To ERCW
V - Improve Containment Performance	1. Install Deliberate Ignition System 2. Install Reactor Cavity Flooding System 3. Install Filtered Containment Venting System 4. Install Core Retention Device 5. Install Containment Inerting System 6. Install Additional Containment Bypass Instrumentation 7. Install Reactor Depressurization System 8. Install Independent Containment Spray System 9. Install AC Independent Air Return Fan Power Supplies
VI - Miscellaneous	1. Install MG Set Trip Breakers In Control Room (ATWS) 2. Improve Procedures To Provide Temporary HVAC During Loss of Room Cooling

category II and is numbered II.2. The following provides a brief summary of the twenty-eight enhancements evaluated and the anticipated benefits of each.

4.1 IMPROVE AVAILABILITY OF ECCS RECIRCULATION

This category of enhancements is intended to address the dominant contributor to the WBN IPE core damage frequency. Approximately 30% of the core damage frequency is contributed by LOCA events. Most of the LOCA core damage event sequences involve failure of ECCS recirculation. For example, 17% of the total CDF is contributed by Small LOCAs with failure of the ECCS recirculation alignment.

The Watts Bar ice condenser design results in actuation of containment spray for nearly all LOCA events, including small LOCAs. The realignment of the low pressure portion of the ECCS recirculation system is accomplished automatically. However, the high pressure realignment is performed manually. When the automatic realignment of low pressure ECCS is complete, the containment spray pumps continue to remove 4000 gpm per pump from the RWST until they are manually realigned. This allows only a limited period of time (~20 minutes) for the operators to perform the manual realignment and respond to any system problems encountered. The IPE identified that roughly 75% of the high pressure recirculation failures were due to common cause failures of motor operated valves (MOVs) in the ECCS systems. The other 25% was due to operator errors. The following implementation options were identified to address this contributor to risk.

4.1.1 Procedure Change to Stop One Train of Sprays

This enhancement involves a change to the WBN emergency operating procedures (EOPs) to direct the stopping of one of the containment spray pumps in the event of a LOCA before recirculation is required. This would reduce the rate of RWST depletion and substantially increase the time for operator actions following a small LOCA. This additional time would manifest itself in a reduction in operator error rates and provide adequate time for local operator recovery actions to manually open MOVs which failed to realign.

4.1.1.1 Existing Capabilities

The existing WBN emergency operating procedures (EOPs) are based on the Westinghouse Owners' Group Emergency Procedure Guidelines (EPGs). These guidelines are generic in nature and provide guidance over a broad spectrum of potential design basis accident conditions. The procedural direction related to containment sprays allows the termination of spray pumps only after the containment pressure has been reduced to low levels.

4.1.1.2 Description of Enhancement

This enhancement involves the revision of the WBN EOPs to allow termination of one train of containment spray during LOCAs requiring high pressure recirculation before ECCS recirculation is established, if the other train is successfully operating. This action would significantly reduce rate of depletion of the RWST and increase the time available for operator actions related to high pressure recirculation. The termination of one train of spray with another successfully operating is within the existing design basis of the plant since one train of spray could be unavailable due to a single failure.

4.1.1.3 Cost Estimate

Since the proposed enhancement is within the existing design basis of the plant, the primary cost associated with the change would be the cost of revising the associated procedures and training plant operators. Table 4-2 provides a summary of the costs associated with a procedure change of this type.

4.1.1.4 Risk Reduction Estimate

The WBN Level 1 and 2 spreadsheet models were used to evaluate the potential risk reduction benefit of the proposed procedure change. The assumptions utilized were intended to maximize the potential benefit of the change. The dominant contributor to failure of high pressure recirculation is failure of motor operated valves to open or close. The delay of RWST depletion would allow more time for operator action to identify these failures and locally open the MOVs manually. A human error rate of 0.1 was assigned to this action. Based on a review of MOV failure data performed as part of the Fermi 2 PRA, the likelihood of local action successfully recovering the valve failure was found to be 0.85. Therefore, the probability of the valve failing to open if the operator successfully identified the valve and attempts to open it is 0.15. The total failure probability is then 0.25 (0.1 + 0.15).

The Level 1 PRA spreadsheets were modified to reflect split fraction values associated with alignment of high pressure recirculation, top event RR, which accounted for the likelihood of operator recovery of the failed valves. Tables 4-3 a,b,c provide a summary of the results of the requantification of the PRA and population dose estimates. Based on this analysis, the total reduction in population dose is estimated to be 34.2 person rem over the 40 year life of the plant.

4.1.1.5 Value Impact Assessment

The value impact of this enhancement is based on a quantitative comparison of the cost of the enhancement and the potential risk reduction benefit. The total estimated cost for

Table 4-2
Cost Estimate for Procedure Change

Scope:		
Perform research or engineering analysis to support development of improved maintenance or operations guidelines and develop, issue and train staff on the use of the improved process.		
Engineering:		
Support and Research 50 manhours * $56	$2.8K	
Procedure Revision Preparation, Review, & Approval 150 manhours * $56	$8.4K	
Development of Training Module 50 manhours * $56	$2.8K	
Training of Operations Staff 6 Shifts * 8 Operators * 4 hrs/operator = 192 Mhrs	$11.2K	
Engineering Cost		$25.2K
Material:		
None		
Construction:		
None		
Equipment Maintenance:		
None		
	Total	$25.2K

TABLE 4-3a
SUMMARY OF PDS AND KRC RESULTS
ENHANCEMENT CASE - PROCEDURE CHANGE TO STOP ONE TRAIN OF SPRAYS

BASE CASE RESULTS				ENHANCEMENT CASE RESULTS				
LEVEL 1 OUTPUT KPDS	BASE CASE KPDS FREQUENCY	LEVEL 2 INPUT KPDS	BASE CASE KPDS FREQUENCY	KPDS FREQUENCY	KRC GROUP FREQUENCY			
					I	II	III	IV
ATV	7.83E-08	ATV	7.83E-08	7.83E-08	7.83E-08			
BCI	4.49E-06	BCI	4.49E-06	3.68E-06	2.27E-08		2.81E-06	8.47E-07
EGI	0.00	EGI	0.00	6.69E-08	5.35E-10		6.64E-08	
EIB	5.52E-06	EIB	5.52E-06	3.43E-06		3.43E-06		
ENB	4.58E-07	ENB	4.58E-07	4.58E-07		4.58E-07		
ENI	3.84E-05	ENIYA	3.00E-05	2.95E-05	2.36E-07		4.69E-07	2.88E-05
ENS	2.24E-06	ENIYB	1.10E-06	1.08E-06	8.66E-09		1.07E-06	
FCI	2.46E-05	ENIYN	7.30E-06	7.18E-06	5.75E-08		7.13E-06	
FGI	0.00	ENSYA	5.20E-07	5.19E-07		5.19E-07		
FNI	0.00	ENSYB	1.65E-07	1.64E-07		1.64E-07		
GNI	4.95E-06	ENSYC	1.76E-07	1.76E-07		1.76E-07		
HCI	1.23E-06	ENSYN	1.37E-06	1.37E-06		1.37E-06		
HGI	1.11E-06	FCI	2.46E-05	1.44E-05	7.84E-08		4.86E-07	1.38E-05
HNI	0.00	FGI	0.00	3.44E-07	2.75E-09		2.93E-07	4.78E-08
KNI	0.00	FNI	0.00	5.80E-07	4.64E-09		4.95E-07	8.05E-08
KNS	0.00	GNIYA	3.49E-06	3.44E-06	8.44E-07		2.60E-06	
LCI	0.00	GNIYN	1.47E-06	1.45E-06	3.56E-07	0.00	1.09E-06	
LNI	0.00	HCI	1.23E-06	1.09E-06	8.69E-09		5.39E-08	1.02E-06
OTHERS	0.00	HGI	1.11E-06	1.11E-06	2.25E-07		8.81E-07	
		HNI	0.00	1.26E-07	9.98E-09		1.16E-07	
		KNI	0.00	0.00	0.00		0.00	
		KNSYA	0.00	0.00	0.00	0.00		
		KNSYC	0.00	0.00	0.00	0.00		
		LCI	0.00	0.00	0.00		0.00	0.00
		LNIYA	0.00	0.00				0.00
		LNIYC	0.00	0.00	0.00		0.00	
		OTHERS	0.00	0.00				
		TOTALS	8.31E-05	7.03E-05	1.93E-06	6.12E-06	1.76E-05	4.47E-05

TABLE 4-3b
TRANSLATION OF KRC FREQUENCIES TO APBs
ENHANCEMENT CASE - PROCEDURE CHANGE TO STOP ONE TRAIN OF SPRAYS

KRC ID	BASE KRC FREQ	CASE KRC FREQ	APB FREQUENCIES									
			1	2	3	4	5	6	7	8	9	10
R01	6.13E-08	6.13E-08			6.13E-08							
R01DI	1.21E-06	1.21E-06			1.21E-06							
R01I	3.91E-08	3.91E-08			3.91E-08							
R01IF	9.28E-08	9.28E-08			9.28E-08							
R01SI	0.00	0.00	0.00									
R01SIF	0.00	0.00	0.00									
R01SUI	0.00	0.00	0.00									
R01SUIF	0.00	0.00	0.00									
R01UI	2.15E-09	2.15E-09			2.15E-09							
R01UIF	5.10E-09	5.10E-09			5.10E-09							
R02IF	0.00	0.00			0.00							
R03	2.39E-08	2.39E-08				2.39E-08						
R03I	5.93E-08	5.93E-08		5.93E-08								
R03IF	2.51E-07	2.51E-07		2.51E-07								
R03SI	0.00	0.00	0.00									
R03SIF	0.00	0.00	0.00									
R03SUI	0.00	0.00	0.00									
R03SUIF	0.00	0.00	0.00									
R03UI	5.87E-11	5.87E-11				5.87E-11						
R03UIF	1.39E-10	1.39E-10				1.39E-10						
R04	1.44E-07	1.06E-07		1.06E-07								
R04IF	0.00	0.00				0.00						
R04UIF	2.77E-08	2.44E-08				2.44E-08						
R05SLI	0.00	0.00	0.00									
R05SLIF	0.00	0.00	0.00									
R05SLUI	0.00	0.00	0.00									
R05SLUIF	0.00	0.00			0.00							
R07SLUI	0.00	0.00	0.00									
R07SLUIF	0.00	0.00	0.00									
R09I	7.93E-07	7.93E-07					7.93E-07					
R09UI	3.07E-07	3.07E-07					3.07E-07					
R11I	7.24E-06	7.24E-06					7.24E-06					
R11IF	1.09E-06	1.09E-06					1.09E-06					
R11UI	7.28E-09	7.28E-09					7.28E-09					
R17L	2.42E-06	2.17E-06					2.17E-06					
R17LU	2.63E-06	2.63E-06					2.63E-06					
R17U	3.26E-06	2.87E-06						2.87E-06				
R18	0.00	0.00							0.00			
R19	7.83E-08	7.83E-08							7.83E-08			
R20	8.21E-06	8.18E-06							8.18E-06			
R21	4.62E-05	4.18E-05								4.18E-05		
R22	8.91E-06	6.61E-06										6.61E-06
OTHERS	0.00	0.00										
TOTALS	8.31E-05	7.56E-05	0.00	4.16E-07	1.41E-06	4.85E-08	1.42E-05	2.87E-06	8.26E-06	4.18E-05	0.00	6.61E-06

TABLE 4-3c

CALCULATION OF AVERTED OFFSITE DOSE ENHANCEMENT CASE - PROCEDURE CHANGE TO STOP ONE TRAIN OF SPRAYS

APB ID	BASE CASE APB FREQUENCY (EVENTS/YR)	REVISED APB FREQUENCY (EVENTS/YR)	BASE CASE POPULATION DOSE RATE (Man-REM/YR)	REVISED POPULATION DOSE RATE (Man-REM/YR)	BASE CASE POPULATION DOSE (Man-REM)	REVISED POPULATION DOSE (Man-REM)	AVERTED POPULATION DOSE (Man-REM)
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	4.54E-07	4.02E-07	8.27E-02	7.32E-02	3.31E+00	2.93E+00	3.79E-01
3	1.41E-06	1.41E-06	4.51E-01	4.48E-01	1.80E+01	1.79E+01	9.96E-02
4	5.18E-08	4.73E-08	1.75E-02	1.60E-02	7.02E-01	6.41E-01	6.03E-02
5	1.45E-05	1.48E-05	9.95E-01	1.02E+00	3.98E+01	4.07E+01	-9.18E-01
6	3.26E-06	2.74E-06	6.98E-02	5.86E-02	2.79E+00	2.34E+00	4.49E-01
7	8.29E-06	6.20E-06	3.38E+00	2.53E+00	1.35E+02	1.01E+02	3.41E+01
8	4.62E-05	3.92E-05	9.24E-03	7.83E-03	3.69E-01	3.13E-01	5.60E-02
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	8.91E-06	5.46E-06	1.04E-03	6.36E-04	4.15E-02	2.54E-02	1.61E-02
TOTAL	8.31E-05	7.03E-05	5.01E+00	4.15E+00	2.00E+02	1.66E+02	34.22

the procedure change to allow termination of one train of containment sprays is $25,200. The risk reduction benefit associated with this change has been conservatively estimated to be 34.2 person-rem over the life of the plant. Therefore, the cost benefit ratio is

C/B Ratio = $25,200/34.2 person-rem = $737/person-rem

This ratio is less than $1000 per person rem. Therefore, based on this analysis, the enhancement to allow termination of one train of containment sprays is considered cost beneficial.

4.1.2 Install Containment Spray Throttle Valves

This enhancement involves a design change to the containment spray system to provide valves to allow throttling of containment spray flow and procedures to support their use. This enhancement would result in additional time for operator recovery actions and would further reduce the susceptibility of the plant to ECCS recirculation failures.

4.1.2.1 Existing Capabilities

The existing containment spray valves do not have throttle capability.

4.1.2.2 Description of Enhancement

This enhancement involves the provision of new valves and controls in the containment spray system which allow throttling of the spray flow. This would require physical changes to the containment spray piping as well as changes to the control room to provide throttling capability. In addition, procedure changes would be required to provide direction on the use of the throttle capability.

4.1.2.3 Cost Estimate

No specific cost estimate was developed for this enhancement. However, based on the cost estimates developed for other enhancements, it was assumed that the cost of designing and installing throttle capability on the containment spray system and the cost of the procedural changes necessary to allow use of the throttle valves would exceed $200,000. Therefore, a cost of greater then $200,000 was assumed for the purposes of the value impact analysis.

4.1.2.4 Risk Reduction Estimate

The risk reduction benefits associated with the provision of throttle valves are essentially equivalent to those estimated for the procedure change to allow termination of one

containment spray train. Therefore, the WBN Level 1 and 2 spreadsheet models developed for enhancement I.1 were used to evaluate the potential risk reduction benefit of this change.

Tables 4-3 a,b,c provide a summary of the results of the requantification of the PRA and population dose estimates. Based on this analysis, the total reduction in population dose is estimated to be 34.2 person rem over the 40 year life of the plant.

4.1.2.5 Value Impact Assessment

The value impact of this enhancement is based on a quantitative comparison of the cost of the enhancement and the potential risk reduction benefit. The total estimated cost for providing throttle capability on the containment spray system is greater than $200,000. The risk reduction benefit associated with this change has been conservatively estimated to be 34.2 person-rem over the life of the plant. Therefore, the cost benefit ratio is

C/B Ratio = >$200,000/34.2 person-rem = >$5,848/person-rem

This ratio is more than $1000 per person rem. Therefore, based on this analysis, the enhancement to provide throttle valves on the containment spray system is not considered cost beneficial.

4.1.3 Redesign to Delay Containment Spray Actuation

This enhancement involves the reanalysis and redesign of the containment spray actuation system. The current WBN design basis requires the spray system to function in the manner modeled in the IPE. However, with additional engineering analysis it is likely that the actuation of containment spray could be precluded in small LOCA events, thereby significantly extending the time before RWST depletion. This additional time would likely be sufficient to allow plant cooldown without ECCS recirculation.

4.1.3.1 Existing Capabilities

The existing containment spray action system for WBN initiates containment spray upon receipt of a Phase B isolation signal. This means that for essentially all LOCAs containment spray is likely to actuate. For smaller LOCAs, the actuation of containment spray significantly increases the rate of depletion of the RWST and decreases the time before ECCS recirculation is required.

4.1.3.2 Description of Enhancement

The purpose of this enhancement is to delay the containment spray actuation in order to extend the time available for injection and result in delaying the time at which switch-over from the RWST to the emergency sump recirculation occurs. Since many of the PRA severe accident scenarios have successful injection but failure to switch-over to recirculation mode, the delay of containment spray actuation would result in extending the time available for injection and may result in fewer core damage accident sequences.

Following a Phase B signal, the containment sprays are designed to actuate immediately. Depletion of the RWST occurs quickly due to the flow rate of the containment spray pumps. Severe accident progression analyses using MAAP, have shown that the actuation of containment sprays prior to depletion of ice has a negligible effect on overall containment performance. Therefore, from a containment performance perspective, the delay of containment response. The proposed design modifications include revising the setpoint and logic for automatic initiation of containment spray and enhancing the operators ability to monitor the water level in the containment sump.

In order to provide maximum credit for this enhancement, the following equipment/ documentation changes may be required.

- Detailed containment analysis will be required to guarantee that design limits for the plant are not violated. In the case where containment pressure may exceed design limits, either additional analyses may be required or credit for the enhancement will not be allowed for operation in this condition.
- Replacement/Requalification of RWST and emergency sump level instrumentation and transmitters.
- Adding an additional source of water for the RWST in the form of an additional tank or cross over piping to an existing water system.
- Revising the setpoint and logic for containment spray actuation.
- Addition of appropriate hardware.

4.1.3.3 Cost Estimate

A partial cost estimate for this enhancement has been performed utilizing existing TVA experience in performing a modification at Sequoyah which is similar to one of the modification associated with this enhancement. Namely, a modification to replace the sump level instrumentation at Sequoyah has been previously performed by TVA. While this modification at Sequoyah was performed for different reasons, the cost associated with the modification are applicable. The actual cost for this task at Sequoyah Unit 1 was

$358,000 in 1989 dollars. Given the benefit cost assessment of the additional items within the scope of this enhancement is not necessary. For the purposes of evaluating the cost-benefit of this candidate enhancement, the cost of $358,000 has been escalated to $381,270 (1994 dollars) and the cost of procedural changes and training has been added ($25,200). Therefore, the total cost estimate for this enhancement is $406,470.

4.1.3.4 Risk Reduction Estimate

The risk reduction associated with this enhancement is essentially the same as described for enhancements I.1 and I.2. Therefore, the WBN Level 1 and 2 spreadsheet models developed for enhancement I.1 were used to evaluate the potential risk reduction benefit of this change.

Tables 4-3 a,b,c provide a summary of the results of the requantification of the PRA and population dose estimates. Based on this analysis, the total reduction in population dose is estimated to be 34.2 person rem over the 40 year life of the plant.

4.1.3.5 Value Impact Assessment

The value impact of this enhancement is based on a quantitative comparison of the cost of the enhancement and the potential risk reduction benefit. The total estimated cost for designing the containment spray system to delay actuation is $406,470. The risk reduction benefit associated with this change has been conservatively estimated to be -34.2 person-rem over the life of the plant. Therefore, the cost benefit ratio is

C/B Ratio = $406,470/34.2 person-rem = >$11,885/person-rem

This ratio is more than $1000 per person rem. Therefore, based on this analysis, the enhancement to delay containment spray actuation is not considered cost beneficial.

4.1.4 Automate High Pressure Recirculation

This enhancement would automate the alignment of ECCS recirculation to the high pressure charging and safety injection pumps. Provision of this enhancement would essentially eliminate the human errors in realignment.

4.1.4.1 Existing Capabilities

The ECCS recirculation system at WBN has an automatic switchover of the low pressure portion of the ECCS system. The existing design automatically opens and closes the appropriate MOVs to align the suction of the RHR pumps from the RWST to the containment sump. However, the realignment of the suction of the safety injection and

charging pumps from the RWST to the discharge of the RHR pumps requires manual operator action in the control room.

4.1.4.2 Description of Enhancement

The purpose of this enhancement is to provide a system to automatically switch the suction of the Safety Injection (SI) and Centrifugal Charging Pumps (CCP) to the residual heat removal (RHR) pump discharge when the level in the Refueling Water Storage Tank (RWST) requires switch-over to the emergency sump recirculation. Automatic switch-over would reduce the potential for operator error and improve the availability of core cooling in the recirculation mode.

Evaluation of this enhancement does not require the development of a detailed scope of the plant enhancement. For the purposes of discussion, the cost estimate prepared by NRC for the Sequoyah Nuclear Plant (Reference 1) and by Texas Utilities for the Comanche Peak Nuclear Plant (Reference 2) will be used.

4.1.4.3 Cost Estimate

Two cost estimates exist in published industry documents that provide applicable estimates for this enhancement at Watts Bar. Draft NUREG-1150 (Reference 1) identified this enhancement as a potential enhancement for the Sequoyah Nuclear Plant and provided a cost estimate that ranged from $1.1 million to $2.8 million (1987 dollars). The central value of the NUREG-1150 estimate was $1.7 million in 1987 dollars or approximately $2.1 million in 1994 dollars.

A second published source which provides an applicable estimate is Texas Utilities' SAMDA evaluation report prepared for Comanche Peak (Reference 2). Reference 2 provides an estimate of $1.5 million in 1989 dollars. Escalation of this amount to 1993 dollars results in an estimate of approximately $1.8 million.

Both of the estimates provided above are comparable and provide a reasonable basis for estimating the cost associated with this enhancement at Watts Bar without performing a Watts Bar-specific detailed cost assessment. While both plants have a similar design regarding the manual actions required for switch-over, the Sequoyah Nuclear Plant is more representative of the Watts Bar design and therefore the estimate provided in NUREG-1150 will be used for the purpose of this assessment.

4.1.4.4 Risk Reduction Estimate

The risk reduction benefit of this enhancement is expected to be less than the other category I enhancements since it primarily addresses the human action element of the

failure of recirculation which is not the dominant contributor. However, it was conservatively assumed that the risk reduction benefit associated with the enhancement I.1 could be used for the purposes of value impact assessment. Therefore, the WBN Level 1 and 2 spreadsheet models developed for enhancement I.1 were used to evaluate the potential risk reduction benefit of this change.

Tables 4-3 a,b,c provide a summary of the results of the requantification of the PRA and population dose estimates. Based on this analysis, the total reduction in population dose is estimated to be 34.2 person rem over the 40 year life of the plant.

4.1.4.5 Value Impact Assessment

The value impact of this enhancement is based on a quantitative comparison of the cost of the enhancement and the potential risk reduction benefit. The total estimated cost for automating high pressure recirculation is $2.1M. The risk reduction benefit associated with this change has been conservatively estimated to be 34.2 person-rem over the life of the plant. Therefore, the cost benefit ratio is

C/B Ratio = $2,100,000/<34.2 person-rem = <$61,403/person-rem

This ratio is more than $1000 per person rem. Therefore, based on this analysis, the enhancement to delay containment spray actuation is not considered cost beneficial.

4.2 IMPROVE AVAILABILITY OF OFFSITE POWER

The second largest contributor to the WBN core damage frequency (~23%) is loss of offsite power (161kV). Roughly 21% is due to station blackout events. This category of enhancement is intended to improve the availability of AC power by providing access to alternate, diverse AC power sources not currently credited in the IPE.

4.2.1 Procedure Change to Facilitate Cross-tie of 500kV and 161kV

The 6.9kV Shutdown Boards at Watts Bar Unit 1 are provided offsite power from the 161kV grid. Another, independent 500kV grid is connected to the WBN site, but is not currently allowed to be tied to the Unit 1 shutdown boards. A physical connection is possible, via bus cross-ties at Unit 2, but the current plant procedures do not support this crosstie. This enhancement would provide procedures and training on the crosstie of the 500kV grid to the Unit 1 shutdown boards.

4.2.1.1 Existing Capabilities

The WBN site is connected to two separate grids, a 161kV grid and a 500kV grid. The Unit 1 shutdown boards are supplied by the 161kV grid and the unit main generator supplies the 500kV grid. Physical ties between the two grids are normally not present. However, in the event the 161kV grid loses power, it would be possible to align existing busses and breakers to feed the Unit 1 shutdown boards from the 500kV grid. Currently, no procedures exist to govern this operation. Consequently, the WBN IPE did not credit this diverse source of offsite power.

4.2.1.2 Description of Enhancement

This enhancement involves the development of a WBN plant procedure which would provide appropriate direction on the cross-tie of 500kV power to the Unit 1 shutdown boards in the event of loss of 161kV supply. This procedure could be incorporated into the existing loss of offsite power procedure or included by reference.

4.2.1.3 Cost Estimate

Since the proposed enhancement is within the existing design capability of the plant, the primary cost associated with the change would be the cost of revising the associated procedures and training plant operators. Table 4-2 provides a summary of the costs associated with a procedure change of this type.

4.2.1.4 Risk Reduction Estimate

The WBN Level 1 and 2 spreadsheet models were used to evaluate the potential risk reduction benefit of the proposed change. The assumptions utilized were intended to maximize the potential benefit of the change. The 500kV grid provides an independent, diverse source of power to the Unit 1 shutdown boards. However, loss of offsite power data used in the IPE includes consideration of severe weather events which could impact both the 161kV and the 500kV grids simultaneously. Roughly 10% of all loss of offsite power events are due to severe weather. It is conservatively assumed that the crosstie of 500kV power would be unsuccessful. In addition, the alignment of breakers and busses to provide a 500kV power to the Unit 1 shutdown boards requires a number of operator actions which would be performed infrequently. Therefore, a human error rate of 0.1 is assumed for these actions. Thus, the total likelihood of failure of the 500kV crosstie is assumed to be 0.2. In order to reflect this in the WBN IPE model, the split fractions associated with non-recovery of loss of offsite power were reduced by a factor of 0.2.

Tables 4-4 a,b,c provide a summary of the results of the requantification of the PRA and population dose estimates. Based on this analysis, the total reduction in population dose is estimated to be 43.6 person rem over the 40 year life of the plant.

4.2.1.5 Value Impact Assessment

The value impact of this enhancement is based on a quantitative comparison of the cost of the enhancement and the potential risk reduction benefit. The total estimated cost for the provision of a procedure to crosstie 500kV power to the Unit 1 shutdown boards is $25,200. The risk reduction benefit associated with this change has been conservatively estimated to be 43.6 person-rem over the life of the plant. Therefore, the cost benefit ratio is

C/B Ratio = $25,200/43.6 person-rem = $578/person-rem

This ratio is less than $1000 per person rem. Therefore, based on this analysis, the enhancement to provide a procedure to crosstie 500kV power to the Unit 1 shutdown boards is considered cost beneficial.

4.2.2 Accelerate Availability of Fifth Diesel

The WBN emergency AC power system design provides a fifth emergency diesel generator (EDG) which can be connected to any of the four 6.9kV shutdown boards. The purpose of the fifth EDG is to provide operational flexibility by providing a installed spare for EDGs which are removed from service. When completed, the fifth EDG will provide a means for ensuring all four shutdown boards are supported by an operable EDG, even while one is under going maintenance. Currently, the startup schedule for WBN Unit 1 does not support the provision of the fifth EDG at the time of plant startup. It is intended to be made available after Unit 1 startup, but due to the large number of outstanding design changes which would be required to make the EDG available, its availability is being deferred. This enhancement evaluates the benefit of the fifth EDG and considers whether the cost associated with accelerating the schedule is commensurate with the benefit.

4.2.2.1 Existing Capabilities

The four 6.9kV shutdown boards are supported by four emergency diesel generators. The original design of the WBN site provided a fifth emergency diesel generator which could serve as a built-in spare in the event one of the four primary diesels was required to remove from service. This capability was provided primarily to allow performance of required diesel maintenance while one or both of the units were operating.

TABLE 4-4a
SUMMARY OF PDS AND KRC RESULTS
ENHANCEMENT CASE - PROCEDURE CHANGE TO FACILITATE CROSS-TIE OF 300KV AND 161KV

BASE CASE RESULTS				ENHANCEMENT CASE RESULTS				
LEVEL 1 OUTPUT KPDS	BASE CASE KPDS FREQUENCY	LEVEL 2 INPUT KPDS	BASE CASE KPDS FREQUENCY	KPDS FREQUENCY	KRC GROUP FREQUENCY			
					I	II	III	IV
ATV	7.83E-08	ATV	7.83E-08	7.83E-08	7.83E-08			
BCI	4.49E-06	BCI	4.49E-06	4.49E-06	2.77E-08		3.43E-06	1.03E-06
EGI	0.00	EGI	0.00	0.00	0.00		0.00	
EIB	5.52E-06	EIB	5.52E-06	5.52E-06		5.52E-06		
ENB	4.58E-07	ENB	4.58E-07	4.58E-07		4.58E-07		
ENI	3.84E-05	ENIYA	3.00E-05	2.20E-05	1.76E-07		3.49E-07	2.15E-05
ENS	2.24E-06	ENIYB	1.10E-06	8.06E-07	6.45E-09		8.00E-07	
FCI	2.46E-05	ENIYN	7.30E-06	5.35E-06	4.28E-08		5.31E-06	
FGI	0.00	ENSYA	5.20E-07	0.00		0.00		
FNI	0.00	ENSYB	1.65E-07	0.00		0.00		
GNI	4.95E-06	ENSYC	1.76E-07	0.00		0.00		
HCI	1.23E-06	ENSYN	1.37E-06	0.00		0.00		
HGI	1.11E-06	FCI	2.46E-05	2.46E-05	1.34E-07		8.30E-07	2.36E-05
HNI	0.00	FGI	0.00	0.00	0.00		0.00	0.00
KNI	0.00	FNI	0.00	0.00	0.00		0.00	0.00
KNS	0.00	GNIYA	3.49E-06	3.49E-06	8.55E-07		2.63E-06	
LCI	0.00	GNIYN	1.47E-06	1.47E-06	3.60E-07	0.00	1.11E-06	
LNI	0.00	HCI	1.23E-06	1.23E-06	9.80E-09		6.08E-08	1.16E-06
OTHERS	0.00	HGI	1.11E-06	1.11E-06	2.25E-07		8.81E-07	
		HNI	0.00	0.00	0.00		0.00	
		KNI	0.00	0.00	0.00		0.00	
		KNSYA	0.00	0.00	0.00	0.00		
		KNSYC	0.00	0.00	0.00	0.00		
		LCI	0.00	0.00	0.00		0.00	0.00
		LNIYA	0.00	0.00				0.00
		LNIYC	0.00	0.00	0.00		0.00	
		OTHERS	0.00	0.00				
		TOTALS	8.31E-05	7.06E-05	1.92E-06	5.97E-06	1.54E-05	4.73E-05

TABLE 4-4b
TRANSLATION OF KRC FREQUENCIES TO APBs
ENHANCEMENT CASE - PROCEDURE CHANGE TO FACILITATE CROSS-TIE OF 300KV AND 161KV

KRC ID	BASE KRC FREQ	CASE KRC FREQ	APB FREQUENCIES									
			1	2	3	4	5	6	7	8	9	10
R01	6.13E-08	6.13E-08			6.13E-08							
R01DI	1.21E-06	1.21E-06			1.21E-06							
R01I	3.91E-08	3.91E-08			3.91E-08							
R01IF	9.28E-08	9.28E-08			9.28E-08							
R01SI	0.00	0.00	0.00									
R01SIF	0.00	0.00	0.00									
R01SUI	0.00	0.00	0.00									
R01SUIF	0.00	0.00	0.00									
R01UI	2.15E-09	2.15E-09			2.15E-09							
R01UIF	5.10E-09	5.10E-09			5.10E-09							
R02IF	0.00	0.00			0.00							
R03	2.39E-08	2.39E-08				2.39E-08						
R03I	5.93E-08	4.37E-08		4.37E-08								
R03IF	2.51E-07	1.85E-07		1.85E-07								
R03SI	0.00	0.00	0.00									
R03SIF	0.00	0.00	0.00									
R03SUI	0.00	0.00	0.00									
R03SUIF	0.00	0.00	0.00									
R03UI	5.87E-11	5.87E-11				5.87E-11						
R03UIF	1.39E-10	1.39E-10				1.39E-10						
R04	1.44E-07	1.44E-07		1.44E-07								
R04IF	0.00	0.00				0.00						
R04UIF	2.77E-08	2.77E-08				2.77E-08						
R05SLI	0.00	0.00	0.00									
R05SLIF	0.00	0.00	0.00									
R05SLUI	0.00	0.00	0.00									
R05SLUIF	0.00	0.00			0.00							
R07SLUI	0.00	0.00	0.00									
R07SLUIF	0.00	0.00	0.00									
R09I	7.93E-07	7.93E-07					7.93E-07					
R09UI	3.07E-07	3.07E-07					3.07E-07					
R11I	7.24E-06	5.31E-06					5.31E-06					
R11IF	1.09E-06	8.00E-07					8.00E-07					
R11UI	7.28E-09	7.28E-09					7.28E-09					
R17L	2.42E-06	2.29E-06					2.29E-06					
R17LU	2.63E-06	2.63E-06					2.63E-06					
R17U	3.26E-06	3.26E-06						3.26E-06				
R18	0.00	0.00							0.00			
R19	7.83E-08	7.83E-08							7.83E-08			
R20	8.21E-06	5.97E-06							5.97E-06			
R21	4.62E-05	3.84E-05								3.84E-05		
R22	8.91E-06	8.91E-06										8.91E-06
OTHERS	0.00	0.00										
TOTALS	8.31E-05	7.06E-05	0.00	3.72E-07	1.41E-06	5.18E-08	1.21E-05	3.26E-06	6.05E-06	3.84E-05	0.00	8.91E-06

TABLE 4-4c

CALCULATION OF AVERTED OFFSITE DOSE
ENHANCEMENT CASE - PROCEDURE CHANGE TO FACILITATE CROSS-TIE OF 300KV AND 161KV

APB ID	BASE CASE APB FREQUENCY (EVENTS/YR)	REVISED APB FREQUENCY (EVENTS/YR)	BASE CASE POPULATION DOSE RATE (Man-REM/YR)	REVISED POPULATION DOSE RATE (Man-REM/YR)	BASE CASE POPULATION DOSE (Man-REM)	REVISED POPULATION DOSE (Man-REM)	AVERTED POPULATION DOSE (Man-REM)
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	4.54E-07	3.72E-07	8.27E-02	6.78E-02	3.31E+00	2.71E+00	5.98E-01
3	1.41E-06	1.41E-06	4.51E-01	4.51E-01	1.80E+01	1.80E+01	0.00
4	5.18E-08	5.18E-08	1.75E-02	1.75E-02	7.02E-01	7.02E-01	0.00
5	1.45E-05	1.21E-05	9.95E-01	8.34E-01	3.98E+01	3.33E+01	6.46E+00
6	3.26E-06	3.26E-06	6.98E-02	6.98E-02	2.79E+00	2.79E+00	0.00
7	8.29E-06	6.05E-06	3.38E+00	2.47E+00	1.35E+02	9.88E+01	3.65E+01
8	4.62E-05	3.84E-05	9.24E-03	7.67E-03	3.69E-01	3.07E-01	6.25E-02
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	8.91E-06	8.91E-06	1.04E-03	1.04E-03	4.15E-02	4.15E-02	0.00
TOTAL	8.31E-05	7.06E-05	5.01E+00	3.92E+00	2.00E+02	1.57E+02	4.36E+01

Currently, the fifth diesel generator is not being prepared for plant startup. A large number of design changes are required to be implemented to make the diesel functional. The design portion of these changes have been completed, but the field installation and testing is still required. The current backlog of design changes includes both changes which are required to allow the fifth diesel to be operable in accordance with the plant technical specifications. These design changes were reviewed to determine the minimum set of changes required to make the diesel functionally available rather than tech spec operable. This minimum set is what was used in the cost analysis.

4.2.2.2 Description of Enhancement

This enhancement involves the acceleration of the schedule for the fifth diesel to ensure it is functional in time to support plant startup. The current schedule for the fifth diesel supports its availability during a future refueling outage. The fifth diesel is functionally redundant to each of the existing diesels.

4.2.2.3 Cost Estimate

The existing backlog of design changes for the fifth diesel was reviewed in order to determine the minimum set of changes required to be implemented in order to make the fifth diesel functional as a backup to the existing diesels. Any changes required simply to make the diesel tech spec operable were excluded from the minimum set. Site construction managers were requested to estimate the resources associated with each of the changes on the minimum list. Table 4-5 provides a summary of the cost estimate associated with these changes. In addition, since the benefit of the fifth diesel will be calculated over the 40 year plant life, an estimate of the cost of maintaining the diesel has also been included.

The total cost of making the diesel functionally available for the 40 year plant life is $513,300. However, procedure changes would be required to allow alignment and its use. Therefore, an additional $25,200 was added to the cost estimate. This results in a total cost of $538,500.

4.2.2.4 Risk Reduction Estimate

The WBN Level 1 and 2 spreadsheet models were used to evaluate the potential risk reduction benefit of the proposed change. The assumptions utilized were intended to maximize the potential benefit of the change. The following assumptions were used to quantify the effect of the fifth diesel:

1. This diesel is assumed to be primarily a maintenance replacement for the installed diesel generators.

Table 4-5
Fifth Diesel Generator Completion

Scope:

Complete the below listed DCNs which have been determined necessary to make the fifth DG functionally. (Note: the EDG would not necessarily be Technical Specification operational, but would be available for use in the event of a beyond design basis accident.)

M-01051 - Replaces Fuse Blocks	M-01469 - Instrument ID for Sense Lines
M-02671 - Voltage Regulator	M-03328 - Voltage Regulator
M-03564 - Provide Ashcoft Switches	M-05840 - Resolve AC Configuration
M-09487 - Resolve B/M Differences	M-09587 - Cables Failed Ampacity Calc
M-11050 - Cable Replacement GRP 4	M-11277 - Ampacity Cable Replacements
M-11793 - Battery Replacement	M-13013 - Cable Tray Voltage Level Markers
M-16145 - Rewire 80 & 15 Amp Fuse	M-16401 - Replace Flow Switches
M-16531 - Neutral Resistor	M-17597 - APP R MCR Isolation
M-18199 - Ground Fault Protection	M-21836 - Add Isolation Fuses

Engineering:		
None Outstanding		
Material:		
Engineered Items: Approximately	$80K	
Bulk Commodities: Approximately	$60K	
Material Cost		$140K
Construction:		
Trade and Labor 6,970 manhours * $25 per manhour	$174.3K	
Management and Oversight (10% T & L) 697 manhours * $56 per manhour	$39K	
Construction Cost		$213.3K
Equipment Maintenance:		
160 manhours/yr * 40 years to maintain DG * $25/hour	$160K	
Maintenance Cost		$160K
	Total	$513.3K

2. As a replacement, this diesel will automatically start and load on loss of power to the affected 6.9kV bus.
3. It requires approximately four hours to complete the alignment and testing necessary to use the fifth diesel as a replacement.
4. The maintenance frequency for the installed EDGs remains the same, the maintenance duration is reduced to four hours from 13.8 hours.
5. When used as a recovery diesel, it requires approximately one hour for the operators to complete the line-up of and start the fifth diesel.
6. The maintenance unavailability of the fifth diesel is four times the maintenance unavailability of the installed EDGs.
7. Recovery of power using the fifth diesel with the other four diesel failed is not quantified.

Using these assumptions, the intermediate split fractions used to quantify the top events for the existing diesels (GA, GB, GC, and GD). The failure frequency for top event REC was changed by adding the unavailability of a single emergency diesel generator, 9.74E-02, and four times the maintenance unavailability of a single emergency diesel generator, 2.51E-02. A likelihood of operator failure of 0.1 was assumed for bringing the fifth diesel on line and tieing it into a 6.9kV shutdown board.

Tables 4-6 a,b,c provide a summary of the results of the requantification of the PRA and population dose estimates. Based on this analysis, the total reduction in population dose is estimated to be 64.1 person rem over the 40 year life of the plant.

4.2.2.5 Value Impact Assessment

The value impact of this enhancement is based on a quantitative comparison of the cost of the enhancement and the potential risk reduction benefit. The total estimated cost for accelerating the availability of the fifth diesel is $538,500. The risk reduction benefit associated with this change has been conservatively estimated to be 64.1 person-rem over the life of the plant. Therefore, the cost benefit ratio is

C/B Ratio = $538,500/64.1 person-rem = $8,396/person-rem

This ratio is more than $1000 per person rem. Therefore, based on this analysis, the enhancement to accelerate the availability of the fifth diesel is not considered cost beneficial.

4.2.3 Procedure Change and Fifth Diesel

This enhancement is a combination of II.1 and II.2. It involves the provision of both the procedure for the crosstie of the 500kV grid to the Unit 1 shutdown boards and the fifth EDG.

4.2.3.1 Existing Capabilities

The existing capabilities associated with this enhancement are described in Sections 4.2.1 and 4.2.2.

TABLE 4-6a
SUMMARY OF PDS AND KRC RESULTS
ENHANCEMENT CASE - ACCELERATE AVAILABILITY OF FIFTH EMERGENCY DIESEL GENERATOR

BASE CASE RESULTS				ENHANCEMENT CASE RESULTS				
LEVEL 1 OUTPUT KPDS	BASE CASE KPDS FREQUENCY	LEVEL 2 INPUT KPDS	BASE CASE KPDS FREQUENCY	KPDS FREQUENCY	KRC GROUP FREQUENCY			
					I	II	III	IV
ATV	7.83E-08	ATV	7.83E-08	7.83E-08	7.83E-08			
BCI	4.49E-06	BCI	4.49E-06	4.47E-06	2.75E-08		3.42E-06	1.03E-06
EGI	0.00	EGI	0.00	6.69E-08	5.35E-10		6.64E-08	
EIB	5.52E-06	EIB	5.52E-06	3.43E-06		3.43E-06		
ENB	4.58E-07	ENB	4.58E-07	4.58E-07		4.58E-07		
ENI	3.84E-05	ENIYA	3.00E-05	2.40E-05	1.92E-07		3.81E-07	2.35E-05
ENS	2.24E-06	ENIYB	1.10E-06	8.80E-07	7.04E-09		8.73E-07	
FCI	2.46E-05	ENIYN	7.30E-06	5.84E-06	4.68E-08		5.80E-06	
FGI	0.00	ENSYA	5.20E-07	3.29E-07		3.29E-07		
FNI	0.00	ENSYB	1.65E-07	1.04E-07		1.04E-07		
GNI	4.95E-06	ENSYC	1.76E-07	1.12E-07		1.12E-07		
HCI	1.23E-06	ENSYN	1.37E-06	8.70E-07		8.70E-07		
HGI	1.11E-06	FCI	2.46E-05	2.46E-05	1.34E-07		8.29E-07	2.36E-05
HNI	0.00	FGI	0.00	4.52E-07	3.61E-09		3.85E-07	6.27E-08
KNI	0.00	FNI	0.00	6.02E-07	4.81E-09		5.13E-07	8.35E-08
KNS	0.00	GNIYA	3.49E-06	2.06E-06	5.06E-07		1.56E-06	
LCI	0.00	GNIYN	1.47E-06	8.68E-07	2.13E-07	0.00	6.55E-07	
LNI	0.00	HCI	1.23E-06	1.22E-06	9.75E-09		6.05E-08	1.15E-06
OTHERS	0.00	HGI	1.11E-06	3.30E-07	6.73E-08		2.63E-07	
		HNI	0.00	1.02E-07	8.11E-09		9.40E-08	
		KNI	0.00	0.00	0.00		0.00	
		KNSYA	0.00	0.00	0.00	0.00		
		KNSYC	0.00	0.00	0.00	0.00		
		LCI	0.00	0.00	0.00		0.00	0.00
		LNIYA	0.00	0.00				0.00
		LNIYC	0.00	0.00	0.00		0.00	
		OTHERS	0.00	0.00				
		TOTALS	8.31E-05	7.09E-05	1.30E-06	5.31E-06	1.49E-05	4.94E-05

TABLE 4-6b
TRANSLATION OF KRC FREQUENCIES TO APBs
ENHANCEMENT CASE - ACCELERATE AVAILABILITY OF FIFTH EMERGENCY DIESEL GENERATOR

KRC ID	BASE KRC FREQ	CASE KRC FREQ	APB FREQUENCIES									
			1	2	3	4	5	6	7	8	9	10
R01	6.13E-08	1.83E-08			1.83E-08							
R01DI	1.21E-06	6.83E-07			6.83E-07							
R01I	3.91E-08	2.31E-08			2.31E-08							
R01IF	9.28E-08	5.49E-08			5.49E-08							
R01SI	0.00	0.00	0.00									
R01SIF	0.00	0.00	0.00									
R01SUI	0.00	0.00	0.00									
R01SUIF	0.00	0.00	0.00									
R01UI	2.15E-09	1.27E-09			1.27E-09							
R01UIF	5.10E-09	3.01E-09			3.01E-09							
R02IF	0.00	0.00			0.00							
R03	2.39E-08	7.13E-09				7.13E-09						
R03I	5.93E-08	4.73E-08		4.73E-08								
R03IF	2.51E-07	2.11E-07		2.11E-07								
R03SI	0.00	0.00	0.00									
R03SIF	0.00	0.00	0.00									
R03SUI	0.00	0.00	0.00									
R03SUIF	0.00	0.00	0.00									
R03UI	5.87E-11	3.47E-11				3.47E-11						
R03UIF	1.39E-10	6.18E-10				6.18E-10						
R04	1.44E-07	1.43E-07		1.43E-07								
R04IF	0.00	0.00				0.00						
R04UIF	2.77E-08	2.75E-08				2.75E-08						
R05SLI	0.00	0.00	0.00									
R05SLIF	0.00	0.00	0.00									
R05SLUI	0.00	0.00	0.00									
R05SLUIF	0.00	0.00			0.00							
R07SLUI	0.00	0.00	0.00									
R07SLUIF	0.00	0.00	0.00									
R09I	7.93E-07	4.69E-07					4.69E-07					
R09UI	3.07E-07	1.82E-07					1.82E-07					
R11I	7.24E-06	5.80E-06					5.80E-06					
R11IF	1.09E-06	8.73E-07					8.73E-07					
R11UI	7.28E-09	4.31E-09					4.31E-09					
R17L	2.42E-06	2.70E-06					2.70E-06					
R17LU	2.63E-06	1.56E-06					1.56E-06					
R17U	3.26E-06	3.31E-06						3.31E-06				
R18	0.00	0.00							0.00			
R19	7.83E-08	7.83E-08							7.83E-08			
R20	8.21E-06	5.31E-06							5.31E-06			
R21	4.62E-05	4.05E-05								4.05E-05		
R22	8.91E-06	8.89E-06										8.89E-06
OTHERS	0.00	0.00										
TOTALS	8.31E-05	7.09E-05	0.00	4.01E-07	7.84E-07	3.53E-08	1.16E-05	3.31E-06	5.38E-06	4.05E-05	0.00	8.89E-06

TABLE 4-6c

CALCULATION OF AVERTED OFFSITE DOSE
ENHANCEMENT CASE - ACCELERATE AVAILABILITY OF FIFTH EMERGENCY DIESEL GENERATOR

APB ID	BASE CASE APB FREQUENCY (EVENTS/YR)	REVISED APB FREQUENCY (EVENTS/YR)	BASE CASE POPULATION DOSE RATE (Man-REM/YR)	REVISED POPULATION DOSE RATE (Man-REM/YR)	BASE CASE POPULATION DOSE (Man-REM)	REVISED POPULATION DOSE (Man-REM)	AVERTED POPULATION DOSE (Man-REM)
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	4.54E-07	4.01E-07	8.27E-02	7.31E-02	3.31E+00	2.93E+00	3.84E-01
3	1.41E-06	7.84E-07	4.51E-01	2.50E-01	1.80E+01	9.99E+00	8.03E+00
4	5.18E-08	3.53E-08	1.75E-02	1.20E-02	7.02E-01	4.79E-01	2.23E-01
5	1.45E-05	1.16E-05	9.95E-01	7.95E-01	3.98E+01	3.18E+01	7.99E+00
6	3.26E-06	3.31E-06	6.98E-02	7.09E-02	2.79E+00	2.83E+00	-4.13E-02
7	8.29E-06	5.38E-06	3.38E+00	2.20E+00	1.35E+02	8.79E+01	4.74E+01
8	4.62E-05	4.05E-05	9.24E-03	8.09E-03	3.69E-01	3.24E-01	4.57E-02
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	8.91E-06	8.89E-06	1.04E-03	1.04E-03	4.15E-02	4.14E-02	5.49E-05
TOTAL	8.31E-05	7.09E-05	5.01E+00	3.41E+00	2.00E+02	1.36E+02	64.06

4.2.3.2 Description of Enhancement

This enhancement involves the provision of both Enhancement II.1 and II.2.

4.2.3.3 Cost Estimate

The cost associated with the two enhancements is the sum of the costs associated with each or $563,700.

4.2.3.4 Risk Reduction Estimate

The WBN Level 1 and 2 spreadsheet models were used to evaluate the potential risk reduction benefit of the proposed change. The assumptions utilized were intended to maximize the potential benefit of the change. The risk reduction associated with the combination of these two enhancements was calculated by combining the risk reduction changes described in Sections 4.2.1.4 and 4.2.2.4.

Tables 4-7 a,b,c provide a summary of the results of the requantification of the PRA and population dose estimates. Based on this analysis, the total reduction in population dose is estimated to be 70.6 person rem over the 40 year life of the plant.

4.2.3.5 Value Impact Assessment

The value impact of this enhancement is based on a quantitative comparison of the cost of the enhancement and the potential risk reduction benefit. The total estimated cost for the 500kV crosstie procedure change and fifth diesel is $563,700. The risk reduction benefit associated with this change has been conservatively estimated to be 70.6 person-rem over the life of the plant. Therefore, the cost benefit ratio is

C/B Ratio = $563,700/70.6 person-rem = $7,980/person-rem

This ratio is more than $1000 per person rem. Therefore, based on this analysis, the enhancement to provide both the 500kV crosstie procedure change and fifth diesel is not considered cost beneficial.

4.3 IMPROVE ABILITY TO COPE WITH LOSS OF AC POWER & STATION BLACKOUT

This category involves those enhancements which improve the ability of the plant to cope with an extended loss of offsite power or station blackout. While the Category II enhancements involved restoration of AC power, this category involves items which would make coping with loss of AC power less likely to lead to core damage and/or containment failure.

TABLE 4-7a
SUMMARY OF PDS AND KRC RESULTS
ENHANCEMENT CASE - PROCEDURE CHANGE AND FIFTH DIESEL

BASE CASE RESULTS				ENHANCEMENT CASE RESULTS				
LEVEL 1 OUTPUT KPDS	BASE CASE KPDS FREQUENCY	LEVEL 2 INPUT KPDS	BASE CASE KPDS FREQUENCY	KPDS FREQUENCY	KRC GROUP FREQUENCY			
					I	II	III	IV
ATV	7.83E-08	ATV	7.83E-08	7.83E-08	7.83E-08			
BCI	4.49E-06	BCI	4.49E-06	4.47E-06	2.75E-08		3.42E-06	1.03E-06
EGI	0.00	EGI	0.00	6.69E-08	5.35E-10		6.64E-08	
EIB	5.52E-06	EIB	5.52E-06	3.43E-06		3.43E-06		
ENB	4.58E-07	ENB	4.58E-07	4.58E-07		4.58E-07		
ENI	3.84E-05	ENIYA	3.00E-05	2.29E-05	1.83E-07		3.63E-07	2.23E-05
ENS	2.24E-06	ENIYB	1.10E-06	8.37E-07	6.70E-09		8.30E-07	
FCI	2.46E-05	ENIYN	7.30E-06	5.56E-06	4.45E-08		5.51E-06	
FGI	0.00	ENSYA	5.20E-07	2.89E-07		2.89E-07		
FNI	0.00	ENSYB	1.65E-07	9.16E-08		9.16E-08		
GNI	4.95E-06	ENSYC	1.76E-07	9.82E-08		9.82E-08		
HCI	1.23E-06	ENSYN	1.37E-06	7.65E-07		7.65E-07		
HGI	1.11E-06	FCI	2.46E-05	2.46E-05	1.34E-07		8.29E-07	2.36E-05
HNI	0.00	FGI	0.00	4.51E-07	3.61E-09		3.85E-07	6.27E-08
KNI	0.00	FNI	0.00	6.02E-07	4.81E-09		5.13E-07	8.35E-08
KNS	0.00	GNIYA	3.49E-06	1.79E-06	4.39E-07		1.35E-06	
LCI	0.00	GNIYN	1.47E-06	7.53E-07	1.85E-07	0.00	5.68E-07	
LNI	0.00	HCI	1.23E-06	1.22E-06	9.75E-09		6.05E-08	1.15E-06
OTHERS	0.00	HGI	1.11E-06	1.86E-07	3.78E-08		1.48E-07	
		HNI	0.00	9.81E-08	7.80E-09		9.03E-08	
		KNI	0.00	0.00	0.00		0.00	
		KNSYA	0.00	0.00	0.00	0.00		
		KNSYC	0.00	0.00	0.00	0.00		
		LCI	0.00	0.00	0.00		0.00	0.00
		LNIYA	0.00	0.00				0.00
		LNIYC	0.00	0.00	0.00		0.00	
		OTHERS	0.00	0.00				
		TOTALS	8.31E-05	6.87E-05	1.16E-06	5.14E-06	1.41E-05	4.82E-05

TABLE 4-7b
TRANSLATION OF KRC FREQUENCIES TO APBs
ENHANCEMENT CASE - PROCEDURE CHANGE AND FIFTH DIESEL

KRC ID	BASE KRC FREQ	CASE KRC FREQ	APB FREQUENCIES									
			1	2	3	4	5	6	7	8	9	10
R01	6.13E-08	1.03E-08			1.03E-08							
R01DI	1.21E-06	5.80E-07			5.80E-07							
R01I	3.91E-08	2.00E-08			2.00E-08							
R01IF	9.28E-08	4.76E-08			4.76E-08							
R01SI	0.00	0.00	0.00									
R01SIF	0.00	0.00	0.00									
R01SUI	0.00	0.00	0.00									
R01SUIF	0.00	0.00	0.00									
R01UI	2.15E-09	1.10E-09			1.10E-09							
R01UIF	5.10E-09	2.61E-09			2.61E-09							
R02IF	0.00	0.00			0.00							
R03	2.39E-08	4.01E-09				4.01E-09						
R03I	5.93E-08	4.49E-08		4.49E-08								
R03IF	2.51E-07	2.01E-07		2.01E-07								
R03SI	0.00	0.00	0.00									
R03SIF	0.00	0.00	0.00									
R03SUI	0.00	0.00	0.00									
R03SUIF	0.00	0.00	0.00									
R03UI	5.87E-11	3.01E-11				3.01E-11						
R03UIF	1.39E-10	6.07E-10				6.07E-10						
R04	1.44E-07	1.43E-07		1.43E-07								
R04IF	0.00	0.00				0.00						
R04UIF	2.77E-08	2.75E-08				2.75E-08						
R05SLI	0.00	0.00	0.00									
R05SLIF	0.00	0.00	0.00									
R05SLUI	0.00	0.00	0.00									
R05SLUIF	0.00	0.00			0.00							
R07SLUI	0.00	0.00	0.00									
R07SLUIF	0.00	0.00	0.00									
R09I	7.93E-07	4.07E-07					4.07E-07					
R09UI	3.07E-07	1.58E-07					1.58E-07					
R11I	7.24E-06	5.51E-06					5.51E-06					
R11IF	1.09E-06	8.30E-07					8.30E-07					
R11UI	7.28E-09	3.73E-09					3.73E-09					
R17L	2.42E-06	2.56E-06					2.56E-06					
R17LU	2.63E-06	1.35E-06					1.35E-06					
R17U	3.26E-06	3.31E-06						3.31E-06				
R18	0.00	0.00							0.00			
R19	7.83E-08	7.83E-08							7.83E-08			
R20	8.21E-06	5.14E-06							5.14E-06			
R21	4.62E-05	3.94E-05								3.94E-05		
R22	8.91E-06	8.89E-06										8.89E-06
OTHERS	0.00	0.00										
TOTALS	8.31E-05	6.87E-05	0.00	3.89E-07	6.62E-07	3.22E-08	1.08E-05	3.31E-06	5.21E-06	3.94E-05	0.00	8.89E-06

TABLE 4-7c

CALCULATION OF AVERTED OFFSITE DOSE ENHANCEMENT CASE - PROCEDURE CHANGE AND FIFTH DIESEL

APB ID	BASE CASE APB FREQUENCY (EVENTS/YR)	REVISED APB FREQUENCY (EVENTS/YR)	BASE CASE POPULATION DOSE RATE (Man-REM/YR)	REVISED POPULATION DOSE RATE (Man-REM/YR)	BASE CASE POPULATION DOSE (Man-REM)	REVISED POPULATION DOSE (Man-REM)	AVERTED POPULATION DOSE (Man-REM)
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	4.54E-07	3.89E-07	8.27E-02	7.09E-02	3.31E+00	2.84E+00	4.74E-01
3	1.41E-06	6.62E-07	4.51E-01	2.11E-01	1.80E+01	8.44E+00	9.59E+00
4	5.18E-08	3.22E-08	1.75E-02	1.09E-02	7.02E-01	4.36E-01	2.65E-01
5	1.45E-05	1.08E-05	9.95E-01	7.43E-01	3.98E+01	2.97E+01	1.01E+01
6	3.26E-06	3.31E-06	6.98E-02	7.09E-02	2.79E+00	2.83E+00	-4.13E-02
7	8.29E-06	5.21E-06	3.38E+00	2.13E+00	1.35E+02	8.51E+01	5.02E+01
8	4.62E-05	3.94E-05	9.24E-03	7.86E-03	3.69E-01	3.14E-01	5.49E-02
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	8.91E-06	8.89E-06	1.04E-03	1.04E-03	4.15E-02	4.14E-02	5.82E-05
TOTAL	8.31E-05	6.87E-05	5.01E+00	3.24E+00	2.00E+02	1.30E+02	70.62

4.3.1 Procedure Change to Utilize Existing Spare 6900V/480V Transformers

WBN Unit 1 has two additional spare 6900V/480V transformers which can be aligned to provide power to the 480V shutdown boards and MOV boards in the event one of the normal transformers fail. In the review of dominant split fractions from the IPE, it was identified that a procedure could be developed to assist plant operators in making the necessary bus/transformer alignments.

4.3.1.1 Existing Capabilities

The existing plant design provides additional spare 6.9kV/480V transformers which can be utilized to backup the normally aligned transformers. However, little procedural guidance exists for the alignment and use of these transformers during an accident.

4.3.1.2 Description of Enhancement

This enhancement would provide additional procedures to direct the use of the spare transformers as needed to backup failed transformers. The purpose of these procedures would be to facilitate the use of the spare transformers in the event of failure of an operating transformer during plant shutdown.

4.3.1.3 Cost Estimate

Since the proposed enhancement is within the existing design capability of the plant, the primary cost associated with the change would be the cost of developing associated procedures and training plant operators. Table 4-2 provides a summary of the costs associated with a procedure change of this type.

4.3.1.4 Risk Reduction Estimate

The WBN Level 1 and 2 spreadsheet models were used to evaluate the potential risk reduction benefit of the proposed procedure change. The assumptions utilized were intended to maximize the potential benefit of the change. The system models do not credit the spare 6900/480V transformers that are provided for each pair of boards. This transformer can be used as a maintenance spare to replace a failed 6900/480V normal transformer thus reducing the maintenance unavailability quantified for these boards. The proposed enhancement would involve verifying that the procedures for failure of the 6900/480V transformer includes the steps, precautions, etc. to align the spare transformer. The enhancement was modeled by reducing the frequency of failure for the split fractions that model the 480V shutdown boards by the unavailability due to transformer maintenance.

Tables 4-8 a,b,c provide a summary of the results of the requantification of the PRA and population dose estimates. Based on this analysis, the total reduction in population dose is estimated to be 5.2 person rem over the 40 year life of the plant.

4.3.1.5 Value Impact Assessment

The value impact of this enhancement is based on a quantitative comparison of the cost of the enhancement and the potential risk reduction benefit. The total estimated cost for providing a procedure for use of the spare 6.9kV/480V transformers is $25,200. The risk reduction benefit associated with this change has been conservatively estimated to be 5.2 person-rem over the life of the plant. Therefore, the cost benefit ratio is

C/B Ratio = $25,200/5.2 person-rem = $4,846/person-rem

This ratio is more than $1000 per person rem. Therefore, based on this analysis, the enhancement to provide a procedure for use of the spare 6.9kV/480V transformers is not considered cost beneficial.

4.3.2 Install Improved RCP Seals

One of the dominant contributors to the WBN core damage frequency (~21%) is station blackout. Many of the station blackout sequences involve overheating and failure of the RCP O-rings seals and depletion of primary system inventory prior to restoration of AC power for makeup. Westinghouse has recently begun to provide an improved RCP O-ring material which is made of elastomers which can withstand higher temperatures and have a higher likelihood of remaining intact under conditions such as station blackout. The expert elicitation performed as part of NUREG-1150 identified that seal with the improved O-rings would be roughly four times less likely to cause significant reactor coolant loss.

4.3.2.1 Existing Capabilities

The existing RCP seals are standard Westinghouse seals.

4.3.2.2 Description of Enhancement

The enhancement involves the installation (replacement) of the existing seals with improved seals which utilize high temperature elastomers.

4.3.2.3 Cost Estimate

The primary cost associated with the replacement of the existing seals with the high temperature seals is the cost of the seals and labor to perform the replacement.

TABLE 4-8a
SUMMARY OF PDS AND KRC RESULTS
ENHANCEMENT CASE - PROCEDURE CHANGE TO UTILIZE EXISTING SPARE 6900V/480V TRANSFORMERS

BASE CASE RESULTS				ENHANCEMENT CASE RESULTS				
LEVEL 1 OUTPUT KPDS	BASE CASE KPDS FREQUENCY	LEVEL 2 INPUT KPDS	BASE CASE KPDS FREQUENCY	KPDS FREQUENCY	KRC GROUP FREQUENCY			
					I	II	III	IV
ATV	7.83E-08	ATV	7.83E-08	7.83E-08	7.83E-08			
BCI	4.49E-06	BCI	4.49E-06	4.49E-06	2.76E-08		3.43E-06	1.03E-06
EGI	0.00	EGI	0.00	0.00	0.00		0.00	
EIB	5.52E-06	EIB	5.52E-06	5.51E-06		5.51E-06		
ENB	4.58E-07	ENB	4.58E-07	4.40E-07		4.40E-07		
ENI	3.84E-05	ENIYA	3.00E-05	2.73E-05	2.18E-07		4.33E-07	2.66E-05
ENS	2.24E-06	ENIYB	1.10E-06	1.00E-06	8.00E-09		9.92E-07	
FCI	2.46E-05	ENIYN	7.30E-06	6.64E-06	5.31E-08		6.59E-06	
FGI	0.00	ENSYA	5.20E-07	4.88E-07		4.88E-07		
FNI	0.00	ENSYB	1.65E-07	1.54E-07		1.54E-07		
GNI	4.95E-06	ENSYC	1.76E-07	1.65E-07		1.65E-07		
HCI	1.23E-06	ENSYN	1.37E-06	1.29E-06		1.29E-06		
HGI	1.11E-06	FCI	2.46E-05	2.43E-05	1.32E-07		8.21E-07	2.34E-05
HNI	0.00	FGI	0.00	0.00	0.00		0.00	0.00
KNI	0.00	FNI	0.00	0.00	0.00		0.00	0.00
KNS	0.00	GNIYA	3.49E-06	3.49E-06	8.55E-07		2.63E-06	
LCI	0.00	GNIYN	1.47E-06	1.47E-06	3.60E-07	0.00	1.11E-06	
LNI	0.00	HCI	1.23E-06	1.23E-06	9.80E-09		6.08E-08	1.16E-06
OTHERS	0.00	HGI	1.11E-06	1.10E-06	2.23E-07		8.73E-07	
		HNI	0.00	0.00	0.00		0.00	
		KNI	0.00	0.00	0.00		0.00	
		KNSYA	0.00	0.00	0.00	0.00		
		KNSYC	0.00	0.00	0.00	0.00		
		LCI	0.00	0.00	0.00		0.00	0.00
		LNIYA	0.00	0.00				0.00
		LNIYC	0.00	0.00	0.00		0.00	
		OTHERS	0.00	0.00				
		TOTALS	8.31E-05	7.92E-05	1.97E-06	8.05E-06	1.69E-05	5.22E-05

TABLE 4-8b
TRANSLATION OF KRC FREQUENCIES TO APBs
ENHANCEMENT CASE - PROCEDURE CHANGE TO UTILIZE EXISTING SPARE 6900V/480V TRANSFORMERS

KRC ID	BASE KRC FREQ	CASE KRC FREQ	APB FREQUENCIES									
			1	2	3	4	5	6	7	8	9	10
R01	6.13E-08	6.08E-08			6.08E-08							
R01DI	1.21E-06	1.21E-06			1.21E-06							
R01I	3.91E-08	3.91E-08			3.91E-08							
R01IF	9.28E-08	9.28E-08			9.28E-08							
R01SI	0.00	0.00	0.00									
R01SIF	0.00	0.00	0.00									
R01SUI	0.00	0.00	0.00									
R01SUIF	0.00	0.00	0.00									
R01UI	2.15E-09	2.15E-09			2.15E-09							
R01UIF	5.10E-09	5.10E-09			5.10E-09							
R02IF	0.00	0.00			0.00							
R03	2.39E-08	2.37E-08				2.37E-08						
R03I	5.93E-08	5.40E-08		5.40E-08								
R03IF	2.51E-07	2.29E-07		2.29E-07								
R03SI	0.00	0.00	0.00									
R03SIF	0.00	0.00	0.00									
R03SUI	0.00	0.00	0.00									
R03SUIF	0.00	0.00	0.00									
R03UI	5.87E-11	5.87E-11				5.87E-11						
R03UIF	1.39E-10	1.39E-10				1.39E-10						
R04	1.44E-07	1.42E-07		1.42E-07								
R04IF	0.00	0.00				0.00						
R04UIF	2.77E-08	2.76E-08				2.76E-08						
R05SLI	0.00	0.00	0.00									
R05SLIF	0.00	0.00	0.00									
R05SLUI	0.00	0.00	0.00									
R05SLUIF	0.00	0.00			0.00							
R07SLUI	0.00	0.00	0.00									
R07SLUIF	0.00	0.00	0.00									
R09I	7.93E-07	7.93E-07					7.93E-07					
R09UI	3.07E-07	3.07E-07					3.07E-07					
R11I	7.24E-06	6.59E-06					6.59E-06					
R11IF	1.09E-06	9.92E-07					9.92E-07					
R11UI	7.28E-09	7.28E-09					7.28E-09					
R17L	2.42E-06	2.36E-06					2.36E-06					
R17LU	2.63E-06	2.63E-06					2.63E-06					
R17U	3.26E-06	3.26E-06						3.26E-06				
R18	0.00	0.00							0.00			
R19	7.83E-08	7.83E-08							7.83E-08			
R20	8.21E-06	8.05E-06							8.05E-06			
R21	4.62E-05	4.34E-05								4.34E-05		
R22	8.91E-06	8.82E-06										8.82E-06
OTHERS	0.00	0.00										
TOTALS	8.31E-05	7.92E-05	0.00	4.25E-07	1.41E-06	5.15E-08	1.37E-05	3.26E-06	8.13E-06	4.34E-05	0.00	8.82E-06

TABLE 4-8c

CALCULATION OF AVERTED OFFSITE DOSE
ENHANCEMENT CASE - PROCEDURE CHANGE TO UTILIZE EXISTING SPARE 6900V/480V TRANSFORMERS

APB ID	BASE CASE APB FREQUENCY (EVENTS/YR)	REVISED APB FREQUENCY (EVENTS/YR)	BASE CASE POPULATION DOSE RATE (Man-REM/YR)	REVISED POPULATION DOSE RATE (Man-REM/YR)	BASE CASE POPULATION DOSE (Man-REM)	REVISED POPULATION DOSE (Man-REM)	AVERTED POPULATION DOSE (Man-REM)
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	4.54E-07	4.25E-07	8.27E-02	7.74E-02	3.31E+00	3.09E+00	2.14E-01
3	1.41E-06	1.41E-06	4.51E-01	4.50E-01	1.80E+01	1.80E+01	2.35E-02
4	5.18E-08	5.15E-08	1.75E-02	1.75E-02	7.02E-01	6.98E-01	3.48E-03
5	1.45E-05	1.37E-05	9.95E-01	9.39E-01	3.98E+01	3.76E+01	2.25E+00
6	3.26E-06	3.26E-06	6.98E-02	6.97E-02	2.79E+00	2.79E+00	3.78E-03
7	8.29E-06	8.13E-06	3.38E+00	3.32E+00	1.35E+02	1.33E+02	2.64E+00
8	4.62E-05	4.34E-05	9.24E-03	8.67E-03	3.69E-01	3.47E-01	2.26E-02
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	8.91E-06	8.82E-06	1.04E-03	1.03E-03	4.15E-02	4.11E-02	4.00E-04
TOTAL	8.31E-05	7.92E-05	5.01E+00	4.88E+00	2.00E+02	1.95E+02	5.15E+00

Table 4-9 provides a summary of the estimate developed for WBN Unit 1. The total estimated cost of this enhancement is $162,800.

4.3.2.4 Risk Reduction Estimate

The WBN Level 1 and 2 spreadsheet models were used to evaluate the potential risk reduction benefit of the proposed procedure change. The assumptions utilized were intended to maximize the potential benefit of the change. The NUREG-1150 expert elicitation showed that the new seal materials were roughly one-fourth as likely to lead to a large seal LOCA as the existing seal. The likelihood of recovery of offsite power was reduced by a factor of 10 to reflect the additional time available to recover offsite power.

Tables 4-10 a,b,c provide a summary of the results of the requantification of the PRA and population dose estimates. Based on this analysis, the total reduction in population dose is estimated to be 41.5 person rem over the 40 year life of the plant.

4.3.2.5 Value Impact Assessment

1The value impact of this enhancement is based on a quantitative comparison of the cost of the enhancement and the potential risk reduction benefit. The total estimated cost for installation of new RCP seals is $ 162,800. The risk reduction benefit associated with this change has been conservatively estimated to be 41.5 person-rem over the life of the plant. Therefore, the cost benefit ratio is

C/B Ratio = $162,800/41.5 person-rem = $3,923/person-rem

This ratio is more than $1000 per person rem. Therefore, based on this analysis, the enhancement to install new RCP seals is not considered cost beneficial.

4.3.3 Install Independent RCP Seal Cooling System

Another alternative to ensuring that the RCP seals remain intact and that the RCS inventory is sufficient to support secondary heat removal is to provide an alternative, AC independent RCP seal cooling system. At least two other Westinghouse plants have such a system. This enhancement involves the provision of a non-safety grade, independently powered (separate small EDG), independently cooled (non-CCS/ERCW) seal injection pump which could be manually actuated by the plant operators.

4.3.3.1 Existing Capabilities

The existing WBN design provides RCP seal cooling via charging seal injection and thermal barrier cooling. If the RCPs are tripped, either of these is adequate to ensure

Table 4-9
New RCP Seals

Scope:		
Installation of Model 93A CSC RCP Reactor Coolant Pump high temperature O-ring seals under next seal rebuild maintenance activity.		
Engineering:		
Minor Generic Replacement DCN		
50 manhours * $56 per manhour	$2.8K	
Engineering Cost		$2.8K
Materials:		
4 Replacement Seal Cartridges @ $40K	$160K	
Material Cost		$160K
Construction:		
NONE - would be done as a part of routine seal re-build operations during refueling outages so no additional costs would be incurred.		
Equipment Maintenance:		
NONE - would be done as a part of routine seal re-build operations during refueling outages so no additional costs would be incurred.		
	Total	$162.8K

TABLE 4-10a
SUMMARY OF PDS AND KRC RESULTS
ENHANCEMENT CASE - INSTALL IMPROVED RCP SEALS

BASE CASE RESULTS				ENHANCEMENT CASE RESULTS				
LEVEL 1 OUTPUT KPDS	BASE CASE KPDS FREQUENCY	LEVEL 2 INPUT KPDS	BASE CASE KPDS FREQUENCY	KPDS FREQUENCY	KRC GROUP FREQUENCY			
					I	II	III	IV
ATV	7.83E-08	ATV	7.83E-08	7.83E-08	7.83E-08			
BCI	4.49E-06	BCI	4.49E-06	4.47E-06	2.75E-08		3.42E-06	1.03E-06
EGI	0.00	EGI	0.00	6.69E-08	5.35E-10		6.64E-08	
EIB	5.52E-06	EIB	5.52E-06	3.43E-06		3.43E-06		
ENB	4.58E-07	ENB	4.58E-07	4.51E-07		4.51E-07		
ENI	3.84E-05	ENIYA	3.00E-05	2.01E-05	1.61E-07		3.19E-07	1.96E-05
ENS	2.24E-06	ENIYB	1.10E-06	7.36E-07	5.89E-09		7.31E-07	
FCI	2.46E-05	ENIYN	7.30E-06	4.89E-06	3.91E-08		4.85E-06	
FGI	0.00	ENSYA	5.20E-07	4.88E-07		4.88E-07		
FNI	0.00	ENSYB	1.65E-07	1.54E-07		1.54E-07		
GNI	4.95E-06	ENSYC	1.76E-07	1.66E-07		1.66E-07		
HCI	1.23E-06	ENSYN	1.37E-06	1.29E-06		1.29E-06		
HGI	1.11E-06	FCI	2.46E-05	2.36E-05	1.28E-07		7.97E-07	2.27E-05
HNI	0.00	FGI	0.00	3.50E-07	2.80E-09		2.98E-07	4.86E-08
KNI	0.00	FNI	0.00	1.10E-07	8.79E-10		9.37E-08	1.53E-08
KNS	0.00	GNIYA	3.49E-06	2.37E-06	5.82E-07		1.79E-06	
LCI	0.00	GNIYN	1.47E-06	9.99E-07	2.45E-07	0.00	7.54E-07	
LNI	0.00	HCI	1.23E-06	1.22E-06	9.79E-09		6.07E-08	1.15E-06
OTHERS	0.00	HGI	1.11E-06	1.05E-06	2.13E-07		8.33E-07	
		HNI	0.00	1.01E-07	7.99E-09		9.26E-08	
		KNI	0.00	0.00	0.00		0.00	
		KNSYA	0.00	0.00	0.00	0.00		
		KNSYC	0.00	0.00	0.00	0.00		
		LCI	0.00	0.00	0.00		0.00	0.00
		LNIYA	0.00	0.00				0.00
		LNIYC	0.00	0.00	0.00		0.00	
		OTHERS	0.00	0.00				
		TOTALS	8.31E-05	6.61E-05	1.50E-06	5.98E-06	1.41E-05	4.46E-05

TABLE 4-10b
TRANSLATION OF KRC FREQUENCIES TO APBs
ENHANCEMENT CASE - INSTALL IMPROVED RCP SEALS

KRC ID	BASE KRC FREQ	CASE KRC FREQ	APB FREQUENCIES									
			1	2	3	4	5	6	7	8	9	10
R01	6.13E-08	5.80E-08			5.80E-08							
R01DI	1.21E-06	8.69E-07			8.69E-07							
R01I	3.91E-08	2.66E-08			2.66E-08							
R01IF	9.28E-08	6.31E-08			6.31E-08							
R01SI	0.00	0.00	0.00									
R01SIF	0.00	0.00	0.00									
R01SUI	0.00	0.00	0.00									
R01SUIF	0.00	0.00	0.00									
R01UI	2.15E-09	1.46E-09			1.46E-09							
R01UIF	5.10E-09	3.47E-09			3.47E-09							
R02IF	0.00	0.00			0.00							
R03	2.39E-08	2.26E-08				2.26E-08						
R03I	5.93E-08	3.97E-08		3.97E-08								
R03IF	2.51E-07	1.74E-07		1.74E-07								
R03SI	0.00	0.00	0.00									
R03SIF	0.00	0.00	0.00									
R03SUI	0.00	0.00	0.00									
R03SUIF	0.00	0.00	0.00									
R03UI	5.87E-11	4.00E-11				4.00E-11						
R03UIF	1.39E-10	6.30E-10				6.30E-10						
R04	1.44E-07	1.38E-07		1.38E-07								
R04IF	0.00	0.00				0.00						
R04UIF	2.77E-08	2.75E-08				2.75E-08						
R05SLI	0.00	0.00	0.00									
R05SLIF	0.00	0.00	0.00									
R05SLUI	0.00	0.00	0.00									
R05SLUIF	0.00	0.00			0.00							
R07SLUI	0.00	0.00	0.00									
R07SLUIF	0.00	0.00	0.00									
R09I	7.93E-07	5.40E-07					5.40E-07					
R09UI	3.07E-07	2.09E-07					2.09E-07					
R11I	7.24E-06	4.85E-06					4.85E-06					
R11IF	1.09E-06	7.31E-07					7.31E-07					
R11UI	7.28E-09	4.95E-09					4.95E-09					
R17L	2.42E-06	2.66E-06					2.66E-06					
R17LU	2.63E-06	1.79E-06					1.79E-06					
R17U	3.26E-06	3.31E-06						3.31E-06				
R18	0.00	0.00							0.00			
R19	7.83E-08	7.83E-08							7.83E-08			
R20	8.21E-06	5.98E-06							5.98E-06			
R21	4.62E-05	3.60E-05								3.60E-05		
R22	8.91E-06	8.59E-06										8.59E-06
OTHERS	0.00	0.00										
TOTALS	8.31E-05	6.61E-05	0.00	3.52E-07	1.02E-06	5.08E-08	1.08E-05	3.31E-06	6.06E-06	3.60E-05	0.00	8.59E-06

TABLE 4-10c

CALCULATION OF AVERTED OFFSITE DOSE ENHANCEMENT CASE - INSTALL IMPROVED RCP SEALS

APB ID	BASE CASE APB FREQUENCY (EVENTS/YR)	REVISED APB FREQUENCY (EVENTS/YR)	BASE CASE POPULATION DOSE RATE (Man-REM/YR)	REVISED POPULATION DOSE RATE (Man-REM/YR)	BASE CASE POPULATION DOSE (Man-REM)	REVISED POPULATION DOSE (Man-REM)	AVERTED POPULATION DOSE (Man-REM)
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	4.54E-07	3.52E-07	8.27E-02	6.40E-02	3.31E+00	2.56E+00	7.47E-01
3	1.41E-06	1.02E-06	4.51E-01	3.26E-01	1.80E+01	1.30E+01	5.00E+00
4	5.18E-08	5.08E-08	1.75E-02	1.72E-02	7.02E-01	6.89E-01	1.31E-02
5	1.45E-05	1.08E-05	9.95E-01	7.41E-01	3.98E+01	2.96E+01	1.02E+01
6	3.26E-06	3.31E-06	6.98E-02	7.09E-02	2.79E+00	2.83E+00	-4.13E-02
7	8.29E-06	6.06E-06	3.38E+00	2.47E+00	1.35E+02	9.90E+01	3.64E+01
8	4.62E-05	3.60E-05	9.24E-03	7.19E-03	3.69E-01	2.88E-01	8.19E-02
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	8.91E-06	8.59E-06	1.04E-03	1.00E-03	4.15E-02	4.00E-02	1.48E-03
TOTAL	8.31E-05	6.61E-05	5.01E+00	3.70E+00	2.00E+02	1.48E+02	5.23E+01

RCP integrity. However, the systems which provide cooling, charging for seal injection and component cooling system (CCS) for thermal barrier cooling, share common dependencies such as AC power and essential raw cooling water (ERCW).

4.3.3.2 Description of Enhancement

The purpose of this enhancement is to provide independent seal injection system with the capability to reduce the probability of a RCP seal LOCA. The present design of Westinghouse RCP seals requires seal cooling to ensure RCP seal integrity. In the present design, RCP seal injection is provided by the Centrifugal Charging Pumps (CCPs). This enhancement will reduce the vulnerability of a RCP seal LOCA for scenarios where the CCPs are failed.

This system will be required to provide high pressure flow of cooling water to the seals of each RCP. The flow requirement for the seals of each RCP is a minimum of 8 GPM (Reference 1). The system should be designed to provide between 8 to 13 GPM per RCP or 32 to 52 GPM for each reactor. System pressure at the inlet to the seal injection orifice must be 2500 psi. The source of cooling water should not exceed 130°F and should be sized to provide the desired flow for at least 24 hours.

Design Assumptions:

1) It is assumed that the normal offsite and emergency EDG power supplies have been lost.

2) It is assumed that the containment is intact.

3) It is assumed that the use of AC motor-operated valves is acceptable if a dedicated AC power source is available. This AC power source can be the same source that provides AC power to the dedicated seal injection pump.

4) Credit is allowed for limited manual actions outside of the control room; however, no credit is allowed for manual actions inside containment or in areas that would have high radiation in the Auxiliary building after a core damage event.

5) The dedicated seal injection pump, associated piping, and water source is not safety related, but will require an appropriate isolation and interface at the selected junction to the existing safety grade piping.

6) To minimize the cost, an existing water storage tank can be utilized as the water source.

7) The dedicated EDG is not safety related an d should be appropriately isolated from the safety-related components, e.g., MOVs, that are required to be powered to support the independent seal injection system.

8) The dedicated EDG shall have its own dedicated fuel oil storage tank.

9) The dedicated EDG shall have its own dedicated DC battery source for cranking, control and field flashing capabilities.

10) A dedicated and independent structure designed to commercial building code requirements shall be constructed. This building shall provide for adequate ventilation to support long term operation of the EDG during any expected weather condition. Provisions shall also include a commercial non-safety HVAC system to maintain an acceptable day-to-day environmental condition.

11) This building shall also be equipped with appropriate fire detection and suppression capabilities.

12) The routing of the new power leads to required electrical devices and additional piping shall not compromise the functional integrity of any structure, system or component.

13) Seismic and harsh environmental qualification is only required where failure may impact existing safety systems.

4.3.3.3 Cost Estimate

The following cost estimate includes the engineering, construction, and materials required to implement this enhancement based on the scope description provided above. Licensing and Maintenance costs have not been included.

Note that these estimates have been prepared for scoping purposes only to support the cost-benefit assessment required for this candidate enhancement. Due to the general magnitude of the cost associated with a plant modification of this type relative to the maximum theoretical benefit at Watts Bar, an exhaustive detailed cost estimate has not been performed. The values reflected below are conservative and the actual cost to implement a modification of this type is expected to be higher than estimated below.

DESCRIPTION	COST $ (THOUSANDS)
Engineering Total for Independent Diesel Generator	$112.3
Construction Total for Independent Diesel Generator	$239.6
Materials for Independent Diesel Generator	$651.3
Materials for Diesel Generator Building	$114.6
Engineering, Construction and Materials for Alternate Seal Injection Pump and Hardware	$2,415.1
TOTAL	$3,532.9

Note that a more detailed cost assessment has been performed by TVA for the Sequoyah Nuclear Plant. The scope of the cost assessment for Sequoyah was limited to replacement of the PD pumps with centrifugal type pumps. The modification scoped for Sequoyah is practically identical to this enhancement with the exception that an independent power supply was not included. The total cost estimated for Sequoyah was approximately $3.7 million. While the Sequoyah estimate has some cost that are not applicable at Watts Bar such as disposal of a contaminated PD pump and other radiological concerns, the Sequoyah estimate provides a reasonable reference to demonstrate the conservatism in the Watts Bar estimate. Note the Watts Bar estimate includes an independent power source which was not included in the Sequoyah estimate. The cost of procedure changes associated with this major of a design change is assumed to be included in the overall cost and is not accounted for separately. For the purposes of this analysis a cost estimate of $3.5M will be used.

4.3.3.4 Risk Reduction Estimate

The WBN Level 1 and 2 spreadsheet models were used to evaluate the potential risk reduction benefit of the proposed change. The assumptions utilized were intended to maximize the potential benefit of the change. The risk reduction for this enhancement was calculated by adding a recovery to sequences which would benefit from the new seal injection system. For loss of offsite power and station blackout sequences, the probability of non-recovery of offsite power was changed to reflect the additional time available to recover offsite power given a seal LOCA was avoided.

Tables 4-11 a,b,c provide a summary of the results of the requantification of the PRA and population dose estimates. Based on this analysis, the total reduction in population dose is estimated to be 52.3 person rem over the 40 year life of the plant.

4.3.3.5 Value Impact Assessment

The value impact of this enhancement is based on a quantitative comparison of the cost of the enhancement and the potential risk reduction benefit. The total estimated cost for providing an independent RCP seal injection system is $3.5M. The risk reduction benefit associated with this change has been conservatively estimated to be 52.3 person-rem over the life of the plant. Therefore, the cost benefit ratio is

C/B Ratio = $3,500,000/52.3 person-rem = $66,922/person-rem

This ratio is more than $1000 per person rem. Therefore, based on this analysis, the enhancement to provide an independent RCP seal injection system is not considered cost beneficial.

4.3.4 Provide Accumulators For Turbine Driven AFW Pump

Another contributor to loss of offsite power event sequences is loss of the turbine driven AFW pump due to loss of control air to the flow control valves to the steam generators. These valves are normally provided control air by the essential control air system which is EDG-backed, but introduces additional dependencies for the AFW system. In the current design, if control air is lost, the plant operators must perform a local manual action to align nitrogen bottles to the AFW flow control valves and steam generator PORVs. This enhancement considers providing control air accumulators for the turbine driven AFW flow control valves, the motor driven AFW pressure control valves and the steam generator PORVs.

4.3.4.1 Existing Capabilities

The existing turbine driven AFW flow control valves and steam generator PORVs require control air in order to operate. Under station blackout conditions control air is not available, but a local operator action can be performed to valve in bottled nitrogen to the flow control valves. However, this action requires local actions in a limited period of time under station blackout conditions. Provision of accumulators for the valve operators would significantly increase the amount of time for this action and improve the reliability of the systems.

4.3.4.2 Description of Enhancement

This enhancement would provide safety grade accumulators on the turbine driven AFW flow control valves and steam generator PORVs to allow immediate operation of the valves for approximately 1 hour following loss of control air. This will allow additional time for local operator actions to be completed.

TABLE 4-11a
SUMMARY OF PDS AND KRC RESULTS
ENHANCEMENT CASE - INSTALL INDEPENDENT RCP SEAL COOLING SYSTEM

BASE CASE RESULTS				ENHANCEMENT CASE RESULTS				
LEVEL 1 OUTPUT KPDS	BASE CASE KPDS FREQUENCY	LEVEL 2 INPUT KPDS	BASE CASE KPDS FREQUENCY	KPDS FREQUENCY	KRC GROUP FREQUENCY			
					I	II	III	IV
ATV	7.83E-08	ATV	7.83E-08	7.83E-08	7.83E-08			
BCI	4.49E-06	BCI	4.49E-06	4.47E-06	2.75E-08		3.42E-06	1.03E-06
EGI	0.00	EGI	0.00	6.69E-08	5.35E-10		6.64E-08	
EIB	5.52E-06	EIB	5.52E-06	3.43E-06		3.43E-06		
ENB	4.58E-07	ENB	4.58E-07	4.50E-07		4.50E-07		
ENI	3.84E-05	ENIYA	3.00E-05	2.00E-05	1.60E-07		3.17E-07	1.95E-05
ENS	2.24E-06	ENIYB	1.10E-06	7.32E-07	5.86E-09		7.26E-07	
FCI	2.46E-05	ENIYN	7.30E-06	4.86E-06	3.89E-08		4.82E-06	
FGI	0.00	ENSYA	5.20E-07	4.86E-07		4.86E-07		
FNI	0.00	ENSYB	1.65E-07	1.54E-07		1.54E-07		
GNI	4.95E-06	ENSYC	1.76E-07	1.65E-07		1.65E-07		
HCI	1.23E-06	ENSYN	1.37E-06	1.28E-06		1.28E-06		
HGI	1.11E-06	FCI	2.46E-05	2.36E-05	1.28E-07		7.96E-07	2.27E-05
HNI	0.00	FGI	0.00	3.48E-07	2.78E-09		2.96E-07	4.83E-08
KNI	0.00	FNI	0.00	1.36E-07	1.09E-09		1.16E-07	1.90E-08
KNS	0.00	GNIYA	3.49E-06	2.41E-06	5.91E-07		1.82E-06	
LCI	0.00	GNIYN	1.47E-06	1.01E-06	2.49E-07	0.00	7.65E-07	
LNI	0.00	HCI	1.23E-06	1.22E-06	9.79E-09		6.07E-08	1.15E-06
OTHERS	0.00	HGI	1.11E-06	1.04E-06	2.11E-07		8.26E-07	
		HNI	0.00	9.99E-08	7.93E-09		9.19E-08	
		KNI	0.00	0.00	0.00		0.00	
		KNSYA	0.00	0.00	0.00	0.00		
		KNSYC	0.00	0.00	0.00	0.00		
		LCI	0.00	0.00	0.00		0.00	0.00
		LNIYA	0.00	0.00				0.00
		LNIYC	0.00	0.00	0.00		0.00	
		OTHERS	0.00	0.00				
		TOTALS	8.31E-05	6.60E-05	1.51E-06	5.97E-06	1.41E-05	4.44E-05

TABLE 4-11b
TRANSLATION OF KRC FREQUENCIES TO APBs
ENHANCEMENT CASE - INSTALL INDEPENDENT RCP SEAL COOLING SYSTEM

KRC ID	BASE KRC FREQ	CASE KRC FREQ	APB FREQUENCIES									
			1	2	3	4	5	6	7	8	9	10
R01	6.13E-08	5.75E-08			5.75E-08							
R01DI	1.21E-06	8.79E-07			8.79E-07							
R01I	3.91E-08	2.70E-08			2.70E-08							
R01IF	9.28E-08	6.41E-08			6.41E-08							
R01SI	0.00	0.00	0.00									
R01SIF	0.00	0.00	0.00									
R01SUI	0.00	0.00	0.00									
R01SUIF	0.00	0.00	0.00									
R01UI	2.15E-09	1.48E-09			1.48E-09							
R01UIF	5.10E-09	3.52E-09			3.52E-09							
R02IF	0.00	0.00			0.00							
R03	2.39E-08	2.24E-08				2.24E-08						
R03I	5.93E-08	3.95E-08		3.95E-08								
R03IF	2.51E-07	1.73E-07		1.73E-07								
R03SI	0.00	0.00	0.00									
R03SIF	0.00	0.00	0.00									
R03SUI	0.00	0.00	0.00									
R03SUIF	0.00	0.00	0.00									
R03UI	5.87E-11	4.06E-11				4.06E-11						
R03UIF	1.39E-10	6.32E-10				6.32E-10						
R04	1.44E-07	1.38E-07		1.38E-07								
R04IF	0.00	0.00				0.00						
R04UIF	2.77E-08	2.75E-08				2.75E-08						
R05SLI	0.00	0.00	0.00									
R05SLIF	0.00	0.00	0.00									
R05SLUI	0.00	0.00	0.00									
R05SLUIF	0.00	0.00			0.00							
R07SLUI	0.00	0.00	0.00									
R07SLUIF	0.00	0.00	0.00									
R09I	7.93E-07	5.48E-07					5.48E-07					
R09UI	3.07E-07	2.12E-07					2.12E-07					
R11I	7.24E-06	4.82E-06					4.82E-06					
R11IF	1.09E-06	7.26E-07					7.26E-07					
R11UI	7.28E-09	5.03E-09					5.03E-09					
R17L	2.42E-06	2.68E-06					2.68E-06					
R17LU	2.63E-06	1.82E-06					1.82E-06					
R17U	3.26E-06	3.31E-06						3.31E-06				
R18	0.00	0.00							0.00			
R19	7.83E-08	7.83E-08							7.83E-08			
R20	8.21E-06	5.97E-06							5.97E-06			
R21	4.62E-05	3.58E-05								3.58E-05		
R22	8.91E-06	8.58E-06										8.58E-06
OTHERS	0.00	0.00										
TOTALS	8.31E-05	6.60E-05	0.00	3.50E-07	1.03E-06	5.06E-08	1.08E-05	3.31E-06	6.05E-06	3.58E-05	0.00	8.58E-06

TABLE 4-11c

CALCULATION OF AVERTED OFFSITE DOSE
ENHANCEMENT CASE - INSTALL INDEPENDENT RCP SEAL COOLING SYSTEM

APB ID	BASE CASE APB FREQUENCY (EVENTS/YR)	REVISED APB FREQUENCY (EVENTS/YR)	BASE CASE POPULATION DOSE RATE (Man-REM/YR)	REVISED POPULATION DOSE RATE (Man-REM/YR)	BASE CASE POPULATION DOSE (Man-REM)	REVISED POPULATION DOSE (Man-REM)	AVERTED POPULATION DOSE (Man-REM)
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	4.54E-07	3.50E-07	8.27E-02	6.38E-02	3.31E+00	2.55E+00	7.55E-01
3	1.41E-06	1.03E-06	4.51E-01	3.29E-01	1.80E+01	1.32E+01	4.86E+00
4	5.18E-08	5.06E-08	1.75E-02	1.72E-02	7.02E-01	6.86E-01	1.54E-02
5	1.45E-05	1.08E-05	9.95E-01	7.42E-01	3.98E+01	2.97E+01	1.01E+01
6	3.26E-06	3.31E-06	6.98E-02	7.09E-02	2.79E+00	2.83E+00	-4.13E-02
7	8.29E-06	6.05E-06	3.38E+00	2.47E+00	1.35E+02	9.88E+01	3.65E+01
8	4.62E-05	3.58E-05	9.24E-03	7.16E-03	3.69E-01	2.86E-01	8.29E-02
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	8.91E-06	8.58E-06	1.04E-03	9.99E-04	4.15E-02	4.00E-02	1.52E-03
TOTAL	8.31E-05	6.60E-05	5.01E+00	3.70E+00	2.00E+02	1.48E+02	52.33

4.3.4.3 Cost Estimate

The cost estimate for the provision of an alternate source of air for the AFW level control valves and steam generator PORVs includes the engineering, materials and construction costs. The total cost of this design change is $299,400 as summarized in Table 4-12. In addition, procedural changes would be required to address the new hardware installation. As described in Table 4-2, an additional $25,200 in costs is associated with such procedure changes. Thus, the total cost of this enhancement is $324,600.

4.3.4.4 Risk Reduction Estimate

The WBN Level 1 and 2 spreadsheet models were used to evaluate the potential risk reduction benefit of the proposed change. The assumptions utilized were intended to maximize the potential benefit of the change. The enhancement was reflected in the PRA model by eliminating the dependence of these valves on the essential control air system and reducing the operator error rate for station blackout conditions.

Tables 4-13 a,b,c provide a summary of the results of the requantification of the PRA and population dose estimates. Based on this analysis, the total reduction in population dose is estimated to be 52.4 person rem over the 40 year life of the plant.

4.3.4.5 Value Impact Assessment

The value impact of this enhancement is based on a quantitative comparison of the cost of the enhancement and the potential risk reduction benefit. The total estimated cost for providing an alternate source of air supply to the AFW level control valves and steam generator PORVs is $324,600. The risk reduction benefit associated with this change has been conservatively estimated to be 52.4 person-rem over the life of the plant. Therefore, the cost benefit ratio is

C/B Ratio = $324,600/52.4person-rem = $6,195/person-rem

This ratio is more than $1000 per person rem. Therefore, based on this analysis, the enhancement to provide an alternate source of air supply to the AFW level control valves and steam generator PORVs is not considered cost beneficial.

4.3.5 Provide DC Load Shed Analysis and Procedure

The WBN DC power system is supported by four 125V vital batteries. In response to the Station Blackout Rule, it was determined that these batteries were sufficient as designed to cope for at least four hours under station blackout conditions. This enhancement

Table 4-12
Alternate Source of Air for AFW Level Control Valve

Scope:		
Design and install safety grade accumulators on the SG PORVs and Turbine Driven AFW PP LCVs to allow immediate operation of the valve for approximately 1 hour until the compensatory actions can be completed to valve in the back-up nitrogen supply. A remotely mounted accumulator would be installed near each of the PORVs/FCV. Each accumulator would have a valve station containing manual isolation valves for air supply to accumulator and to PORV/FCV, check valve, relief valve, air regulator, pressure indicator and pressure switch with alarm capability to the MCR.		
Engineering:		
Average DCN = 410 manhours		
Seismic Analysis = 350 manhours		
DCN = 410 manhours * $56 per manhour	$22.9K	
SA = 350 manhours * $100 per manhour	$35K	
Engineering Cost		$57.9K
Materials:		
Engineered Items:		
Accumulators 8 @ $5K	$40K	
Pressure Switches/Alarms 8 @ $3.5K	$28K	
Relief Valves 8@ $2.5K	$20K	
Bulk Commodities	$18.5K	
Material Cost		$106.5K
Construction:		
Trade and Labor:		
4,425 manhours * $25 per manhour	$110.6K	
Management and Oversight (10% T & L):		
442 manhours * $56 per manhour	$24.8K	
Construction Cost		$135K
	Total	$299.4K

TABLE 4-13a
SUMMARY OF PDS AND KRC RESULTS
ENHANCEMENT CASE - PROVIDE ACCUMULATORS FOR TURBINE DRIVEN AFW PUMP

BASE CASE RESULTS				ENHANCEMENT CASE RESULTS				
LEVEL 1 OUTPUT KPDS	BASE CASE KPDS FREQUENCY	LEVEL 2 INPUT KPDS	BASE CASE KPDS FREQUENCY	KPDS FREQUENCY	KRC GROUP FREQUENCY			
					I	II	III	IV
ATV	7.83E-08	ATV	7.83E-08	7.83E-08	7.83E-08			
BCI	4.49E-06	BCI	4.49E-06	4.47E-06	2.75E-08		3.42E-06	1.03E-06
EGI	0.00	EGI	0.00	6.69E-08	5.35E-10		6.64E-08	
EIB	5.52E-06	EIB	5.52E-06	2.98E-06		2.98E-06		
ENB	4.58E-07	ENB	4.58E-07	4.30E-07		4.30E-07		
ENI	3.84E-05	ENIYA	3.00E-05	2.96E-05	2.37E-07		4.69E-07	2.89E-05
ENS	2.24E-06	ENIYB	1.10E-06	1.08E-06	8.66E-09		1.07E-06	
FCI	2.46E-05	ENIYN	7.30E-06	7.19E-06	5.75E-08		7.13E-06	
FGI	0.00	ENSYA	5.20E-07	5.19E-07		5.19E-07		
FNI	0.00	ENSYB	1.65E-07	1.64E-07		1.64E-07		
GNI	4.95E-06	ENSYC	1.76E-07	1.76E-07		1.76E-07		
HCI	1.23E-06	ENSYN	1.37E-06	1.37E-06		1.37E-06		
HGI	1.11E-06	FCI	2.46E-05	2.43E-05	1.32E-07		8.20E-07	2.34E-05
HNI	0.00	FGI	0.00	4.53E-07	3.62E-09		3.86E-07	6.29E-08
KNI	0.00	FNI	0.00	6.02E-07	4.81E-09		5.13E-07	8.35E-08
KNS	0.00	GNIYA	3.49E-06	2.47E-06	6.07E-07		1.87E-06	
LCI	0.00	GNIYN	1.47E-06	1.04E-06	2.55E-07	0.00	7.86E-07	
LNI	0.00	HCI	1.23E-06	9.02E-07	7.21E-09		4.47E-08	8.50E-07
OTHERS	0.00	HGI	1.11E-06	7.46E-09	1.52E-09		5.94E-09	
		HNI	0.00	7.05E-08	5.60E-09		6.49E-08	
		KNI	0.00	0.00	0.00		0.00	
		KNSYA	0.00	0.00	0.00	0.00		
		KNSYC	0.00	0.00	0.00	0.00		
		LCI	0.00	0.00	0.00		0.00	0.00
		LNIYA	0.00	0.00				0.00
		LNIYC	0.00	0.00	0.00		0.00	
		OTHERS	0.00	0.00				
		TOTALS	8.31E-05	7.80E-05	1.43E-06	5.64E-06	1.66E-05	5.43E-05

TABLE 4-13b
TRANSLATION OF KRC FREQUENCIES TO APBs
ENHANCEMENT CASE - PROVIDE ACCUMULATORS FOR TURBINE DRIVEN AFW PUMPS

KRC ID	BASE KRC FREQ	CASE KRC FREQ	APB FREQUENCIES									
			1	2	3	4	5	6	7	8	9	10
R01	6.13E-08	4.14E-10			4.14E-10							
R01DI	1.21E-06	7.67E-07			7.67E-07							
RO1I	3.91E-08	2.77E-08			2.77E-08							
R01IF	9.28E-08	6.58E-08			6.58E-08							
R01SI	0.00	0.00	0.00									
R01SIF	0.00	0.00	0.00									
R01SUI	0.00	0.00	0.00									
R01SUIF	0.00	0.00	0.00									
R01UI	2.15E-09	1.52E-09			1.52E-09							
R01UIF	5.10E-09	3.61E-09			3.61E-09							
R02IF	0.00	0.00			0.00							
R03	2.39E-08	1.61E-10				1.61E-10						
R03I	5.93E-08	5.82E-08		5.82E-08								
R03IF	2.51E-07	2.56E-07		2.56E-07								
R03SI	0.00	0.00	0.00									
R03SIF	0.00	0.00	0.00									
R03SUI	0.00	0.00	0.00									
R03SUIF	0.00	0.00	0.00									
R03UI	5.87E-11	4.16E-11				4.16E-11						
R03UIF	1.39E-10	6.34E-10				6.34E-10						
R04	1.44E-07	1.40E-07		1.40E-07								
R04IF	0.00	0.00				0.00						
R04UIF	2.77E-08	2.75E-08				2.75E-08						
R05SLI	0.00	0.00	0.00									
R05SLIF	0.00	0.00	0.00									
R05SLUI	0.00	0.00	0.00									
R05SLUIF	0.00	0.00			0.00							
R07SLUI	0.00	0.00	0.00									
R07SLUIF	0.00	0.00	0.00									
R09I	7.93E-07	5.63E-07					5.63E-07					
R09UI	3.07E-07	2.18E-07					2.18E-07					
R11I	7.24E-06	7.13E-06					7.13E-06					
R11IF	1.09E-06	1.07E-06					1.07E-06					
R11UI	7.28E-09	5.16E-09					5.16E-09					
R17L	2.42E-06	2.48E-06					2.48E-06					
R17LU	2.63E-06	1.87E-06					1.87E-06					
R17U	3.26E-06	3.31E-06						3.31E-06				
R18	0.00	0.00							0.00			
R19	7.83E-08	7.83E-08							7.83E-08			
R20	8.21E-06	5.64E-06							5.64E-06			
R21	4.62E-05	4.54E-05								4.54E-05		
R22	8.91E-06	8.81E-06										8.81E-06
OTHERS	0.00	0.00										
TOTALS	8.31E-05	7.80E-05	0.00	4.54E-07	8.66E-07	2.84E-08	1.33E-05	3.31E-06	5.72E-06	4.54E-05	0.00	8.81E-06

TABLE 4-13c

CALCULATION OF AVERTED OFFSITE DOSE
ENHANCEMENT CASE - PROVIDE ACCUMULATORS FOR TURBINE DRIVEN AFW PUMP

APB ID	BASE CASE APB FREQUENCY (EVENTS/YR)	REVISED APB FREQUENCY (EVENTS/YR)	BASE CASE POPULATION DOSE RATE (Man-REM/YR)	REVISED POPULATION DOSE RATE (Man-REM/YR)	BASE CASE POPULATION DOSE (Man-REM)	REVISED POPULATION DOSE (Man-REM)	AVERTED POPULATION DOSE (Man-REM)
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	4.54E-07	4.54E-07	8.27E-02	8.27E-02	3.31E+00	3.31E+00	3.06E-04
3	1.41E-06	8.66E-07	4.51E-01	2.76E-01	1.80E+01	1.10E+01	6.99E+00
4	5.18E-08	2.84E-08	1.75E-02	9.62E-03	7.02E-01	3.85E-01	3.17E-01
5	1.45E-05	1.33E-05	9.95E-01	9.16E-01	3.98E+01	3.66E+01	3.17E+00
6	3.26E-06	3.31E-06	6.98E-02	7.09E-02	2.79E+00	2.83E+00	-4.13E-02
7	8.29E-06	5.72E-06	3.38E+00	2.34E+00	1.35E+02	9.34E+01	4.19E+01
8	4.62E-05	4.54E-05	9.24E-03	9.08E-03	3.69E-01	3.63E-01	6.24E-03
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	8.91E-06	8.81E-06	1.04E-03	1.03E-03	4.15E-02	4.10E-02	4.38E-04
TOTAL	8.31E-05	7.80E-05	5.01E+00	3.70E+00	2.00E+02	1.48E+02	52.38

involves the development of engineering analyses and procedures which would extend battery life by shedding unnecessary DC loads under station blackout conditions. The benefit of this enhancement is that it would allow operation of the turbine driven AFW pump for a longer period of time and would facilitate restoration of offsite power after 4 hours by ensuring availability of breaker control power.

4.3.5.1 Existing Capabilities

As part of the analyses performed to support compliance with 10 CFR 50.63 (Station Blackout Rule), the WBN plant was found to have adequate DC power capacity to cope for a station blackout lasting four hours. The analyses performed were focused on determining the plants ability to cope for four hours rather than determining the maximum coping duration. Additional battery capacity beyond four hours is probably available, especially is non-essential DC loads are shed early in the station blackout. Additional engineering analyses could be performed to determine the best strategies for extending coping capability.

4.3.5.2 Description of Enhancement

This enhancement involves the review and undate of the existing station blackout coping analysis with the following engineering, procedural and training changes:

- Revise the station blackout coping analysis
  - develop minimum battery load list
  - identify loads to shed
  - revise coping strategy
  - verify other station blackout constraints (room cooling, condensate makeup, primary system inventory, etc.)
- Revise station blackout procedures to incorporate new strategy
- Provide additional training for operators
- Develop and submit new station blackout licensing submittals to address changes in coping capability

4.3.5.3 Cost Estimate

The primary costs associated with this enhancement involves the engineering, licensing and implementation of the load shedding procedure. The following table summarizes the individual cost elements:

DESCRIPTION	COST
Engineering - TVA	$ 3,200
Engineering - Contractor	$ 75,000
Procedure Changes	$ 25,200
Licensing Support	$ 9,800
Total	$113,200

4.3.5.4 Risk Reduction Estimate

The WBN Level 1 and 2 spreadsheet models were used to evaluate the potential risk reduction benefit of the proposed procedure change. The assumptions utilized were intended to maximize the potential benefit of the change. The assumed increase in battery capacity is from 4 hours to 8 hours. Based on the WBN offsite power curve, the maximum reduction in the probability of non-recovery expected would be a factor of 10.

Tables 4-14 a,b,c provide a summary of the results of the requantification of the PRA and population dose estimates. Based on this analysis, the total reduction in population dose is estimated to be 41.5 person rem over the 40 year life of the plant.

4.3.5.5 Value Impact Assessment

The value impact of this enhancement is based on a quantitative comparison of the cost of the enhancement and the potential risk reduction benefit. The total estimated cost for providing a DC load shed analysis and procedure to increase battery life is $113,200. The risk reduction benefit associated with this change has been conservatively estimated to be 41.5 person-rem over the life of the plant. Therefore, the cost benefit ratio is

C/B Ratio = $113,200/ 41.5 person-rem = $2,728 /person-rem

This ratio is more than $1000 per person rem. Therefore, based on this analysis, the enhancement to provide a DC load shed analysis and procedure to increase battery life is not considered cost beneficial.

4.3.6 Provide Portable Battery Charger

This enhancement would provide a portable, diesel driven battery charger which would assure DC power would be available under station blackout conditions. The benefit of

this enhancement is similar to item III.5, except the battery life could be extended essentially indefinitely.

TABLE 4-14a
SUMMARY OF PDS AND KRC RESULTS
ENHANCEMENT CASE - INSTALL DC LOAD SHEDDING ANALYSIS AND PROCEDURE

BASE CASE RESULTS				ENHANCEMENT CASE RESULTS				
LEVEL 1 OUTPUT KPDS	BASE CASE KPDS FREQUENCY	LEVEL 2 INPUT KPDS	BASE CASE KPDS FREQUENCY	KPDS FREQUENCY	KRC GROUP FREQUENCY			
					I	II	III	IV
ATV	7.83E-08	ATV	7.83E-08	7.83E-08	7.83E-08			
BCI	4.49E-06	BCI	4.49E-06	4.47E-06	2.75E-08		3.42E-06	1.03E-06
EGI	0.00	EGI	0.00	6.69E-08	5.35E-10		6.64E-08	
EIB	5.52E-06	EIB	5.52E-06	3.43E-06		3.43E-06		
ENB	4.58E-07	ENB	4.58E-07	4.51E-07		4.51E-07		
ENI	3.84E-05	ENIYA	3.00E-05	2.01E-05	1.61E-07		3.19E-07	1.96E-05
ENS	2.24E-06	ENIYB	1.10E-06	7.36E-07	5.89E-09		7.31E-07	
FCI	2.46E-05	ENIYN	7.30E-06	4.89E-06	3.91E-08		4.85E-06	
FGI	0.00	ENSYA	5.20E-07	4.88E-07		4.88E-07		
FNI	0.00	ENSYB	1.65E-07	1.54E-07		1.54E-07		
GNI	4.95E-06	ENSYC	1.76E-07	1.66E-07		1.66E-07		
HCI	1.23E-06	ENSYN	1.37E-06	1.29E-06		1.29E-06		
HGI	1.11E-06	FCI	2.46E-05	2.36E-05	1.28E-07		7.97E-07	2.27E-05
HNI	0.00	FGI	0.00	3.50E-07	2.80E-09		2.98E-07	4.86E-08
KNI	0.00	FNI	0.00	1.10E-07	8.79E-10		9.37E-08	1.53E-08
KNS	0.00	GNIYA	3.49E-06	2.37E-06	5.82E-07		1.79E-06	
LCI	0.00	GNIYN	1.47E-06	9.99E-07	2.45E-07	0.00	7.54E-07	
LNI	0.00	HCI	1.23E-06	1.22E-06	9.79E-09		6.07E-08	1.15E-06
OTHERS	0.00	HGI	1.11E-06	1.05E-06	2.13E-07		8.33E-07	
		HNI	0.00	1.01E-07	7.99E-09		9.26E-08	
		KNI	0.00	0.00	0.00		0.00	
		KNSYA	0.00	0.00	0.00	0.00		
		KNSYC	0.00	0.00	0.00	0.00		
		LCI	0.00	0.00	0.00		0.00	0.00
		LNIYA	0.00	0.00				0.00
		LNIYC	0.00	0.00	0.00		0.00	
		OTHERS	0.00	0.00				
		TOTALS	8.31E-05	6.61E-05	1.50E-06	5.98E-06	1.41E-05	4.46E-05

TABLE 4-14b
TRANSLATION OF KRC FREQUENCIES TO APBs
ENHANCEMENT CASE - INSTALL DC LOAD SHEDDING ANALYSIS AND PROCEDURE

KRC ID	BASE KRC FREQ	CASE KRC FREQ	APB FREQUENCIES									
			1	2	3	4	5	6	7	8	9	10
R01	6.13E-08	5.80E-08			5.80E-08							
R01DI	1.21E-06	8.69E-07			8.69E-07							
R01I	3.91E-08	2.66E-08			2.66E-08							
R01IF	9.28E-08	6.31E-08			6.31E-08							
R01SI	0.00	0.00	0.00									
R01SIF	0.00	0.00	0.00									
R01SUI	0.00	0.00	0.00									
R01SUIF	0.00	0.00	0.00									
R01UI	2.15E-09	1.46E-09			1.46E-09							
R01UIF	5.10E-09	3.47E-09			3.47E-09							
R02IF	0.00	0.00			0.00							
R03	2.39E-08	2.26E-08				2.26E-08						
R03I	5.93E-08	3.97E-08		3.97E-08								
R03IF	2.51E-07	1.74E-07		1.74E-07								
R03SI	0.00	0.00	0.00									
R03SIF	0.00	0.00	0.00									
R03SUI	0.00	0.00	0.00									
R03SUIF	0.00	0.00	0.00									
R03UI	5.87E-11	4.00E-11				4.00E-11						
R03UIF	1.39E-10	6.30E-10				6.30E-10						
R04	1.44E-07	1.38E-07		1.38E-07								
R04IF	0.00	0.00				0.00						
R04UIF	2.77E-08	2.75E-08				2.75E-08						
R05SLI	0.00	0.00	0.00									
R05SLIF	0.00	0.00	0.00									
R05SLUI	0.00	0.00	0.00									
R05SLUIF	0.00	0.00			0.00							
R07SLUI	0.00	0.00	0.00									
R07SLUIF	0.00	0.00	0.00									
R09I	7.93E-07	5.40E-07					5.40E-07					
R09UI	3.07E-07	2.09E-07					2.09E-07					
R11I	7.24E-06	4.85E-06					4.85E-06					
R11IF	1.09E-06	7.31E-07					7.31E-07					
R11UI	7.28E-09	4.95E-09					4.95E-09					
R17L	2.42E-06	2.66E-06					2.66E-06					
R17LU	2.63E-06	1.79E-06					1.79E-06					
R17U	3.26E-06	3.31E-06						3.31E-06				
R18	0.00	0.00							0.00			
R19	7.83E-08	7.83E-08							7.83E-08			
R20	8.21E-06	5.98E-06							5.98E-06			
R21	4.62E-05	3.60E-05								3.60E-05		
R22	8.91E-06	8.59E-06										8.59E-06
OTHERS	0.00	0.00										
TOTALS	8.31E-05	6.61E-05	0.00	3.52E-07	1.02E-06	5.08E-08	1.08E-05	3.31E-06	6.06E-06	3.60E-05	0.00	8.59E-06

TABLE 4-14c

CALCULATION OF AVERTED OFFSITE DOSE
ENHANCEMENT CASE - INSTALL DC SHEDDING ANALYSIS AND PROCEDURE

APB ID	BASE CASE APB FREQUENCY (EVENTS/YR)	REVISED APB FREQUENCY (EVENTS/YR)	BASE CASE POPULATION DOSE RATE (Man-REM/YR)	REVISED POPULATION DOSE RATE (Man-REM/YR)	BASE CASE POPULATION DOSE (Man-REM)	REVISED POPULATION DOSE (Man-REM)	AVERTED POPULATION DOSE (Man-REM)
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	4.54E-07	3.52E-07	8.27E-02	6.40E-02	3.31E+00	2.56E+00	7.47E-01
3	1.41E-06	1.02E-06	4.51E-01	3.26E-01	1.80E+01	1.30E+01	5.00E+00
4	5.18E-08	5.08E-08	1.75E-02	1.72E-02	7.02E-01	6.89E-01	1.31E-02
5	1.45E-05	1.08E-05	9.95E-01	7.41E-01	3.98E+01	2.96E+01	1.02E+01
6	3.26E-06	3.31E-06	6.98E-02	7.09E-02	2.79E+00	2.83E+00	-4.13E-02
7	8.29E-06	6.06E-06	3.38E+00	2.47E+00	1.35E+02	9.90E+01	3.64E+01
8	4.62E-05	3.60E-05	9.24E-03	7.19E-03	3.69E-01	2.88E-01	8.19E-02
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	8.91E-06	8.59E-06	1.04E-03	1.00E-03	4.15E-02	4.00E-02	1.48E-03
TOTAL	8.31E-05	6.61E-05	5.01E+00	3.70E+00	2.00E+02	1.48E+02	5.23E+01

4.3.6.1 Existing Capabilities

As described above for enhancement III.5, the WBN station blackout analysis assumes that the existing battery capacity is four hours.

4.3.6.2 Description of Enhancement

This enhancement involves the provision of a portable diesel generator which could be used to provide battery charging during station blackout conditions. The enhancement included all hardware and procedures necessary for connecting the portable diesel.

4.3.6.3 Cost Estimate

The cost estimate for the provision of an portable diesel generator for battery charging includes the engineering, materials and construction costs. The total cost of this design change is $108,600 as summarized in Table 4-15. In addition, procedural changes would be required to all use of the new hardware. As described in Table 4-2, an additional $25,200 in costs is associated with such procedure changes. Thus, the total cost of this enhancement is $133,800.

4.3.6.4 Risk Reduction Estimate

The WBN Level 1 and 2 spreadsheet models were used to evaluate the potential risk reduction benefit of the proposed change. The assumptions utilized were intended to maximize the potential benefit of the change. In this case the same assumptions regarding the improvement in AC power recovery were made as for enhancement III.5. Even though in this case AFW would be expected to be available for an extended period of time, the loss of primary system inventory due to RCP seal LOCAs would be likely to lead to core uncovery in 8 hours.

Therefore, Tables 4-14 a,b,c are considered representative of the results of the requantification of the PRA and population dose estimates for this enhancement. Based on this analysis, the total reduction in population dose is estimated to be 41.5 person rem over the 40 year life of the plant.

4.3.6.5 Value Impact Assessment

The value impact of this enhancement is based on a quantitative comparison of the cost of the enhancement and the potential risk reduction benefit. The total estimated cost for a portable battery charger is $133,800. The risk reduction benefit associated with this change has been conservatively estimated to be 41.5 person-rem over the life of the plant.

Table 4-15
Provide Portable Battery Chargers

Scope:		
Provide a source of continuous DC power to the instrumentation for the Turbine Driven AFW pumps so that in the event of Loss of Off-site power and the depletion of the batteries to the AFW pump can remain functioning. A portable diesel generator set would be connected via the existing permanent plant switchgear the battery charger via temporary cables and a breaker would be racked out and the power feed to the battery charger breaker would be disconnected and the DG connected in its place. This would have to be done early on in the station blackout scenario so that the batteries would not deplete too far for the trickle charge of the battery charger to maintain adequate voltage on the DC bus under use.		
Engineering:		
Average DCN = 300 manhours with no significant special analyses		
DCN = 300 manhours * $56 per manhour	$16.6K	
Engineering Cost		$16.6K
Material:		
Engineered Items:		
Diesel Generator Set 1 @ $35K	$35K	
Breaker 8 @ $1K	$ 8K	
Bulk Commodities:		
Cabling & Protective Conduit (as needed)	$ 9K	
Material Cost		$52K
Construction:		
NONE - Design is all portable		
Equipment Maintenance:		
40 manhours/yr x 40 years to maintain DG x $25/hr	$40K	
Maintenance Cost		$40K
	Total	$108.6K

Therefore, the cost benefit ratio is

C/B Ratio = $133,800/41.5 person-rem = $3,224 /person-rem

This ratio is more than $1000 per person rem. Therefore, based on this analysis, the enhancement to provide a portable battery charger is not considered cost beneficial.

4.3.7 Install AC Independent Coolant Injection System

This enhancement would provide an AC independent coolant injection system which could be used under station blackout conditions (as well as others) to provide feed and bleed cooling of the RCS. The system evaluated included an independent emergency diesel generator, a pump and associated controls necessary to provide adequate makeup to the RCS.

4.3.7.1 Existing Capabilities

Currently, all WBN primary coolant injection systems are dependent upon AC power. During station blackout conditions, no AC power is available. Provision of an AC independent coolant injection source could greatly reduce the core damage potential due to station blackout.

4.3.7.2 Description of Enhancement

The purpose of this enhancement is to provide an alternate means of core injection by providing the capability for injection makeup water to the reactor vessel using an independently powered pump. The pump would serve as a backup, in the event of failure of the high pressure injection, to the front-line injection systems, and could be used to maintain core cooling for small break LOCA scenarios.

To most effectively utilize the existing layout of the Watts Bar plant, the dedicated alternate core injection pump will occupy the space originally designed for the positive displacement (PD) charging pump. Utilization of this space will minimize the physical modifications within the plant for this enhancement. To establish the desired independence of this system a dedicated diesel generator housed in a commercial/industrial-type building is also proposed.

Design Assumptions:

1. It is assumed that the normal offsite and Emergency Diesel Generator (EDG) power supplies have been lost.

2. It is assumed that the containment is intact.

3. It is assumed that the use of AC motor-operated valves is acceptable if a dedicated AC power source is available. This AC power source can be the same source that provides AC power to the dedicated alternate core injection pump.

4. Credit is allowed for limited manual actions outside of the control room; however, no credit is allowed for manual actions inside containment or in areas that would have high radiation in the Auxiliary building after a core damage event.

5. The dedicated core injection pump and associated piping are not safety related, but will require an appropriate isolation and interface at the selected junction to the existing safety grade piping.

6. To minimize the cost, the existing rooms and injection flow path of the exiting PD pumps can be utilized. However, replacement of existing flow limiting pipe may be required.

7. The dedicated diesel generator is not safety related and should be appropriately isolated from the safety-related component, e.g. MOVs, that are required to be powered to support the independent core injection system.

8. The dedicated diesel generator shall have its own dedicated fuel oil storage tank.

9. The dedicated diesel generator shall have its own dedicated DC battery source for cranking, control and field flashing capabilities.

10. A dedicated and independent structure designed to commercial/industrial building code requirements shall be constructed. This building shall provide for adequate ventilation to support long term operation of the dedicated diesel generator during any expected weather condition. Provisions shall also include a commercial non-safety HVAC system to maintain an acceptable day-to-day environmental condition.

11. This building shall also be equipped with appropriate fire detection and suppression capabilities.

12. The routing of the new power leads to required electrical devices and additional piping shall not compromise the functional integrity of any structure, system or component.

13. Seismic and harsh environmental qualification is only required where failure may impact existing safety systems.

4.3.7.3 Cost Estimate

The following cost estimate includes the Engineering, Construction and Materials required to implement this enhancement based on the scope description provided in Section 2.0 above. Licensing and Maintenance cost have not been included.

Note that these estimates have been prepared for scoping purposes only to support the cost-benefit assessment required for this candidate enhancement. Due to the general magnitude of the cost associated with a plant modification of this type, relative to the maximum theoretical benefit at Watts Bar, an exhaustive detailed cost estimate has not been performed. The values reflected below are believed to be very conservative and the actual cost to implement a modification of this type is expected to be higher than estimated below.

DESCRIPTION	COST $ (THOUSANDS)
Engineering Total for Independent Diesel Generator	$100.55
Construction Total for Independent Diesel Generator	$214.50
Materials for Independent Diesel Generator	$583.00
Materials for Diesel Generator Building	$102.60
Engineering, Construction and Materials for Alternate Core Injection Pump	$2,507.00
TOTAL	$3,507.65

Note that a more detailed cost assessment has been performed by TVA for the Sequoyah Nuclear Plant. The scope of the cost assessment for Sequoyah was limited to replacement of the PD Pumps with centrifugal type pumps. The modification scoped for Sequoyah was also for a system with lower flow requirements (i.e., the flow requirements for a reactor coolant pump seal injection system) than are required for this enhancement. The total cost estimated for Sequoyah was approximately required for this enhancement. The total cost estimated for Sequoyah was approximately $3.7 million. While the Sequoyah estimate has some cost that are not applicable at Watts Bar, such a disposal of a contaminated PD pump and other radiological concerns, the Sequoyah estimate provides a reasonable reference to demonstrate the conservatism in the Watts Bar estimate. Not the Watts Bar cost estimate includes an independent power source which was not included in the Sequoyah estimate.

4.3.7.4 Risk Reduction Estimate

The WBN Level 1 and 2 spreadsheet models were used to evaluate the potential risk reduction benefit of the proposed change. The assumptions utilized were intended to maximize the potential benefit of the change. The analysis of this enhancement credited the alternate coolant injection for all core damage events except containment bypass. Thus, for a bounding case, the estimated population dose reduction can be taken as the elimination of all APBs except APB #7. This enhancement was not credited for bypass sequences because a review of the dominant bypass event sequences identified that human errors and isolation failures were the dominant contributors and this enhancement would not significantly impact those failures. From Table 3-12 it is seen that the non-bypass APBs contribute roughly 1.62 person-rem per year. Based on these assumptions, the maximum total reduction in population dose is estimated to be 65.0 person rem over the 40 year life of the plant.

4.3.7.5 Value Impact Assessment

The value impact of this enhancement is based on a quantitative comparison of the cost of the enhancement and the potential risk reduction benefit. The total estimated cost for the AC independent coolant injection system is $3.5M. The risk reduction benefit associated with this change has been conservatively estimated to be 65.0 person-rem over the life of the plant. Therefore, the cost benefit ratio is

C/B Ratio = $3,500,000/65.0 person-rem = $53,846/person-rem

This ratio is more than $1000 per person rem. Therefore, based on this analysis, the enhancement to provide an AC independent coolant injection system is not considered cost beneficial.

4.4 IMPROVE ABILITY TO COPE WITH LOSS OF RCP SEAL COOLING

The third largest contributor to the WBN Unit 1 core damage frequency involves event sequences with loss of RCP seal cooling (non-station blackout). These sequences are characterized by simultaneous loss of RCP thermal barrier cooling and loss of seal injection. This category of enhancements includes items which would either improve RCP seal performance under such conditions or prevent failure of the seals altogether.

4.4.1 Install Improved RCP Seals

As described in enhancement III.2, Westinghouse has recently developed an improved O-ring for RCP seals which has a much lower likelihood of failure under loss of cooling

conditions. However, such a modification would still require the plant operators to trip the RCPs before significant overheating of the seal occurred. The current RCP seals are assumed to lead to a small LOCA under loss of cooling conditions. This results in actuation of ECCS and containment spray and a need to initiate high pressure recirculation. However, many of the systems required to support RCP seal cooling (i.e., CCS, ERCW and charging) are used in high pressure recirculation. Improved seals could prevent containment spray actuation and allow a normal plant cooldown using AFW. The quantification of benefit of this enhancement includes both station blackout and non-station blackout events such as loss of CCS or loss of ERCW.

The value impact of this enhancement is based on a quantitative estimate made for enhancement III.2. The total estimated cost for installation of new RCP seals is $ 162,800. The risk reduction benefit associated with this change has been conservatively estimated to be 41.5 person-rem over the life of the plant. Therefore, the cost benefit ratio is

C/B Ratio = $162,800/41.5 person-rem = $3,923/person-rem

This ratio is more than $1000 per person rem. Therefore, based on this analysis, the enhancement to install new RCP seals is not considered cost beneficial.

4.4.2 Install Independent RCP Seal Cooling System (w/o new EDG)

This enhancement is essentially identical to enhancement III.3. except it does not include one of the significant cost elements, the emergency diesel generator. Therefore, the quantified benefit of this enhancement includes only non-station blackout seal LOCAs.

4.4.2.1 Existing Capabilities

The existing RCP seal cooling capability is dependent upon either CCS or charging seal injection.

4.4.2.2 Description of Enhancement

This enhancement is essentially identical to enhancement III.3 (section 4.3.3), except it does not include the standby emergency diesel generator included in III.3.

4.4.2.3 Cost Estimate

The cost estimate for this enhancement is based on the same assumptions as described in section 4.3.3 except the cost of the emergency diesel generator ($1.1M) is eliminated. Thus, the cost of the independent RCP seal cooling system is $2.4M.

4.4.2.4 Risk Reduction Estimate

The WBN Level 1 and 2 spreadsheet models were used to evaluate the potential risk reduction benefit of the proposed procedure change. The assumptions utilized were intended to maximize the potential benefit of the change. The risk reduction was estimated by providing a new recovery action on each event sequence involving loss of RCP seal cooling. The independent RCP seal cooling system was assumed to have minimal unavailability and high reliability, but require an operator action to initiate. Due to the fact that RCP seal can over heat and fail rather quickly and that the action to start and utilize the independent system would be relatively unfamiliar to the operators, a fairly high human error rate could be justified. However, in order to make the analysis conservative, a mean human error rate of 0.05 was assumed. The system was assumed to have an overall availability of 0.01. Thus, all sequences in which this system could be effective were reduced by a factor of 0.06.

Tables 4-16 a,b,c provide a summary of the results of the requantification of the PRA and population dose estimates. Based on this analysis, the total reduction in population dose is estimated to be 43.0 person rem over the 40 year life of the plant.

4.4.2.5 Value Impact Assessment

The value impact of this enhancement is based on a quantitative comparison of the cost of the enhancement and the potential risk reduction benefit. The total estimated cost for an independent RCP seal cooling system is $2.4M. The risk reduction benefit associated with this change has been conservatively estimated to be 43.0 person-rem over the life of the plant. Therefore, the cost benefit ratio is

C/B Ratio = $2,400,000/43.0 person-rem = $55,814/person-rem

This ratio is more than $1000 per person rem. Therefore, based on this analysis, the enhancement to provide an independent RCP seal cooling system is not considered cost beneficial.

4.4.3 Change Charging Pump Cooling From CCS to ERCW

One of the key contributors to loss of RCP seal cooling is event sequences involving loss of CCS. The CCS system provides thermal barrier cooling to the RCPs and is the primary cooling medium for the centrifugal charging pumps (CCP) which provide seal injection. Consequently, when CCS is lost, RCP seal cooling is lost. One of the CCPs (1A-A) currently has the capability to be cooled by ERCW. This enhancement involves the provision of ERCW cooling to the other CCP.

TABLE 4-16a
SUMMARY OF PDS AND KRC RESULTS
ENHANCEMENT CASE - INSTALL INDEPENDENT RCP SEAL COOLING SYSTEM (W/O NEW EDG)

BASE CASE RESULTS				ENHANCEMENT CASE RESULTS				
LEVEL 1 OUTPUT KPDS	BASE CASE KPDS FREQUENCY	LEVEL 2 INPUT KPDS	BASE CASE KPDS FREQUENCY	KPDS FREQUENCY	KRC GROUP FREQUENCY			
					I	II	III	IV
ATV	7.83E-08	ATV	7.83E-08	7.83E-08	7.83E-08			
BCI	4.49E-06	BCI	4.49E-06	4.47E-06	2.75E-08		3.42E-06	1.03E-06
EGI	0.00	EGI	0.00	6.69E-08	5.35E-10		6.64E-08	
EIB	5.52E-06	EIB	5.52E-06	3.43E-06		3.43E-06		
ENB	4.58E-07	ENB	4.58E-07	4.50E-07		4.50E-07		
ENI	3.84E-05	ENIYA	3.00E-05	2.03E-05	1.63E-07		3.23E-07	1.99E-05
ENS	2.24E-06	ENIYB	1.10E-06	7.45E-07	5.96E-09		7.39E-07	
FCI	2.46E-05	ENIYN	7.30E-06	4.95E-06	3.96E-08		4.91E-06	
FGI	0.00	ENSYA	5.20E-07	5.04E-07		5.04E-07		
FNI	0.00	ENSYB	1.65E-07	1.59E-07		1.59E-07		
GNI	4.95E-06	ENSYC	1.76E-07	1.71E-07		1.71E-07		
HCI	1.23E-06	ENSYN	1.37E-06	1.33E-06		1.33E-06		
HGI	1.11E-06	FCI	2.46E-05	2.36E-05	1.28E-07		7.96E-07	2.27E-05
HNI	0.00	FGI	0.00	3.48E-07	2.78E-09		2.97E-07	4.83E-08
KNI	0.00	FNI	0.00	9.92E-08	7.94E-10		8.46E-08	1.38E-08
KNS	0.00	GNIYA	3.49E-06	3.43E-06	8.42E-07		2.59E-06	
LCI	0.00	GNIYN	1.47E-06	1.44E-06	3.54E-07	0.00	1.09E-06	
LNI	0.00	HCI	1.23E-06	1.22E-06	9.79E-09		6.07E-08	1.15E-06
OTHERS	0.00	HGI	1.11E-06	1.11E-06	2.25E-07		8.81E-07	
		HNI	0.00	1.01E-07	8.04E-09		9.32E-08	
		KNI	0.00	0.00	0.00		0.00	
		KNSYA	0.00	0.00	0.00	0.00		
		KNSYC	0.00	0.00	0.00	0.00		
		LCI	0.00	0.00	0.00		0.00	0.00
		LNIYA	0.00	0.00				0.00
		LNIYC	0.00	0.00	0.00		0.00	
		OTHERS	0.00	0.00				
		TOTALS	8.31E-05	6.81E-05	1.89E-06	6.05E-06	1.53E-05	4.48E-05

TABLE 4-16b
TRANSLATION OF KRC FREQUENCIES TO APBs
ENHANCEMENT CASE - INSTALL INDEPENDENT RCP SEAL COOLING SYSTEM (W/O NEW EDG)

KRC ID	BASE KRC FREQ	CASE KRC FREQ	APB FREQUENCIES									
			1	2	3	4	5	6	7	8	9	10
R01	6.13E-08	6.13E-08			6.13E-08							
R01DI	1.21E-06	1.20E-06			1.20E-06							
R01I	3.91E-08	3.84E-08			3.84E-08							
R01IF	9.28E-08	9.13E-08			9.13E-08							
R01SI	0.00	0.00	0.00									
R01SIF	0.00	0.00	0.00									
R01SUI	0.00	0.00	0.00									
R01SUIF	0.00	0.00	0.00									
R01UI	2.15E-09	2.11E-09			2.11E-09							
R01UIF	5.10E-09	5.01E-09			5.01E-09							
R02IF	0.00	0.00			0.00							
R03	2.39E-08	2.39E-08				2.39E-08						
R03I	5.93E-08	4.05E-08		4.05E-08								
R03IF	2.51E-07	1.76E-07		1.76E-07								
R03SI	0.00	0.00	0.00									
R03SIF	0.00	0.00	0.00									
R03SUI	0.00	0.00	0.00									
R03SUIF	0.00	0.00	0.00									
R03UI	5.87E-11	5.78E-11				5.78E-11						
R03UIF	1.39E-10	6.72E-10				6.72E-10						
R04	1.44E-07	1.38E-07		1.38E-07								
R04IF	0.00	0.00				0.00						
R04UIF	2.77E-08	2.75E-08				2.75E-08						
R05SLI	0.00	0.00	0.00									
R05SLIF	0.00	0.00	0.00									
R05SLUI	0.00	0.00	0.00									
R05SLUIF	0.00	0.00			0.00							
R07SLUI	0.00	0.00	0.00									
R07SLUIF	0.00	0.00	0.00									
R09I	7.93E-07	7.80E-07					7.80E-07					
R09UI	3.07E-07	3.02E-07					3.02E-07					
R11I	7.24E-06	4.91E-06					4.91E-06					
R11IF	1.09E-06	7.39E-07					7.39E-07					
R11UI	7.28E-09	7.16E-09					7.16E-09					
R17L	2.42E-06	2.71E-06					2.71E-06					
R17LU	2.63E-06	2.59E-06					2.59E-06					
R17U	3.26E-06	3.31E-06						3.31E-06				
R18	0.00	0.00							0.00			
R19	7.83E-08	7.83E-08							7.83E-08			
R20	8.21E-06	6.05E-06							6.05E-06			
R21	4.62E-05	3.62E-05								3.62E-05		
R22	8.91E-06	8.58E-06										8.58E-06
OTHERS	0.00	0.00										
TOTALS	8.31E-05	6.81E-05	0.00	3.55E-07	1.40E-06	5.22E-08	1.20E-05	3.31E-06	6.13E-06	3.62E-05	0.00	8.58E-06

TABLE 4-16c

CALCULATION OF AVERTED OFFSITE DOSE
ENHANCEMENT CASE - INSTALL INDEPENDENT RCP SEAL COOLING SYSTEM (W/O NEW EDG)

APB ID	BASE CASE APB FREQUENCY (EVENTS/YR)	REVISED APB FREQUENCY (EVENTS/YR)	BASE CASE POPULATION DOSE RATE (Man-REM/YR)	REVISED POPULATION DOSE RATE (Man-REM/YR)	BASE CASE POPULATION DOSE (Man-REM)	REVISED POPULATION DOSE (Man-REM)	AVERTED POPULATION DOSE (Man-REM)
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	4.54E-07	3.55E-07	8.27E-02	6.46E-02	3.31E+00	2.59E+00	7.24E-01
3	1.41E-06	1.40E-06	4.51E-01	4.46E-01	1.80E+01	1.79E+01	1.71E-01
4	5.18E-08	5.22E-08	1.75E-02	1.77E-02	7.02E-01	7.07E-01	-5.47E-03
5	1.45E-05	1.20E-05	9.95E-01	8.26E-01	3.98E+01	3.31E+01	6.75E+00
6	3.26E-06	3.31E-06	6.98E-02	7.09E-02	2.79E+00	2.83E+00	-4.13E-02
7	8.29E-06	6.13E-06	3.38E+00	2.50E+00	1.35E+02	1.00E+02	3.53E+01
8	4.62E-05	3.62E-05	9.24E-03	7.23E-03	3.69E-01	2.89E-01	8.01E-02
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	8.91E-06	8.58E-06	1.04E-03	9.99E-04	4.15E-02	4.00E-02	1.52E-03
TOTAL	8.31E-05	6.81E-05	5.01E+00	3.94E+00	2.00E+02	1.57E+02	42.97

4.4.3.1 Existing Capabilities

The purpose of this enhancement is to provide a cross-connection between the Essential Raw Cooling Water (ERCW) system to the CCP lube oil heat exchangers and to increase the lube oil storage capacity. The primary lube oil cooling is provided by the Component Cooling Water System (CCS). In the event of loss of CCS cooling to the CCPs, the time available for continued operation of the CCPs would be limited to the time before the lube oil overheats which leads to the failure of the CCPs. This enhancement will reduce the vulnerability of RCP seal failure given a loss of CCS.

The present design currently has this cross-connection capability on CCP A for Unit 1. In order to provide maximum credit for this enhancement, the cross-connection must be designed, installed, and tested for the remaining Unit 1 CCP and both Unit 2 CCPs. The proposed cross-connection provides a backup supply of water to the CCP lube oil cooling heat exchangers which should be capable of maintaining adequate cooling. The continued operation of the CCPs following the loss of CCS is important due to the fact that the CCPs provide cooling water to the Reactor Coolant Pump (RCP) seals. Continued injection from the CCPs to the RCP seals will preclude the failure of the RCP seals and a resultant RCP seal LOCA.

4.4.3.2 Description of Enhancement

The current design must be evaluated for the intended application and includes the following physical changes and new equipment.

- Piping to connect the ERCW header to the shell side of the CCP lube oil heat exchanger.
- Additional capacity lube oil reservoir hardware.
- Appropriate valves and related hardware.
- Appropriate instrumentation and controls for actuation of ERCW backup.

4.4.3.3 Cost Estimate

The following cost estimate includes the design, construction, and associated documentation required to implement this enhancement for Watts Bar Unit 1, based on the scope description provided above. Note the cost to implement this enhancement for Unit 2 would be slightly higher due to the need for an additional cross-tie.

Description	Cost $
Engineering - TVA	16,000
Engineering - Contractor	159,000
Construction	75,000
Equipment, Materials, Misc.	20,000
Training, Procedure Upgrade, Licensing Support, System Maintenance	25,200
TOTAL	295,200

4.4.3.4 Risk Reduction Estimate

The WBN Level 1 and 2 spreadsheet models were used to evaluate the potential risk reduction benefit of the proposed procedure change. The assumptions utilized were intended to maximize the potential benefit of the change. The benefit of this enhancement was conservatively assumed to eliminate all core damage sequences involving loss of CCS cooling. This was calculated based on setting the dominant loss of CCS initiators (CCSTL and CCSA) to zero and eliminating the failure probability for realignment of the charging pump cooling from CCS to ERCW (CCPR and CCSR) to zero.

Tables 4-17 a,b,c provide a summary of the results of the requantification of the PRA and population dose estimates. Based on this analysis, the total reduction in population dose is estimated to be 43.5 person rem over the 40 year life of the plant.

4.4.3.5 Value Impact Assessment

The value impact of this enhancement is based on a quantitative comparison of the cost of the enhancement and the potential risk reduction benefit. The total estimated cost for changing the charging pump cooling to ERCW is $ 295,200. The risk reduction benefit associated with this change has been conservatively estimated to be 43.5 person-rem over the life of the plant. Therefore, the cost benefit ratio is

C/B Ratio = $295,200/43.5 person-rem = $6,786/person-rem

This ratio is more than $1000 per person rem. Therefore, based on this analysis, the enhancement to change the charging pump cooling to ERCW is not considered cost beneficial.

TABLE 4-17a
SUMMARY OF PDS AND KRC RESULTS
ENHANCEMENT CASE - CHANGE CHARGING PUMP COOLING FROM CCS TO ERCW

BASE CASE RESULTS				ENHANCEMENT CASE RESULTS				
LEVEL 1 OUTPUT KPDS	BASE CASE KPDS FREQUENCY	LEVEL 2 INPUT KPDS	BASE CASE KPDS FREQUENCY	KPDS FREQUENCY	KRC GROUP FREQUENCY			
					I	II	III	IV
ATV	7.83E-08	ATV	7.83E-08	7.83E-08	7.83E-08			
BCI	4.49E-06	BCI	4.49E-06	4.47E-06	2.75E-08		3.42E-06	1.03E-06
EGI	0.00	EGI	0.00	6.69E-08	5.35E-10		6.64E-08	
EIB	5.52E-06	EIB	5.52E-06	3.43E-06		3.43E-06		
ENB	4.58E-07	ENB	4.58E-07	4.58E-07		4.58E-07		
ENI	3.84E-05	ENIYA	3.00E-05	1.98E-05	1.58E-07		3.14E-07	1.93E-05
ENS	2.24E-06	ENIYB	1.10E-06	7.26E-07	5.81E-09		7.20E-07	
FCI	2.46E-05	ENIYN	7.30E-06	4.82E-06	3.85E-08		4.78E-06	
FGI	0.00	ENSYA	5.20E-07	5.03E-07		5.03E-07		
FNI	0.00	ENSYB	1.65E-07	1.59E-07		1.59E-07		
GNI	4.95E-06	ENSYC	1.76E-07	1.70E-07		1.70E-07		
HCI	1.23E-06	ENSYN	1.37E-06	1.33E-06		1.33E-06		
HGI	1.11E-06	FCI	2.46E-05	2.36E-05	1.28E-07		7.95E-07	2.26E-05
HNI	0.00	FGI	0.00	3.41E-07	2.73E-09		2.91E-07	4.73E-08
KNI	0.00	FNI	0.00	6.71E-08	5.37E-10		5.73E-08	9.32E-09
KNS	0.00	GNIYA	3.49E-06	3.43E-06	8.42E-07		2.59E-06	
LCI	0.00	GNIYN	1.47E-06	1.45E-06	3.55E-07	0.00	1.09E-06	
LNI	0.00	HCI	1.23E-06	1.22E-06	9.79E-09		6.07E-08	1.15E-06
OTHERS	0.00	HGI	1.11E-06	1.11E-06	2.25E-07		8.81E-07	
		HNI	0.00	1.03E-07	8.20E-09		9.50E-08	
		KNI	0.00	0.00	0.00		0.00	
		KNSYA	0.00	0.00	0.00	0.00		
		KNSYC	0.00	0.00	0.00	0.00		
		LCI	0.00	0.00	0.00		0.00	0.00
		LNIYA	0.00	0.00				0.00
		LNIYC	0.00	0.00.	0.00		0.00	
		OTHERS	0.00	0.00				
		TOTALS	8.31E-05	6.73E-05	1.88E-06	6.05E-06	1.52E-05	4.42E-05

TABLE 4-17b
TRANSLATION OF KRC FREQUENCIES TO APBs
ENHANCEMENT CASE - CHANGE CHARGING PUMP COOLING FROM CCS TO ERCW

KRC ID	BASE KRC FREQ	CASE KRC FREQ	APB FREQUENCIES									
			1	2	3	4	5	6	7	8	9	10
R01	6.13E-08	6.13E-08			6.13E-08							
R01DI	1.21E-06	1.20E-06			1.20E-06							
RO1I	3.91E-08	3.85E-08			3.85E-08							
R01IF	9.28E-08	9.14E-08			9.14E-08							
R01SI	0.00	0.00	0.00									
R01SIF	0.00	0.00	0.00									
R01SUI	0.00	0.00	0.00									
R01SUIF	0.00	0.00	0.00									
R01UI	2.15E-09	2.11E-09			2.11E-09							
R01UIF	5.10E-09	5.02E-09			5.02E-09							
R02IF	0.00	0.00			0.00							
R03	2.39E-08	2.39E-08				2.39E-08						
R03I	5.93E-08	3.94E-08		3.94E-08								
R03IF	2.51E-07	1.71E-07		1.71E-07								
R03SI	0.00	0.00	0.00									
R03SIF	0.00	0.00	0.00									
R03SUI	0.00	0.00	0.00									
R03SUIF	0.00	0.00	0.00									
R03UI	5.87E-11	5.78E-11				5.78E-11						
R03UIF	1.39E-10	6.72E-10				6.72E-10						
R04	1.44E-07	1.38E-07		1.38E-07								
R04IF	0.00	0.00				0.00						
R04UIF	2.77E-08	2.75E-08				2.75E-08						
R05SLI	0.00	0.00	0.00									
R05SLIF	0.00	0.00	0.00									
R05SLUI	0.00	0.00	0.00									
R05SLUIF	0.00	0.00			0.00							
R07SLUI	0.00	0.00	0.00									
R07SLUIF	0.00	0.00	0.00									
R09I	7.93E-07	7.81E-07					7.81E-07					
R09UI	3.07E-07	3.02E-07					3.02E-07					
R11I	7.24E-06	4.78E-06					4.78E-06					
R11IF	1.09E-06	7.20E-07					7.20E-07					
R11UI	7.28E-09	7.17E-09					7.17E-09					
R17L	2.42E-06	2.66E-06					2.66E-06					
R17LU	2.63E-06	2.59E-06					2.59E-06					
R17U	3.26E-06	3.31E-06						3.31E-06				
R18	0.00	0.00							0.00			
R19	7.83E-08	7.83E-08							7.83E-08			
R20	8.21E-06	6.05E-06							6.05E-06			
R21	4.62E-05	3.56E-05								3.56E-05		
R22	8.91E-06	8.57E-06										8.57E-06
OTHERS	0.00	0.00										
TOTALS	8.31E-05	6.73E-05	0.00	3.49E-07	1.40E-06	5.22E-08	1.18E-05	3.31E-06	6.13E-06	3.56E-05	0.00	8.57E-06

TABLE 4-17c

CALCULATION OF AVERTED OFFSITE DOSE ENHANCEMENT CASE - CHANGE CHARGING PUMP COOLING FROM CCS TO ERCW

APB ID	BASE CASE APB FREQUENCY (EVENTS/YR)	REVISED APB FREQUENCY (EVENTS/YR)	BASE CASE POPULATION DOSE RATE (Man-REM/YR)	REVISED POPULATION DOSE RATE (Man-REM/YR)	BASE CASE POPULATION DOSE (Man-REM)	REVISED POPULATION DOSE (Man-REM)	AVERTED POPULATION DOSE (Man-REM)
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	4.54E-07	3.49E-07	8.27E-02	6.35E-02	3.31E+00	2.54E+00	7.67E-01
3	1.41E-06	1.40E-06	4.51E-01	4.47E-01	1.80E+01	1.79E+01	1.53E-01
4	5.18E-08	5.22E-08	1.75E-02	1.77E-02	7.02E-01	7.07E-01	-5.47E-03
5	1.45E-05	1.18E-05	9.95E-01	8.14E-01	3.98E+01	3.25E+01	7.26E+00
6	3.26E-06	3.31E-06	6.98E-02	7.09E-02	2.79E+00	2.83E+00	-4.13E-02
7	8.29E-06	6.13E-06	3.38E+00	2.50E+00	1.35E+02	1.00E+02	3.52E+01
8	4.62E-05	3.56E-05	9.24E-03	7.12E-03	3.69E-01	2.85E-01	8.45E-02
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	8.91E-06	8.57E-06	1.04E-03	9.98E-04	4.15E-02	3.99E-02	1.57E-03
TOTAL	8.31E-05	6.73E-05	5.01E+00	3.92E+00	2.00E+02	1.57E+02	43.46

4.5 IMPROVE CONTAINMENT PERFORMANCE

As discussed in above, the WBN Level 2 PRA identified several containment failure mechanisms as primary contributors to release from containment. These mechanisms include late hydrogen burns, late overpressurization and basemat melt through. Additionally, containment bypass, although not strictly a containment issue, was identified as a key contributor.

4.5.1 Install Deliberate Ignition System

This enhancement would provide a system to promote ignition of combustible gases generated within the containment during severe accident scenarios. This enhancement will reduce the vulnerability to SBO and other scenarios in which significant amounts of hydrogen are generated.

4.5.1.1 Existing Capabilities

The existing WBN design includes hydrogen ignitors. However, these ignitors are powered by AC power and are unavailable in some severe accident scenarios. The proposed enhancement would make the ignitors available in more severe accidents and could reduce the potential for hydrogen burns which could threaten containment integrity.

4.5.1.2 Description of Enhancement

A viable design alternative which provides the discussed enhancement to the existing hydrogen ignition capabilities at Watts Bar is presented in the draft NUREG-1150 (Reference 1). While this alternative was originally developed for Sequoyah, it is directly applicable to Watts Bar. The scope of the proposed system is to add hydrogen ignitors throughout the containment powered by a source independent of existing AC and DC power systems. Given the high cost associated with this design alternative, a detailed scope of this proposed improvement is not necessary to determine the cost effective of this candidate enhancement at Watts Bar.

4.5.1.3 Cost Estimate

A cost estimate for this enhancement is presented in the draft NUREG-1150. This estimate provides a central value of $4.9 million (1987 dollars). For the purpose of this evaluation, this estimate escalated to 1993 dollars or $6.1 million provides a reasonable and applicable value.

4.5.1.4 Risk Reduction Estimate

The WBN Level 2 spreadsheet models were used to evaluate the potential risk reduction benefit of the proposed change. The assumptions utilized were intended to maximize the potential benefit of the change. In this case it is assumed that all hydrogen burn related containment failures could be eliminated by this enhancement. Based on the Level 2 PRA results it was determined that the risk reduction worth of hydrogen burns was 0.99634 for early containment failures and 0.536 for late containment failures. Therefore, the population dose estimates for APB 3, 4 and 5 were adjusted accordingly. This resulted in an estimated reduction in the annual population dose risk of 0.535 person-rem per year. Based on this analysis, the total reduction in population dose is estimated to be 21.4 person rem over the 40 year life of the plant.

4.5.1.5 Value Impact Assessment

The value impact of this enhancement is based on a quantitative comparison of the cost of the enhancement and the potential risk reduction benefit. The total estimated cost for a deliberate ignition system is $6.1M. The risk reduction benefit associated with this change has been conservatively estimated to be 21.4 person-rem over the life of the plant. Therefore, the cost benefit ratio is

C/B Ratio = $6,100,000/21.4 person-rem = $285,047/person-rem

This ratio is more than $1000 per person rem. Therefore, based on this analysis, the enhancement to provide a deliberate ignition system is not considered cost beneficial.

4.5.2 Install Reactor Cavity Flooding System

This enhancement would provide a method to flood the reactor cavity region of the containment. The design of the reactor cavity in ice-condenser containments is such that the introduction of large quantities of water into the reactor cavity region and lower compartment can essentially preclude the possibility of direct contact of postulated ex-core hot debris with the containment liner and has potentially mitigating effects on corium-concrete interaction and direct containment heating. This enhancement will provide a means to inject a large quantity of water (on the order of the equivalent of two RWSTs) into the lower compartment and reactor cavity, and a capability of replenishing the water during boil-off.

4.5.2.1 Existing Capabilities

The existing design provides containment spray system which can be used to provide large quantities of water to the containment. However, its effectiveness is limited by it availability. Many of the WBN IPE severe accident scenarios involve failure of support systems such as AC power, CCS and ERCW which are required to operate the containment spray system.

4.5.2.2 Description of Enhancement

This system would consist of a diesel-driven pump to deliver water to the containment from a very large source. Following the initial injection, flow would be throttled to maintain the depth above the core debris. This aspect would require the ability to monitor beyond design basis water levels inside containment. Given the high cost associated with this enhancement, a detailed scope of this proposed improvement is not necessary to determine its cost effectiveness at Watts Bar.

4.5.2.3 Cost Estimate

Two cost estimates exist in published industry documents that provide applicable estimates for this enhancement at Watts Bar. Draft NUREG-1150 (Reference 1) identified this enhancement as a potential enhancement for the Sequoyah Nuclear Plant and provided a cost estimate that ranged from $5.3 million to $14 million (1987 dollars). The central value of the NUREG-1150 estimate was $7 million in 1987 dollars or approximately $8.75 million in 1993 dollars.

A second published source which provides an estimate is Texas Utilities' SAMDA evaluation report prepared for Comanche Peak (Reference 2). Reference 2 provides an estimate of $1.7 million in 1989 dollars. Escalation this amount to 1993 dollars results in an estimate of approximately $2.0 million.

The Comanche Peak cost estimate is based on the ability to use existing system and does not address the addition of an independently powered pump, additional stored water sources, additional piping and controls. The physical configuration of Comanche Peak's reactor cavity and sump is described in Reference 1 as follows:

> Due to the relative elevations of the containment sumps and the reactor cavity, the cavity will be partially filled if the sumps overflow. Following a LOCA and/or containment spray actuation, the containment will be flooded with most of the contents of the Reactor Coolant System (about 90,000 gallons) plus the contents of the RWST (about 500,000 gallons).

The physical configuration of Watts Bar's ice condenser containment is much different than Comanche Peak's dry containment. Watts Bar would require, at a minimum, an independently powered pump with access to a large water source for this enhancement to be effective as documented in NUREG/CR-5589 (Reference 3). Noting the additional equipment and materials that would be required for Watts Bar, it is clear without doing a detailed cost assessment that the cost estimate suggested by NRC in NUREG-1150 for Sequoyah provides a more representative cost for this enhancement at Watts Bar.

4.5.2.4 Risk Reduction Estimate

The WBN Level 2 spreadsheet models were used to evaluate the potential risk reduction benefit of the proposed change. The assumptions utilized were intended to maximize the potential benefit of the change. In this case, the reactor cavity flooding system could have beneficial impacts on all severe accidents except bypass events by either preventing vessel failure or containment failure. Based on Table 3-12, the total non-bypass population dose risk is 1.62 person-rem per year. Based on these assumptions, the maximum total reduction in population dose is estimated to be 65.0 person rem over the 40 year life of the plant.

4.5.2.5 Value Impact Assessment

The value impact of this enhancement is based on a quantitative comparison of the cost of the enhancement and the potential risk reduction benefit. The total estimated cost for the cavity flooding system is $8.75M. The risk reduction benefit associated with this change has been conservatively estimated to be 65.0 person-rem over the life of the plant. Therefore, the cost benefit ratio is

C/B Ratio = $8,750,000/65.0 person-rem = $133,800/person-rem

This ratio is more than $1000 per person rem. Therefore, based on this analysis, the enhancement to provide a cavity flooding system is not considered cost beneficial.

4.5.3 Install Filtered Containment Venting System

This enhancement would provide the capability to vent the containment through a vent path routed to an external filter. The filtered containment vent (FCV) would mitigate challenges to containment from long-term over-pressure and hydrogen burns by reducing the baseline containment pressure. The FCV may not be effective for mitigating energetic events such as hydrogen burns coincident with RCS failure. This enhancement will reduce the vulnerability to scenarios in which the containment over-pressure cannot be controlled.

4.5.3.1 Existing Capabilities

The WBN plant does not currently have a containment vent capability.

4.5.3.2 Description of Enhancement

Various options for the design of filtered containment venting system have been investigated by Philadelphia Electric Company for Limerick Nuclear Plant (Reference 1), by Texas Utilities for Comanche Peak Nuclear (Reference 2) by NRC (Reference 3) and by NRC Contractors (Reference 4). Given the high cost associated with each of this proposed improvement is not necessary to determine the cost effectiveness of this candidate enhancement at Watts Bar.

4.5.3.3 Cost Estimate

The cost estimate submitted by Philadelphia Electric and Texas Utilities ranged from $5.7 million to $16.5 million (both in 1989 dollars). In Reference 3, NRC estimate the cost for a FCV at Sequoyah to be on the order of $16 million (1987 dollars). While a specific dollar amount was not specified in NUREG/CR 5589, the cost for a FCV for an Ice Condenser Containment like Watts Bar's was categorized as "very high". For the purpose of this evaluation, the estimate provided in NUREG-1150 escalated to 1993 dollars or $20 million will be used.

4.5.3.4 Risk Reduction Estimate

The WBN Level 2 spreadsheet models were used to evaluate the potential risk reduction benefit of the proposed change. The assumptions utilized were intended to maximize the potential benefit of the change. In this case, the filtered containment venting system could have beneficial impacts on all severe accidents except bypass events by either preventing vessel failure or containment failure. Based on Table 3-12, the total non-bypass population dose risk is 1.62 person-rem per year. Based on these assumptions, the maximum total reduction in population dose is estimated to be 65.0 person rem over the 40 year life of the plant.

4.5.3.5 Value Impact Assessment

The value impact of this enhancement is based on a quantitative comparison of the cost of the enhancement and the potential risk reduction benefit. The total estimated cost for the filtered containment vent system is $20.0M. The risk reduction benefit associated with this change has been conservatively estimated to be 65.0 person-rem over the life of the plant. Therefore, the cost benefit ratio is

C/B Ratio = $20,000,000/65.0 person-rem = $307,700/person-rem

This ratio is more than $1000 per person rem. Therefore, based on this analysis, the enhancement to provide a filtered containment vent system is not considered cost beneficial.

4.5.4 Install Core Retention Device

This enhancement would provide a core debris control (CDC) system to prevent the direct impingement of core debris onto the primary containment steel shell during a high pressure core melt ejection (HPME) event. The CDC system would prevent the molten core material from contacting the containment shell by providing a barrier between the seal table and the containment shell in the seal table room. This enhancement will reduce the vulnerability of prompt containment failure for scenarios in which HPME may occur.

4.5.4.1 Existing Capabilities

The existing WBN design does not have a core retention device. In the existing design, if vessel failure occurs due to core melt with the RCS at low pressure, then the bulk of the core debris would be retained in the reactor cavity. However, the ability of cool the core debris in this geometry is limited.

4.5.4.2 Description of Enhancement

Various core debris control systems have been envisioned to provide the function described above. Two different systems were presented in Limerick's SAMDA submittal (Reference 1). The alternative investigated at Limerick were a basemat rubble bed core retention system and a dry crucible core retention system. A slightly different system is described in NUREG/CR-5589 (Reference 2) for ice condenser plants. The NUREG/CR-5589 alternative is to construct a "curb" of refractory or heat absorbing material around the containment wall in the seal table room to prevent or inhibit contact between core debris and the containment wall. Give the high cost associated with the two options defined in Reference 1, a detailed scope of this proposed improvement is not necessary to determine the cost effectiveness of this candidate enhancement at Watts Bar. Note that a cost estimate associated with this enhancement is not addressed in NUREG/CR-5589; however, the described benefits apply to a very limited scope of severe accidents.

4.5.4.3 Cost Estimate

The cost estimates developed for this SAMDA at Limerick ranged from $38 million to $119 million (1989 dollars). While the configuration of a core retention device at the Limerick

Nuclear Plant would be somewhat different than that for Watts Bar, the material properties and retention capabilities would be comparable. For the purposes of this evaluation, the lower estimate escalated to 1993 dollars or $44.5 million provides a reasonable value.

4.5.4.4 Risk Reduction Estimate

The WBN Level 2 spreadsheet models were used to evaluate the potential risk reduction benefit of the proposed change. The assumptions utilized were intended to maximize the potential benefit of the change. In this case, the core retention device could have beneficial impacts on all severe accidents except bypass events (APB #7) and containment failures which occur with the vessel intact (APBS #1 & 2) by preventing containment failure. Based on Table 3-12, the total population dose risk associated with these events is 1.54 person-rem per year. Based on these assumptions, the maximum total reduction in population dose is estimated to be 61.6 person rem over the 40 year life of the plant.

4.5.4.5 Value Impact Assessment

The value impact of this enhancement is based on a quantitative comparison of the cost of the enhancement and the potential risk reduction benefit. The total estimated cost for a core retention device is $44.5M. The risk reduction benefit associated with this change has been conservatively estimated to be 61.6 person-rem over the life of the plant. Therefore, the cost benefit ratio is

C/B Ratio = $44,500,000/61.6 person-rem = $722,400/person-rem

This ratio is more than $1000 per person rem. Therefore, based on this analysis, the enhancement to provide a core retention device is not considered cost beneficial.

4.5.5 Install Containment Inerting System

This enhancement would provide a containment inerting system (CIS) which would assure an inerted containment atmosphere to prevent the combustion of hydrogen and carbon monoxide produced during core damage scenarios. This enhancement will reduce the vulnerability of containment failure for scenarios in which the combustion of flammable gases may threaten containment integrity.

4.5.5.1 Existing Capabilities

The existing WBN design does not provide any inerting capability. Hydrogen accumulation is controlled through the use of ignitors.

4.5.5.2 Description of Enhancement

Two basic strategies exist for containment inerting systems. One strategy is to provide a system to maintain an inerted containment condition during operation. The other strategy is to provide a system which has the capability to inert the containment after an accident but before the formation of a significant amount of hydrogen. The benefits and limitations of each strategy are briefly discussed in NUREG/CR-5589 (Reference 1) and draft NUREG-1150 (Reference 2). Given the high cost associated with each of the options investigated in the references noted above, a detailed scope of this proposed improvement is not necessary to determine the cost effectiveness of this candidate enhancement at Watts Bar.

4.5.5.3 Cost Estimate

A cost estimate for a CIS for the Sequoyah Nuclear Plant, which has an ice condenser containment similar to Watts Bar, is presented in the draft NUREG-1150. This estimate provides a central value of $8.7 million (1987 dollars). While a specific dollar amount was not specified in NUREG/CR-5589, the cost for this enhancement was categorized as "high." For the purposes of this evaluation, the NUREG-1150 estimate escalated to 1993 dollars or $10.9 million provides a reasonable and applicable value.

4.5.5.4 Risk Reduction Estimate

The WBN Level 2 spreadsheet models were used to evaluate the potential risk reduction benefit of the proposed change. The assumptions utilized were intended to maximize the potential benefit of the change. In this case, as for enhancement V.1, it is assumed that all hydrogen burn related containment failures could be eliminated by this enhancement. Based on the Level 2 PRA results it was determined that the risk reduction worth of hydrogen burns was 0.99634 for early containment failures and 0.536 for late containment failures. Therefore, the population dose estimates for APB 3, 4 and 5 were adjusted accordingly. This resulted in an estimated reduction in the annual population dose risk of 0.535 person-rem per year. Based on this analysis, the total reduction in population dose is estimated to be 21.4 person rem over the 40 year life of the plant.

4.5.5.5 Value Impact Assessment

The value impact of this enhancement is based on a quantitative comparison of the cost of the enhancement and the potential risk reduction benefit. The total estimated cost for a containment inerting system is $10.9M. The risk reduction benefit associated with this change has been conservatively estimated to be 21.4 person-rem over the life of the plant. Therefore, the cost benefit ratio is

C/B Ratio = $10,900,000/21.4 person-rem = $509,300/person-rem

This ratio is more than $1000 per person rem. Therefore, based on this analysis, the enhancement to provide a containment inerting system is not considered cost beneficial.

4.5.6 Install Additional Containment Bypass Instrumentation

This enhancement involves the installation of pressure-monitoring instrumentation (permanent pressure sensors) between the first two pressure isolation valves on the low-pressure injection lines, RHR suction lines, and high-pressure injection lines. The additional instrumentation would improve the ability to detect valve leakage or open valves, and would decrease the frequency of Interfacing Systems Loss of Coolant Accident (ISLOCA). This enhancement will reduce the vulnerability to ISLOCA scenarios.

4.5.6.1 Existing Capabilities

No permanently installed instrumentation exists to detect increased pressure between these isolation valves. Local testing using temporary instruments is performed every refueling outage to ensure valve integrity.

4.5.6.2 Description of Enhancement

Evaluation of this enhancement does not require the development of a detailed scope of the plant enhancement. For the purpose of discussion the cost estimate prepared by Texas Utilities for the Comanche Peak Nuclear Plant (Reference 1) will be used.

4.5.6.3 Cost Estimate

The cost estimate submitted by Texas Utilities is as follows:

DESCRIPTION	COST $
Equipment, Materials, and Subcontracts	$ 100,000
Installation (Labor, Overhead, and Supervision)	$1,300,000
Engineering and QA	$ 300,000
Owner's Support Cost	$ 300,000
TOTAL	$2,000,000*

*(1989 Dollars or $2.3 million in 1994 dollars)

4.5.6.4 Risk Reduction Estimate

The WBN Level 1 and 2 spreadsheet models were used to evaluate the potential risk reduction benefit of the proposed procedure change. The assumptions utilized were intended to maximize the potential benefit of the change. In this case a 50% reduction in the ISLOCA frequency was assumed to be warranted based on the installation of the new instrumentation. Tables 4-18 a,b,c provide a summary of the results of the requantification of the PRA and population dose estimates. Based on this analysis, the total reduction in population dose is estimated to be 0.64 person rem over the 40 year life of the plant.

4.5.6.5 Value Impact Assessment

The value impact of this enhancement is based on a quantitative comparison of the cost of the enhancement and the potential risk reduction benefit. The total estimated cost for improved containment bypass instrumentation is $2.3M. The risk reduction benefit associated with this change has been conservatively estimated to be 0.64 person-rem over the life of the plant. Therefore, the cost benefit ratio is

C/B Ratio = $2,300,000/0.64 person-rem = $3,593,750/person-rem

This ratio is more than $1000 per person rem. Therefore, based on this analysis, the enhancement to provide improved containment bypass instrumentation is not considered cost beneficial.

4.5.7 Install Reactor Depressurization System

This enhancement would provide the capability to rapidly depressurize the reactor coolant system (RCS), thus allowing injection utilizing low-pressure systems. This would reduce the threat of direct containment heating (DCH) and induced failures of steam generator tubes and RCS piping in the event of low-pressure injection systems not being available. RCM depressurization could be achieved by a system specially designed to manually depressurize the RCS or by actuation of existing pressurizer power-operated relief valves (PORVs), reactor vessel head vent valves, and secondary system valves.

4.5.7.1 Existing Capabilities

The existing PORVs are inadequate to ensure that reactor pressure remains low during all core damage events.

TABLE 4-14
SUMMARY OF PDS AND KRC RESULTS
ENHANCEMENT CASE - INSTALL ADDITIONAL CONTAINMENT BYPASS INSTRUMENTATION

BASE CASE RESULTS				ENHANCEMENT CASE RESULTS				
LEVEL 1 OUTPUT KPDS	BASE CASE KPDS FREQUENCY	LEVEL 2 INPUT KPDS	BASE CASE KPDS FREQUENCY	KPDS FREQUENCY	KRC GROUP FREQUENCY			
					I	II	III	IV
ATV	7.83E-08	ATV	7.83E-08	3.93E-08	3.93E-08			
BCI	4.49E-06	BCI	4.49E-06	4.49E-06	2.77E-08		3.43E-06	1.03E-06
EGI	0.00	EGI	0.00	0.00	0.00		0.00	
EIB	5.52E-06	EIB	5.52E-06	5.52E-06		5.52E-06		
ENB	4.58E-07	ENB	4.58E-07	4.58E-07		4.58E-07		
ENI	3.84E-05	ENIYA	3.00E-05	3.00E-05	2.40E-07		4.77E-07	2.93E-05
ENS	2.24E-06	ENIYB	1.10E-06	1.10E-06	8.80E-09		1.09E-06	
FCI	2.46E-05	ENIYN	7.30E-06	7.30E-06	5.84E-08		7.24E-06	
FGI	0.00	ENSYA	5.20E-07	5.20E-07		5.20E-07		
FNI	0.00	ENSYB	1.65E-07	1.65E-07		1.65E-07		
GNI	4.95E-06	ENSYC	1.76E-07	1.76E-07		1.76E-07		
HCI	1.23E-06	ENSYN	1.37E-06	1.37E-06		1.37E-06		
HGI	1.11E-06	FCI	2.46E-05	2.46E-05	1.34E-07		8.30E-07	2.36E-05
HNI	0.00	FGI	0.00	0.00	0.00		0.00	0.00
KNI	0.00	FNI	0.00	0.00	0.00		0.00	0.00
KNS	0.00	GNIYA	3.49E-06	3.49E-06	8.55E-07		2.63E-06	
LCI	0.00	GNIYN	1.47E-06	1.47E-06	3.60E-07	0.00	1.11E-06	
LNI	0.00	HCI	1.23E-06	1.23E-06	9.80E-09		6.08E-08	1.16E-06
OTHERS	0.00	HGI	1.11E-06	1.11E-06	2.25E-07		8.81E-07	
		HNI	0.00	0.00	0.00		0.00	
		KNI	0.00	0.00	0.00		0.00	
		KNSYA	0.00	0.00	0.00	0.00		
		KNSYC	0.00	0.00	0.00	0.00		
		LCI	0.00	0.00	0.00		0.00	0.00
		LNIYA	0.00	0.00				0.00
		LNIYC	0.00	0.00	0.00		0.00	
		OTHERS	0.00	0.00				
		TOTALS	8.31E-05	8.31E-05	1.96E-06	8.21E-06	1.78E-05	5.51E-05

TABLE 4-14
TRANSLATION OF KRC FREQUENCIES TO APBs
ENHANCEMENT CASE - INSTALL ADDITIONAL CONTAINMENT BYPASS INSTRUMENTATION

KRC ID	BASE KRC FREQ	CASE KRC FREQ	APB FREQUENCIES									
			1	2	3	4	5	6	7	8	9	10
R01	6.13E-08	6.13E-08			6.13E-08							
R01DI	1.21E-06	1.21E-06			1.21E-06							
RO1I	3.91E-08	3.91E-08			3.91E-08							
R01IF	9.28E-08	9.28E-08			9.28E-08							
R01SI	0.00	0.00	0.00									
R01SIF	0.00	0.00	0.00									
R01SUI	0.00	0.00	0.00									
R01SUIF	0.00	0.00	0.00									
R01UI	2.15E-09	2.15E-09			2.15E-09							
R01UIF	5.10E-09	5.10E-09			5.10E-09							
R02IF	0.00	0.00			0.00							
R03	2.39E-08	2.39E-08				2.39E-08						
R03I	5.93E-08	5.93E-08		5.93E-08								
R03IF	2.51E-07	2.51E-07		2.51E-07								
R03SI	0.00	0.00	0.00									
R03SIF	0.00	0.00	0.00									
R03SUI	0.00	0.00	0.00									
R03SUIF	0.00	0.00	0.00									
R03UI	5.87E-11	5.87E-11				5.87E-11						
R03UIF	1.39E-10	1.39E-10				1.39E-10						
R04	1.44E-07	1.44E-07		1.44E-07								
R04IF	0.00	0.00				0.00						
R04UIF	2.77E-08	2.77E-08				2.77E-08						
R05SLI	0.00	0.00	0.00									
R05SLIF	0.00	0.00	0.00									
R05SLUI	0.00	0.00	0.00									
R05SLUIF	0.00	0.00			0.00							
R07SLUI	0.00	0.00	0.00									
R07SLUIF	0.00	0.00	0.00									
R09I	7.93E-07	7.93E-07					7.93E-07					
R09UI	3.07E-07	3.07E-07					3.07E-07					
R11I	7.24E-06	7.24E-06					7.24E-06					
R11IF	1.09E-06	1.09E-06					1.09E-06					
R11UI	7.28E-09	7.28E-09					7.28E-09					
R17L	2.42E-06	2.42E-06					2.42E-06					
R17LU	2.63E-06	2.63E-06					2.63E-06					
R17U	3.26E-06	3.26E-06						3.26E-06				
R18	0.00	0.00							0.00			
R19	7.83E-08	3.93E-08							3.93E-08			
R20	8.21E-06	8.21E-06							8.21E-06			
R21	4.62E-05	4.62E-05								4.62E-05		
R22	8.91E-06	8.91E-06										8.91E-06
OTHERS	0.00	0.00										
TOTALS	8.31E-05	8.31E-05	0.00	4.54E-07	1.41E-06	5.18E-08	1.45E-05	3.26E-06	8.25E-06	4.62E-05	0.00	8.91E-06

TABLE 4-14

CALCULATION OF AVERTED OFFSITE DOSE
ENHANCEMENT CASE - INSTALL ADDITIONAL CONTAINMENT BYPASS INSTRUMENTATION

APB ID	BASE CASE APB FREQUENCY (EVENTS/YR)	REVISED APB FREQUENCY (EVENTS/YR)	BASE CASE POPULATION DOSE RATE (Man-REM/YR)	REVISED POPULATION DOSE RATE (Man-REM/YR)	BASE CASE POPULATION DOSE (Man-REM)	REVISED POPULATION DOSE (Man-REM)	AVERTED POPULATION DOSE (Man-REM)
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	4.54E-07	4.54E-07	8.27E-02	8.27E-02	3.31E+00	3.31E+00	0.00
3	1.41E-06	1.41E-06	4.51E-01	4.51E-01	1.80E+01	1.80E+01	0.00
4	5.18E-08	5.18E-08	1.75E-02	1.75E-02	7.02E-01	7.02E-01	0.00
5	1.45E-05	1.45E-05	9.95E-01	9.95E-01	3.98E+01	3.98E+01	0.00
6	3.26E-06	3.26E-06	6.98E-02	6.98E-02	2.79E+00	2.79E+00	0.00
7	8.29E-06	8.25E-06	3.38E+00	3.37E+00	1.35E+02	1.35E+02	6.37E-01
8	4.62E-05	4.62E-05	9.24E-03	9.24E-03	3.69E-01	3.69E-01	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	8.91E-06	8.91E-06	1.04E-03	1.04E-03	4.15E-02	4.15E-02	0.00
TOTAL	8.31E-05	8.31E-05	5.01E+00	4.99E+00	2.00E+02	2.00E+02	6.37E-01

4.5.7.2 Description of Enhancement

A risk reduction measure which provides a system for depressurization of the RCS is presented in the draft NUREG-1150 (Reference 1). While the enhancement described in NUREG-1150 was originally developed for Sequoyah, it is directly applicable to Watts Bar. Given the high cost associated with this design alternative, a detailed scope of this proposed improvement is not necessary to determine the cost effectiveness of this candidate enhancement at Watts Bar.

4.5.7.3 Cost Estimate

A cost estimate for this enhancement is presented in the draft NUREG-1150. This estimate provides a central value of $3.7 million (1987 dollars) or $4.6 million in 1993 dollars. For the purpose of this evaluation, the estimate provides a reasonable and applicable value.

4.5.7.4 Risk Reduction Estimate

The WBN Level 1 and 2 spreadsheet models were used to evaluate the potential risk reduction benefit of the proposed procedure change. The assumptions utilized were intended to maximize the potential benefit of the change. This enhancement impacts primarily the severe accident sequences which involve containment failure due to high pressure melt ejection (HPME). These contribute to APB #3. Assuming that all the sequences in APB # 3 could be eliminated and mitigated in containment. This lead to a risk reduction of 0.45 person-rem per year. Based on this assumption, the total reduction in population dose is estimated to be 18.0 person rem over the 40 year life of the plant.

4.5.7.5 Value Impact Assessment

The value impact of this enhancement is based on a quantitative comparison of the cost of the enhancement and the potential risk reduction benefit. The total estimated cost for a reactor depressurization system is $4.6M. The risk reduction benefit associated with this change has been conservatively estimated to be 18.0 person-rem over the life of the plant. Therefore, the cost benefit ratio is

C/B Ratio = $4,600,000/18.0 person-rem = $255,600/person-rem

This ratio is more than $1000 per person rem. Therefore, based on this analysis, the enhancement to provide a reactor depressurization system is not considered cost beneficial.

4.5.8 Install Independent Containment Spray System

This enhancement would provide an independent containment spray system. The spray system would cool the core debris and provide containment heat removal thus preventing over-temperature and long-term over-pressure by steam. This enhancement will reduce the vulnerability to SBO and other scenarios where steam overpressure and/or quench of core debris ex-vessel is important.

4.5.8.1 Existing Capabilities

The existing containment spray system provides a means of containment heat removal and containment pressure control and is credited in the WBN IPE. However, it shares many common support systems (AC/DC power, CCS, ERCW, etc.) with the systems required to prevent core damage. Therefore, it is in some cases unavailable after core damage to perform these functions.

4.5.8.2 Description of Enhancement

Two design alternatives which provide an enhancement to the containment spray system are presented in the draft NUREG-1150 (Reference 1). These alternatives were originally developed for Sequoyah, but they are applicable to Watts Bar as well. These alternatives are: 1) the installation of an independent train of containment spray with injection capability only; and 2) the addition of a train of containment spray with recirculation and heat removal capabilities, but independent of existing support systems. Given the high cost associated with either of the alternatives described above, a detailed scope of this proposed improvement is not necessary to determine the cost effectiveness of this candidate enhancement at Watts Bar.

4.5.8.3 Cost Estimate

A cost estimate for these two alternatives for the Sequoyah Nuclear Plant, which has an existing containment spray system similar to that at Watts Bar, is presented in the draft NUREG-1150. This estimate provides a central value of $4.6 million for alternative 1 and $9.7 million for alternative 2 (both in 1987 dollars). For the purposes of this evaluation, the lower estimate escalated to 1993 dollars or $5.8 million provides a reasonable and applicable estimate for Watts Bar.

4.5.8.4 Risk Reduction Estimate

The WBN Level 2 spreadsheet models were used to evaluate the potential risk reduction benefit of the proposed change. The assumptions utilized were intended to maximize the potential benefit of the change. In this case, the independent containment spray system

could have beneficial impacts on all severe accidents except bypass events (APB #7) and containment failures which occur with the vessel intact (APBS #1 & 2) by preventing containment failure. Based on Table 3-12, the total population dose risk associated with these events is 1.54 person-rem per year. Based on these assumptions, the maximum total reduction in population dose is estimated to be 61.6 person rem over the 40 year life of the plant.

4.5.8.5 Value Impact Assessment

The value impact of this enhancement is based on a quantitative comparison of the cost of the enhancement and the potential risk reduction benefit. The total estimated cost for - an independent containment spray system is $5.8M. The risk reduction benefit associated with this change has been conservatively estimated to be 61.6 person-rem over the life of the plant. Therefore, the cost benefit ratio is

C/B Ratio = $5,800,000/61.6 person-rem = $94,000/person-rem

This ratio is more than $1000 per person rem. Therefore, based on this analysis, the enhancement to provide an independent containment spray system is not considered cost beneficial.

4.5.9 AC Independent Air Return Fan Power Supplies

The containment system at Watts Bar includes two ARF each having 100% capacity. The design function of each ARF is to create forced recirculation from the upper containment to the lower containment which ultimately forces the air back up through the ice condenser again. This function serves to maximize the pressure suppression capabilities of the ice condenser, and promote mixing within the containment regions to prevent the accumulation of detonable concentrations of hydrogen within the containment. This enhancement will provide the ARF functions for accident scenarios in which normal operation is not possible, e.g., Station Blackout.

4.5.9.1 Existing Capabilities

The existing air return fans are dependent upon dependent upon 1E AC power.

4.5.9.2 Description of Enhancement

An enhancement of the ARF is identified as a candidate enhancement in NUREG/CR-5589 (Reference 1). The most likely cause of fan failures is the unavailability of AC power. Therefore, the design scope of enhancement is to provide an independent

power source to improve the reliability of the fans. This independent power source must be capable of powering at least one of the ARF.

Design Assumptions:

1) It is assumed that the normal offsite and emergency EDG power supplies have been lost.

2) It is assumed that the containment is intact.

3) Credit is allowed for limited manual actions outside of the control room; however, no credit is allowed for manual actions inside containment or in areas that would have high radiation in the Auxiliary building after a core damage event.

4) The dedicated EDG is not safety related an d should be appropriately isolated from the safety-related board that normally powers the ARF.

5) The dedicated EDG shall have its own dedicated fuel oil storage tank.

6) The dedicated EDG shall have its own dedicated DC battery source for cranking, control and field flashing capabilities.

7) A dedicated and independent structure designed to commercial building code requirements shall be constructed. This building shall provide for adequate ventilation to support long term operation of the EDG during any expected weather condition. Provisions shall also include a commercial non-safety HVAC system to maintain an acceptable day-to-day environmental condition.

8) This building shall also be equipped with appropriate fire detection and suppression capabilities.

9) The routing of the new power leads to required electrical devices and additional piping shall not compromise the functional integrity of any structure, system or component.

10) Seismic and harsh environmental qualification is only required where failure may impact existing safety systems.

4.5.9.3 Cost Estimate

The following cost estimate includes the engineering, construction, and materials required to implement this enhancement based on the scope description provided above. Licensing and Maintenance costs have not been included. The following table summarizes these costs and provides the total estimated cost for this enhancement.

DESCRIPTION	COST $ (THOUSANDS)
Engineering Total for Independent Diesel Generator	$100.55
Construction Total for Independent Diesel Generator	$214.50
Materials for Independent Diesel Generator	$583.00
Materials for Diesel Generator Building	$102.60
Additional Engineering and Materials Cost to Tie Diesel Generator to Safety-Related Board Which Normally Powers the ARF	$27.00
TOTAL	$1,027.65

4.5.9.4 Risk Reduction Estimate

The WBN Level 2 spreadsheet models were used to evaluate the potential risk reduction benefit of the proposed change. The assumptions utilized were intended to maximize the potential benefit of the change. In this case, as for enhancement V.1, it is assumed that all hydrogen burn related containment failures could be eliminated by this enhancement. Based on the Level 2 PRA results it was determined that the risk reduction worth of hydrogen burns was 0.99634 for early containment failures and 0.536 for late containment failures. Therefore, the population dose estimates for APB 3, 4 and 5 were adjusted accordingly. This resulted in an estimated reduction in the annual population dose risk of 0.535 person-rem per year. Based on this analysis, the total reduction in population dose is estimated to be 21.4 person rem over the 40 year life of the plant.

4.5.9.5 Value Impact Assessment

The value impact of this enhancement is based on a quantitative comparison of the cost of the enhancement and the potential risk reduction benefit. The total estimated cost for AC independent air return fan power supplies is $1.0M. The risk reduction benefit associated with this change has been conservatively estimated to be 21.4 person-rem over the life of the plant. Therefore, the cost benefit ratio is

C/B Ratio = $1,000,000/21.4 person-rem = $46,700/person-rem

This ratio is more than $1000 per person rem. Therefore, based on this analysis, the enhancement to provide AC independent air return fan power supplies is not considered cost beneficial.

4.6 MISCELLANEOUS

As part of the detailed review of the dominant contributors to core damage and containment failure, several other potential enhancements were identified.

4.6.1 Install MG Set Trip Breakers in Control Room (ATWS)

This enhancement would provide trip breakers for the MG sets in the WBN control room. In the current design, if an ATWS were to occur, the plant operators would be instructed to trip the MG sets which would require an immediate action outside the control room. This enhancement would simplify that action and decrease the risk of an ATWS event.

4.6.1.1 Existing Capabilities

The current plant design requires an operator outside the control room to locally trip the breakers providing power to the MG sets. This requires additional time and communications which could be avoided by installing switches in the control room to perform the same function.

4.6.1.2 Description of Enhancement

This enhancement would implement a non-safety grade method of triping the CRDM MG supply breakers from the main Control Room in the event of an ATWS and the failure of the existing relays/circuitry to trip the reactor. The design would require a main control room control panel modification to install a new trip switch and associated cable runs. A new relaying panel would need to be mounted near the CRDM MG supply breakers and several relays mounted. Internal wiring changes within the MG breakers and on the relay panel would connect the new switch into the supply breaker circuit.

4.6.1.3 Cost Estimate

The cost elements associated with hardware changes for this enhancement are summarized in Table 4-19. In addition to the hardware changes, a procedural change would be required. This cost is assumed to be the same as the cost summarized in Table 4-2 ($25,200). The total cost $142,500.

4.6.1.4 Risk Reduction Estimate

The WBN Level 1 and 2 spreadsheet models were used to evaluate the potential risk reduction benefit of the proposed change. The assumptions utilized were intended to maximize the potential benefit of the change. In this case, the assumed benefit was conservatively represented as the elimination of all failure to trip the reactor. This estimate is highly conservative because it ignores any mechanical faults in the reactor trip system which would be unaffected by the electrical design change. Tables 4-20 a,b,c provide a summary of the results of the requantification of the PRA and population dose estimates. Based on this analysis, the total reduction in population dose is estimated to be 2.06 person rem over the 40 year life of the plant.

4.6.1.5 Value Impact Assessment

The value impact of this enhancement is based on a quantitative comparison of the cost of the enhancement and the potential risk reduction benefit. The total estimated cost for providing control room switches to trip the reactor trip breaker MG sets is $142,500. The risk reduction benefit associated with this change has been conservatively estimated to be 2.06 person-rem over the life of the plant. Therefore, the cost benefit ratio is

C/B Ratio = $142,500/2.06 person-rem = $69,175/person-rem

This ratio is more than $1000 per person rem. Therefore, based on this analysis, the enhancement to provide control room switches to trip the reactor trip breaker MG sets is not considered cost beneficial.

4.6.2 Improve Procedures to Provide Temporary HVAC During Loss of Cooling (Loss of CCS)

Many rooms which contain ECCS, electrical and other key support equipment require room cooling to ensure availability of components. This enhancement involves the development of procedures to cope with loss of a room cooler by providing a temporary means of room cooling. Loss of an existing room cooler could lead to overheating of equipment and subsequent failure. However, depending upon the component, conditions and configuration failure could be delayed significantly (i.e., an hour or more). Thus, time could be available for plant operators to provide a temporary means of room cooling until the normal cooling could be restored.

4.6.2.1 Existing Capabilities

Existing room cooling for ECCS equipment of concern is provided by room coolers cooled by CCS and powered from 1E AC buses. Most room are large enough to require

Table 4-19
CRDMG Supply Breaker Trip From Main Control Room

Scope:		
Design and implement a non safety grade method of triping the CRDM MG supply breakers from the main Control Room in the event of an ATWAS and the failure of the existing relays/circuitry to trip the reactor. Design would require a MCR control panel modification to install new trip switch, approximately 3 cable runs of 500ft each of which about 100ft each would have to be in conduit. A new relaying panel would need to be mounted near the CRDM MG supply breakers and several relays mounted. Internal wiring changes within the MG breakers and the on relay panel would connect the new switch into the supply breaker circuit.		
Engineering:		
Medium Large DCN = 615 hours with no special analyses required		
615 hours * $56 per hour	$34.4K	
Engineering Cost		$34.4K
Materials:		
Engineered Materials: None		
Bulk Commodities	$11.7K	
Material Cost		$11.7K
Construction:		
Trade and Labor 2,327 manhours * $25 per manhour	$58.2K	
Management & Oversight (10% of T & L) 233 manhours * $56 per manhour	$13K	
Construction Cost		$71.2K
	Total	$117.3K

TABLE 4-20a
SUMMARY OF PDS AND KRC RESULTS
ENHANCEMENT CASE - INSTALL MG SET TRIP BREAKERS IN CONTROL ROOM (ATWS)

BASE CASE RESULTS				ENHANCEMENT CASE RESULTS				
LEVEL 1 OUTPUT KPDS	BASE CASE KPDS FREQUENCY	LEVEL 2 INPUT KPDS	BASE CASE KPDS FREQUENCY	KPDS FREQUENCY	KRC GROUP FREQUENCY			
					I	II	III	IV
ATV	7.83E-08	ATV	7.83E-08	7.83E-08	7.83E-08			
BCI	4.49E-06	BCI	4.49E-06	4.17E-06	2.57E-08		3.19E-06	9.60E-07
EGI	0.00	EGI	0.00	0.00	0.00		0.00	
EIB	5.52E-06	EIB	5.52E-06	5.45E-06		5.45E-06		
ENB	4.58E-07	ENB	4.58E-07	4.58E-07		4.58E-07		
ENI	3.84E-05	ENIYA	3.00E-05	3.00E-05	2.40E-07		4.77E-07	2.93E-05
ENS	2.24E-06	ENIYB	1.10E-06	1.10E-06	8.80E-09		1.09E-06	
FCI	2.46E-05	ENIYN	7.30E-06	7.30E-06	5.84E-08		7.24E-06	
FGI	0.00	ENSYA	5.20E-07	5.18E-07		5.18E-07		
FNI	0.00	ENSYB	1.65E-07	1.64E-07		1.64E-07		
GNI	4.95E-06	ENSYC	1.76E-07	1.76E-07		1.76E-07		
HCI	1.23E-06	ENSYN	1.37E-06	1.37E-06		1.37E-06		
HGI	1.11E-06	FCI	2.46E-05	2.09E-05	1.14E-07		7.06E-07	2.01E-05
HNI	0.00	FGI	0.00	0.00	0.00		0.00	0.00
KNI	0.00	FNI	0.00	0.00	0.00		0.00	0.00
KNS	0.00	GNIYA	3.49E-06	3.49E-06	8.55E-07		2.63E-06	
LCI	0.00	GNIYN	1.47E-06	1.47E-06	3.60E-07	0.00	1.11E-06	
LNI	0.00	HCI	1.23E-06	1.01E-06	8.05E-09		4.99E-08	9.48E-07
OTHERS	0.00	HGI	1.11E-06	1.11E-06	2.25E-07		8.81E-07	
		HNI	0.00	0.00	0.00		0.00	
		KNI	0.00	0.00	0.00		0.00	
		KNSYA	0.00	0.00	0.00	0.00		
		KNSYC	0.00	0.00	0.00	0.00		
		LCI	0.00	0.00	0.00		0.00	0.00
		LNIYA	0.00	0.00				0.00
		LNIYC	0.00	0.00	0.00		0.00	
		OTHERS	0.00	0.00				
		TOTALS	8.31E-05	7.88E-05	1.97E-06	8.13E-06	1.74E-05	5.13E-05

TABLE 4-20b
TRANSLATION OF KRC FREQUENCIES TO APBs
ENHANCEMENT CASE - INSTALL MG SET TRIP BREAKERS IN CONTROL ROOM (ATWS)

KRC ID	BASE KRC FREQ	CASE KRC FREQ	APB FREQUENCIES									
			1	2	3	4	5	6	7	8	9	10
R01	6.13E-08	6.13E-08			6.13E-08							
R01DI	1.21E-06	1.21E-06			1.21E-06							
R01I	3.91E-08	3.91E-08			3.91E-08							
R01IF	9.28E-08	9.28E-08			9.28E-08							
R01SI	0.00	0.00	0.00									
R01SIF	0.00	0.00	0.00									
R01SUI	0.00	0.00	0.00									
R01SUIF	0.00	0.00	0.00									
R01UI	2.15E-09	2.15E-09			2.15E-09							
R01UIF	5.10E-09	5.10E-09			5.10E-09							
R02IF	0.00	0.00			0.00							
R03	2.39E-08	2.39E-08				2.39E-08						
R03I	5.93E-08	5.93E-08		5.93E-08								
R03IF	2.51E-07	2.51E-07		2.51E-07								
R03SI	0.00	0.00	0.00									
R03SIF	0.00	0.00	0.00									
R03SUI	0.00	0.00	0.00									
R03SUIF	0.00	0.00	0.00									
R03UI	5.87E-11	5.87E-11				5.87E-11						
R03UIF	1.39E-10	1.39E-10				1.39E-10						
R04	1.44E-07	1.22E-07		1.22E-07								
R04IF	0.00	0.00				0.00						
R04UIF	2.77E-08	2.57E-08				2.57E-08						
R05SLI	0.00	0.00	0.00									
R05SLIF	0.00	0.00	0.00									
R05SLUI	0.00	0.00	0.00									
R05SLUIF	0.00	0.00			0.00							
R07SLUI	0.00	0.00	0.00									
R07SLUIF	0.00	0.00	0.00									
R09I	7.93E-07	7.93E-07					7.93E-07					
R09UI	3.07E-07	3.07E-07					3.07E-07					
R11I	7.24E-06	7.24E-06					7.24E-06					
R11IF	1.09E-06	1.09E-06					1.09E-06					
R11UI	7.28E-09	7.28E-09					7.28E-09					
R17L	2.42E-06	2.27E-06					2.27E-06					
R17LU	2.63E-06	2.63E-06					2.63E-06					
R17U	3.26E-06	3.03E-06						3.03E-06				
R18	0.00	0.00							0.00			
R19	7.83E-08	7.83E-08							7.83E-08			
R20	8.21E-06	8.13E-06							8.13E-06			
R21	4.62E-05	4.37E-05								4.37E-05		
R22	8.91E-06	7.66E-06										7.66E-06
OTHERS	0.00	0.00										
TOTALS	8.31E-05	7.88E-05	0.00	4.32E-07	1.41E-06	4.98E-08	1.43E-05	3.03E-06	8.21E-06	4.37E-05	0.00	7.66E-06

TABLE 4-20c

CALCULATION OF AVERTED OFFSITE DOSE
ENHANCEMENT CASE - INSTALL MG SET TRIP BREAKERS IN CONTROL ROOM (ATWS)

APB ID	BASE CASE APB FREQUENCY (EVENTS/YR)	REVISED APB FREQUENCY (EVENTS/YR)	BASE CASE POPULATION DOSE RATE (Man-REM/YR)	REVISED POPULATION DOSE RATE (Man-REM/YR)	BASE CASE POPULATION DOSE (Man-REM)	REVISED POPULATION DOSE (Man-REM)	AVERTED POPULATION DOSE (Man-REM)
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	4.54E-07	4.32E-07	8.27E-02	7.88E-02	3.31E+00	3.15E+00	1.58E-01
3	1.41E-06	1.41E-06	4.51E-01	4.51E-01	1.80E+01	1.80E+01	0.00
4	5.18E-08	4.98E-08	1.75E-02	1.69E-02	7.02E-01	6.75E-01	2.66E-02
5	1.45E-05	1.43E-05	9.95E-01	9.85E-01	3.98E+01	3.94E+01	4.03E-01
6	3.26E-06	3.03E-06	6.98E-02	6.49E-02	2.79E+00	2.59E+00	1.98E-01
7	8.29E-06	8.21E-06	3.38E+00	3.35E+00	1.35E+02	1.34E+02	1.25E+00
8	4.62E-05	4.37E-05	9.24E-03	8.73E-03	3.69E-01	3.49E-01	2.04E-02
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	8.91E-06	7.66E-06	1.04E-03	8.92E-04	4.15E-02	3.57E-02	5.79E-03
TOTAL	8.31E-05	7.88E-05	5.01E+00	4.96E+00	2.00E+02	1.98E+02	2.06E+00

a significant period of time (i.e., hours) to heatup. However, some rooms are not large enough or do not contain adequate heat sinks to avoid overheating of components within the mission time required. Additional capability is possible, if temporary cooling could b established.

4.6.2.2 Description of Enhancement

Provide procedures to direct the use of temporary fans to provide circulation of air to/from rooms without cooling.

4.6.2.3 Cost Estimate

The cost associated with this change only involve the development of procedural direction since fans are available on site for use. The cost estimate presented in Table 4-2 for procedure change and training was used as the basis for this enhancement.

4.6.2.4 Risk Reduction Estimate

The WBN Level 1 and 2 spreadsheet models were used to evaluate the potential risk reduction benefit of the proposed procedure change. The assumptions utilized were intended to maximize the potential benefit of the change. In this case, the dominant split fractions containing failure of room coolers were requantified to eliminate the need for room cooling. This provides a bounding estimate of impact of room coolers on risk. The actual benefit of this enhancement would be slightly less when the human action was accounted for.

Tables 4-21 a,b,c provide a summary of the results of the requantification of the PRA and population dose estimates. Based on this analysis, the total reduction in population dose is estimated to be 0.5 person rem over the 40 year life of the plant.

4.6.2.5 Value Impact Assessment

The value impact of this enhancement is based on a quantitative comparison of the cost of the enhancement and the potential risk reduction benefit. The total estimated cost for improved procedures to provide temporary HVAC during loss of cooling is $25,200. The risk reduction benefit associated with this change has been conservatively estimated to be 0.5 person-rem over the life of the plant. Therefore, the cost benefit ratio is

C/B Ratio = $25,200/0.5 person-rem = $50,400/person-rem

This ratio is more than $1000 per person rem. Therefore, based on this analysis, the enhancement to provide improved procedures to provide temporary HVAC during loss of cooling is not considered cost beneficial.

TABLE 4-21a
SUMMARY OF PDS AND KRC RESULTS
ENHANCEMENT CASE - IMPROVE PROCEDURES TO PROVIDE TEMPORARY HVAC DURING LOSS OF COOLING (LOSS OF CCS)

BASE CASE RESULTS				ENHANCEMENT CASE RESULTS				
LEVEL 1 OUTPUT KPDS	BASE CASE KPDS FREQUENCY	LEVEL 2 INPUT KPDS	BASE CASE KPDS FREQUENCY	KPDS FREQUENCY	KRC GROUP FREQUENCY			
					I	II	III	IV
ATV	7.83E-08	ATV	7.83E-08	7.83E-08	7.83E-08			
BCI	4.49E-06	BCI	4.49E-06	4.43E-06	2.73E-08		3.38E-06	1.02E-06
EGI	0.00	EGI	0.00	0.00	0.00		0.00	
EIB	5.52E-06	EIB	5.52E-06	5.53E-06		5.53E-06		
ENB	4.58E-07	ENB	4.58E-07	4.37E-07		4.37E-07		
ENI	3.84E-05	ENIYA	3.00E-05	2.99E-05	2.39E-07		4.74E-07	2.92E-05
ENS	2.24E-06	ENIYB	1.10E-06	1.09E-06	8.76E-09		1.09E-06	
FCI	2.46E-05	ENIYN	7.30E-06	7.27E-06	5.81E-08		7.21E-06	
FGI	0.00	ENSYA	5.20E-07	5.20E-07		5.20E-07		
FNI	0.00	ENSYB	1.65E-07	1.65E-07		1.65E-07		
GNI	4.95E-06	ENSYC	1.76E-07	1.76E-07		1.76E-07		
HCI	1.23E-06	ENSYN	1.37E-06	1.37E-06		1.37E-06		
HGI	1.11E-06	FCI	2.46E-05	2.39E-05	1.30E-07		8.05E-07	2.29E-05
HNI	0.00	FGI	0.00	0.00	0.00		0.00	0.00
KNI	0.00	FNI	0.00	0.00	0.00		0.00	0.00
KNS	0.00	GNIYA	3.49E-06	3.49E-06	8.55E-07		2.63E-06	
LCI	0.00	GNIYN	1.47E-06	1.47E-06	3.60E-07	0.00	1.11E-06	
LNI	0.00	HCI	1.23E-06	1.19E-06	9.55E-09		5.92E-08	1.12E-06
OTHERS	0.00	HGI	1.11E-06	1.11E-06	2.25E-07		8.81E-07	
		HNI	0.00	0.00	0.00		0.00	
		KNI	0.00	0.00	0.00		0.00	
		KNSYA	0.00	0.00	0.00	0.00		
		KNSYC	0.00	0.00	0.00	0.00		
		LCI	0.00	0.00	0.00		0.00	0.00
		LNIYA	0.00	0.00				0.00
		LNIYC	0.00	0.00	0.00		0.00	
		OTHERS	0.00	0.00				
		TOTALS	8.31E-05	8.21E-05	1.99E-06	8.20E-06	1.76E-05	5.42E-05

TABLE 4-21b
TRANSLATION OF KRC FREQUENCIES TO APBs
ENHANCEMENT CASE - IMPROVE PROCEDURES TO PROVIDE TEMPORARY HVAC DURING LOSS OF COOLING (LOSS OF CCS)

KRC ID	BASE KRC FREQ	CASE KRC FREQ	APB FREQUENCIES									
			1	2	3	4	5	6	7	8	9	10
R01	6.13E-08	6.13E-08			6.13E-08							
R01DI	1.21E-06	1.21E-06			1.21E-06							
RO1I	3.91E-08	3.91E-08			3.91E-08							
R01IF	9.28E-08	9.28E-08			9.28E-08							
R01SI	0.00	0.00	0.00									
R01SIF	0.00	0.00	0.00									
R01SUI	0.00	0.00	0.00									
R01SUIF	0.00	0.00	0.00									
R01UI	2.15E-09	2.15E-09			2.15E-09							
R01UIF	5.10E-09	5.10E-09			5.10E-09							
R02IF	0.00	0.00			0.00							
R03	2.39E-08	2.39E-08				2.39E-08						
R03I	5.93E-08	5.91E-08		5.91E-08								
R03IF	2.51E-07	2.50E-07		2.50E-07								
R03SI	0.00	0.00	0.00									
R03SIF	0.00	0.00	0.00									
R03SUI	0.00	0.00	0.00									
R03SUIF	0.00	0.00	0.00									
R03UI	5.87E-11	5.87E-11				5.87E-11						
R03UIF	1.39E-10	1.39E-10				1.39E-10						
R04	1.44E-07	1.39E-07		1.39E-07								
R04IF	0.00	0.00				0.00						
R04UIF	2.77E-08	2.73E-08				2.73E-08						
R05SLI	0.00	0.00	0.00									
R05SLIF	0.00	0.00	0.00									
R05SLUI	0.00	0.00	0.00									
R05SLUIF	0.00	0.00			0.00							
R07SLUI	0.00	0.00	0.00									
R07SLUIF	0.00	0.00	0.00									
R09I	7.93E-07	7.93E-07					7.93E-07					
R09UI	3.07E-07	3.07E-07					3.07E-07					
R11I	7.24E-06	7.21E-06					7.21E-06					
R11IF	1.09E-06	1.09E-06					1.09E-06					
R11UI	7.28E-09	7.28E-09					7.28E-09					
R17L	2.42E-06	2.39E-06					2.39E-06					
R17LU	2.63E-06	2.63E-06					2.63E-06					
R17U	3.26E-06	3.21E-06						3.21E-06				
R18	0.00	0.00							0.00			
R19	7.83E-08	7.83E-08							7.83E-08			
R20	8.21E-06	8.20E-06							8.20E-06			
R21	4.62E-05	4.56E-05								4.56E-05		
R22	8.91E-06	8.65E-06										8.65E-06
OTHERS	0.00	0.00										
TOTALS	8.31E-05	8.21E-05	0.00	4.48E-07	1.41E-06	5.14E-08	1.44E-05	3.21E-06	8.28E-06	4.56E-05	0.00	8.65E-06

TABLE 4-21c

CALCULATION OF AVERTED OFFSITE DOSE
ENHANCEMENT CASE - IMPROVE PROCEDURES TO PROVIDE TEMPORARY HVAC DURING LOSS OF COOLING (LOSS OF CCS)

APB ID	BASE CASE APB FREQUENCY (EVENTS/YR)	REVISED APB FREQUENCY (EVENTS/YR)	BASE CASE POPULATION DOSE RATE (Man-REM/YR)	REVISED POPULATION DOSE RATE (Man-REM/YR)	BASE CASE POPULATION DOSE (Man-REM)	REVISED POPULATION DOSE (Man-REM)	AVERTED POPULATION DOSE (Man-REM)
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	4.54E-07	4.48E-07	8.27E-02	8.17E-02	3.31E+00	3.27E+00	4.19E-02
3	1.41E-06	1.41E-06	4.51E-01	4.51E-01	1.80E+01	1.80E+01	3.55E-04
4	5.18E-08	5.14E-08	1.75E-02	1.74E-02	7.02E-01	6.96E-01	5.68E-03
5	1.45E-05	1.44E-05	9.95E-01	9.90E-01	3.98E+01	3.96E+01	1.95E-01
6	3.26E-06	3.21E-06	6.98E-02	6.88E-02	2.79E+00	2.75E+00	4.19E-02
7	8.29E-06	8.28E-06	3.38E+00	3.38E+00	1.35E+02	1.35E+02	1.84E-01
8	4.62E-05	4.56E-05	9.24E-03	9.11E-03	3.69E-01	3.64E-01	5.16E-03
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	8.91E-06	8.65E-06	1.04E-03	1.01E-03	4.15E-02	4.03E-02	1.18E-03
TOTAL	8.31E-05	8.21E-05	5.01E+00	5.00E+00	2.00E+02	2.00E+02	4.75E-01

Section 5
CONCLUSIONS

A comprehensive, systematic effort to identify potentially cost beneficial plant enhancement for Watts Bar Unit 1 has been completed. This analysis included the identification of potential enhancements based on the review of plant specific results and insights from the Watts Bar Unit 1 updated Individual Plant Examination (IPE), review of other ice condenser plant IPEs and review of industry and NRC studies of potential plant improvements. Plant specific cost benefit analyses were performed to provide a basis for recommendations. A summary of the quantitative results of the cost benefit analyses is shown in Table 5-1.

Based on the results of the cost benefit analysis, two potential plant enhancements are recommended for implementation. The first involves development of appropriate procedural guidance for incorporation into plant emergency operating procedures which would direct plant operators to place one train of containment spray in standby prior to establishing high pressure recirculation. This enhancement addresses the largest contributor to core damage, small LOCA with failure of ECCS recirculation, by providing additional time for operator actions to align high pressure recirculation and response to hardware failures.

The second enhancement involves the development of a plant procedure which would facilitate the cross-tie of 500kV offsite power to the 6.9kV shutdown boards at Unit 1. This procedure would provide an additional, diverse source of offsite power in the event of loss of the normal 161kV offsite power supply to the shutdown boards. This enhancement addresses the second largest contributor to core damage risk: station blackout.

All other potential enhancements were found to be non-cost beneficial. Several of the potential enhancements were found to be within a factor of two to five of being cost beneficial. All of these are related to either loss of offsite power or failure of ECCS recirculation which will be addressed by the implementation of the two identified enhancements. However, when the identified enhancements are implemented, these would be even less cost beneficial. Therefore, no other plant enhancements are recommended for consideration.

TABLE 5-1

SUMMARY OF VALUE IMPACT RESULTS

ENHANCEMENT CATEGORY	IMPLEMENTATION OPTION	COST ($)	MAXIMUM RISK REDUCTION[1] (person-rem)	COST-BENEFIT RATIO ($/person-rem)
I - Improve Availability of ECCS Recirculation	1. Procedure Change To Stop One Train of Sprays	$25,200	34.2	**$737**
	2. Install Containment Spray Throttle Valves	>$200,000[2]	34.2	> $5,848
	3. Redesign To Delay Containment Spray Actuation	$406,470	34.2	$11,885
	4. Install Automatic High Pressure Recirculation	$2.1M	< 34.2	> $61,403
II - Improve Availability of AC Power	1. Procedure Change To Facilitate Cross-tie of 500kV and 161kV AC Power	$25,200	43.6	**$578**
	2. Accelerate Availability of Fifth Emergency Diesel Generator	$538,200	64.1	$8,396
	3. Procedure Change & Fifth Diesel	$563,700	70.6	$7,980
III - Improve Ability To Cope With Loss of AC Power & Station Blackout	1. Procedure Change To Utilize Existing Spare 6900V/480V Transformers	$25,200	5.2	$4,846
	2. Install Improved RCP Seals	$162,800	41.5	$3,923
	3. Install Independent RCP Seal Cooling System	$3.5M	52.3	$66,922
	4. Install Accumulators For Turbine Driven AFW Pump Flow Control Valves	$324,600	52.4	$6,195
	5. Provide DC Load Shed Analysis & Procedure	$113,200	41.5	$2,728
	6. Provide Portable Battery Charger	$133,800	41.5	$3,224
	7. Install AC Independent Coolant Injection System	$3.5M	65.0	$53,846
IV - Improve Ability To Cope With Loss of RCP Seal Cooling	1. Install Improved RCP Seals	$162,800	41.5	$3,923
	2. Install Independent RCP Seal Cooling System (w/o new EDG)	$2.4M	43.0	$55,814
	3. Modify Charging Pump Cooling From CCS To ERCW	$295,200	43.5	$6,786

TABLE 5-1

SUMMARY OF VALUE IMPACT RESULTS

ENHANCEMENT CATEGORY	IMPLEMENTATION OPTION	COST ($)	MAXIMUM RISK REDUCTION(1) (person-rem)	COST-BENEFIT RATIO ($/person-rem)
V - Improve Containment Performance	1. Install Deliberate Ignition System	$6.1M	21.4	$285,047
	2. Install Reactor Cavity Flooding System	$8.75M	65.0	$133,800
	3. Install Filtered Containment Venting System	$20.0M	65.0	$307,700
	4. Install Core Retention Device	$44.5M	61.6	$722,400
	5. Install Containment Inerting System	$10.9M	21.4	$509,300
	6. Install Additional Containment Bypass Instrumentation	$2.3M	0.64	$3,593,750
	7. Install Reactor Depressurization System	$4.6M	18.0	$255,600
	8. Install Independent Containment Spray System	$5.8M	61.6	$94,000
	9. Install AC Independent Air Return Fan Power Supplies	$1.0M	21.4	$46,700
VI - Miscellaneous	1. Install MG Set Trip Breakers In Control Room (ATWS)	$142,500	2.06	$69,175
	2. Improve Procedures To Provide Temporary HVAC During Loss of Room Cooling	$25,200	0.5	$50,400

NOTES:

(1) Based on 40 year plant life.

(2) No specific cost estimate developed for these enhancements. However, due to the nature of the design changes involved a reasonable lower bound cost estimate of $200,000 was assumed.

Section 6

REFERENCES

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2. Letter to NRC, "Watts Bar Nuclear Plant (WBN) Units 1 and 2 - Generic Letter (GL) 88-20 - Individual Plant Examination (IPE) for Severe Accident Vulnerabilities - Response (TAC M74488)," dated September 1, 1992.

3. NUREG-1150, "Probabilistic Risk Assessment (PRA) Reference Document, Final Report," dated September 1984.

4. NUREG/CR-4243, "Value/Impact Analysis for Evaluating Alternative Mitigation Systems," dated January 1988.

5. Updated FSAR for SQN, Amendment 9.

6. FSAR for WBN, Amendment 72.

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9. TVA's MESOPUFF II Model for the WBN Site: Annual Averaged χ/Q Based on 1978 Meteorological Data with an Assumed 2 Puffs per Hour and a Minimum Sampling Rate of 2 Times per Hour.

10. NUREG/CR-4551, Volume 5, Revision 1, Part 1, "Evaluation of Severe Accident Risks: Sequoyah, Unit 1," dated December 1990.

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12. NUREG-1150, "Reactor Risk Reference Document," Draft for Comment, February 1987.

13. Letter from W. J. Cahill of TU Electric to NRC, "Comanche Peak Steam Electric Station, Docket Nos. 50-455 and 50-446, Severe Accident Mitigation Design Alternatives," dated September 22, 1989.

14. Letter from G. A. Humger, Jr. of Philadelphia Electric Company to NRC, "Limerick Generating Station, Units 1 and 2 - Response to Additional Information Regarding Consideration of Severe Accident Mitigation Design Alternatives," dated June 23, 1989.

15. NUREG/CR-5589, "Assessment of Ice-Condenser Containment Performance Issues," dated July 1990.

16. U. S. Department of Commerce, "Statistical Abstract of the United States - 1992."

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18. NUREG-1150, "Probabilistic Risk Assessment (PRA) Reference Document, Final Report," dated December 1990.

19. TVA Report, "Watts Bar Nuclear Plant Evaluation of Severe Accident Mitigation Design Alternatives," dated May 24, 1993.

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21. NUREG/CR-3568, "A Handbook for Value-impact Assessment," prepared by Battelle Memorial Institute Pacific Northwest Laboratory, December 1983.

22. NUREG/BR-0184, "Regulatory Analysis Technical Evaluation Handbook - Draft Report," Office of Nuclear Regulatory Research, August 1993.

23. Memorandum from S. D. Ferrell of TVA to J. K. Liming of ERIN Engineering and Research, Inc., "Cost Estimates for Use in Enhancement Report," dated May 13, 1994.

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25. System Description for Component Cooling System, N3-70-4002, Revision 3, March 16, 1993, RIMS # T29 930316 908, Tennessee Valley Authority.

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27. "Watts Bar IPE Update Merit Technical Specification Review Package," ERIN Engineering and Research, Inc. prepared for the Tennessee Valley Authority, March 23, 1994, TVA RIMS # T28 940330 812.

28. U.S. Nuclear Regulatory Commission, "Individual Plant Examination: Submittal Guidance," NUREG-1335, August 1989.

29. Sequoyah Individual Plant Examination, August 1992.

30. DC Cook Individual Plant Examination, April 1992.

31. Catawba Individual Plant Examination, September 1992.

32. Tennessee Valley Authority, "Watts Bar Nuclear Plant Final Safety Analysis Report," Amendment 76, 17 Volumes, July 1993.

33. Henry, R. E., and M. G. Plys, "MAAP-3.0B – Modular Accident Analysis Program for LWR Power Plants," Electric Power Research Institute, EPRI NP-7071-CCML, November 1990.

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Appendix A

DOMINANT SEQUENCE LISTING

TABLE 2-16

Top-Ranking Sequences Contributing to Group: MELT Frequency

09:12:47 08 FEB 1994

MODEL Name: WBN-UPDATE

MELT = ALL CORE DAMAGE SEQUENCES

Rank No.	Sequence Description	Guaranteed Events/Comments	End State	Frequency (per year)	Percent
1	Small LOCA Non-Isolable (RCP Seal LOCA) Failure of Automatic/Manual Swapover to Cont. Sump for RHR &	Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Sump Recirculation is Required Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF RHR Spray Recirculation Failed	FCI	3.83E-06	4.8%
2	Loss of 6.9 Shutdown Board 1B-B Loss of Train A Component Cooling Water System Failure to Align CCP A to ERCW Train A on Loss of CCS A	Loss of 6.9kV Shutdown Board Unit 1 Train B Loss of 480V Shutdown Board 1B1-B Loss of 480V Shutdown Board 1B2-B Loss of 480V SD Transformer Room 1B Ventilation Loss of 480V SD BD Room B Ventilation in 6 Hours No Power at 6.9kV Shutdown Board 1B-B No Power at 480V Shutdown Board 1B1-B No Power at 480V Shutdown Board 1B2-B Two Out of Four MSIVs Stay open Loss of Motor Driven AFW Pump 1B-B	ENI	3.23E-06	4.0%

TABLE 2-16
(continued)

Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Operator fails to Depress. the RCS Using SG PORVs
Operator fails to Depress. the RCS Using the PZR Sprays and PORVs
Loss of RHR Pump 1A-A
Loss of RHR Pump 1B-B
Core is Melted During Injection Mode
Failure of Train A Cont. Spray
Failure of Train B Cont. Spray
Failure of Train B Sump Swapover Valve
Failure of Automatic/Manual Swapover to Cont. Sump for RHR
Failure of Cont. Spray Heat Exchangers
Recovery Action
Core Melt
RCS Pressure <2,000 psia
Melt with Cont. not Isolated
IYAF
Cont. Spray Injection Failed
Cont. Spray Recirculation Failed
RHR Spray Recirculation Failed
No Water in Reactor Cavity

TABLE 2-16
(continued)

3	Small LOCA Non-Isolable (RCP Seal LOCA) Failure of Makeup to the RWST Failure of Automatic/Manual Swapover to Cont. Sump for RHR	Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Sump Recirculation is Required Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF RHR Spray Recirculation Failed	FCI	3.04E-06	3.8%
4	Loss of Offsite Power Failure to Recover Offsite Power in 1 Hour Loss of Unit 1 Diesel Generator 1A-A Loss of Unit 1 Diesel Generator 1B-B Recovery Action	Loss of 161kV Offsite Power Loss of 6.9kV Shutdown Board Unit 1 Train A Loss of 480V Shutdown Board 1A1-A Loss of 480V Shutdown Board 1A2-A Loss of 480V SD Transformer Room 1A Ventilation Loss of Unit 1 120V AC Instrument Board 1A Loss of 6.9kV Shutdown Board Unit 1 Train B Loss of 480V Shutdown Board 1B1-B Loss of 480V Shutdown Board 1B2-B Loss of 480V SD Transformer Room 1B Ventilation Loss of 480V SD BD Room B Ventilation in 6 Hours Loss of Common Board A Loss of Common Board B Loss of 6.9kV Unit Board 1A Loss of 6.9kV Unit Board 1B	ENI	2.93E-06	3.6%

TABLE 2-16
(continued)

Loss of 6.9kV Unit Board 1C
Loss of 6.9kV Unit Board 1D
No Power at 6.9kV Shutdown Board 1A-A
No Power at 480V Shutdown Board 1A1-A
No Power at 480V Shutdown Board 1A2-A
No Power at 6.9kV Shutdown Board 1B-B
No Power at 480V Shutdown Board 1B1-B
No Power at 480V Shutdown Board 1B2-B
Failure of Control Air (Non-Essential Air)
Failure to Recover CCS HTX by Realigning ERCW
Loss of Train A Component Cooling Water System
Failure to Align CCP A to ERCW Train A on Loss of CCS A
Failure of Makeup to the RWST
Failure of Makeup to the CST
Loss of Motor Driven AFW Pump 1A-A
Loss of Motor Driven AFW Pump 1B-B
Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Loss of RHR Pump 1A-A
Loss of RHR Pump 1B-B
Core is Melted During Injection Mode
Failure of Air Return Fans
Failure of Train A Cont. Spray

TABLE 2-16
(continued)

		Failure of Train B Cont. Spray Failure of Train A Sump Swapover Valve Failure of Train B Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Failure of Hydrogen Ignitors Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
5	Small LOCA Non-Isolable (RCP Seal LOCA) Failure of Makeup to the RWST Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B	Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Sump Recirculation is Required Failure of Automatic/Manual Swapover to Cont. Sump for RHR Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF RHR Spray Recirculation Failed	FCI	2.82E-06	3.5%

TABLE 2-16
(continued)

6	Flooding - ERCW Strainer Room, Train A Loss of ERCW Header 1B		ENI	2.35E-06	2.9%
		Loss of ERCW Train A Pumps			
		Loss of ERCW Header 1A			
		Loss of ERCW Header 2A			
		Failure of ERCW Cooling to CAS Compressors			
		Failure of Control Air (Non-Essential Air)			
		Loss of Train A Essential Air			
		Failure to Recover CCS HTX by Realigning ERCW			
		Loss of Train A Component Cooling Water System			
		Failure to Align CCP A to ERCW Train A on Loss of CCS A			
		Failure of Makeup to the RWST			
		Loss of Motor Driven AFW Pump 1A-A			
		Loss of Centrifugal Charging Pump 1A-A			
		Loss of Centrifugal Charging Pump 1B-B			
		Loss of Cold Leg Injection Path from CCPs			
		Failure of Thermal Barriers to the RCPs			
		RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops			
		Failure of Safety Injection Pump 1A-A			
		Failure of Safety Injection Pump 1B-B			
		Loss of Cold Leg Injection Paths			
		Operator fails to Depress. the RCS Using SG PORVs			
		Operator fails to Depress. the RCS Using the PZR Sprays and PORVs			
		Loss of RHR Pump 1A-A			
		Loss of RHR Pump 1B-B			
		Core is Melted During Injection Mode			
		Failure of Train A Cont. Spray			
		Failure of Train B Cont. Spray			
		Failure of Automatic/Manual Swapover to Cont. Sump for RHR			
		Failure of Cont. Spray Heat Exchangers			

TABLE 2-16
(continued)

		Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
7	Flooding - ERCW Strainer Room, Train B Loss of ERCW Header 1A	Loss of ERCW Train B Pumps Loss of ERCW Header 1B Loss of ERCW Header 2B Failure of ERCW Cooling to CAS Compressors Failure of Control Air (Non-Essential Air) Loss of Train A Essential Air Loss of Train B Essential Air Loss of Train B Component Cooling Water System Failure of Makeup to the RWST Loss of Motor Driven AFW Pump 1A-A Loss of Motor Driven AFW Pump 1B-B Loss of Centrifugal Charging Pump 1A-A Loss of Centrifugal Charging Pump 1B-B Loss of Cold Leg Injection Path from CCPs Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Failure of Safety Injection Pump 1A-A Failure of Safety Injection Pump 1B-B	ENI	2.17E-06	2.7%

TABLE 2-16
(continued)

		Loss of Cold Leg Injection Paths Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
8	Steam Generator Tube Rupture Failure of Makeup to the RWST Operator fails to Depress. the RCS Using SG PORVs	Two Out of Four MSIVs Stay open Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Loss of RHR Normal Decay Heat Removal Core is Melted During Injection Mode Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Cont. Spray Heat Exchangers Recovery Action	EIB	2.11E-06	2.6%

TABLE 2-16
(continued)

		Core Melt RCS Pressure <2,000 psia Melt with Cont. Bypassed BYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed No Water in Reactor Cavity			
9	Total Loss of ERCW		ENI	1.30E-06	1.6%
		Loss of ERCW Train A Pumps Loss of ERCW Train B Pumps Loss of ERCW Header 1A Loss of ERCW Header 2A Loss of ERCW Header 1B Loss of ERCW Header 2B Failure of ERCW Cooling to CAS Compressors Failure of Control Air (Non-Essential Air) Loss of Train A Essential Air Loss of Train B Essential Air Failure to Recover CCS HTX by Realigning ERCW Loss of Train A Component Cooling Water System Loss of Train B Component Cooling Water System Failure to Align CCP A to ERCW Train A on Loss of CCS A Failure of Makeup to the RWST Loss of Motor Driven AFW Pump 1A-A Loss of Motor Driven AFW Pump 1B-B Loss of Centrifugal Charging Pump 1A-A Loss of Centrifugal Charging Pump 1B-B Loss of Cold Leg Injection Path from CCPs			

TABLE 2-16
(continued)

		Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Failure of Safety Injection Pump 1A-A Failure of Safety Injection Pump 1B-B Loss of Cold Leg Injection Paths Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
10	Large LOCA Failure of RHR & SIS Hot Leg Recirculation	Recovery Action Core Melt Melt with Cont. not Isolated IYAF RHR Spray Recirculation Failed	BCI	9.07E-07	1.1%

TABLE 2-16
(continued)

11	Loss of Offsite Power Failure to Recover Offsite Power in 1 Hour Loss of Unit 1 Diesel Generator 1A-A Loss of Unit 1 Diesel Generator 1B-B Loss of Unit 2 Diesel Generator 2A-A Loss of Unit 2 Diesel Generator 2B-B Recovery Action	Loss of 161kV Offsite Power Loss of 6.9kV Shutdown Board Unit 1 Train A Loss of 480V Shutdown Board 1A1-A Loss of 480V Shutdown Board 1A2-A Loss of 480V SD Transformer Room 1A Ventilation Loss of Unit 1 120V AC Instrument Board 1A Loss of 6.9kV Shutdown Board Unit 1 Train B Loss of 480V Shutdown Board 1B1-B Loss of 480V Shutdown Board 1B2-B Loss of 480V SD Transformer Room 1B Ventilation Loss of 480V SD BD Room B Ventilation in 6 Hours Loss of Common Board A Loss of Common Board B Loss of 6.9kV Unit Board 1A Loss of 6.9kV Unit Board 1B Loss of 6.9kV Unit Board 1C Loss of 6.9kV Unit Board 1D Loss of 6.9kV Shutdown Board Unit 2 Train A Loss of 480V Shutdown Board 2A1-A Loss of 480V Shutdown Board 2A2-A Loss of 480V SD Transformer Room 2A Ventilation Loss of Unit 2 120V AC Instrument Board 2A Loss of 6.9kV Shutdown Board Unit 2 Train B Loss of 480V Shutdown Board 2B1-B Loss of 480V Shutdown Board 2B2-B Loss of 480V SD Transformer Room 2B Ventilation Loss of 480V SD BD Room 2B Ventilation in 6 Hours	ENI	9.06E-07	1.1%

TABLE 2-16
(continued)

Unit 1 Shutdown Board Ventilation System
Recovery of Unit 1 Shutdown Board Room Ventilation
Unit 2 Shutdown Board Ventilation System
Recovery of Unit 2 Shutdown Board Room Ventilation
Loss of ERCW Train A Pumps
Loss of ERCW Train B Pumps
Loss of ERCW Header 1A
Loss of ERCW Header 2A
Loss of ERCW Header 1B
Loss of ERCW Header 2B
Failure to Recover ERCW to Diesel from Opposite Train
No Power at 6.9kV Shutdown Board 1A-A
No Power at 480V Shutdown Board 1A1-A
No Power at 480V Shutdown Board 1A2-A
No Power at 6.9kV Shutdown Board 2A-A
No Power at 480V Shutdown Board 2A1-A
No Power at 480V Shutdown Board 2A2-A
No Power at 6.9kV Shutdown Board 1B-B
No Power at 480V Shutdown Board 1B1-B
No Power at 480V Shutdown Board 1B2-B
No Power at 6.9kV Shutdown Board 2B-B
No Power at 480V Shutdown Board 2B1-B
No Power at 480V Shutdown Board 2B2-B
Failure of ERCW Cooling to CAS Compressors
Failure of Control Air (Non-Essential Air)
Loss of Train A Essential Air
Loss of Train B Essential Air
Failure to Recover CCS HTX by Realigning ERCW
Loss of Train A Component Cooling Water System

TABLE 2-16
(continued)

Loss of Train B Component Cooling Water System
Failure to Align CCP A to ERCW Train A on Loss of CCS A
Failure of Makeup to the RWST
Failure of Makeup to the CST
Loss of Motor Driven AFW Pump 1A-A
Loss of Motor Driven AFW Pump 1B-B
Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Loss of RHR Pump 1A-A
Loss of RHR Pump 1B-B
Core is Melted During Injection Mode
Failure of Air Return Fans
Failure of Train A Cont. Spray
Failure of Train B Cont. Spray
Failure of Train A Sump Swapover Valve
Failure of Train B Sump Swapover Valve
Failure of Automatic/Manual Swapover to Cont. Sump for RHR
Failure of Cont. Spray Heat Exchangers
Failure of Hydrogen Ignitors
Core Melt
RCS Pressure <2,000 psia
Melt with Cont. not Isolated
IYAF

TABLE 2-16
(continued)

		Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
12	Loss of Offsite Power Failure to Recover Offsite Power in 1 Hour Loss of Unit 1 Diesel Generator 1A-A Loss of Unit 1 Diesel Generator 1B-B Loss of Unit 2 Diesel Generator 2B-B Recovery Action	Loss of 161kV Offsite Power Loss of 6.9kV Shutdown Board Unit 1 Train A Loss of 480V Shutdown Board 1A1-A Loss of 480V Shutdown Board 1A2-A Loss of 480V SD Transformer Room 1A Ventilation Loss of Unit 1 120V AC Instrument Board 1A Loss of 6.9kV Shutdown Board Unit 1 Train B Loss of 480V Shutdown Board 1B1-B Loss of 480V Shutdown Board 1B2-B Loss of 480V SD Transformer Room 1B Ventilation Loss of 480V SD BD Room B Ventilation in 6 Hours Loss of Common Board A Loss of Common Board B Loss of 6.9kV Unit Board 1A Loss of 6.9kV Unit Board 1B Loss of 6.9kV Unit Board 1C Loss of 6.9kV Unit Board 1D Loss of 6.9kV Shutdown Board Unit 2 Train B Loss of 480V Shutdown Board 2B1-B Loss of 480V Shutdown Board 2B2-B Loss of 480V SD Transformer Room 2B Ventilation Loss of 480V SD BD Room 2B Ventilation in 6 Hours Unit 2 Shutdown Board Ventilation System	ENI	8.75E-07	1.1%

TABLE 2-16
(continued)

Recovery of Unit 2 Shutdown Board Room Ventilation
Loss of ERCW Train B Pumps
Loss of ERCW Header 1B
Loss of ERCW Header 2B
No Power at 6.9kV Shutdown Board 1A-A
No Power at 480V Shutdown Board 1A1-A
No Power at 480V Shutdown Board 1A2-A
No Power at 6.9kV Shutdown Board 1B-B
No Power at 480V Shutdown Board 1B1-B
No Power at 480V Shutdown Board 1B2-B
No Power at 6.9kV Shutdown Board 2B-B
No Power at 480V Shutdown Board 2B1-B
No Power at 480V Shutdown Board 2B2-B
Failure of Control Air (Non-Essential Air)
Loss of Train B Essential Air
Failure to Recover CCS HTX by Realigning ERCW
Loss of Train A Component Cooling Water System
Loss of Train B Component Cooling Water System
Failure to Align CCP A to ERCW Train A on Loss of CCS A
Failure of Makeup to the RWST
Failure of Makeup to the CST
Loss of Motor Driven AFW Pump 1A-A
Loss of Motor Driven AFW Pump 1B-B
Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A

TABLE 2-16 (continued)

		Failure of Safety Injection Pump 1B-B Loss of Cold Leg Injection Paths Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Air Return Fans Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Train A Sump Swapover Valve Failure of Train B Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Failure of Hydrogen Ignitors Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
13	Loss of Offsite Power Failure to Recover Offsite Power in 1 Hour Loss of Unit 1 Diesel Generator 1A-A Loss of Unit 1 Diesel Generator 1B-B Loss of Unit 2 Diesel Generator 2A-A Recovery Action	Loss of 161kV Offsite Power Loss of 6.9kV Shutdown Board Unit 1 Train A Loss of 480V Shutdown Board 1A1-A Loss of 480V Shutdown Board 1A2-A Loss of 480V SD Transformer Room 1A Ventilation Loss of Unit 1 120V AC Instrument Board 1A	ENI	8.71E-07	1.1%

TABLE 2-16
(continued)

Loss of 6.9kV Shutdown Board Unit 1 Train B
Loss of 480V Shutdown Board 1B1-B
Loss of 480V Shutdown Board 1B2-B
Loss of 480V SD Transformer Room 1B Ventilation
Loss of 480V SD BD Room B Ventilation in 6 Hours
Loss of Common Board A
Loss of Common Board B
Loss of 6.9kV Unit Board 1A
Loss of 6.9kV Unit Board 1B
Loss of 6.9kV Unit Board 1C
Loss of 6.9kV Unit Board 1D
Loss of 6.9kV Shutdown Board Unit 2 Train A
Loss of 480V Shutdown Board 2A1-A
Loss of 480V Shutdown Board 2A2-A
Loss of 480V SD Transformer Room 2A Ventilation
Loss of Unit 2 120V AC Instrument Board 2A
Unit 1 Shutdown Board Ventilation System
Recovery of Unit 1 Shutdown Board Room Ventilation
Loss of ERCW Train A Pumps
Loss of ERCW Header 1A
Loss of ERCW Header 2A
No Power at 6.9kV Shutdown Board 1A-A
No Power at 480V Shutdown Board 1A1-A
No Power at 480V Shutdown Board 1A2-A
No Power at 6.9kV Shutdown Board 2A-A
No Power at 480V Shutdown Board 2A1-A
No Power at 480V Shutdown Board 2A2-A
No Power at 6.9kV Shutdown Board 1B-B
No Power at 480V Shutdown Board 1B1-B

TABLE 2-16
(continued)

No Power at 480V Shutdown Board 1B2-B
Failure of Control Air (Non-Essential Air)
Loss of Train A Essential Air
Failure to Recover CCS HTX by Realigning ERCW
Loss of Train A Component Cooling Water System
Failure to Align CCP A to ERCW Train A on Loss of CCS A
Failure of Makeup to the RWST
Failure of Makeup to the CST
Loss of Motor Driven AFW Pump 1A-A
Loss of Motor Driven AFW Pump 1B-B
Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Loss of RHR Pump 1A-A
Loss of RHR Pump 1B-B
Core is Melted During Injection Mode
Failure of Air Return Fans
Failure of Train A Cont. Spray
Failure of Train B Cont. Spray
Failure of Train A Sump Swapover Valve
Failure of Train B Sump Swapover Valve
Failure of Automatic/Manual Swapover to Cont. Sump for RHR
Failure of Cont. Spray Heat Exchangers
Failure of Hydrogen Ignitors

TABLE 2-16
(continued)

		Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
14	Large LOCA Failure of 2/3 Cold Leg Accumulators	Recovery Action Core Melt Melt with Cont. not Isolated IYAF RHR Spray Recirculation Failed	BCI	6.44E-07	0.8%
15	Loss of Offsite Power Loss of 6.9kV Shutdown Board Unit 1 Train A Loss of 6.9kV Shutdown Board Unit 1 Train B Loss of 6.9kV Shutdown Board Unit 2 Train B	Loss of 161kV Offsite Power Loss of 480V Shutdown Board 1A1-A Loss of 480V Shutdown Board 1A2-A Loss of 480V SD Transformer Room 1A Ventilation Loss of Unit 1 120V AC Instrument Board 1A Loss of 480V Shutdown Board 1B1-B Loss of 480V Shutdown Board 1B2-B Loss of 480V SD Transformer Room 1B Ventilation Loss of 480V SD BD Room B Ventilation in 6 Hours Loss of 6.9kV Shutdown Board Unit 2 Train A Loss of 480V Shutdown Board 2A1-A Loss of 480V Shutdown Board 2A2-A	ENI	6.00E-07	0.7%

TABLE 2-16
(continued)

Loss of 480V SD Transformer Room 2A Ventilation
Loss of Unit 2 120V AC Instrument Board 2A
Loss of 480V Shutdown Board 2B1-B
Loss of 480V Shutdown Board 2B2-B
Loss of 480V SD Transformer Room 2B Ventilation
Loss of 480V SD BD Room 2B Ventilation in 6 Hours
Unit 1 Shutdown Board Ventilation System
Recovery of Unit 1 Shutdown Board Room Ventilation
Unit 2 Shutdown Board Ventilation System
Recovery of Unit 2 Shutdown Board Room Ventilation
Loss of ERCW Train A Pumps
Loss of ERCW Train B Pumps
Loss of ERCW Header 1A
Loss of ERCW Header 2A
Loss of ERCW Header 1B
Loss of ERCW Header 2B
No Power at 6.9kV Shutdown Board 1A-A
No Power at 480V Shutdown Board 1A1-A
No Power at 480V Shutdown Board 1A2-A
No Power at 6.9kV Shutdown Board 2A-A
No Power at 480V Shutdown Board 2A1-A
No Power at 480V Shutdown Board 2A2-A
No Power at 6.9kV Shutdown Board 1B-B
No Power at 480V Shutdown Board 1B1-B
No Power at 480V Shutdown Board 1B2-B
No Power at 6.9kV Shutdown Board 2B-B
No Power at 480V Shutdown Board 2B1-B
No Power at 480V Shutdown Board 2B2-B
Failure of ERCW Cooling to CAS Compressors

TABLE 2-16
(continued)

Failure of Control Air (Non-Essential Air)
Loss of Train A Essential Air
Loss of Train B Essential Air
Failure to Recover CCS HTX by Realigning ERCW
Loss of Train A Component Cooling Water System
Loss of Train B Component Cooling Water System
Failure to Align CCP A to ERCW Train A on Loss of CCS A
Failure of Makeup to the RWST
Failure of Makeup to the CST
Loss of Motor Driven AFW Pump 1A-A
Loss of Motor Driven AFW Pump 1B-B
Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Loss of RHR Pump 1A-A
Loss of RHR Pump 1B-B
Core is Melted During Injection Mode
Failure of Air Return Fans
Failure of Train A Cont. Spray
Failure of Train B Cont. Spray
Failure of Train A Sump Swapover Valve
Failure of Train B Sump Swapover Valve
Failure of Automatic/Manual Swapover to Cont. Sump for RHR
Failure of Cont. Spray Heat Exchangers

TABLE 2-16
(continued)

		Failure of Hydrogen Ignitors Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
16	Medium LOCA Failure of Automatic/Manual Swapover to Cont. Sump for RHR	Recovery Action Core Melt RCS Pressure Low (>200 psia) Melt with Cont. not Isolated IYAF RHR Spray Recirculation Failed	BCI	5.98E-07	0.7%
17	Flooding - ERCW Strainer Room, Train A Loss of 480V Shutdown Board 1B1-B	Loss of 480V SD Transformer Room 1B Ventilation Loss of ERCW Train A Pumps Loss of ERCW Header 1A Loss of ERCW Header 2A No Power at 480V Shutdown Board 1B1-B Two Out of Four MSIVs Stay open Loss of Centrifugal Charging Pump 1A-A Loss of Centrifugal Charging Pump 1B-B Loss of Cold Leg Injection Path from CCPs	ENI	5.89E-07	0.7%

TABLE 2-16
(continued)

		Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Failure of Safety Injection Pump 1A-A Failure of Safety Injection Pump 1B-B Loss of Cold Leg Injection Paths Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Train B Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
18	Partial Loss of Main Feedwater Failure to Trip Reactor and Insert Control Rods Power Level is Greater than 40%	Two Out of Four MSIVs Stay open Main Feedwater Fails to Continue During ATWS Event Failure of Steam Relief, ATWS Only, Rx Press is <3200 psia	FCI	5.80E-07	0.7%

TABLE 2-16
(continued)

		Failure of PZR PORVs to Open to Control RCS Pressure & Reclose Core is Melted During Injection Mode Operator Fails to Control Cont. Spray Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF			
19	Flooding - ERCW Strainer Room, Train B Loss of 480V Shutdown Board 1A1-A	Loss of 480V SD Transformer Room 1A Ventilation Loss of Unit 1 120V AC Instrument Board 1A Loss of ERCW Train B Pumps Loss of ERCW Header 1B Loss of ERCW Header 2B No Power at 480V Shutdown Board 1A1-A Failure of Makeup to the RWST Two Out of Four MSIVs Stay open Loss of Centrifugal Charging Pump 1A-A Loss of Centrifugal Charging Pump 1B-B Loss of Cold Leg Injection Path from CCPs Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Failure of Safety Injection Pump 1A-A Failure of Safety Injection Pump 1B-B Loss of Cold Leg Injection Paths Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Loss of RHR Pump 1A-A	ENI	5.64E-07	0.7%

TABLE 2-16
(continued)

		Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Train A Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
20	Loss of Component Cooling Water Train A Loss of 480V Shutdown Board 1B1-B Failure to Align CCP A to ERCW Train A on Loss of CCS A	Loss of 480V SD Transformer Room 1B Ventilation No Power at 480V Shutdown Board 1B1-B Loss of Train A Component Cooling Water System Two Out of Four MSIVs Stay open Loss of Centrifugal Charging Pump 1A-A Loss of Centrifugal Charging Pump 1B-B Loss of Cold Leg Injection Path from CCPs Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Failure of Safety Injection Pump 1A-A Failure of Safety Injection Pump 1B-B	ENI	5.35E-07	0.7%

TABLE 2-16
(continued)

		Loss of Cold Leg Injection Paths Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Train B Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
21	Loss of Offsite Power Failure to Recover Offsite Power in 1 Hour Loss of Unit 1 Diesel Generator 1A-A Loss of Unit 2 Diesel Generator 2B-B Failure of Turbine Driven AFW Pump Failure to Recover TD AFW Pump Start Failures in 30 Minutes Recovery Action	Loss of 161kV Offsite Power Loss of 6.9kV Shutdown Board Unit 1 Train A Loss of 480V Shutdown Board 1A1-A Loss of 480V Shutdown Board 1A2-A Loss of 480V SD Transformer Room 1A Ventilation Loss of Unit 1 120V AC Instrument Board 1A Loss of Common Board A	GNI	5.04E-07	0.6%

TABLE 2-16
(continued)

Loss of Common Board B
Loss of 6.9kV Unit Board 1A
Loss of 6.9kV Unit Board 1B
Loss of 6.9kV Unit Board 1C
Loss of 6.9kV Unit Board 1D
Loss of 6.9kV Shutdown Board Unit 2 Train B
Loss of 480V Shutdown Board 2B1-B
Loss of 480V Shutdown Board 2B2-B
Loss of 480V SD Transformer Room 2B Ventilation
Loss of 480V SD BD Room 2B Ventilation in 6 Hours
No Power at 6.9kV Shutdown Board 1A-A
No Power at 480V Shutdown Board 1A1-A
No Power at 480V Shutdown Board 1A2-A
No Power at 6.9kV Shutdown Board 2B-B
No Power at 480V Shutdown Board 2B1-B
No Power at 480V Shutdown Board 2B2-B
Failure of Control Air (Non-Essential Air)
Loss of Train B Essential Air
Loss of Train B Component Cooling Water System
Failure of Makeup to the RWST
Failure of Makeup to the CST
Loss of Motor Driven AFW Pump 1A-A
Loss of Motor Driven AFW Pump 1B-B
Failure of Equipment Needed to Recover Main Feedwater
Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of PZR PORVs to Open to Control RCS Pressure & Reclose
Failure of Safety Injection Pump 1A-A

TABLE 2-16
(continued)

		Failure of Safety Injection Pump 1B-B Loss of Cold Leg Injection Paths Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Train A Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Core Melt RCS Pressure <2,000 psia Steam Generator Cooling Failed Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
22	Loss of Offsite Power Loss of 6.9kV Shutdown Board Unit 1 Train A Loss of 6.9kV Shutdown Board Unit 1 Train B	Loss of 161kV Offsite Power Loss of 480V Shutdown Board 1A1-A Loss of 480V Shutdown Board 1A2-A Loss of 480V SD Transformer Room 1A Ventilation Loss of Unit 1 120V AC Instrument Board 1A Loss of 480V Shutdown Board 1B1-B Loss of 480V Shutdown Board 1B2-B Loss of 480V SD Transformer Room 1B Ventilation	ENI	4.95E-07	0.6%

TABLE 2-16
(continued)

Loss of 480V SD BD Room B Ventilation in 6 Hours
No Power at 6.9kV Shutdown Board 1A-A
No Power at 480V Shutdown Board 1A1-A
No Power at 480V Shutdown Board 1A2-A
No Power at 6.9kV Shutdown Board 1B-B
No Power at 480V Shutdown Board 1B1-B
No Power at 480V Shutdown Board 1B2-B
Failure to Recover CCS HTX by Realigning ERCW
Loss of Train A Component Cooling Water System
Failure to Align CCP A to ERCW Train A on Loss of CCS A
Failure of Makeup to the RWST
Failure of Makeup to the CST
Two Out of Four MSIVs Stay open
Fail to Cooldown Using Steam Dumps, Condenser, & Hotwell Pumps
Loss of Motor Driven AFW Pump 1A-A
Loss of Motor Driven AFW Pump 1B-B
Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Loss of RHR Pump 1A-A
Loss of RHR Pump 1B-B
Core is Melted During Injection Mode
Failure of Air Return Fans
Failure of Train A Cont. Spray

TABLE 2-16
(continued)

		Failure of Train B Cont. Spray Failure of Train A Sump Swapover Valve Failure of Train B Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Failure of Hydrogen Ignitors Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
23	Loss of Offsite Power Failure to Recover Offsite Power in 1 Hour Loss of Unit 1 Diesel Generator 1A-A Loss of Unit 1 Diesel Generator 1B-B Failure of Turbine Driven AFW Pump Failure to Recover TD AFW Pump Start Failures in 30 Minutes Recovery Action	Loss of 161kV Offsite Power Loss of 6.9kV Shutdown Board Unit 1 Train A Loss of 480V Shutdown Board 1A1-A Loss of 480V Shutdown Board 1A2-A Loss of 480V SD Transformer Room 1A Ventilation Loss of Unit 1 120V AC Instrument Board 1A Loss of 6.9kV Shutdown Board Unit 1 Train B Loss of 480V Shutdown Board 1B1-B Loss of 480V Shutdown Board 1B2-B Loss of 480V SD Transformer Room 1B Ventilation Loss of 480V SD BD Room B Ventilation in 6 Hours Loss of Common Board A	GNI	4.91E-07	0.6%

TABLE 2-16
(continued)

Loss of Common Board B
Loss of 6.9kV Unit Board 1A
Loss of 6.9kV Unit Board 1B
Loss of 6.9kV Unit Board 1C
Loss of 6.9kV Unit Board 1D
No Power at 6.9kV Shutdown Board 1A-A
No Power at 480V Shutdown Board 1A1-A
No Power at 480V Shutdown Board 1A2-A
No Power at 6.9kV Shutdown Board 1B-B
No Power at 480V Shutdown Board 1B1-B
No Power at 480V Shutdown Board 1B2-B
Failure of Control Air (Non-Essential Air)
Failure to Recover CCS HTX by Realigning ERCW
Loss of Train A Component Cooling Water System
Failure to Align CCP A to ERCW Train A on Loss of CCS A
Failure of Makeup to the RWST
Failure of Makeup to the CST
Loss of Motor Driven AFW Pump 1A-A
Loss of Motor Driven AFW Pump 1B-B
Failure of Equipment Needed to Recover Main Feedwater
Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of PZR PORVs to Open to Control RCS Pressure & Reclose
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths

TABLE 2-16
(continued)

		Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Air Return Fans Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Train A Sump Swapover Valve Failure of Train B Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Failure of Hydrogen Ignitors Core Melt RCS Pressure <2,000 psia Steam Generator Cooling Failed Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
24	Reactor Trip Loss of 480V Shutdown Board 1B1-B Loss of Train A Component Cooling Water System Failure to Align CCP A to ERCW Train A on Loss of CCS A	Loss of 480V SD Transformer Room 1B Ventilation No Power at 480V Shutdown Board 1B1-B Two Out of Four MSIVs Stay open Loss of Centrifugal Charging Pump 1A-A Loss of Centrifugal Charging Pump 1B-B Loss of Cold Leg Injection Path from CCPs Failure of Thermal Barriers to the RCPs	ENI	4.76E-07	0.6%

TABLE 2-16
(continued)

		RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Failure of Safety Injection Pump 1A-A Failure of Safety Injection Pump 1B-B Loss of Cold Leg Injection Paths Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Train B Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
25	Loss of Offsite Power Failure to Recover Offsite Power in 1 Hour Loss of Unit 1 Diesel Generator 1B-B Loss of Unit 2 Diesel Generator 2A-A Failure of Turbine Driven AFW Pump	Loss of 161kV Offsite Power Loss of 6.9kV Shutdown Board Unit 1 Train B Loss of 480V Shutdown Board 1B1-B Loss of 480V Shutdown Board 1B2-B	HGI	4.29E-07	0.5%

TABLE 2-16
(continued)

Failure to Recover TD AFW Pump Start Failures in 30 Minutes Recovery Action	Loss of 480V SD Transformer Room 1B Ventilation Loss of 480V SD BD Room B Ventilation in 6 Hours Loss of Common Board A Loss of Common Board B Loss of 6.9kV Unit Board 1A Loss of 6.9kV Unit Board 1B Loss of 6.9kV Unit Board 1C Loss of 6.9kV Unit Board 1D Loss of 6.9kV Shutdown Board Unit 2 Train A Loss of 480V Shutdown Board 2A1-A Loss of 480V Shutdown Board 2A2-A Loss of 480V SD Transformer Room 2A Ventilation Loss of Unit 2 120V AC Instrument Board 2A No Power at 6.9kV Shutdown Board 2A-A No Power at 480V Shutdown Board 2A1-A No Power at 480V Shutdown Board 2A2-A No Power at 6.9kV Shutdown Board 1B-B No Power at 480V Shutdown Board 1B1-B No Power at 480V Shutdown Board 1B2-B Failure of Control Air (Non-Essential Air) Loss of Train A Essential Air Failure of Makeup to the RWST Failure of Makeup to the CST Loss of Motor Driven AFW Pump 1A-A Loss of Motor Driven AFW Pump 1B-B Failure of Equipment Needed to Recover Main Feedwater Loss of Centrifugal Charging Pump 1B-B Failure of PZR PORVs to Open to Control RCS Pressure & Reclose Failure of Safety Injection Pump 1B-B

TABLE 2-16
(continued)

		Loss of RHR Pump 1B-B Sump Recirculation is Required Failure of Train B Cont. Spray Failure of Train B Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Core Melt RCS Pressure <2,000 psia Steam Generator Cooling Failed Melt with Cont. not Isolated IYAF Cont. Spray Recirculation Failed RHR Spray Recirculation Failed			
26	Loss of 6.9 Shutdown Board 1B-B Loss of ERCW Header 1A	Loss of 6.9kV Shutdown Board Unit 1 Train B Loss of 480V Shutdown Board 1B1-B Loss of 480V Shutdown Board 1B2-B Loss of 480V SD Transformer Room 1B Ventilation Loss of 480V SD BD Room B Ventilation in 6 Hours No Power at 6.9kV Shutdown Board 1B-B No Power at 480V Shutdown Board 1B1-B No Power at 480V Shutdown Board 1B2-B Two Out of Four MSIVs Stay open Loss of Motor Driven AFW Pump 1B-B Loss of Centrifugal Charging Pump 1A-A Loss of Centrifugal Charging Pump 1B-B Loss of Cold Leg Injection Path from CCPs Failure of Thermal Barriers to the RCPs	ENI	4.15E-07	0.5%

TABLE 2-16
(continued)

		RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Failure of Safety Injection Pump 1A-A Failure of Safety Injection Pump 1B-B Loss of Cold Leg Injection Paths Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Train B Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
27	Flooding - ERCW Strainer Room, Train B Loss of Train A Component Cooling Water System Failure to Align CCP A to ERCW Train A on Loss of CCS A	Loss of ERCW Train B Pumps Loss of ERCW Header 1B Loss of ERCW Header 2B Two Out of Four MSIVs Stay open	ENI	4.14E-07	0.5%

TABLE 2-16
(continued)

Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Operator fails to Depress. the RCS Using SG PORVs
Operator fails to Depress. the RCS Using the PZR Sprays and PORVs
Loss of RHR Pump 1A-A
Loss of RHR Pump 1B-B
Core is Melted During Injection Mode
Failure of Train A Cont. Spray
Failure of Train B Cont. Spray
Failure of Automatic/Manual Swapover to Cont. Sump for RHR
Failure of Cont. Spray Heat Exchangers
Recovery Action
Core Melt
RCS Pressure <2,000 psia
Melt with Cont. not Isolated
IYAF
Cont. Spray Injection Failed
Cont. Spray Recirculation Failed
RHR Spray Recirculation Failed
No Water in Reactor Cavity

TABLE 2-16
(continued)

28	Loss of 6.9 Shutdown Board 1A-A Loss of Train B Component Cooling Water System Failure of Thermal Barriers to the RCPs	ENI	4.02E-07	0.5%
		Loss of 6.9kV Shutdown Board Unit 1 Train A Loss of 480V Shutdown Board 1A1-A Loss of 480V Shutdown Board 1A2-A Loss of 480V SD Transformer Room 1A Ventilation Loss of Unit 1 120V AC Instrument Board 1A No Power at 6.9kV Shutdown Board 1A-A No Power at 480V Shutdown Board 1A1-A No Power at 480V Shutdown Board 1A2-A Failure of Makeup to the RWST Two Out of Four MSIVs Stay open Fail to Cooldown Using Steam Dumps, Condenser, & Hotwell Pumps Loss of Motor Driven AFW Pump 1A-A Loss of Centrifugal Charging Pump 1A-A Loss of Centrifugal Charging Pump 1B-B Loss of Cold Leg Injection Path from CCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Failure of Safety Injection Pump 1A-A Failure of Safety Injection Pump 1B-B Loss of Cold Leg Injection Paths Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Train A Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR		

TABLE 2-16
(continued)

		Failure of Cont. Spray Heat Exchangers Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
29	Loss of 6.9 Shutdown Board 1A-A Loss of ERCW Header 1B	Loss of 6.9kV Shutdown Board Unit 1 Train A Loss of 480V Shutdown Board 1A1-A Loss of 480V Shutdown Board 1A2-A Loss of 480V SD Transformer Room 1A Ventilation Loss of Unit 1 120V AC Instrument Board 1A No Power at 6.9kV Shutdown Board 1A-A No Power at 480V Shutdown Board 1A1-A No Power at 480V Shutdown Board 1A2-A Failure to Recover CCS HTX by Realigning ERCW Loss of Train A Component Cooling Water System Failure of Makeup to the RWST Two Out of Four MSIVs Stay open Fail to Cooldown Using Steam Dumps, Condenser, & Hotwell Pumps Loss of Motor Driven AFW Pump 1A-A Loss of Centrifugal Charging Pump 1A-A Loss of Centrifugal Charging Pump 1B-B Loss of Cold Leg Injection Path from CCPs	ENI	3.99E-07	0.5%

TABLE 2-16
(continued)

		Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Failure of Safety Injection Pump 1A-A Failure of Safety Injection Pump 1B-B Loss of Cold Leg Injection Paths Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Train A Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
30	Partial Loss of Main Feedwater Loss of 480V Shutdown Board 1B1-B Loss of Train A Component Cooling Water System Failure to Align CCP A to ERCW Train A on Loss of CCS A	Loss of 480V SD Transformer Room 1B Ventilation No Power at 480V Shutdown Board 1B1-B Two Out of Four MSIVs Stay open	ENI	3.99E-07	0.5%

TABLE 2-16
(continued)

Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Operator fails to Depress. the RCS Using SG PORVs
Operator fails to Depress. the RCS Using the PZR Sprays and PORVs
Loss of RHR Pump 1A-A
Loss of RHR Pump 1B-B
Core is Melted During Injection Mode
Failure of Train A Cont. Spray
Failure of Train B Cont. Spray
Failure of Train B Sump Swapover Valve
Failure of Automatic/Manual Swapover to Cont. Sump for RHR
Failure of Cont. Spray Heat Exchangers
Recovery Action
Core Melt
RCS Pressure <2,000 psia
Melt with Cont. not Isolated
IYAF
Cont. Spray Injection Failed
Cont. Spray Recirculation Failed
RHR Spray Recirculation Failed
No Water in Reactor Cavity

TABLE 2-16
(continued)

31	Small LOCA Non-Isolable (RCP Seal LOCA) Loss of RHR Pump 1B-B Failure of Automatic/Manual Swapover to Cont. Sump for RHR	Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Sump Recirculation is Required Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF RHR Spray Recirculation Failed	FCI	3.98E-07	0.5%
32	Small LOCA Non-Isolable (RCP Seal LOCA) Loss of RHR Pump 1A-A Failure of Automatic/Manual Swapover to Cont. Sump for RHR	Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Sump Recirculation is Required Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF RHR Spray Recirculation Failed	FCI	3.95E-07	0.5%
33	Loss of Offsite Power Failure to Recover Offsite Power in 1 Hour Loss of Unit 1 Diesel Generator 1A-A	Loss of 161kV Offsite Power Loss of 6.9kV Shutdown Board Unit 1 Train A	ENS	3.84E-07	0.5%

TABLE 2-16
(continued)

Loss of Unit 1 Diesel Generator 1B-B	Loss of 480V Shutdown Board 1A1-A
Failure of Cont. Isolation	Loss of 480V Shutdown Board 1A2-A
Recovery Action	Loss of 480V SD Transformer Room 1A Ventilation
	Loss of Unit 1 120V AC Instrument Board 1A
	Loss of 6.9kV Shutdown Board Unit 1 Train B
	Loss of 480V Shutdown Board 1B1-B
	Loss of 480V Shutdown Board 1B2-B
	Loss of 480V SD Transformer Room 1B Ventilation
	Loss of 480V SD BD Room B Ventilation in 6 Hours
	Loss of Common Board A
	Loss of Common Board B
	Loss of 6.9kV Unit Board 1A
	Loss of 6.9kV Unit Board 1B
	Loss of 6.9kV Unit Board 1C
	Loss of 6.9kV Unit Board 1D
	No Power at 6.9kV Shutdown Board 1A-A
	No Power at 480V Shutdown Board 1A1-A
	No Power at 480V Shutdown Board 1A2-A
	No Power at 6.9kV Shutdown Board 1B-B
	No Power at 480V Shutdown Board 1B1-B
	No Power at 480V Shutdown Board 1B2-B
	Failure of Control Air (Non-Essential Air)
	Failure to Recover CCS HTX by Realigning ERCW
	Loss of Train A Component Cooling Water System
	Failure to Align CCP A to ERCW Train A on Loss of CCS A
	Failure of Makeup to the RWST
	Failure of Makeup to the CST
	Loss of Motor Driven AFW Pump 1A-A
	Loss of Motor Driven AFW Pump 1B-B

TABLE 2-16
(continued)

Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Loss of RHR Pump 1A-A
Loss of RHR Pump 1B-B
Core is Melted During Injection Mode
Failure of Air Return Fans
Failure of Train A Cont. Spray
Failure of Train B Cont. Spray
Failure of Train A Sump Swapover Valve
Failure of Train B Sump Swapover Valve
Failure of Automatic/Manual Swapover to Cont. Sump for RHR
Failure of Cont. Spray Heat Exchangers
Failure of Hydrogen Ignitors
Core Melt
RCS Pressure <2,000 psia
Melt with Small Penetration Isolation Failure
SYNF
Cont. Spray Injection Failed
Cont. Spray Recirculation Failed
RHR Spray Recirculation Failed
No Water in Reactor Cavity

TABLE 2-16
(continued)

34	Turbine Trip Loss of 480V Shutdown Board 1B1-B Loss of Train A Component Cooling Water System Failure to Align CCP A to ERCW Train A on Loss of CCS A	ENI	3.78E-07	0.5%
		Loss of 480V SD Transformer Room 1B Ventilation No Power at 480V Shutdown Board 1B1-B Two Out of Four MSIVs Stay open Loss of Centrifugal Charging Pump 1A-A Loss of Centrifugal Charging Pump 1B-B Loss of Cold Leg Injection Path from CCPs Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Failure of Safety Injection Pump 1A-A Failure of Safety Injection Pump 1B-B Loss of Cold Leg Injection Paths Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Train B Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed		

TABLE 2-16
(continued)

		RHR Spray Recirculation Failed No Water in Reactor Cavity			
35	Flooding - ERCW Strainer Room, Train A Loss of Train B Component Cooling Water System Failure of Thermal Barriers to the RCPs	Loss of ERCW Train A Pumps Loss of ERCW Header 1A Loss of ERCW Header 2A Two Out of Four MSIVs Stay open Loss of Centrifugal Charging Pump 1A-A Loss of Centrifugal Charging Pump 1B-B Loss of Cold Leg Injection Path from CCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Failure of Safety Injection Pump 1A-A Failure of Safety Injection Pump 1B-B Loss of Cold Leg Injection Paths Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF	ENI	3.2851E-07	0.4%

TABLE 2-16
(continued)

		Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
36	Loss of Offsite Power Failure to Recover Offsite Power in 1 Hour Loss of 125V DC Battery Board III Loss of Unit 2 Diesel Generator 2B-B	Loss of 161kV Offsite Power Loss of Common Board A Loss of Common Board B Loss of 6.9kV Unit Board 1A Loss of 6.9kV Unit Board 1B Loss of 6.9kV Unit Board 1C Loss of 6.9kV Unit Board 1D Loss of 6.9kV Shutdown Board Unit 2 Train B Loss of 480V Shutdown Board 2B1-B Loss of 480V Shutdown Board 2B2-B Loss of 480V SD Transformer Room 2B Ventilation Loss of 480V SD BD Room 2B Ventilation in 6 Hours No Power at 6.9kV Shutdown Board 1A-A No Power at 480V Shutdown Board 1A1-A No Power at 480V Shutdown Board 1A2-A No Power at 6.9kV Shutdown Board 2A-A No Power at 480V Shutdown Board 2A1-A No Power at 480V Shutdown Board 2A2-A No Power at 6.9kV Shutdown Board 2B-B No Power at 480V Shutdown Board 2B1-B No Power at 480V Shutdown Board 2B2-B Failure of Control Air (Non-Essential Air) Loss of Train A Essential Air	GNI	3.18E-07	0.4%

TABLE 2-16
(continued)

Loss of Train B Essential Air
Loss of Train B Component Cooling Water System
Failure of Makeup to the RWST
Failure of Makeup to the CST
Failure of Turbine Driven AFW Pump
Failure to Recover TD AFW Pump Start Failures in 30 Minutes
Loss of Motor Driven AFW Pump 1A-A
Loss of Motor Driven AFW Pump 1B-B
Failure of Equipment Needed to Recover Main Feedwater
Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of PZR PORVs to Open to Control RCS Pressure & Reclose
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Loss of RHR Pump 1A-A
Loss of RHR Pump 1B-B
Core is Melted During Injection Mode
Failure of Train A Cont. Spray
Failure of Train B Cont. Spray
Failure of Train A Sump Swapover Valve
Failure of Automatic/Manual Swapover to Cont. Sump for RHR
Failure of Cont. Spray Heat Exchangers
Recovery Action
Core Melt
RCS Pressure <2,000 psia
Steam Generator Cooling Failed
Melt with Cont. not Isolated

TABLE 2-16
(continued)

		IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
37	Medium LOCA Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B	Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of RHR & SIS Hot Leg Recirculation Recovery Action Core Melt Melt with Cont. not Isolated IYAF RHR Spray Recirculation Failed	DCI	3.18E-07	0.4%
38	Small LOCA Non-Isolable (RCP Seal LOCA) Failure of Makeup to the RWST Loss of RHR Pump 1B-B Failure of Automatic/Manual Swapover to Cont. Sump for RHR	Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Sump Recirculation is Required Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF RHR Spray Recirculation Failed	FCI	3.16E-07	0.4%

TABLE 2-16
(continued)

39	Small LOCA Non-Isolable (RCP Seal LOCA) Failure of Makeup to the RWST Loss of RHR Pump 1A-A Failure of Automatic/Manual Swapover to Cont. Sump for RHR	Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Sump Recirculation is Required Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF RHR Spray Recirculation Failed	FCI	3.13E-07	0.4%
40	Loss of 6.9 Shutdown Board 1A-A Loss of 480V Shutdown Board 1B1-B Failure to Align CCP A to ERCW Train A on Loss of CCS A	Loss of 6.9kV Shutdown Board Unit 1 Train A Loss of 480V Shutdown Board 1A1-A Loss of 480V Shutdown Board 1A2-A Loss of 480V SD Transformer Room 1A Ventilation Loss of Unit 1 120V AC Instrument Board 1A Loss of 480V SD Transformer Room 1B Ventilation No Power at 6.9kV Shutdown Board 1A-A No Power at 480V Shutdown Board 1A1-A No Power at 480V Shutdown Board 1A2-A No Power at 480V Shutdown Board 1B1-B Loss of Train A Component Cooling Water System Failure of Makeup to the RWST Two Out of Four MSIVs Stay open Fail to Cooldown Using Steam Dumps, Condenser, & Hotwell Pumps Loss of Motor Driven AFW Pump 1A-A	ENI	3.13E-07	0.4%

TABLE 2-16
(continued)

Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Loss of RHR Pump 1A-A
Loss of RHR Pump 1B-B
Core is Melted During Injection Mode
Failure of Train A Cont. Spray
Failure of Train B Cont. Spray
Failure of Train A Sump Swapover Valve
Failure of Train B Sump Swapover Valve
Failure of Automatic/Manual Swapover to Cont. Sump for RHR
Failure of Cont. Spray Heat Exchangers
Failure of Hydrogen Ignitors
Recovery Action
Core Melt
RCS Pressure <2,000 psia
Melt with Cont. not Isolated
IYAF
Cont. Spray Injection Failed
Cont. Spray Recirculation Failed
RHR Spray Recirculation Failed
No Water in Reactor Cavity

TABLE 2-16
(continued)

41	Loss of Offsite Power Failure to Recover Offsite Power in 1 Hour Loss of Unit 1 Diesel Generator 1B-B Loss of 125V DC Battery Board III	GNI	3.12E-07	0.4%
		Loss of 161kV Offsite Power Loss of 6.9kV Shutdown Board Unit 1 Train B Loss of 480V Shutdown Board 1B1-B Loss of 480V Shutdown Board 1B2-B Loss of 480V SD Transformer Room 1B Ventilation Loss of 480V SD BD Room B Ventilation in 6 Hours Loss of Common Board A Loss of Common Board B Loss of 6.9kV Unit Board 1A Loss of 6.9kV Unit Board 1B Loss of 6.9kV Unit Board 1C Loss of 6.9kV Unit Board 1D No Power at 6.9kV Shutdown Board 1A-A No Power at 480V Shutdown Board 1A1-A No Power at 480V Shutdown Board 1A2-A No Power at 6.9kV Shutdown Board 2A-A No Power at 480V Shutdown Board 2A1-A No Power at 480V Shutdown Board 2A2-A No Power at 6.9kV Shutdown Board 1B-B No Power at 480V Shutdown Board 1B1-B No Power at 480V Shutdown Board 1B2-B Failure of Control Air (Non-Essential Air) Loss of Train A Essential Air Failure to Recover CCS HTX by Realigning ERCW Loss of Train A Component Cooling Water System Failure to Align CCP A to ERCW Train A on Loss of CCS A Failure of Makeup to the RWST Failure of Makeup to the CST			

TABLE 2-16
(continued)

Failure of Turbine Driven AFW Pump
Failure to Recover TD AFW Pump Start Failures in 30 Minutes
Loss of Motor Driven AFW Pump 1A-A
Loss of Motor Driven AFW Pump 1B-B
Failure of Equipment Needed to Recover Main Feedwater
Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of PZR PORVs to Open to Control RCS Pressure & Reclose
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Loss of RHR Pump 1A-A
Loss of RHR Pump 1B-B
Core is Melted During Injection Mode
Failure of Air Return Fans
Failure of Train A Cont. Spray
Failure of Train B Cont. Spray
Failure of Train A Sump Swapover Valve
Failure of Train B Sump Swapover Valve
Failure of Automatic/Manual Swapover to Cont. Sump for RHR
Failure of Cont. Spray Heat Exchangers
Failure of Hydrogen Ignitors
Recovery Action
Core Melt
RCS Pressure <2,000 psia
Steam Generator Cooling Failed

TABLE 2-16
(continued)

		Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
42	Loss of 6.9 Shutdown Board 1B-B Loss of 480V Shutdown Board 1A1-A Failure to Align CCP A to ERCW Train A on Loss of CCS A	Loss of 480V SD Transformer Room 1A Ventilation Loss of Unit 1 120V AC Instrument Board 1A Loss of 6.9kV Shutdown Board Unit 1 Train B Loss of 480V Shutdown Board 1B1-B Loss of 480V Shutdown Board 1B2-B Loss of 480V SD Transformer Room 1B Ventilation Loss of 480V SD BD Room B Ventilation in 6 Hours No Power at 480V Shutdown Board 1A1-A No Power at 6.9kV Shutdown Board 1B-B No Power at 480V Shutdown Board 1B1-B No Power at 480V Shutdown Board 1B2-B Loss of Train A Component Cooling Water System Failure of Makeup to the RWST Two Out of Four MSIVs Stay open Loss of Motor Driven AFW Pump 1B-B Loss of Centrifugal Charging Pump 1A-A Loss of Centrifugal Charging Pump 1B-B Loss of Cold Leg Injection Path from CCPs Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Failure of Safety Injection Pump 1A-A	ENI	3.10E-07	0.4%

TABLE 2-16 (continued)

		Failure of Safety Injection Pump 1B-B Loss of Cold Leg Injection Paths Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Air Return Fans Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Train A Sump Swapover Valve Failure of Train B Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Failure of Hydrogen Ignitors Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
43	Loss of 6.9 Shutdown Board 1A-A Loss of 480V Shutdown Board 1B1-B	Loss of 6.9kV Shutdown Board Unit 1 Train A Loss of 480V Shutdown Board 1A1-A Loss of 480V Shutdown Board 1A2-A Loss of 480V SD Transformer Room 1A Ventilation Loss of Unit 1 120V AC Instrument Board 1A	ENI	3.09E-07	0.4%

TABLE 2-16
(continued)

Loss of 480V SD Transformer Room 1B Ventilation
No Power at 6.9kV Shutdown Board 1A-A
No Power at 480V Shutdown Board 1A1-A
No Power at 480V Shutdown Board 1A2-A
No Power at 480V Shutdown Board 1B1-B
Loss of Train A Component Cooling Water System
Failure of Makeup to the RWST
Two Out of Four MSIVs Stay open
Fail to Cooldown Using Steam Dumps, Condenser, & Hotwell Pumps
Loss of Motor Driven AFW Pump 1A-A
Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Loss of RHR Pump 1A-A
Loss of RHR Pump 1B-B
Core is Melted During Injection Mode
Failure of Train A Cont. Spray
Failure of Train B Cont. Spray
Failure of Train A Sump Swapover Valve
Failure of Train B Sump Swapover Valve
Failure of Automatic/Manual Swapover to Cont. Sump for RHR
Failure of Cont. Spray Heat Exchangers
Failure of Hydrogen Ignitors
Recovery Action

TABLE 2-16
(continued)

		Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
44	Loss of 6.9 Shutdown Board 1B-B Loss of 480V Shutdown Board 1A1-A	Loss of 480V SD Transformer Room 1A Ventilation Loss of Unit 1 120V AC Instrument Board 1A Loss of 6.9kV Shutdown Board Unit 1 Train B Loss of 480V Shutdown Board 1B1-B Loss of 480V Shutdown Board 1B2-B Loss of 480V SD Transformer Room 1B Ventilation Loss of 480V SD BD Room B Ventilation in 6 Hours No Power at 480V Shutdown Board 1A1-A No Power at 6.9kV Shutdown Board 1B-B No Power at 480V Shutdown Board 1B1-B No Power at 480V Shutdown Board 1B2-B Loss of Train A Component Cooling Water System Failure of Makeup to the RWST Two Out of Four MSIVs Stay open Loss of Motor Driven AFW Pump 1B-B Loss of Centrifugal Charging Pump 1A-A Loss of Centrifugal Charging Pump 1B-B Loss of Cold Leg Injection Path from CCPs Failure of Thermal Barriers to the RCPs	ENI	3.06E-07	0.4%

TABLE 2-16
(continued)

		RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Failure of Safety Injection Pump 1A-A Failure of Safety Injection Pump 1B-B Loss of Cold Leg Injection Paths Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Air Return Fans Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Train A Sump Swapover Valve Failure of Train B Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Failure of Hydrogen Ignitors Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
45	Small LOCA Non-Isolable (RCP Seal LOCA) Failure of Makeup to the RWST Loss of RHR Pump 1B-B Failure of Train A Sump Swapover Valve	Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Operator fails to Depress. the RCS Using SG PORVs	FCI	3.05E-07	0.4%

TABLE 2-16
(continued)

		Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Sump Recirculation is Required Failure of Automatic/Manual Swapover to Cont. Sump for RHR Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF RHR Spray Recirculation Failed			
46	Small LOCA Non-Isolable (RCP Seal LOCA) Failure of Makeup to the RWST Loss of RHR Pump 1A-A Failure of Train B Sump Swapover Valve	Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Sump Recirculation is Required Failure of Automatic/Manual Swapover to Cont. Sump for RHR Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF RHR Spray Recirculation Failed	FCI	2.89E-07	0.4%
47	Steam Generator Tube Rupture Failure of Makeup to the RWST Operator fails to Depress. the RCS Using SG PORVs	Two Out of Four MSIVs Stay open Operator Fails to Identify & Isolate Ruptured Steam Generator Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Loss of RHR Normal Decay Heat Removal	EIB	2.86E-07	0.4%

TABLE 2-16
(continued)

		Core is Melted During Injection Mode Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Cont. Spray Heat Exchangers Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. Bypassed BYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed No Water in Reactor Cavity			
48	Loss of 6.9 Shutdown Board 1B-B Loss of ERCW Train B Pumps Loss of Train A Component Cooling Water System Failure to Align CCP A to ERCW Train A on Loss of CCS A	Loss of 6.9kV Shutdown Board Unit 1 Train B Loss of 480V Shutdown Board 1B1-B Loss of 480V Shutdown Board 1B2-B Loss of 480V SD Transformer Room 1B Ventilation Loss of 480V SD BD Room B Ventilation in 6 Hours Loss of ERCW Header 1B Loss of ERCW Header 2B No Power at 6.9kV Shutdown Board 1B-B No Power at 480V Shutdown Board 1B1-B No Power at 480V Shutdown Board 1B2-B Two Out of Four MSIVs Stay open Loss of Motor Driven AFW Pump 1B-B Loss of Centrifugal Charging Pump 1A-A Loss of Centrifugal Charging Pump 1B-B Loss of Cold Leg Injection Path from CCPs	ENI	2.53E-07	0.3%

TABLE 2-16
(continued)

		Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Failure of Safety Injection Pump 1A-A Failure of Safety Injection Pump 1B-B Loss of Cold Leg Injection Paths Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Train B Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
49	Small LOCA Non-Isolable (RCP Seal LOCA) Failure of Train A Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR	Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Operator fails to Depress. the RCS Using SG PORVs	FCI	2.23E-07	0.3%

TABLE 2-16
(continued)

		Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Sump Recirculation is Required Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF RHR Spray Recirculation Failed			
50	Loss of Offsite Power Failure to Recover Offsite Power in 1 Hour Loss of Unit 1 Diesel Generator 1A-A Loss of Unit 1 Diesel Generator 1B-B Operator fails to Depress. the RCS Using SG PORVs Recovery Action	Loss of 161kV Offsite Power Loss of 6.9kV Shutdown Board Unit 1 Train A Loss of 480V Shutdown Board 1A1-A Loss of 480V Shutdown Board 1A2-A Loss of 480V SD Transformer Room 1A Ventilation Loss of Unit 1 120V AC Instrument Board 1A Loss of 6.9kV Shutdown Board Unit 1 Train B Loss of 480V Shutdown Board 1B1-B Loss of 480V Shutdown Board 1B2-B Loss of 480V SD Transformer Room 1B Ventilation Loss of 480V SD BD Room B Ventilation in 6 Hours Loss of Common Board A Loss of Common Board B Loss of 6.9kV Unit Board 1A Loss of 6.9kV Unit Board 1B Loss of 6.9kV Unit Board 1C Loss of 6.9kV Unit Board 1D No Power at 6.9kV Shutdown Board 1A-A No Power at 480V Shutdown Board 1A1-A	ENI	2.23E-07	0.3%

TABLE 2-16
(continued)

No Power at 480V Shutdown Board 1A2-A
No Power at 6.9kV Shutdown Board 1B-B
No Power at 480V Shutdown Board 1B1-B
No Power at 480V Shutdown Board 1B2-B
Failure of Control Air (Non-Essential Air)
Failure to Recover CCS HTX by Realigning ERCW
Loss of Train A Component Cooling Water System
Failure to Align CCP A to ERCW Train A on Loss of CCS A
Failure of Makeup to the RWST
Failure of Makeup to the CST
Loss of Motor Driven AFW Pump 1A-A
Loss of Motor Driven AFW Pump 1B-B
Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Operator fails to Depress. the RCS Using the PZR Sprays and PORVs
Loss of RHR Pump 1A-A
Loss of RHR Pump 1B-B
Core is Melted During Injection Mode
Failure of Air Return Fans
Failure of Train A Cont. Spray
Failure of Train B Cont. Spray
Failure of Train A Sump Swapover Valve
Failure of Train B Sump Swapover Valve

TABLE 2-16
(continued)

		Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Failure of Hydrogen Ignitors Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
51	Loss of Offsite Power Failure to Recover Offsite Power in 1 Hour Loss of Unit 1 Diesel Generator 1A-A Loss of ERCW Train B Pumps Failure of Turbine Driven AFW Pump Failure to Recover TD AFW Pump Start Failures in 30 Minutes	Loss of 161kV Offsite Power Loss of 6.9kV Shutdown Board Unit 1 Train A Loss of 480V Shutdown Board 1A1-A Loss of 480V Shutdown Board 1A2-A Loss of 480V SD Transformer Room 1A Ventilation Loss of Unit 1 120V AC Instrument Board 1A Loss of Common Board A Loss of Common Board B Loss of 6.9kV Unit Board 1A Loss of 6.9kV Unit Board 1B Loss of 6.9kV Unit Board 1C Loss of 6.9kV Unit Board 1D Loss of ERCW Header 1B Loss of ERCW Header 2B No Power at 6.9kV Shutdown Board 1A-A No Power at 480V Shutdown Board 1A1-A	GNI	2.20E-07	0.3%

TABLE 2-16
(continued)

No Power at 480V Shutdown Board 1A2-A
Failure of Control Air (Non-Essential Air)
Loss of Train B Essential Air
Failure to Recover CCS HTX by Realigning ERCW
Loss of Train A Component Cooling Water System
Failure of Makeup to the RWST
Failure of Makeup to the CST
Loss of Motor Driven AFW Pump 1A-A
Loss of Motor Driven AFW Pump 1B-B
Failure of Equipment Needed to Recover Main Feedwater
Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of PZR PORVs to Open to Control RCS Pressure & Reclose
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Loss of RHR Pump 1A-A
Loss of RHR Pump 1B-B
Core is Melted During Injection Mode
Failure of Train A Cont. Spray
Failure of Train B Cont. Spray
Failure of Train A Sump Swapover Valve
Failure of Automatic/Manual Swapover to Cont. Sump for RHR
Failure of Cont. Spray Heat Exchangers
Recovery Action
Core Melt

TABLE 2-16 (continued)

		RCS Pressure <2,000 psia Steam Generator Cooling Failed Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
52	Excessive LOCA	Excessive LOCA Recovery Action Core Melt Melt with Cont. not Isolated IYAF RHR Spray Recirculation Failed	BCI	2.14E-07	0.3%
53	Small LOCA Non-Isolable (RCP Seal LOCA) Failure of Train B Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR	Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Sump Recirculation is Required Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF RHR Spray Recirculation Failed	FCI	2.13E-07	0.3%

TABLE 2-16
(continued)

54	Loss of Offsite Power Failure to Recover Offsite Power in 1 Hour Loss of Unit 1 Diesel Generator 1B-B Loss of ERCW Train A Pumps Failure of Turbine Driven AFW Pump Failure to Recover TD AFW Pump Start Failures in 30 Minutes	GNI	2.09E-07	0.3%
		Loss of 161kV Offsite Power Loss of 6.9kV Shutdown Board Unit 1 Train B Loss of 480V Shutdown Board 1B1-B Loss of 480V Shutdown Board 1B2-B Loss of 480V SD Transformer Room 1B Ventilation Loss of 480V SD BD Room B Ventilation in 6 Hours Loss of Common Board A Loss of Common Board B Loss of 6.9kV Unit Board 1A Loss of 6.9kV Unit Board 1B Loss of 6.9kV Unit Board 1C Loss of 6.9kV Unit Board 1D Loss of ERCW Header 1A Loss of ERCW Header 2A No Power at 6.9kV Shutdown Board 1B-B No Power at 480V Shutdown Board 1B1-B No Power at 480V Shutdown Board 1B2-B Failure of Control Air (Non-Essential Air) Loss of Train A Essential Air Failure of Makeup to the RWST Failure of Makeup to the CST Loss of Motor Driven AFW Pump 1A-A Loss of Motor Driven AFW Pump 1B-B Failure of Equipment Needed to Recover Main Feedwater Loss of Centrifugal Charging Pump 1A-A Loss of Centrifugal Charging Pump 1B-B Loss of Cold Leg Injection Path from CCPs Failure of PZR PORVs to Open to Control RCS Pressure & Reclose		

TABLE 2-16
(continued)

		Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Failure of Safety Injection Pump 1A-A Failure of Safety Injection Pump 1B-B Loss of Cold Leg Injection Paths Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Train B Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Recovery Action Core Melt RCS Pressure <2,000 psia Steam Generator Cooling Failed Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
55	Small LOCA Non-Isolable (RCP Seal LOCA) Failure of Turbine Driven AFW Pump Failure to Recover TD AFW Pump Start Failures in 30 Minutes Failure of Automatic/Manual Swapover to Cont. Sump for RHR	Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs	FCI	2.07E-07	0.3%

TABLE 2-16
(continued)

		Sump Recirculation is Required Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF RHR Spray Recirculation Failed			
56	Steam Generator Tube Rupture Failure of Control Air (Non-Essential Air) Operator fails to Depress. the RCS Using SG PORVs	Failure of Makeup to the RWST Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Loss of RHR Normal Decay Heat Removal Core is Melted During Injection Mode Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Cont. Spray Heat Exchangers Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. Bypassed BYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed No Water in Reactor Cavity	EIB	2.03E-07	0.3%
57	Loss of Battery Board II Loss of Train A Component Cooling Water System Failure to Align CCP A to ERCW Train A on Loss of CCS A	Loss of 125V DC Battery Board II Loss of Motor Driven AFW Pump 1B-B Loss of Centrifugal Charging Pump 1A-A	ENI	1.92E-07	0.2%

TABLE 2-16
(continued)

Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Operator fails to Depress. the RCS Using SG PORVs
Operator fails to Depress. the RCS Using the PZR Sprays and PORVs
Loss of RHR Pump 1A-A
Loss of RHR Pump 1B-B
Core is Melted During Injection Mode
Failure of Train A Cont. Spray
Failure of Train B Cont. Spray
Failure of Automatic/Manual Swapover to Cont. Sump for RHR
Failure of Cont. Spray Heat Exchangers
Recovery Action
Core Melt
RCS Pressure <2,000 psia
Melt with Cont. not Isolated
IYAF
Cont. Spray Injection Failed
Cont. Spray Recirculation Failed
RHR Spray Recirculation Failed
No Water in Reactor Cavity

TABLE 2-16 (continued)

58	Medium LOCA Failure of 2/3 RHR Cold Leg Injection Paths	Recovery Action Core Melt Melt with Cont. not Isolated IYAF RHR Spray Recirculation Failed	DCI	1.89E-07	0.2%
59	Small LOCA Isolable (Pressurizer PORV) Loss of Train B Component Cooling Water System Failure of Makeup to the RWST Loss of Centrifugal Charging Pump 1A-A	Loss of Centrifugal Charging Pump 1B-B Loss of Cold Leg Injection Path from CCPs Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Failure of Safety Injection Pump 1B-B Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Loss of RHR Pump 1B-B Sump Recirculation is Required Failure of Train B Cont. Spray Failure of Automatic/Manual Swapover to Cont. Sump for RHR Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF RHR Spray Recirculation Failed	FCI	1.86E-07	0.2%
60	Small LOCA Non-Isolable (RCP Seal LOCA) Failure of Makeup to the RWST Failure of Train A Sump Swapover Valve	Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops	FCI	1.77E-07	0.2%

TABLE 2-16
(continued)

	Failure of Automatic/Manual Swapover to Cont. Sump for RHR	Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Sump Recirculation is Required Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF RHR Spray Recirculation Failed			
61	Total Loss of Component Cooling Water Failure to Align CCP A to ERCW Train A on Loss of CCS A	Loss of Train A Component Cooling Water System Loss of Train B Component Cooling Water System Two Out of Four MSIVs Stay open Loss of Centrifugal Charging Pump 1A-A Loss of Centrifugal Charging Pump 1B-B Loss of Cold Leg Injection Path from CCPs Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Failure of Safety Injection Pump 1A-A Failure of Safety Injection Pump 1B-B Loss of Cold Leg Injection Paths Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Train A Cont. Spray Failure of Train B Cont. Spray	ENI	1.77E-07	0.2%

TABLE 2-16
(continued)

		Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
62	Loss of 6.9 Shutdown Board 1B-B Loss of Train A Component Cooling Water System Failure to Align CCP A to ERCW Train A on Loss of CCS A Failure of Turbine Driven AFW Pump Failure to Recover TD AFW Pump Start Failures in 30 Minutes	Loss of 6.9kV Shutdown Board Unit 1 Train B Loss of 480V Shutdown Board 1B1-B Loss of 480V Shutdown Board 1B2-B Loss of 480V SD Transformer Room 1B Ventilation Loss of 480V SD BD Room B Ventilation in 6 Hours No Power at 6.9kV Shutdown Board 1B-B No Power at 480V Shutdown Board 1B1-B No Power at 480V Shutdown Board 1B2-B Two Out of Four MSIVs Stay open Loss of Motor Driven AFW Pump 1B-B Loss of Centrifugal Charging Pump 1A-A Loss of Centrifugal Charging Pump 1B-B Loss of Cold Leg Injection Path from CCPs Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Failure of Safety Injection Pump 1A-A	ENI	1.74E-07	0.2%

TABLE 2-16
(continued)

		Failure of Safety Injection Pump 1B-B Loss of Cold Leg Injection Paths Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Train B Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
63	Small LOCA Non-Isolable (RCP Seal LOCA) Failure of Makeup to the RWST Failure of Train A Sump Swapover Valve Failure of Train B Sump Swapover Valve	Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Sump Recirculation is Required Failure of Automatic/Manual Swapover to Cont. Sump for RHR	FCI	1.72E-07	0.2%

TABLE 2-16
(continued)

		Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF RHR Spray Recirculation Failed			
64	Excessive Main Feedwater Loss of Train A ESFAS Loss of Train B ESFAS Failure of Manual Operator Backup of ESFAS Alignments	Two Out of Four MSIVs Stay open Failure of Turbine Driven AFW Pump Failure to Recover TD AFW Pump Start Failures in 30 Minutes Loss of Motor Driven AFW Pump 1A-A Loss of Motor Driven AFW Pump 1B-B Failure of Equipment Needed to Recover Main Feedwater Loss of Centrifugal Charging Pump 1B-B Loss of Cold Leg Injection Path from CCPs Failure of PZR PORVs to Open to Control RCS Pressure & Reclose Failure of Safety Injection Pump 1A-A Failure of Safety Injection Pump 1B-B Loss of Cold Leg Injection Paths Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Air Return Fans Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Failure of Cont. Isolation	GNS	1.71E-07	0.2%

TABLE 2-16 (continued)

		Recovery Action Core Melt RCS Pressure <2,000 psia Steam Generator Cooling Failed Melt with Small Penetration Isolation Failure SYCF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
65	Small LOCA Non-Isolable (RCP Seal LOCA) Failure of Makeup to the RWST Failure of Train B Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR	Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Sump Recirculation is Required Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF RHR Spray Recirculation Failed	FCI	1.69E-07	0.2%
66	Loss of Offsite Power Failure to Recover Offsite Power in 1 Hour Loss of ERCW Train A Pumps Loss of ERCW Train B Pumps	Loss of 161kV Offsite Power Loss of Common Board A Loss of Common Board B Loss of 6.9kV Unit Board 1A	ENI	1.67E-07	0.2%

TABLE 2-16
(continued)

Loss of 6.9kV Unit Board 1B
Loss of 6.9kV Unit Board 1C
Loss of 6.9kV Unit Board 1D
Loss of ERCW Header 1A
Loss of ERCW Header 2A
Loss of ERCW Header 1B
Loss of ERCW Header 2B
Failure to Recover ERCW to Diesel from Opposite Train
No Power at 6.9kV Shutdown Board 1A-A
No Power at 480V Shutdown Board 1A1-A
No Power at 480V Shutdown Board 1A2-A
No Power at 6.9kV Shutdown Board 2A-A
No Power at 480V Shutdown Board 2A1-A
No Power at 480V Shutdown Board 2A2-A
No Power at 6.9kV Shutdown Board 1B-B
No Power at 480V Shutdown Board 1B1-B
No Power at 480V Shutdown Board 1B2-B
No Power at 6.9kV Shutdown Board 2B-B
No Power at 480V Shutdown Board 2B1-B
No Power at 480V Shutdown Board 2B2-B
Failure of ERCW Cooling to CAS Compressors
Failure of Control Air (Non-Essential Air)
Loss of Train A Essential Air
Loss of Train B Essential Air
Failure to Recover CCS HTX by Realigning ERCW
Loss of Train A Component Cooling Water System
Loss of Train B Component Cooling Water System
Failure to Align CCP A to ERCW Train A on Loss of CCS A
Failure of Makeup to the RWST

TABLE 2-16
(continued)

Failure of Makeup to the CST
Loss of Motor Driven AFW Pump 1A-A
Loss of Motor Driven AFW Pump 1B-B
Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Loss of RHR Pump 1A-A
Loss of RHR Pump 1B-B
Core is Melted During Injection Mode
Failure of Air Return Fans
Failure of Train A Cont. Spray
Failure of Train B Cont. Spray
Failure of Train A Sump Swapover Valve
Failure of Train B Sump Swapover Valve
Failure of Automatic/Manual Swapover to Cont. Sump for RHR
Failure of Cont. Spray Heat Exchangers
Failure of Hydrogen Ignitors
Recovery Action
Core Melt
RCS Pressure <2,000 psia
Melt with Cont. not Isolated
IYAF
Cont. Spray Injection Failed
Cont. Spray Recirculation Failed

TABLE 2-16
(continued)

		RHR Spray Recirculation Failed No Water in Reactor Cavity			
67	Loss of Offsite Power Failure to Recover Offsite Power in 1 Hour Loss of Unit 1 Diesel Generator 1A-A Loss of Unit 2 Diesel Generator 2B-B Failure of Thermal Barriers to the RCPs Recovery Action	Loss of 161kV Offsite Power Loss of 6.9kV Shutdown Board Unit 1 Train A Loss of 480V Shutdown Board 1A1-A Loss of 480V Shutdown Board 1A2-A Loss of 480V SD Transformer Room 1A Ventilation Loss of Unit 1 120V AC Instrument Board 1A Loss of Common Board A Loss of Common Board B Loss of 6.9kV Unit Board 1A Loss of 6.9kV Unit Board 1B Loss of 6.9kV Unit Board 1C Loss of 6.9kV Unit Board 1D Loss of 6.9kV Shutdown Board Unit 2 Train B Loss of 480V Shutdown Board 2B1-B Loss of 480V Shutdown Board 2B2-B Loss of 480V SD Transformer Room 2B Ventilation Loss of 480V SD BD Room 2B Ventilation in 6 Hours No Power at 6.9kV Shutdown Board 1A-A No Power at 480V Shutdown Board 1A1-A No Power at 480V Shutdown Board 1A2-A No Power at 6.9kV Shutdown Board 2B-B No Power at 480V Shutdown Board 2B1-B No Power at 480V Shutdown Board 2B2-B Failure of Control Air (Non-Essential Air) Loss of Train B Essential Air	ENI	1.65E-07	0.2%

TABLE 2-16
(continued)

Loss of Train B Component Cooling Water System
Failure of Makeup to the RWST
Failure of Makeup to the CST
Loss of Motor Driven AFW Pump 1A-A
Loss of Motor Driven AFW Pump 1B-B
Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Operator fails to Depress. the RCS Using SG PORVs
Operator fails to Depress. the RCS Using the PZR Sprays and PORVs
Loss of RHR Pump 1A-A
Loss of RHR Pump 1B-B
Core is Melted During Injection Mode
Failure of Train A Cont. Spray
Failure of Train B Cont. Spray
Failure of Train A Sump Swapover Valve
Failure of Automatic/Manual Swapover to Cont. Sump for RHR
Failure of Cont. Spray Heat Exchangers
Core Melt
RCS Pressure <2,000 psia
Melt with Cont. not Isolated
IYAF
Cont. Spray Injection Failed
Cont. Spray Recirculation Failed
RHR Spray Recirculation Failed
No Water in Reactor Cavity

TABLE 2-16
(continued)

68	Total Loss of Main Feedwater Loss of Train A ESFAS Loss of Train B ESFAS Failure of Manual Operator Backup of ESFAS Alignments	GNS	1.65E-07	0.2%
		Two Out of Four MSIVs Stay open Failure of Turbine Driven AFW Pump Failure to Recover TD AFW Pump Start Failures in 30 Minutes Loss of Motor Driven AFW Pump 1A-A Loss of Motor Driven AFW Pump 1B-B Failure of Equipment Needed to Recover Main Feedwater Loss of Centrifugal Charging Pump 1B-B Loss of Cold Leg Injection Path from CCPs Failure of PZR PORVs to Open to Control RCS Pressure & Reclose Failure of Safety Injection Pump 1A-A Failure of Safety Injection Pump 1B-B Loss of Cold Leg Injection Paths Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Air Return Fans Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Failure of Cont. Isolation Recovery Action Core Melt RCS Pressure <2,000 psia Steam Generator Cooling Failed Melt with Small Penetration Isolation Failure SYCF Cont. Spray Injection Failed			

TABLE 2-16 (continued)

		Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
69	Small LOCA Non-Isolable (RCP Seal LOCA) Failure of Makeup to the RWST Failure of Turbine Driven AFW Pump Failure to Recover TD AFW Pump Start Failures in 30 Minutes Failure of Automatic/Manual Swapover to Cont. Sump for RHR	Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Sump Recirculation is Required Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF RHR Spray Recirculation Failed	FCI	1.64E-07	0.2%
70	Loss of Component Cooling Water Train A RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Failure of Automatic/Manual Swapover to Cont. Sump for RHR	Loss of Train A Component Cooling Water System Two Out of Four MSIVs Stay open Failure of Thermal Barriers to the RCPs Failure of Safety Injection Pump 1A-A Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Loss of RHR Pump 1A-A Sump Recirculation is Required Failure of Train A Cont. Spray Recovery Action Core Melt	FCI	1.62E-07	0.2%

TABLE 2-16
(continued)

		RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF RHR Spray Recirculation Failed			
71	Flooding - ERCW Strainer Room, Train B Loss of Train A Component Cooling Water System Loss of Centrifugal Charging Pump 1A-A	Loss of ERCW Train B Pumps Loss of ERCW Header 1B Loss of ERCW Header 2B Two Out of Four MSIVs Stay open Loss of Centrifugal Charging Pump 1B-B Loss of Cold Leg Injection Path from CCPs Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Failure of Safety Injection Pump 1A-A Failure of Safety Injection Pump 1B-B Loss of Cold Leg Injection Paths Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Recovery Action Core Melt RCS Pressure <2,000 psia	ENI	1.59E-07	0.2%

TABLE 2-16 (continued)

		Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
72	Turbine Trip Failure to Trip Reactor and Insert Controls Rods Power Level is Greater than 40% Failure of Emergency Boration (Operator Actions & Equipment)	Two Out of Four MSIVs Stay open Failure of PZR PORVs to Open to Control RCS Pressure & Reclose Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Core is Melted During Injection Mode Operator Fails to Control Cont. Spray Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF	FCI	1.58E-07	0.2%
73	Small LOCA Isolable (Pressurizer PORV) Loss of Train A ESFAS Loss of Train B ESFAS Failure of Manual Operator Backup of ESFAS Alignments	Two Out of Four MSIVs Stay open Failure of Turbine Driven AFW Pump Failure to Recover TD AFW Pump Start Failures in 30 Minutes Loss of Motor Driven AFW Pump 1A-A Loss of Motor Driven AFW Pump 1B-B Failure of Supply to CVCS Loss of Cold Leg Injection Path from CCPs Failure of Thermal Barriers to the RCPs	ENS	1.57E-07	0.2%

TABLE 2-16
(continued)

		RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Failure of Safety Injection Pump 1A-A Failure of Safety Injection Pump 1B-B Loss of Cold Leg Injection Paths Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Air Return Fans Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Failure of Cont. Isolation Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Small Penetration Isolation Failure SYCF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
74	Loss of 6.9 Shutdown Board 1A-A Loss of ERCW Train A Pumps Maintenance on ERCW Header 1B	Loss of 6.9kV Shutdown Board Unit 1 Train A Loss of 480V Shutdown Board 1A1-A Loss of 480V Shutdown Board 1A2-A	ENI	1.54E-07	0.2%

TABLE 2-16
(continued)

Loss of 480V SD Transformer Room 1A Ventilation
Loss of Unit 1 120V AC Instrument Board 1A
Loss of ERCW Header 1A
Loss of ERCW Header 2A
Loss of ERCW Header 1B
No Power at 6.9kV Shutdown Board 1A-A
No Power at 480V Shutdown Board 1A1-A
No Power at 480V Shutdown Board 1A2-A
Failure of ERCW Cooling to CAS Compressors
Failure of Control Air (Non-Essential Air)
Loss of Train A Essential Air
Failure to Recover CCS HTX by Realigning ERCW
Loss of Train A Component Cooling Water System
Failure to Align CCP A to ERCW Train A on Loss of CCS A
Failure of Makeup to the RWST
Loss of Motor Driven AFW Pump 1A-A
Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Operator fails to Depress. the RCS Using SG PORVs
Operator fails to Depress. the RCS Using the PZR Sprays and PORVs
Loss of RHR Pump 1A-A
Loss of RHR Pump 1B-B
Core is Melted During Injection Mode

TABLE 2-16 (continued)

		Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Train A Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
75	Small LOCA Non-Isolable (RCP Seal LOCA) Failure of Makeup to the RWST Failure of Turbine Driven AFW Pump Failure to Recover TD AFW Pump Start Failures in 30 Minutes Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B	Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Sump Recirculation is Required Failure of Automatic/Manual Swapover to Cont. Sump for RHR Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF RHR Spray Recirculation Failed	FCI	1.52E-07	0.2%

TABLE 2-16
(continued)

76	Loss of Offsite Power Failure to Recover Offsite Power in 1 Hour Loss of Unit 1 Diesel Generator 1A-A Loss of Unit 2 Diesel Generator 2A-A Loss of Unit 2 Diesel Generator 2B-B Failure of Turbine Driven AFW Pump Failure to Recover TD AFW Pump Start Failures in 30 Minutes Recovery Action	GNI	1.49E-07	0.2%
		Loss of 161kV Offsite Power Loss of 6.9kV Shutdown Board Unit 1 Train A Loss of 480V Shutdown Board 1A1-A Loss of 480V Shutdown Board 1A2-A Loss of 480V SD Transformer Room 1A Ventilation Loss of Unit 1 120V AC Instrument Board 1A Loss of Common Board A Loss of Common Board B Loss of 6.9kV Unit Board 1A Loss of 6.9kV Unit Board 1B Loss of 6.9kV Unit Board 1C Loss of 6.9kV Unit Board 1D Loss of 6.9kV Shutdown Board Unit 2 Train A Loss of 480V Shutdown Board 2A1-A Loss of 480V Shutdown Board 2A2-A Loss of 480V SD Transformer Room 2A Ventilation Loss of Unit 2 120V AC Instrument Board 2A Loss of 6.9kV Shutdown Board Unit 2 Train B Loss of 480V Shutdown Board 2B1-B Loss of 480V Shutdown Board 2B2-B Loss of 480V SD Transformer Room 2B Ventilation Loss of 480V SD BD Room 2B Ventilation in 6 Hours Unit 1 Shutdown Board Ventilation System Recovery of Unit 1 Shutdown Board Room Ventilation Loss of ERCW Train A Pumps Loss of ERCW Header 1A Loss of ERCW Header 2A No Power at 6.9kV Shutdown Board 1A-A			

TABLE 2-16
(continued)

No Power at 480V Shutdown Board 1A1-A
No Power at 480V Shutdown Board 1A2-A
No Power at 6.9kV Shutdown Board 2A-A
No Power at 480V Shutdown Board 2A1-A
No Power at 480V Shutdown Board 2A2-A
No Power at 6.9kV Shutdown Board 2B-B
No Power at 480V Shutdown Board 2B1-B
No Power at 480V Shutdown Board 2B2-B
Failure of Control Air (Non-Essential Air)
Loss of Train A Essential Air
Loss of Train B Essential Air
Loss of Train B Component Cooling Water System
Failure of Makeup to the RWST
Failure of Makeup to the CST
Loss of Motor Driven AFW Pump 1A-A
Loss of Motor Driven AFW Pump 1B-B
Failure of Equipment Needed to Recover Main Feedwater
Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of PZR PORVs to Open to Control RCS Pressure & Reclose
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Loss of RHR Pump 1A-A
Loss of RHR Pump 1B-B
Core is Melted During Injection Mode
Failure of Train A Cont. Spray
Failure of Train B Cont. Spray

TABLE 2-16
(continued)

		Failure of Train A Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Core Melt RCS Pressure <2,000 psia Steam Generator Cooling Failed Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
77	Partial Loss of Main Feedwater Failure to Trip Reactor and Insert Controls Rods Power Level is Greater than 40% Failure of Emergency Boration (Operator Actions & Equipment)	Two Out of Four MSIVs Stay open Main Feedwater Fails to Continue During ATWS Event Failure of PZR PORVs to Open to Control RCS Pressure & Reclose Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Core is Melted During Injection Mode Operator Fails to Control Cont. Spray Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF	FCI	1.47E-07	0.2%

TABLE 2-16
(continued)

78	Loss of Offsite Power Failure to Recover Offsite Power in 1 Hour Loss of Unit 1 Diesel Generator 1A-A Loss of Unit 1 Diesel Generator 1B-B Loss of Unit 2 Diesel Generator 2B-B Failure of Turbine Driven AFW Pump Failure to Recover TD AFW Pump Start Failures in 30 Minutes Recovery Action	GNI	1.47E-07	0.2%
		Loss of 161kV Offsite Power Loss of 6.9kV Shutdown Board Unit 1 Train A Loss of 480V Shutdown Board 1A1-A Loss of 480V Shutdown Board 1A2-A Loss of 480V SD Transformer Room 1A Ventilation Loss of Unit 1 120V AC Instrument Board 1A Loss of 6.9kV Shutdown Board Unit 1 Train B Loss of 480V Shutdown Board 1B1-B Loss of 480V Shutdown Board 1B2-B Loss of 480V SD Transformer Room 1B Ventilation Loss of 480V SD BD Room B Ventilation in 6 Hours Loss of Common Board A Loss of Common Board B Loss of 6.9kV Unit Board 1A Loss of 6.9kV Unit Board 1B Loss of 6.9kV Unit Board 1C Loss of 6.9kV Unit Board 1D Loss of 6.9kV Shutdown Board Unit 2 Train B Loss of 480V Shutdown Board 2B1-B Loss of 480V Shutdown Board 2B2-B Loss of 480V SD Transformer Room 2B Ventilation Loss of 480V SD BD Room 2B Ventilation in 6 Hours Unit 2 Shutdown Board Ventilation System Recovery of Unit 2 Shutdown Board Room Ventilation Loss of ERCW Train B Pumps Loss of ERCW Header 1B Loss of ERCW Header 2B No Power at 6.9kV Shutdown Board 1A-A			

TABLE 2-16
(continued)

No Power at 480V Shutdown Board 1A1-A
No Power at 480V Shutdown Board 1A2-A
No Power at 6.9kV Shutdown Board 1B-B
No Power at 480V Shutdown Board 1B1-B
No Power at 480V Shutdown Board 1B2-B
No Power at 6.9kV Shutdown Board 2B-B
No Power at 480V Shutdown Board 2B1-B
No Power at 480V Shutdown Board 2B2-B
Failure of Control Air (Non-Essential Air)
Loss of Train B Essential Air
Failure to Recover CCS HTX by Realigning ERCW
Loss of Train A Component Cooling Water System
Loss of Train B Component Cooling Water System
Failure to Align CCP A to ERCW Train A on Loss of CCS A
Failure of Makeup to the RWST
Failure of Makeup to the CST
Loss of Motor Driven AFW Pump 1A-A
Loss of Motor Driven AFW Pump 1B-B
Failure of Equipment Needed to Recover Main Feedwater
Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of PZR PORVs to Open to Control RCS Pressure & Reclose
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Loss of RHR Pump 1A-A

TABLE 2-16
(continued)

		Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Air Return Fans Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Train A Sump Swapover Valve Failure of Train B Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Failure of Hydrogen Ignitors Core Melt RCS Pressure <2,000 psia Steam Generator Cooling Failed Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
79	Loss of Offsite Power Failure to Recover Offsite Power in 1 Hour Loss of Unit 1 Diesel Generator 1A-A Loss of Unit 1 Diesel Generator 1B-B Loss of Unit 2 Diesel Generator 2A-A Failure of Turbine Driven AFW Pump Failure to Recover TD AFW Pump Start Failures in 30 Minutes Recovery Action	Loss of 161kV Offsite Power Loss of 6.9kV Shutdown Board Unit 1 Train A Loss of 480V Shutdown Board 1A1-A Loss of 480V Shutdown Board 1A2-A Loss of 480V SD Transformer Room 1A Ventilation Loss of Unit 1 120V AC Instrument Board 1A Loss of 6.9kV Shutdown Board Unit 1 Train B Loss of 480V Shutdown Board 1B1-B	GNI	1.46E-07	0.2%

TABLE 2-16
(continued)

Loss of 480V Shutdown Board 1B2-B
Loss of 480V SD Transformer Room 1B Ventilation
Loss of 480V SD BD Room B Ventilation in 6 Hours
Loss of Common Board A
Loss of Common Board B
Loss of 6.9kV Unit Board 1A
Loss of 6.9kV Unit Board 1B
Loss of 6.9kV Unit Board 1C
Loss of 6.9kV Unit Board 1D
Loss of 6.9kV Shutdown Board Unit 2 Train A
Loss of 480V Shutdown Board 2A1-A
Loss of 480V Shutdown Board 2A2-A
Loss of 480V SD Transformer Room 2A Ventilation
Loss of Unit 2 120V AC Instrument Board 2A
Unit 1 Shutdown Board Ventilation System
Recovery of Unit 1 Shutdown Board Room Ventilation
Loss of ERCW Train A Pumps
Loss of ERCW Header 1A
Loss of ERCW Header 2A
No Power at 6.9kV Shutdown Board 1A-A
No Power at 480V Shutdown Board 1A1-A
No Power at 480V Shutdown Board 1A2-A
No Power at 6.9kV Shutdown Board 2A-A
No Power at 480V Shutdown Board 2A1-A
No Power at 480V Shutdown Board 2A2-A
No Power at 6.9kV Shutdown Board 1B-B
No Power at 480V Shutdown Board 1B1-B
No Power at 480V Shutdown Board 1B2-B
Failure of Control Air (Non-Essential Air)

TABLE 2-16
(continued)

Loss of Train A Essential Air
Failure to Recover CCS HTX by Realigning ERCW
Loss of Train A Component Cooling Water System
Failure to Align CCP A to ERCW Train A on Loss of CCS A
Failure of Makeup to the RWST
Failure of Makeup to the CST
Loss of Motor Driven AFW Pump 1A-A
Loss of Motor Driven AFW Pump 1B-B
Failure of Equipment Needed to Recover Main Feedwater
Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of PZR PORVs to Open to Control RCS Pressure & Reclose
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Loss of RHR Pump 1A-A
Loss of RHR Pump 1B-B
Core is Melted During Injection Mode
Failure of Air Return Fans
Failure of Train A Cont. Spray
Failure of Train B Cont. Spray
Failure of Train A Sump Swapover Valve
Failure of Train B Sump Swapover Valve
Failure of Automatic/Manual Swapover to Cont. Sump for RHR
Failure of Cont. Spray Heat Exchangers
Failure of Hydrogen Ignitors

TABLE 2-16
(continued)

		Core Melt RCS Pressure <2,000 psia Steam Generator Cooling Failed Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
80	Loss of Offsite Power Failure to Recover Offsite Power in 1 Hour Loss of Unit 1 Diesel Generator 1B-B Loss of ERCW Train A Pumps Recovery Action	Loss of 161kV Offsite Power Loss of 6.9kV Shutdown Board Unit 1 Train B Loss of 480V Shutdown Board 1B1-B Loss of 480V Shutdown Board 1B2-B Loss of 480V SD Transformer Room 1B Ventilation Loss of 480V SD BD Room B Ventilation in 6 Hours Loss of Common Board A Loss of Common Board B Loss of 6.9kV Unit Board 1A Loss of 6.9kV Unit Board 1B Loss of 6.9kV Unit Board 1C Loss of 6.9kV Unit Board 1D Loss of ERCW Header 1A Loss of ERCW Header 2A No Power at 6.9kV Shutdown Board 1B-B No Power at 480V Shutdown Board 1B1-B No Power at 480V Shutdown Board 1B2-B Failure of Control Air (Non-Essential Air)	ENI	1.46E-07	0.2%

TABLE 2-16
(continued)

Loss of Train A Essential Air
Failure of Makeup to the RWST
Failure of Makeup to the CST
Loss of Motor Driven AFW Pump 1A-A
Loss of Motor Driven AFW Pump 1B-B
Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Operator fails to Depress. the RCS Using SG PORVs
Operator fails to Depress. the RCS Using the PZR Sprays and PORVs
Loss of RHR Pump 1A-A
Loss of RHR Pump 1B-B
Core is Melted During Injection Mode
Failure of Train A Cont. Spray
Failure of Train B Cont. Spray
Failure of Train B Sump Swapover Valve
Failure of Automatic/Manual Swapover to Cont. Sump for RHR
Failure of Cont. Spray Heat Exchangers
Core Melt
RCS Pressure <2,000 psia
Melt with Cont. not Isolated
IYAF
Cont. Spray Injection Failed
Cont. Spray Recirculation Failed

TABLE 2-16
(continued)

		RHR Spray Recirculation Failed No Water in Reactor Cavity			
81	Large LOCA Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B	Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of RHR & SIS Hot Leg Recirculation Recovery Action Core Melt Melt with Cont. not Isolated IYAF RHR Spray Recirculation Failed	BCI	1.40E-07	0.2%
82	Loss of 6.9 Shutdown Board 1B-B Failure of Control Air (Non-Essential Air) Loss of Train A Component Cooling Water System Failure to Align CCP A to ERCW Train A on Loss of CCS A	Loss of 6.9kV Shutdown Board Unit 1 Train B Loss of 480V Shutdown Board 1B1-B Loss of 480V Shutdown Board 1B2-B Loss of 480V SD Transformer Room 1B Ventilation Loss of 480V SD BD Room B Ventilation in 6 Hours No Power at 6.9kV Shutdown Board 1B-B No Power at 480V Shutdown Board 1B1-B No Power at 480V Shutdown Board 1B2-B Failure of Makeup to the RWST Loss of Motor Driven AFW Pump 1B-B Loss of Centrifugal Charging Pump 1A-A Loss of Centrifugal Charging Pump 1B-B Loss of Cold Leg Injection Path from CCPs Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Failure of Safety Injection Pump 1A-A	ENI	1.33E-07	0.2%

TABLE 2-16
(continued)

		Failure of Safety Injection Pump 1B-B Loss of Cold Leg Injection Paths Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Train B Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
83	Loss of Offsite Power Failure to Recover Offsite Power in 1 Hour Loss of Unit 1 Diesel Generator 1A-A Loss of ERCW Train B Pumps Recovery Action	Loss of 161kV Offsite Power Loss of 6.9kV Shutdown Board Unit 1 Train A Loss of 480V Shutdown Board 1A1-A Loss of 480V Shutdown Board 1A2-A Loss of 480V SD Transformer Room 1A Ventilation Loss of Unit 1 120V AC Instrument Board 1A	ENI	1.33E-07	0.2%

TABLE 2-16
(continued)

Loss of Common Board A
Loss of Common Board B
Loss of 6.9kV Unit Board 1A
Loss of 6.9kV Unit Board 1B
Loss of 6.9kV Unit Board 1C
Loss of 6.9kV Unit Board 1D
Loss of ERCW Header 1B
Loss of ERCW Header 2B
No Power at 6.9kV Shutdown Board 1A-A
No Power at 480V Shutdown Board 1A1-A
No Power at 480V Shutdown Board 1A2-A
Failure of Control Air (Non-Essential Air)
Loss of Train B Essential Air
Failure to Recover CCS HTX by Realigning ERCW
Loss of Train A Component Cooling Water System
Failure of Makeup to the RWST
Failure of Makeup to the CST
Loss of Motor Driven AFW Pump 1A-A
Loss of Motor Driven AFW Pump 1B-B
Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Operator fails to Depress. the RCS Using SG PORVs
Operator fails to Depress. the RCS Using the PZR Sprays and PORVs

TABLE 2-16
(continued)

		Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Train A Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
84	Flooding - ERCW Strainer Room, Train B Loss of Train A Component Cooling Water System RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops	Loss of ERCW Train B Pumps Loss of ERCW Header 1B Loss of ERCW Header 2B Two Out of Four MSIVs Stay open Loss of Centrifugal Charging Pump 1B-B Failure of Thermal Barriers to the RCPs Failure of Safety Injection Pump 1A-A Failure of Safety Injection Pump 1B-B Loss of Cold Leg Injection Paths Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs	FNI	1.32E-07	0.2%

TABLE 2-16
(continued)

		Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Sump Recirculation is Required Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed			
85	Small LOCA Non-Isolable (RCP Seal LOCA) Loss of Train B Component Cooling Water System Failure of Makeup to the RWST Loss of RHR Pump 1A-A	Loss of Centrifugal Charging Pump 1B-B Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Failure of Safety Injection Pump 1B-B Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Loss of RHR Pump 1B-B Sump Recirculation is Required Failure of Train B Cont. Spray Failure of Automatic/Manual Swapover to Cont. Sump for RHR Recovery Action Core Melt	FCI	1.30E-07	0.2%

TABLE 2-16
(continued)

		RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF RHR Spray Recirculation Failed			
86	Loss of Offsite Power Failure to Recover Offsite Power in 1 Hour Loss of Unit 1 Diesel Generator 1A-A Loss of Unit 2 Diesel Generator 2A-A Loss of Unit 2 Diesel Generator 2B-B Failure of Discharge Path from the AFW Pumps to the SGs Recovery Action	Loss of 161kV Offsite Power Loss of 6.9kV Shutdown Board Unit 1 Train A Loss of 480V Shutdown Board 1A1-A Loss of 480V Shutdown Board 1A2-A Loss of 480V SD Transformer Room 1A Ventilation Loss of Unit 1 120V AC Instrument Board 1A Loss of Common Board A Loss of Common Board B Loss of 6.9kV Unit Board 1A Loss of 6.9kV Unit Board 1B Loss of 6.9kV Unit Board 1C Loss of 6.9kV Unit Board 1D Loss of 6.9kV Shutdown Board Unit 2 Train A Loss of 480V Shutdown Board 2A1-A Loss of 480V Shutdown Board 2A2-A Loss of 480V SD Transformer Room 2A Ventilation Loss of Unit 2 120V AC Instrument Board 2A Loss of 6.9kV Shutdown Board Unit 2 Train B Loss of 480V Shutdown Board 2B1-B Loss of 480V Shutdown Board 2B2-B Loss of 480V SD Transformer Room 2B Ventilation Loss of 480V SD BD Room 2B Ventilation in 6 Hours Unit 1 Shutdown Board Ventilation System	GNI	1.27E-07	0.2%

TABLE 2-16
(continued)

Recovery of Unit 1 Shutdown Board Room Ventilation
Loss of ERCW Train A Pumps
Loss of ERCW Header 1A
Loss of ERCW Header 2A
No Power at 6.9kV Shutdown Board 1A-A
No Power at 480V Shutdown Board 1A1-A
No Power at 480V Shutdown Board 1A2-A
No Power at 6.9kV Shutdown Board 2A-A
No Power at 480V Shutdown Board 2A1-A
No Power at 480V Shutdown Board 2A2-A
No Power at 6.9kV Shutdown Board 2B-B
No Power at 480V Shutdown Board 2B1-B
No Power at 480V Shutdown Board 2B2-B
Failure of Control Air (Non-Essential Air)
Loss of Train A Essential Air
Loss of Train B Essential Air
Loss of Train B Component Cooling Water System
Failure of Makeup to the RWST
Failure of Makeup to the CST
Loss of Motor Driven AFW Pump 1A-A
Loss of Motor Driven AFW Pump 1B-B
Failure of Equipment Needed to Recover Main Feedwater
Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of PZR PORVs to Open to Control RCS Pressure & Reclose
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths

TABLE 2-16
(continued)

		Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Train A Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Core Melt RCS Pressure <2,000 psia Steam Generator Cooling Failed Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
87	Flooding - ERCW Strainer Room, Train A Loss of ERCW Header 1B Failure of Turbine Driven AFW Pump Failure to Recover TD AFW Pump Start Failures in 30 Minutes	Loss of ERCW Train A Pumps Loss of ERCW Header 1A Loss of ERCW Header 2A Failure of ERCW Cooling to CAS Compressors Failure of Control Air (Non-Essential Air) Loss of Train A Essential Air Failure to Recover CCS HTX by Realigning ERCW Loss of Train A Component Cooling Water System Failure to Align CCP A to ERCW Train A on Loss of CCS A Failure of Makeup to the RWST	ENI	1.27E-07	0.2%

TABLE 2-16
(continued)

Loss of Motor Driven AFW Pump 1A-A
Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Operator fails to Depress. the RCS Using SG PORVs
Operator fails to Depress. the RCS Using the PZR Sprays and PORVs
Loss of RHR Pump 1A-A
Loss of RHR Pump 1B-B
Core is Melted During Injection Mode
Failure of Train A Cont. Spray
Failure of Train B Cont. Spray
Failure of Automatic/Manual Swapover to Cont. Sump for RHR
Failure of Cont. Spray Heat Exchangers
Recovery Action
Core Melt
RCS Pressure <2,000 psia
Melt with Cont. not Isolated
IYAF
Cont. Spray Injection Failed
Cont. Spray Recirculation Failed
RHR Spray Recirculation Failed
No Water in Reactor Cavity

TABLE 2-16
(continued)

88	Loss of Offsite Power Failure to Recover Offsite Power in 1 Hour Loss of Unit 1 Diesel Generator 1B-B Loss of Unit 2 Diesel Generator 2A-A Loss of Unit 2 Diesel Generator 2B-B Failure of Turbine Driven AFW Pump Failure to Recover TD AFW Pump Start Failures in 30 Minutes Recovery Action	HGI	1.26E-07	0.2%
		Loss of 161kV Offsite Power Loss of 6.9kV Shutdown Board Unit 1 Train B Loss of 480V Shutdown Board 1B1-B Loss of 480V Shutdown Board 1B2-B Loss of 480V SD Transformer Room 1B Ventilation Loss of 480V SD BD Room B Ventilation in 6 Hours Loss of Common Board A Loss of Common Board B Loss of 6.9kV Unit Board 1A Loss of 6.9kV Unit Board 1B Loss of 6.9kV Unit Board 1C Loss of 6.9kV Unit Board 1D Loss of 6.9kV Shutdown Board Unit 2 Train A Loss of 480V Shutdown Board 2A1-A Loss of 480V Shutdown Board 2A2-A Loss of 480V SD Transformer Room 2A Ventilation Loss of Unit 2 120V AC Instrument Board 2A Loss of 6.9kV Shutdown Board Unit 2 Train B Loss of 480V Shutdown Board 2B1-B Loss of 480V Shutdown Board 2B2-B Loss of 480V SD Transformer Room 2B Ventilation Loss of 480V SD BD Room 2B Ventilation in 6 Hours Unit 2 Shutdown Board Ventilation System Recovery of Unit 2 Shutdown Board Room Ventilation Loss of ERCW Train B Pumps Loss of ERCW Header 1B Loss of ERCW Header 2B No Power at 6.9kV Shutdown Board 2A-A			

TABLE 2-16
(continued)

		Steam Generator Cooling Failed Melt with Cont. not Isolated IYAF Cont. Spray Recirculation Failed RHR Spray Recirculation Failed			
89	Small LOCA Isolable (Pressurizer PORV) Loss of Train A ESFAS Loss of Train B ESFAS Failure of Manual Operator Backup of ESFAS Alignments Failure of Makeup to the RWST	Two Out of Four MSIVs Stay open Failure of Turbine Driven AFW Pump Failure to Recover TD AFW Pump Start Failures in 30 Minutes Loss of Motor Driven AFW Pump 1A-A Loss of Motor Driven AFW Pump 1B-B Failure of Supply to CVCS Loss of Cold Leg Injection Path from CCPs Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Failure of Safety Injection Pump 1A-A Failure of Safety Injection Pump 1B-B Loss of Cold Leg Injection Paths Operator fails to Depress. the RCS Using SG PORVs Operator fails to Depress. the RCS Using the PZR Sprays and PORVs Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Air Return Fans Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers	ENS	1.25E-07	0.2%

TABLE 2-16
(continued)

No Power at 480V Shutdown Board 2A1-A
No Power at 480V Shutdown Board 2A2-A
No Power at 6.9kV Shutdown Board 1B-B
No Power at 480V Shutdown Board 1B1-B
No Power at 480V Shutdown Board 1B2-B
No Power at 6.9kV Shutdown Board 2B-B
No Power at 480V Shutdown Board 2B1-B
No Power at 480V Shutdown Board 2B2-B
Failure of Control Air (Non-Essential Air)
Loss of Train A Essential Air
Loss of Train B Essential Air
Failure to Recover CCS HTX by Realigning ERCW
Loss of Train B Component Cooling Water System
Failure of Makeup to the RWST
Failure of Makeup to the CST
Loss of Motor Driven AFW Pump 1A-A
Loss of Motor Driven AFW Pump 1B-B
Failure of Equipment Needed to Recover Main Feedwater
Loss of Centrifugal Charging Pump 1B-B
Failure of PZR PORVs to Open to Control RCS Pressure & Reclose
Failure of Safety Injection Pump 1B-B
Loss of RHR Pump 1B-B
Sump Recirculation is Required
Failure of Train B Cont. Spray
Failure of Train B Sump Swapover Valve
Failure of Automatic/Manual Swapover to Cont. Sump for RHR
Failure of Cont. Spray Heat Exchangers
Core Melt
RCS Pressure <2,000 psia

TABLE 2-16
(continued)

		Failure of Cont. Isolation Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Small Penetration Isolation Failure SYCF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
90	Loss of Offsite Power Loss of 6.9kV Shutdown Board Unit 1 Train A Loss of 6.9kV Shutdown Board Unit 1 Train B Loss of 6.9kV Shutdown Board Unit 2 Train B	Loss of 161kV Offsite Power Loss of 480V Shutdown Board 1A1-A Loss of 480V Shutdown Board 1A2-A Loss of 480V SD Transformer Room 1A Ventilation Loss of Unit 1 120V AC Instrument Board 1A Loss of 480V Shutdown Board 1B1-B Loss of 480V Shutdown Board 1B2-B Loss of 480V SD Transformer Room 1B Ventilation Loss of 480V SD BD Room B Ventilation in 6 Hours Loss of 480V Shutdown Board 2B1-B Loss of 480V Shutdown Board 2B2-B Loss of 480V SD Transformer Room 2B Ventilation Loss of 480V SD BD Room 2B Ventilation in 6 Hours Unit 2 Shutdown Board Ventilation System Recovery of Unit 2 Shutdown Board Room Ventilation Loss of ERCW Train B Pumps Loss of ERCW Header 1B	ENI	1.24E-07	0.2%

TABLE 2-16
(continued)

Loss of ERCW Header 2B
No Power at 6.9kV Shutdown Board 1A-A
No Power at 480V Shutdown Board 1A1-A
No Power at 480V Shutdown Board 1A2-A
No Power at 6.9kV Shutdown Board 1B-B
No Power at 480V Shutdown Board 1B1-B
No Power at 480V Shutdown Board 1B2-B
No Power at 6.9kV Shutdown Board 2B-B
No Power at 480V Shutdown Board 2B1-B
No Power at 480V Shutdown Board 2B2-B
Failure to Recover CCS HTX by Realigning ERCW
Loss of Train A Component Cooling Water System
Loss of Train B Component Cooling Water System
Failure to Align CCP A to ERCW Train A on Loss of CCS A
Failure of Makeup to the RWST
Failure of Makeup to the CST
Two Out of Four MSIVs Stay open
Fail to Cooldown Using Steam Dumps, Condenser, & Hotwell Pumps
Loss of Motor Driven AFW Pump 1A-A
Loss of Motor Driven AFW Pump 1B-B
Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Loss of RHR Pump 1A-A

TABLE 2-16
(continued)

		Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Air Return Fans Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Train A Sump Swapover Valve Failure of Train B Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Failure of Hydrogen Ignitors Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
91	Loss of Offsite Power Failure to Recover Offsite Power in 1 Hour Loss of Unit 1 Diesel Generator 1B-B Loss of Unit 2 Diesel Generator 2A-A Loss of Unit 2 Diesel Generator 2B-B Failure of Discharge Path from the AFW Pumps to the SGs Recovery Action	Loss of 161kV Offsite Power Loss of 6.9kV Shutdown Board Unit 1 Train B Loss of 480V Shutdown Board 1B1-B Loss of 480V Shutdown Board 1B2-B Loss of 480V SD Transformer Room 1B Ventilation Loss of 480V SD BD Room B Ventilation in 6 Hours Loss of Common Board A Loss of Common Board B	HGI	1.24E-07	0.2%

TABLE 2-16
(continued)

Loss of 6.9kV Unit Board 1A
Loss of 6.9kV Unit Board 1B
Loss of 6.9kV Unit Board 1C
Loss of 6.9kV Unit Board 1D
Loss of 6.9kV Shutdown Board Unit 2 Train A
Loss of 480V Shutdown Board 2A1-A
Loss of 480V Shutdown Board 2A2-A
Loss of 480V SD Transformer Room 2A Ventilation
Loss of Unit 2 120V AC Instrument Board 2A
Loss of 6.9kV Shutdown Board Unit 2 Train B
Loss of 480V Shutdown Board 2B1-B
Loss of 480V Shutdown Board 2B2-B
Loss of 480V SD Transformer Room 2B Ventilation
Loss of 480V SD BD Room 2B Ventilation in 6 Hours
Unit 2 Shutdown Board Ventilation System
Recovery of Unit 2 Shutdown Board Room Ventilation
Loss of ERCW Train B Pumps
Loss of ERCW Header 1B
Loss of ERCW Header 2B
No Power at 6.9kV Shutdown Board 2A-A
No Power at 480V Shutdown Board 2A1-A
No Power at 480V Shutdown Board 2A2-A
No Power at 6.9kV Shutdown Board 1B-B
No Power at 480V Shutdown Board 1B1-B
No Power at 480V Shutdown Board 1B2-B
No Power at 6.9kV Shutdown Board 2B-B
No Power at 480V Shutdown Board 2B1-B
No Power at 480V Shutdown Board 2B2-B
Failure of Control Air (Non-Essential Air)

TABLE 2-16
(continued)

Loss of Train A Essential Air
Loss of Train B Essential Air
Failure to Recover CCS HTX by Realigning ERCW
Loss of Train B Component Cooling Water System
Failure of Makeup to the RWST
Failure of Makeup to the CST
Loss of Motor Driven AFW Pump 1A-A
Loss of Motor Driven AFW Pump 1B-B
Failure of Equipment Needed to Recover Main Feedwater
Loss of Centrifugal Charging Pump 1B-B
Failure of PZR PORVs to Open to Control RCS Pressure & Reclose
Failure of Safety Injection Pump 1B-B
Loss of RHR Pump 1B-B
Sump Recirculation is Required
Failure of Train B Cont. Spray
Failure of Train B Sump Swapover Valve
Failure of Automatic/Manual Swapover to Cont. Sump for RHR
Failure of Cont. Spray Heat Exchangers
Core Melt
RCS Pressure <2,000 psia
Steam Generator Cooling Failed
Melt with Cont. not Isolated
IYAF
Cont. Spray Recirculation Failed
RHR Spray Recirculation Failed

TABLE 2-16
(continued)

92	Flooding - ERCW Strainer Room, Train B Loss of ERCW Header 1A Failure of Turbine Driven AFW Pump Failure to Recover TD AFW Pump Start Failures in 30 Minutes	Loss of ERCW Train B Pumps Loss of ERCW Header 1B Loss of ERCW Header 2B Failure of ERCW Cooling to CAS Compressors Failure of Control Air (Non-Essential Air) Loss of Train A Essential Air Loss of Train B Essential Air Loss of Train B Component Cooling Water System Failure of Makeup to the RWST Loss of Motor Driven AFW Pump 1A-A Loss of Motor Driven AFW Pump 1B-B Failure of Equipment Needed to Recover Main Feedwater Loss of Centrifugal Charging Pump 1A-A Loss of Centrifugal Charging Pump 1B-B Loss of Cold Leg Injection Path from CCPs Failure of PZR PORVs to Open to Control RCS Pressure & Reclose Failure of Thermal Barriers to the RCPs RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops Failure of Safety Injection Pump 1A-A Failure of Safety Injection Pump 1B-B Loss of Cold Leg Injection Paths Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers	GNI	1.24E-07	0.2%

TABLE 2-16
(continued)

		Recovery Action Core Melt RCS Pressure <2,000 psia Steam Generator Cooling Failed Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
93	Loss of Offsite Power Loss of 6.9kV Shutdown Board Unit 1 Train A Loss of 6.9kV Shutdown Board Unit 1 Train B	Loss of 161kV Offsite Power Loss of 480V Shutdown Board 1A1-A Loss of 480V Shutdown Board 1A2-A Loss of 480V SD Transformer Room 1A Ventilation Loss of Unit 1 120V AC Instrument Board 1A Loss of 480V Shutdown Board 1B1-B Loss of 480V Shutdown Board 1B2-B Loss of 480V SD Transformer Room 1B Ventilation Loss of 480V SD BD Room B Ventilation in 6 Hours Loss of 6.9kV Shutdown Board Unit 2 Train A Loss of 480V Shutdown Board 2A1-A Loss of 480V Shutdown Board 2A2-A Loss of 480V SD Transformer Room 2A Ventilation Loss of Unit 2 120V AC Instrument Board 2A Unit 1 Shutdown Board Ventilation System Recovery of Unit 1 Shutdown Board Room Ventilation Loss of ERCW Train A Pumps	ENI	1.23E-07	0.2%

TABLE 2-16
(continued)

Loss of ERCW Header 1A
Loss of ERCW Header 2A
No Power at 6.9kV Shutdown Board 1A-A
No Power at 480V Shutdown Board 1A1-A
No Power at 480V Shutdown Board 1A2-A
No Power at 6.9kV Shutdown Board 2A-A
No Power at 480V Shutdown Board 2A1-A
No Power at 480V Shutdown Board 2A2-A
No Power at 6.9kV Shutdown Board 1B-B
No Power at 480V Shutdown Board 1B1-B
No Power at 480V Shutdown Board 1B2-B
Failure to Recover CCS HTX by Realigning ERCW
Loss of Train A Component Cooling Water System
Failure to Align CCP A to ERCW Train A on Loss of CCS A
Failure of Makeup to the RWST
Failure of Makeup to the CST
Two Out of Four MSIVs Stay open
Fail to Cooldown Using Steam Dumps, Condenser, & Hotwell Pumps
Loss of Motor Driven AFW Pump 1A-A
Loss of Motor Driven AFW Pump 1B-B
Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Loss of RHR Pump 1A-A

TABLE 2-16
(continued)

		Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Air Return Fans Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Train A Sump Swapover Valve Failure of Train B Sump Swapover Valve Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Failure of Hydrogen Ignitors Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
94	Flooding - ERCW Strainer Room, Train B Loss of ERCW Header 1A Failure of Discharge Path from the AFW Pumps to the SGs	Loss of ERCW Train B Pumps Loss of ERCW Header 1B Loss of ERCW Header 2B Failure of ERCW Cooling to CAS Compressors Failure of Control Air (Non-Essential Air) Loss of Train A Essential Air Loss of Train B Essential Air Loss of Train B Component Cooling Water System	GNI	1.22E-07	0.2%

TABLE 2-16
(continued)

Failure of Makeup to the RWST
Loss of Motor Driven AFW Pump 1A-A
Loss of Motor Driven AFW Pump 1B-B
Failure of Equipment Needed to Recover Main Feedwater
Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of PZR PORVs to Open to Control RCS Pressure & Reclose
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Loss of RHR Pump 1A-A
Loss of RHR Pump 1B-B
Core is Melted During Injection Mode
Failure of Train A Cont. Spray
Failure of Train B Cont. Spray
Failure of Automatic/Manual Swapover to Cont. Sump for RHR
Failure of Cont. Spray Heat Exchangers
Recovery Action
Core Melt
RCS Pressure <2,000 psia
Steam Generator Cooling Failed
Melt with Cont. not Isolated
IYAF
Cont. Spray Injection Failed
Cont. Spray Recirculation Failed
RHR Spray Recirculation Failed
No Water in Reactor Cavity

TABLE 2-16
(continued)

95	Loss of Condenser Vacuum Loss of Train A ESFAS Loss of Train B ESFAS Failure of Manual Operator Backup of ESFAS Alignments	GNS	1.21E-07	0.2%
		Two Out of Four MSIVs Stay open Fail to Cooldown Using Steam Dumps, Condenser, & Hotwell Pumps Failure of Turbine Driven AFW Pump Failure to Recover TD AFW Pump Start Failures in 30 Minutes Loss of Motor Driven AFW Pump 1A-A Loss of Motor Driven AFW Pump 1B-B Failure of Equipment Needed to Recover Main Feedwater Loss of Centrifugal Charging Pump 1B-B Loss of Cold Leg Injection Path from CCPs Failure of PZR PORVs to Open to Control RCS Pressure & Reclose Failure of Safety Injection Pump 1A-A Failure of Safety Injection Pump 1B-B Loss of Cold Leg Injection Paths Loss of RHR Pump 1A-A Loss of RHR Pump 1B-B Core is Melted During Injection Mode Failure of Air Return Fans Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Automatic/Manual Swapover to Cont. Sump for RHR Failure of Cont. Spray Heat Exchangers Failure of Cont. Isolation Recovery Action Core Melt RCS Pressure <2,000 psia Steam Generator Cooling Failed Melt with Small Penetration Isolation Failure SYCF			

TABLE 2-16
(continued)

		Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
96	Loss of Offsite Power Failure to Recover Offsite Power in 1 Hour Loss of Unit 1 Diesel Generator 1A-A Loss of Unit 1 Diesel Generator 1B-B Loss of Unit 2 Diesel Generator 2A-A Loss of Unit 2 Diesel Generator 2B-B Failure of Cont. Isolation Recovery Action	Loss of 161kV Offsite Power Loss of 6.9kV Shutdown Board Unit 1 Train A Loss of 480V Shutdown Board 1A1-A Loss of 480V Shutdown Board 1A2-A Loss of 480V SD Transformer Room 1A Ventilation Loss of Unit 1 120V AC Instrument Board 1A Loss of 6.9kV Shutdown Board Unit 1 Train B Loss of 480V Shutdown Board 1B1-B Loss of 480V Shutdown Board 1B2-B Loss of 480V SD Transformer Room 1B Ventilation Loss of 480V SD BD Room B Ventilation in 6 Hours Loss of Common Board A Loss of Common Board B Loss of 6.9kV Unit Board 1A Loss of 6.9kV Unit Board 1B Loss of 6.9kV Unit Board 1C Loss of 6.9kV Unit Board 1D Loss of 6.9kV Shutdown Board Unit 2 Train A Loss of 480V Shutdown Board 2A1-A Loss of 480V Shutdown Board 2A2-A Loss of 480V SD Transformer Room 2A Ventilation Loss of Unit 2 120V AC Instrument Board 2A Loss of 6.9kV Shutdown Board Unit 2 Train B	ENS	1.19E-07	0.1%

TABLE 2-16
(continued)

Loss of 480V Shutdown Board 2B1-B
Loss of 480V Shutdown Board 2B2-B
Loss of 480V SD Transformer Room 2B Ventilation
Loss of 480V SD BD Room 2B Ventilation in 6 Hours
Unit 1 Shutdown Board Ventilation System
Recovery of Unit 1 Shutdown Board Room Ventilation
Unit 2 Shutdown Board Ventilation System
Recovery of Unit 2 Shutdown Board Room Ventilation
Loss of ERCW Train A Pumps
Loss of ERCW Train B Pumps
Loss of ERCW Header 1A
Loss of ERCW Header 2A
Loss of ERCW Header 1B
Loss of ERCW Header 2B
Failure to Recover ERCW to Diesel from Opposite Train
No Power at 6.9kV Shutdown Board 1A-A
No Power at 480V Shutdown Board 1A1-A
No Power at 480V Shutdown Board 1A2-A
No Power at 6.9kV Shutdown Board 2A-A
No Power at 480V Shutdown Board 2A1-A
No Power at 480V Shutdown Board 2A2-A
No Power at 6.9kV Shutdown Board 1B-B
No Power at 480V Shutdown Board 1B1-B
No Power at 480V Shutdown Board 1B2-B
No Power at 6.9kV Shutdown Board 2B-B
No Power at 480V Shutdown Board 2B1-B
No Power at 480V Shutdown Board 2B2-B
Failure of ERCW Cooling to CAS Compressors
Failure of Control Air (Non-Essential Air)

TABLE 2-16
(continued)

Loss of Train A Essential Air
Loss of Train B Essential Air
Failure to Recover CCS HTX by Realigning ERCW
Loss of Train A Component Cooling Water System
Loss of Train B Component Cooling Water System
Failure to Align CCP A to ERCW Train A on Loss of CCS A
Failure of Makeup to the RWST
Failure of Makeup to the CST
Loss of Motor Driven AFW Pump 1A-A
Loss of Motor Driven AFW Pump 1B-B
Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Loss of RHR Pump 1A-A
Loss of RHR Pump 1B-B
Core is Melted During Injection Mode
Failure of Air Return Fans
Failure of Train A Cont. Spray
Failure of Train B Cont. Spray
Failure of Train A Sump Swapover Valve
Failure of Train B Sump Swapover Valve
Failure of Automatic/Manual Swapover to Cont. Sump for RHR
Failure of Cont. Spray Heat Exchangers
Failure of Hydrogen Ignitors

TABLE 2-16 (continued)

		Core Melt RCS Pressure <2,000 psia Melt with Small Penetration Isolation Failure SYNF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
97	Partial Loss of Main Feedwater Failure to Trip Reactor and Insert Controls Rods Power Level is Greater than 40% Loss of Motor Driven AFW Pump 1B-B	Two Out of Four MSIVs Stay open Main Feedwater Fails to Continue During ATWS Event Failure of Steam Relief, ATWS Only, Rx Press is <3200 psia Failure of PZR PORVs to Open to Control RCS Pressure & Reclose Core is Melted During Injection Mode Operator Fails to Control Cont. Spray Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF	FCI	1.17E-07	0.1%
98	Partial Loss of Main Feedwater Failure to Trip Reactor and Insert Controls Rods Power Level is Greater than 40% Loss of Motor Driven AFW Pump 1A-A	Two Out of Four MSIVs Stay open Main Feedwater Fails to Continue During ATWS Event Failure of Steam Relief, ATWS Only, Rx Press is <3200 psia Failure of PZR PORVs to Open to Control RCS Pressure & Reclose Core is Melted During Injection Mode Operator Fails to Control Cont. Spray	FCI	1.17E-07	0.1%

TABLE 2-16
(continued)

		Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF			
99	Loss of Offsite Power Failure to Recover Offsite Power in 1 Hour Loss of 6.9kV Shutdown Board Unit 1 Train A Loss of 6.9kV Shutdown Board Unit 1 Train B Loss of 6.9kV Shutdown Board Unit 2 Train B	Loss of 161kV Offsite Power Loss of 480V Shutdown Board 1A1-A Loss of 480V Shutdown Board 1A2-A Loss of 480V SD Transformer Room 1A Ventilation Loss of Unit 1 120V AC Instrument Board 1A Loss of 480V Shutdown Board 1B1-B Loss of 480V Shutdown Board 1B2-B Loss of 480V SD Transformer Room 1B Ventilation Loss of 480V SD BD Room B Ventilation in 6 Hours Loss of Common Board A Loss of Common Board B Loss of 6.9kV Unit Board 1A Loss of 6.9kV Unit Board 1B Loss of 6.9kV Unit Board 1C Loss of 6.9kV Unit Board 1D Loss of 6.9kV Shutdown Board Unit 2 Train A Loss of 480V Shutdown Board 2A1-A Loss of 480V Shutdown Board 2A2-A Loss of 480V SD Transformer Room 2A Ventilation Loss of Unit 2 120V AC Instrument Board 2A Loss of 480V Shutdown Board 2B1-B Loss of 480V Shutdown Board 2B2-B	ENI	1.16E-07	0.1%

TABLE 2-16
(continued)

Loss of 480V SD Transformer Room 2B Ventilation
Loss of 480V SD BD Room 2B Ventilation in 6 Hours
Unit 1 Shutdown Board Ventilation System
Recovery of Unit 1 Shutdown Board Room Ventilation
Unit 2 Shutdown Board Ventilation System
Recovery of Unit 2 Shutdown Board Room Ventilation
Loss of ERCW Train A Pumps
Loss of ERCW Train B Pumps
Loss of ERCW Header 1A
Loss of ERCW Header 2A
Loss of ERCW Header 1B
Loss of ERCW Header 2B
Failure to Recover ERCW to Diesel from Opposite Train
No Power at 6.9kV Shutdown Board 1A-A
No Power at 480V Shutdown Board 1A1-A
No Power at 480V Shutdown Board 1A2-A
No Power at 6.9kV Shutdown Board 2A-A
No Power at 480V Shutdown Board 2A1-A
No Power at 480V Shutdown Board 2A2-A
No Power at 6.9kV Shutdown Board 1B-B
No Power at 480V Shutdown Board 1B1-B
No Power at 480V Shutdown Board 1B2-B
No Power at 6.9kV Shutdown Board 2B-B
No Power at 480V Shutdown Board 2B1-B
No Power at 480V Shutdown Board 2B2-B
Failure of ERCW Cooling to CAS Compressors
Failure of Control Air (Non-Essential Air)
Loss of Train A Essential Air
Loss of Train B Essential Air

TABLE 2-16
(continued)

Failure to Recover CCS HTX by Realigning ERCW
Loss of Train A Component Cooling Water System
Loss of Train B Component Cooling Water System
Failure to Align CCP A to ERCW Train A on Loss of CCS A
Failure of Makeup to the RWST
Failure of Makeup to the CST
Loss of Motor Driven AFW Pump 1A-A
Loss of Motor Driven AFW Pump 1B-B
Loss of Centrifugal Charging Pump 1A-A
Loss of Centrifugal Charging Pump 1B-B
Loss of Cold Leg Injection Path from CCPs
Failure of Thermal Barriers to the RCPs
RCP Seal Cooling Failed or RCPs Not Tripped - LOCA Develops
Failure of Safety Injection Pump 1A-A
Failure of Safety Injection Pump 1B-B
Loss of Cold Leg Injection Paths
Loss of RHR Pump 1A-A
Loss of RHR Pump 1B-B
Core is Melted During Injection Mode
Failure of Air Return Fans
Failure of Train A Cont. Spray
Failure of Train B Cont. Spray
Failure of Train A Sump Swapover Valve
Failure of Train B Sump Swapover Valve
Failure of Automatic/Manual Swapover to Cont. Sump for RHR
Failure of Cont. Spray Heat Exchangers
Failure of Hydrogen Ignitors
Recovery Action
Core Melt

TABLE 2-16 (continued)

		RCS Pressure <2,000 psia Melt with Cont. not Isolated IYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed RHR Spray Recirculation Failed No Water in Reactor Cavity			
100	Steam Generator Tube Rupture Failure of Makeup to the RWST Loss of RHR Normal Decay Heat Removal	Two Out of Four MSIVs Stay open Operator Fails to Identify & Isolate Ruptured Steam Generator Core is Melted During Injection Mode Failure of Train A Cont. Spray Failure of Train B Cont. Spray Failure of Cont. Spray Heat Exchangers Recovery Action Core Melt RCS Pressure <2,000 psia Melt with Cont. Bypassed BYAF Cont. Spray Injection Failed Cont. Spray Recirculation Failed No Water in Reactor Cavity	EIB	1.15E-07	0.1%

Appendix B

ENHANCEMENT SCREENING ANALYSIS SHEETS

Enhancement Screening Analysis Sheet

Source: Generic Letter 88-20, Supplement 2, Item I.b

Description: Throttle Containment Spray to Conserve Water for Core Injection

Discussion:
1. Watts Bar has ice condenser containment design.
2. All LOCA's > 3/8" effective diameter lead to containment spray actuation.
3. Two spray pumps (4000 gpm) will deplete RWST in approximately 30 minutes.
4. MOVs on spray pump discharge are not capable of throttle operation (full open, full close).
5. Chapter 5, 15 FSAR analyses based on single containment spray pump operation (single failure).

Enhancements:
1. Procedural - if containment pressure is only slightly greater than actuation setpoint, consider enhancing emergency procedures by directing operators to stop one containment spray pump (one hour to RWST depletion).
2. Design - Consider modification of CS pump discharge MOV control circuit to allow throttle operation (i.e., no seal in circuit on open/close). Consider valve change to globe (etc.) design for more efficient throttle operation. Limit close operation with automatic initiation signal.
3. Analysis - Containment pressure response analysis may need to be redone to support throttled flow of spray pump. Limit maximum throttling.

Classification: Medium, See analysis sheet 1.
Change in core damage frequency approximately 1 to 5 % based on allowing more time for operator action to complete switch-over to recirculation.

Enhancement Screening Analysis Sheet

Source: Generic Letter 88-20, Supplement 2, Item I.d

Description: Use portable battery chargers or other power sources to recharge batteries.

Discussion:

1. IPE assumes batteries are depleted after four hours if offsite/onsite AC power is not recovered after Loss of Off-site Power (LOSP). Core damage is guaranteed after battery failure.
2. Four batteries/buses, etc. for the Watts Bar units, two per "train"
3. Spare charger on a "train" basis (one spare for two buses).

Enhancements:

1. Investigate feasibility of portable spare battery charger(s).
   a. Portable AC or DC generator (AC to feed installed battery charger DC for battery directly).
   b. Procedure to hook-up generator, and equipment would need to be replaced.
2. Analysis
   a. What charging rate would be required after several (< four) hours to restore battery to some increased capacity?
   b. Can portable battery chargers be purchased/procured with sufficient capacity?
3. A skid mounted AC generator with capability to supply a 480V shutdown board and repower a component cooling pump and an installed battery charger would affect the likelihood of RCP seal LOCA and allow additional time for power/cooling recovery during SBO conditions.

Classification: Low for battery charger only. See Sheet 48.

Enhancement Screening Analysis Sheet

Source: Generic Letter 88-20, Supplement 2, Item I.e

Description: Enable emergency replenishment of gas supply, or otherwise ensure operability of air-operated components.

Discussion:

1. Dominant contributors to core damage at Watts Bar are initiated by a LOSP leading to station blackout or loss of ACAS.
2. The steam generator PORVs are air-operated, fail-close, the motor driven AFW pump LCVs are air operated, fail-open, but the PCVs are air operated, fail-close, the turbine driven AFW pump LCVs are air-operated, fail-close.
3. Station black-out and loss of ACAS sequences require significant operator action outside the control room to ensure sufficient decay heat removal and/or RCS depressurization. In some cases (steam generator PORVs) the environmental conditions are not the best.
4. Loss of air complicates the already complicated recovery process by requiring local handwheel control of several components.

Enhancements:

1. Procedural - None at this time. The procedures guide the operators in what is necessary.
2. Design - Permanently installed air reservoirs for emergency operation of vital equipment such as steam generator PORVs, turbine driven AFW LCVs. This would allow control of plant to initially remain in control room.
3. Size reservoirs for approximately one hour of operation. This would allow more time for operator placement to take over control after event somewhat stable.
4. Design - Permanent N2 backup to same valves. This could be via locally mounted N2 bottles or by connection to installed (?) N2 piping. Connection could be permanent (hard pipe) or quick connect/disconnect. (Modification previously identified for TDP LCVs).

Classification: Low, see analysis sheet 9.
Change in core damage frequency approximately 1%.

Enhancement Screening Analysis Sheet

Source: Generic Letter 88-20, Supplement 2, Item II.a

Description: Use diesel-fire systems for injection to the containment sprays, or the Steam Generators

Discussion:
1. Fire pump diesel is independent of other plant systems. It includes its own battery and fuel supply.
2. The fire pump discharges at approximately 150 psig at 400 gpm.
3. Can supply emergency cooling if aligned in time.

Enhancements:
1. Procedural - determine the maximum time this pump will operate (limited day tank capacity). Assume 4 hours based on limited day tank capacity.
2. Design - spool pieces, etc. would be required to allow quick make-up to the containment spray, steam generators, or residual heat removal.

Classification: Low

Enhancement Screening Analysis Sheet

Source: Generic Letter 88-20, Supplement 2, Item II.a

Description: Use condensate or startup pumps for feedwater injection.

Discussion:

1. Included (partially) in top events MF and CD - necessary to support continued main feedwater pump operation after plant trip.
2. Presently included as an alternate source of water for transients in which AFW has failed and reactor trip has occurred. The MFW system is not credited for initiators which affect the main feedwater system.
3. The condensate system is not included as an independent source of steam generator cooling.
4. Possibly limited effect given the importance of loss of offsite power.

Enhancements:

1. Procedural - Use of the condensate system requires depressurization of the steam generators, which is covered by plant emergency operating procedures.
2. Design - The condensate system has been analyzed as a support system for the main feedwater top event, no other analyses are required.

Classification: Low, see analysis sheet 2.
Loss of offsite power limits use of equipment powered from Unit Boards.

Enhancement Screening Analysis Sheet

Source: Generic Letter 88-20, Supplement 2, Item II.b

Description: Enable emergency cross-tie of ac power between two units

Discussion:
1. LOSP is the largest individual initiator contributor to core damage frequency at Watts Bar
2. LOSP is loss of 161kV to shutdown boards. 500kV may remain available at switchyard.
3. Maintenance cross-tie is available from Unit Boards to Shutdown Boards.

Enhancements:
1. Analysis - What steps would be required to feed shutdown boards from unit boards during emergency conditions such as LOSP? Can 500kV be isolated from generator (disconnects, etc.) such that 500kV will remain to Station Service transformers and repower the Unit Boards after plant trip.
2. Procedural - if feasible, consider inclusion of steps necessary to complete this alignment in AOI-35.

Classification: High, see analysis sheet 4.
LOSP is dominant initiating event. Greater than 10% change in core damage frequency possible.

Enhancement Screening Analysis Sheet

Source: Generic Letter 88-20, Supplement 2, Item II.c

Description: Ensure appropriate recirculation switchover and cope with the failure to switchover in LOCAs

Discussion:
1. Failure to complete switchover (top event RR) is the second most important equipment top event in the Watts Bar model.
2. Sheet 1 describes the effects of containment design on need for sump switchover.
3. The top event is dominated by common cause failure of MOVs in the recirculation path to open on demand.
4. Operator action to locally open MOVs would be beneficial, but because of limited time after initiator to switchover, local operation is not modeled.

Enhancements:
1. MOV 89-10 program may provide better valve failure data and/or increase the likelihood of valve success.
2. Other enhancements - None other than delaying time to recirculation.

Classification: Medium, see analysis sheet 1
High top event importance, but boundary conditions (support system failures) are more important.

Enhancement Screening Analysis Sheet

Source: IPE Update Report, December 16, 1993 Item 1.

Description: Simplify MG set breaker operation

Discussion:

1. Anticipated Transients without Scram require operator action to open the power supply breakers for the control rod MG sets, if the reactor trip breakers cannot be opened from the control room. This is a local action.

Enhancements:

1. Provide control switches to trip the control rod drive motor generator sets in the control room or revise procedure to ensure power to the motor generator sets is tripped in the control room at the lowest voltage level possible.

Classification: Low. See Analysis Sheet 13.
ATWS sequences contributes approximately 4% to core damage frequency and are largely dominated by common cause failure of the reactor trip breakers to operate on demand.

Enhancement Screening Analysis Sheet

Source: IPE Update Report, December 16, 1993 Item 2.

Description: Use containment spray pumps for ECCS recirculation

Discussion:

1. Failure to complete switchover (top event RR) is the second most important equipment top event in the Watts Bar model.
2. Sheet 1 describes the effects of containment design on need for sump switchover.
3. The top event is dominated by common cause failure of MOVs in the recirculation path to open on demand.
4. Containment spray recirculation is successful in approximately 25% of sequences with failure of RR, but RR failure is dominated by MOV failure, not pump failure.
5. Majority of sequences requiring ECCS recirculation are not Large and Medium LOCAs (spray may not be required after one hour of operation).

Enhancements:

1. Design - Investigate piping, material, etc. requirements for allowing flow from containment spray pump discharge (after the CS heat exchanger) to the RHR recirculation line (after the RHR heat exchanger).

Classification: Low, See Sheet 99.
Failure of the CS pumps modeled by CSA and CSB is dominated by failure of support systems, the same support systems fail the RHR pump trains modeled by RA and RB. A larger benefit is achieved by lengthening the time to switchover. See analysis sheet 1.

Enhancement Screening Analysis Sheet

Source: IPE Update Report, December 16, 1993 Item 3.

Description: Alternate power to Motor Driven MFW Pump

Discussion:
1. Supplied by Unit boards from non-vital 161kV after plant trip.
2. The pump may be too large for EDGs.

Enhancements: None

Classification: Low, see analysis sheet 2.

Enhancement Screening Analysis Sheet

Source: IPE Update Report, December 16, 1993 Item 3.

Description: Change TD AFW Pump Flow Control Valves to Fail Open.

Discussion:

1. Dominant contributors to core damage at Watts Bar are initiated by LOSP leading to station blackout or loss of ACAS.
2. The steam generator PORVs are air-operated, fail-close, the turbine driven AFW pump LCVs are air-operated, fail-close.
3. Station black-out and loss of ACAS sequences require significant operator action outside the control room to ensure sufficient decay heat removal and/or RCS depressurization. In some cases (steam generator PORVs) the environmental conditions are not the best.
4. Loss of air complicates the already complicated recovery process by requiring local handwheel control of several components.
5. Loss of air is guaranteed under black-out conditions requiring operator action to open the LCVs locally in order to restore AFW flow to the steam generators.

Enhancements:

1. Procedural - None at this time. The procedures guide the operators in what is necessary.
2. Design - determine need for these LCVs to fail closed. If possible, reanalyze the calculation that determined the failure mode.

Classification: Low, see analysis sheet 9.
Change in core damage frequency approximately 1% based on preliminary change in operator recovery numbers.

Enhancement Screening Analysis Sheet

Source: IPE Update Report, December 16, 1993 Item 4.

Description: Automatic Reactor Trip/RCP Trip on High RCP Motor Bearing Temperature

Discussion:

1. Loss of component cooling to the RCP motor bearing coolers could lead to RCP bearing failure in slightly more than 10 minutes.
2. Sequences with loss of component cooling train A are important in the Watts Bar IPE model.
3. Failure of the operators to trip the RCPs within 10 minutes is assumed to lead to a gross (480 gpm per pump) seal LOCA. This is superimposed on degraded ECCS capability (loss of Train A due to loss of CCS Train A)

Enhancements: None proposed, possible enhancements would include:

1. Design - evaluate cost of developing instrumentation necessary to trip the RCPs on high bearing oil temperature (etc.) prior to damage to the RCP bearings. The instrumentation should prevent as much as possible spurious trips (2/3 logic etc.) and should allow sufficient time for some recovery action.
2. Analysis - Determine the effects of a multiple RCP trip due to loss of CCS cooling without trip (multiple pump locked rotor event?)

Classification: Low
Operator action to trip the RCPs in response to loss of CCS Train A is a low value (less than .01/event).

Enhancement Screening Analysis Sheet

Source: IPE Update Report, December 16, 1993 Item 4.

Description: Alternate Cooling (Fire water) and Power to Positive Displacement Charging Pump.

Discussion:

1. Loss of cooling to RCP seal is assumed to lead to RCP seal LOCA, the variables are the time to failure and the magnitude of the failure.
2. Loss of CCS leads to failure of the centrifugal charging pumps which leads to seal LOCA. Loss of power has the same effect.
3. The positive displacement (PD) charging pump is also cooled by CCS.

Enhancements:

1. Design - Evaluate piping design necessary to supply cooling to the PD charging pump from ERCW and/or fire protection. Piping can be permanent or quick-connect. Note : Low flow requirement for PD pump cooling.
2. Design - Power (later)

Classification: Medium to high, see analysis sheet 14.
Support system failures dominate causes of RCP seal LOCA. The same support systems, in general, would degrade or fail the PD charging pump.

Enhancement Screening Analysis Sheet

Source: IPE Update Report, December 16, 1993 Item 4.

Description: HVAC Procedures

Discussion:

1. The IPE model includes ventilation systems for electric power systems and the ECCS and containment spray pump rooms.
2. Recovery of ventilation is explicitly modeled for 6.9kV shutdown board room ventilation, 480V transformer room ventilation, and inverter area ventilation.
3. Plant abnormal procedures guide the operators in the steps necessary to recover from the losses of ventilation modeled by the ventilation recovery top events.

Enhancements:

1. Ensure loss of room cooling for ECCS pumps and containment spray pumps is covered by plant abnormal operating procedures.

Classification: Medium, see analysis sheet 6.

Enhancement Screening Analysis Sheet

Source: IPE Update Report, December 16, 1993 Item 4.

Description: Fire Water Cooling to CCPs

Discussion:

1. Loss of cooling to RCP seal is assumed to lead to RCP seal LOCA, the variables are the time to failure and the magnitude of the failure.
2. Loss of CCS leads to failure of the centrifugal charging pumps which leads to seal LOCA. Loss of power has the same effect.
3. ERCW is presently supplied to CCP 1A-A.

Enhancements:

1. Design - Evaluate piping design necessary to supply cooling to the 1B-B charging pump from ERCW and both CCPs from fire protection. Piping can be permanent or quick-connect.

Classification: Medium to high, see analysis sheet 14.

Enhancement Screening Analysis Sheet

Source: IPE Update Report, December 16, 1993 Item 4.

Description: Install New RCP Seals

Discussion:
1. Loss of cooling to RCP seal is assumed to lead to RCP seal LOCA, the variables are the time to failure and the magnitude of the failure.
2. Significant amount of work completed by Owners Groups.

Enhancements:
1. Engineering - Cost of obtaining and installing new RCP seals that reduce or eliminate the likelihood of RCP seal failure from loss of cooling.

Classification: High, see analysis sheet 14.
Decreasing likelihood of RCP seal LOCAs significantly extends time for recovery of power, cooling, etc. prior to core damage.

Enhancement Screening Analysis Sheet

Source: IPE Update Report, December 16, 1993 Item 5.

Description: Fifth Emergency Diesel Generator

Discussion:
1. Previously identified by NRC, SAMDA report
2. Presently being incorporated as sensitivity issue in IPE.

Enhancements:
1. Already completed for SAMDA.

Classification: High, see analysis sheet 7.
Preliminary investigation of effect in model without other enhancements in place (e.g., RCP seal enhancements)

Enhancement Screening Analysis Sheet

Source: IPE Update Report, December 16, 1993 Item 5.

Description: Crosstie Capability from Unit 2 to Unit 1 6.9kV Shutdown Boards

Discussion:

1. Similar to Item II.b of Generic Letter 88-20, Supplement 2.
2. Failure of a 6.9kV shutdown board after a loss of offsite power with the associated EDG operating is dominated by failure of the switchgear breakers to operate following a loss of offsite power.
3. Failure of multiple shutdown boards is dominated by common cause failure of the breakers to operate. This failure mode will not be affected by enhancing the cross-tie capability at the 6.9kV shutdown board level. Failure of top event AA after a loss of offsite power is 6.92×10^{-4}, failure of top event BA given failure of AA after a loss of offsite power is 1.010×10^{-1}, failure of top event AB given failure of AA and BA after a loss of offsite power is 5.37×10^{-1}, and failure of BB given failure of AA, BA, and AB after a loss of offsite power is 8.30×10^{-1}).
4.

Enhancements: None

1. The dominant failure mode of the 6.9kV shutdown boards after is loss of offsite power is common cause failure of the switchgear breakers. The addition of additional manually controlled breakers to facilitate the cross-tie capability will not significantly affect this failure mode.
2. Crosstie at shutdown board level down does affect the emergency diesel generators which are the leading contributors to loss of all AC.

Classification: Low, see Sheet 41.

Enhancement Screening Analysis Sheet

Source: IPE Update Report, December 16, 1993 Item 5.

Description: Fifth Battery Bus

Discussion:

1. Loss of the vital DC buses are not risk significant top events in the Watts Bar IPE. Top event DA has a probabilistic importance of 9.91×10^{-3}; Top event DB has a probabilistic importance of 1.07×10^{-2}; Top event DC has a probabilistic importance of 1.11×10^{-2}; and Top event DD has a probabilistic importance of 1.45×10^{-3}.
2. The higher importance of top event DC reflects plant design characteristics, top event DC affects the turbine driven AFW pump. No credit is taken in the Watts Bar IPE for the manual switching capability that exists for the turbine driven AFW pump control power.
3. A significant faction of the importance of top events DA and DB comes from the guaranteed failure assumed after the loss of DC power initiators LVBB1 and LVBB2 which model losses of DA and DB respectively. The guaranteed failed importance of top event DA is 7.47×10^{-3} (75%) and for top event DB is 7.18×10^{-3} (67%).
4. The addition of a fifth battery bus will not affect the initiating event frequency for the loss of DC power initiators LVBB1 and LVBB2.
5. The addition of a fifth battery bus will not affect the importance of top event DC, where no credit is given for the switching capability that currently exists.

Enhancements: None

1. The addition of a fifth battery bus will not affect the likelihood of failure of the DC buses that are currently included in the Watts Bar IPE.
2. Including the current cross-tie capability that exists could have an effect on the frequency of core damage influenced by failures in the DC buses.

Classification: Low, See Sheet 48.

Enhancement Screening Analysis Sheet

Source: SAMDA Alternative 1

Description: Additional Diesel Generator

Discussion:
1. Was considered as a sensitivity case on Level II Update.
2. Previously described in IPE Update Report Item 5.

Enhancements:
See SAMDA Report

Classification: High, see analysis sheet 7.

Enhancement Screening Analysis Sheet

Source: SAMDA Alternative 2

Description: Additional DC Battery Capacity

Discussion:

1. The batteries currently installed at Watts Bar, in conjunction with the Station Blackout Procedures, ensure battery availability to four hours after a LOSP with failure of AC power. This capability allows timely recovery of off-site power to the Watts Bar units if power is restored within four hours.
2. Loss of DC power prior to recovery of off-site power is presently assumed to lead to core damage.
3. Additional battery capacity, either amp-hour capacity or modified load shed procedures, have the potential for reducing the contribution to core damage from extended LOSP events by allowing additional time for recovery of offsite power prior to guaranteeing core damage.
4. Loss of the vital DC buses are not risk significant top events in the Watts Bar IPE. Top event DA has a probabilistic importance of 9.91×10^{-3}; Top event DB has a probabilistic importance of 1.07×10^{-2}; Top event DC has a probabilistic importance of 1.11×10^{-2}; and Top event DD has a probabilistic importance of 1.45×10^{-3}.

Enhancements:

1. Procedural, none.
2. Analysis - investigate the change in core damage frequency from an increase in the available time to restore offsite power.

Classification: Low, see Sheet 48.

Enhancement Screening Analysis Sheet

Source: SAMDA Alternative 3

Description: Alternate Means of Core Injection

Discussion:

1. Loss of support systems, e.g component cooling and/or AC power is the leading cause of failure of the high pressure injection systems at Watts Bar.
2. Failure of the high pressure injection systems require operator action to depressurize the RCS to the accumulator injection pressure to provide make-up to the RCS while recovery actions are underway. NOTE: The support systems that fail the high pressure injection systems also fail the low pressure injection system (RHR).
3. A high pressure injection pump, independent of the existing plant support systems, could provide a method of makeup to the RCS.

Enhancements:

1. Provide an alternate high pressure injection pump which is independent of existing plant support systems.

Classification: Medium to Low.
The maximum change in core damage frequency determined by using the risk reduction ratios for top events VA and VB, the centrifugal charging pumps, is

8.04E-05 * ((1-.98755)+(1-.99894))

or, 1.1E-06 per reactor year. This does not include the effects on the RCP seals which is shown on analysis sheet 14.

Enhancement Screening Analysis Sheet

Source: SAMDA Alternative 4

Description: Improved Availability of Recirculation Mode

Discussion:

1. A small LOCA initiating event requires a high pressure injection source to provide makeup to the RCS. When the contents of the RWST have been injected into the containment, the RHR containment sump recirculation suction valves are signaled open, the RHR suction from the RWST are signaled closed, and the SI pumps mini-flow lines to the RWST are isolated. With the RCS pressure above the shutoff head of the RHR pumps, operator action is necessary to align the RHR pump discharge to the suction of the high head injection pumps.
2. Failure of recirculation switchover (Top Event RR) is the leading contributor to core damage frequency for small LOCA initiators.
3. The top event is dominated by common cause failure of MOVs in the recirculation path to open on demand.
4. Operator action to locally open MOVs would be beneficial, but because of limited time after initiator to switchover, local operation is not modeled.

Enhancements:

1. MOV 89-10 program may provide better valve failure data and/or increase the likelihood of valve success.
2. Other enhancements - none that are not already described

Classification: Medium, see analysis sheet 1.

Enhancement Screening Analysis Sheet

Source: SAMDA Alternative 5

Description: Additional Instrumentation for Bypass Sequences

Discussion:

1. The interfacing systems LOCA has been shown to be important to PDS that model Early Release.
2. These scenarios could benefit from additional instrumentation that improve operator response to the initiator.
3. Does not reduce the likelihood of the initiator, may be of small benefit given the assumptions and current interfacing LOCA models.

Enhancements:
See SAMDA report.

Classification: Low, see Analysis Sheet 12.

Enhancement Screening Analysis Sheet

Source: SAMDA Alternative 6

Description: Deliberate Ignition System

Discussion:

1. Failure of the hydrogen ignitors is dominated by failure of the power supplies to the ignitors.
2. Successful operation of the hydrogen ignitors reduces the challenge to the containment from H2 ignition.

Enhancements:

1. See SAMDA report.

Classification: Low

See Sheet 101.

Enhancement Screening Analysis Sheet

Source: SAMDA Alternative 7

Description: Reactor Depressurization System

Discussion:

1. The effect of high pressure melt ejection on direct containment heating was an important sensitivity issue in the analyses that supported NUREG-1150.
2. Reducing RCS pressure during high pressure core damage scenarios was shown to be effective in reducing the likelihood of high pressure melt injection/direct containment heating challenge, induced SGTR, and RCS piping failure.
3. Sensitivity issue in NUREG-1150 (physics not confirmed).

Enhancements:

1. See SAMDA Report

Classification: Low
Sensitivity evaluation would put risk in perspective.

Enhancement Screening Analysis Sheet

Source: SAMDA Alternative 8

Description: Independent Containment Spray System

Discussion:

1. A means of independently providing containment spray could allow core debris heat removal and provide long-term containment heat removal.
2. Failure of the installed containment spray system is dominated by support system failures (e.g. AC power, room coolers, ERCW cooling to room coolers and heat exchangers).

Enhancements:
Complete evaluation of support system failures first.

Classification: Independent system low
Other enhancements may reduce effectiveness (and cost-benefit) of this enhancement.

Enhancement Screening Analysis Sheet

Source: SAMDA Alternative 9

Description: Reactor Cavity Flooding System

Discussion:
1. Considered in NUREG-1150 for Sequoyah.
2. System would reduce challenge to direct containment attack by core debris.

Enhancements:
Any enhancement to provide cavity flooding could also act to reduce the likelihood of core damage (backup injection systems, etc).

Classification: Low for this specific enhancement.
Enhancements to provide alternate injection capability will reduce effectiveness of this enhancement.

Enhancement Screening Analysis Sheet

Source: SAMDA Alternative 10

Description: Filtered Containment Vent

Discussion:
1. Old issue

Enhancements:
1. Provide a filtered vent system, see SAMDA Report.

Classification: Low

Enhancement Screening Analysis Sheet

Source: SAMDA Alternative 11

Description: Enhancement of Air Return Fans

Discussion:
1. Identified in NUREG/CR-5589
2. Failure of Air Return fans dominated by loss of power to the fans.
3. System would have to provide alternate power to Air Return fans independent of existing emergency power systems.
3. Any power supply enhancement could be used to prevent core damage (e.g., alternate seal injection system) or reduce the likelihood of containment failure (e.g. independent containment spray system).

Enhancements:
1. See SAMDA Report

Classification: Low for this specific issue, may be of benefit in other areas. See Sheet 102.

Enhancement Screening Analysis Sheet

Source: SAMDA Alternative 12

Description: Core Debris Control

Discussion:
1. Evaluated in NUREG-1150 analyses of Sequoyah.
2. High cost item.

Enhancements:
1. See SAMDA Report

Classification: Low
Any proposed enhancement for other issues will reduce effectiveness of this enhancement.

Enhancement Screening Analysis Sheet

Source: SAMDA Alternative 13

Description: Containment Inerting Capability

Discussion:
1. Evaluated in NUREG-1150 analyses of Sequoyah.
2. High cost item.

Enhancements:
1. See SAMDA Report

Classification: Low to Medium
1. Prevention of H_2 burns after core damage an import issue for ice condenser designs.
2. Alternate power to ignitors more cost effective.

Enhancement Screening Analysis Sheet

Source: SAMDA Alternative 14

Description: ERCW Cross-Connection to Centrifugal Charging Pumps and Increased Lube Oil Storage Capacity

Discussion:

1. Loss of cooling to RCP seal is assumed to lead to RCP seal LOCA, the variables are the time to failure and the magnitude of the failure.
2. Loss of CCS leads to failure of the centrifugal charging pumps which leads to seal LOCA. Loss of power has the same effect.
3. ERCW is presently supplied to CCP 1A-A.
4. The time to failure of the CCPs after a loss of CCS cooling is driven by the time to heat the bearing oil to 180°F.

Enhancements:

1. Design - Evaluate piping design necessary to supply cooling to the 1B-B charging pump from ERCW and/or both CCPs from fire protection. Piping can be permanent or quick-connect.
2. Evaluate the effects of an additional capacity lube oil reservoir.

Classification: Medium to high, see analysis sheet 14.

Enhancement Screening Analysis Sheet

Source: SAMDA Alternative 15

Description: Independent RCP Seal Injection System

Discussion:

1. Loss of RCP seal cooling is one of the more important functional failures in the Watts Bar IPE.
2. Seal cooling is lost as a result of support system failures. These failures are in the power supply to the CCS pumps and the CCPS, CCS supply to the CCPs and RCPs, the ERCW to CCS heat exchanger or combinations of these failures.
3. An independent RCP seal cooling and/or injection system could reduce the likelihood of failure of the RCP seals during failures in these support systems.

Enhancements:

1. See SAMDA Report.

Classification: Medium, see analysis sheet 14.

Enhancement Screening Analysis Sheet

Source: SAMDA Alternative 16

Description: Delay of Containment Spray Actuation

Discussion:
1. Watts Bar has ice condenser containment design.
2. All LOCA's > 3/8" effective diameter lead to containment spray actuation.
3. Two spray pumps (4000 gpm) will deplete RWST in approximately 30 minutes.
4. MOVs on spray pump discharge are not capable of throttle operation (full open, full close).
5. Chapter 5, 15 FSAR analyses based on single containment spray pump operation (single failure).

Enhancements:
1. Procedural - if containment pressure is only slightly greater than actuation setpoint, consider enhancing emergency procedures by directing operators to stop one containment spray pump (one hour to RWST depletion).
2. Analysis - Reanalyze containment pressure response given an increase in the actuation setpoint. Determine which size LOCAs could be bounded by the increase in setpoint.

Classification: Medium, see analysis sheet 1.
Change in core damage frequency approximately 1 to 5 % based on allowing more time for operator action to complete switch-over to recirculation.

SUPPORT SYSTEMS
AC POWER

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event REC

Discussion:

1. Top Event REC models the probability of recovering possible core damage sequences prior to actual damage and the probability of recovery of sequences leading to core damage prior to vessel failure. Currently, only LOSP sequences are recovered in the Watts Bar IPE.
2. REC depends on the off-site power grid arrangement, the frequency of loss of off-site power, and the line recovery history at the site, if available.
3. The Watts Bar Station Black-out Report identifies the characteristics, etc. of WBN.
4. The top event importance factors for REC are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
REC	0.99936	0.83568 (83.6%)	.16367 (16.4%)	4.3702	.83633

5. Guaranteed failed sequences are dominated by lack of recovery quantification for all initiators except LOSP.

Enhancements:

1. Investigate the latest NSAC Loss of Off-site Power Report to determine the benefit of developing new off-site power recovery factors.
2. The new recovery split fractions will only affect sequences with a probabilistic importance of 0.16367 (maximum change in core damage frequency 8.04E-05 * (1-.83633), or 1.3E-05 per reactor year).

Classification: Medium

Maximum change in recovery split fraction less than 10% based on a review of newer data, maximum change in core damage frequency is 0.1 * 1.3E-05 or 1.3E-06 per reactor year.

Analysis sheet 4 presents the results of cross-tie of 500kV power between the units.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event OG

Discussion:

1. This top event models the 161kV grid from Watts Bar hydro to Watts Bar Nuclear Plant. The 161kV grid is the normal source of supply to the four 6.9kV Shutdown Boards modeled by top events AA, BA, AB, and BB.
2. This top event is guaranteed failed with a loss of off-site power.
3. Failure of this top event requires the EDGs modeled by GA, GB, GC, and GD start and supply power to the shutdown boards.
4. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
OG	0.23659	0.23508 (99.4%)	0.001506 (0.6%)	15.328	0.99857

Enhancements: None

This top event models the frequency of failure of the off-site (161kV) grid after a plant initiating event and is used as a flag to model the loss of off-site power initiating event. The data used in the quantification is based on data presented in the Watts Bar Station Black-out report.

Classification: Medium

Because this event is used as a flag for the initiating event, the risk reduction ratio does not provide an accurate representation of the change in core damage possible. Reducing the initiating event frequency by a factor of ten would reduce core damage frequency and the top event importance, but would show little or no effect on the risk reduction ratio.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event OGR1

Discussion:

1. This top event models the likelihood of recovery of off-site power within one hour after a loss of offsite power.
2. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
OGR1	0.20260	0.0	0.20260 (100%)	1.5579	0.80903

Enhancements:

1. Cross-tie of the 500kV grid to the 161kV grid through the station transformers has the potential for improving the recovery likelihood for offsite power.
2. The data used in the quantification is based on historical data from other similar distribution grids and the Watts Bar Station Black-out report. Further review of plant data and other data sources does not indicate a significant change in frequency is possible.

Classification: High

Analysis Sheet 5 presents the results of the investigation of the 500kV cross-tie option.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Events GA, GB, GC, and GD

Discussion:

1. These top events model the emergency diesel generators at Watts Bar. Top event GA models 1A-A, GB models 1B-B, GC models 2A-A, and GD models 2B-B.
2. These top events are guaranteed failed on failure of the associated fuel oil train; FA fails GA, FB fails GB, FC fails GC, and FD fails GD.
3. The top event importance factors for these top events are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
GA	0.15304	0.0037844 (2.5%)	0.14925 (97.5%)	1.9528	0.85813
GB	0.15233	0.0038796 (2.6%)	0.14845 (97.4%)	1.6997	0.86077
GC	0.058780	0.0013699 (2.3%)	0.066399 (97.7%)	1.0670	0.98379
GD	0.068067	0.0016677 (2.5%)	0.057410 (97.5%)	1.1181	0.97371

4. The cause of failure of the emergency diesel generators is described below:

Single Diesel (.12956)	Value	Imp.
Fail to Start & Run for 24 hours	8.454E-2	64.7%
Maintenance on EDG or Support	2.514E-2	19.2%
Fan Failure (Generator, etc.)	4.157E-3	3.2%
ERCW MOV Fails to Open	3.639E-3	2.8%

Two Diesels (2.3383E-2)	Value	Imp.
Two EDGs Fail to Start & Run for 24 hours	7.946E-3	45.0%
Maintenance on EDG or Support and Failure of Other EDG (2)	4.726E-3	26.7%
Common Cause Failure to Start & Run for 24 hours	3.979E-4	2.3%
One EDG Fan Failure and Failure of Other EDG (2)	7.816E-3	4.4%
One ERCW MOV Fails to Open and Failure of Other EDG (2)	6.840E-3	3.8%

Enhancement Screening Analysis Sheet

Three Diesels (6.3419E-3)	Value	Imp.
Three EDGs Fail to Start & Run for 24 hours	7.468E-4	24.6%
Common Cause Failure to Start & Run for 24 hours	3.979E-4	13.1%
Maintenance on EDG or Support and Failure of Other EDGs (3)	6.666E-4	22.0%
Common Cause ERCW MOV Failure	8.538E-5	2.8%
Common Cause Fan Failure	7.683E-5	2.5%

Four Diesels (2.4523E-3)	Value	Imp.
Common Cause Failure to Start & Run for 24 hours	3.979E-4	39.8%
Common Cause ERCW MOV Failure	8.538E-5	8.5%
Common Cause Output Breakers	7.683E-5	7.7%
Four EDGs Fail to Start & Run for 24 hours	7.019E-5	7.0%
Maintenance on EDG or Support and Failure of Other EDGs (4)	8.588E-5	8.4%

Enhancements:

1. Modeling of the fifth diesel will reduce the contribution of maintenance to diesel generator failure.
2. Collection and evaluation of EDG maintenance data from Sequoyah may allow a reduction in the maintenance unavailability assigned to the EDGs.

Classification: High, see analysis sheet 7.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Events AA, BA, AB and BB

Discussion:

1. These top events model the 6.9kV Shutdown Boards at Watts Bar. Top event AA models Shutdown Board 1A-A, BA models Shutdown Board 1B-B, AB models Shutdown Board 2A-A, and BB models Shutdown Board 2B-B.
2. These top events are guaranteed to be failed on failure of the power to the board: 1A-A (AA) fails when the offsite grid fails (OG=F) and EDG 1A-A fails (GA=F) and the grid is not recovered in one hour (-OGR1=S) (recovery after one hour is modeled by top event REC); 1B-B (BA) fails when OG=F and EDG 1B-B fails (GB=F) and -OGR1=S; 2A-A (AB) fails when OG=F and EDG 2A-A fails (GC=F) and -OGR1=S; 2B-B (BB) fails when OG=F and EDG 2B-B fails (GD=F) and -OGR1=S.
3. Initiators LASD and LBSD guarantee failure of top events AA and BA respectively.
4. The top event importance factors for these top events are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
AA	0.22506	0.18755 (83.3%)	0.037512 (16.7%)	164.60	0.96255
BA	0.27021	0.23190 (85.8%)	0.038317 (14.2%)	191.97	0.96208
AB	0.076668	0.05878 (76.7%)		0.017888 (23.3%)	3.0866
0.99919					
BB	0.086564	0.06807 (78.6%)		0.018497 (21.4%)	4.5540
0.99781					

5. Failure of these top events after LOSP, given the associated EDG operates, is dominated by failure of the switchgear breakers to operate (normal supply must open, various feeders must open, EDG supply must close, and feeders reclose).

Enhancements: None

1. Failure of these top events after a LOSP is dominated by EDG failure. The fraction of these failures that are not caused by support system failure are dominated by breaker failure to operate, either open or close, and common cause failure to operate.
2. The maximum change in core damage frequency possible is determined by calculating the change in core damage frequency using the Risk Reduction Ratio, or:

   8.04E-05 * ((1-.96255) + (1-.96208) + (1-.99919) + (1-.99781))

Enhancement Screening Analysis Sheet

or 6.3E-06. No enhancement was identified for the 6.9kV breakers that must change state. Collection of new failure data has a potential for reducing the importance of these top events, and some potential for increasing the failure rate. A fifty percent reduction in failure rate would change core damage frequency by 0.5 * 6.3E-06 or 3.15E-06 per reactor year. A more likely ten percent change reduces core damage frequency to 6.3E-07 per reactor year.

Classification: Low

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Events AAL, BAL, ABL and BBL

Discussion:

1. These top events model the 6.9kV Shutdown Boards at Watts Bar and the include the effects of other support systems such as ventilation, on these top events. Top event AAL models Shutdown Board 1A-A, BAL models Shutdown Board 1B-B, ABL models Shutdown Board 2A-A, and BBL models Shutdown Board 2B-B.
2. These top events are guaranteed to be failed on failure of the power to the board: AAL fails when AA=F or OG=F and OGR1=F and cooling is lost to EDG 1A-A or switchgear ventilation (top event V1) is failed and not recovered (V1R); BAL fails when BA=F or OG=F and OGR1=F and cooling is lost to EDG 1B-B or switchgear ventilation (top event V2) is failed and not recovered (V2R); ABL fails when AB=F or OG=F and OGR1=F and cooling is lost to EDG 2A-A or switchgear ventilation (top event V1) is failed and not recovered (V1R); BBL fails when BB=F or OG=F and OGR1=F and cooling is lost to EDG 2B-B or switchgear ventilation (top event V2) is failed and not recovered (V2R). NOTE: the effect of the vital DC distribution system is included in these top events, failure of channel I or III (top events DA and DC) fail top events AAL and ABL; failure of channel II or IV (top events DB and DD) fail top events BAL and BBL.
3. The top event importance factors for these top events are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.	
AAL	0.24382	0.24382 (100%)	0.0 (0%)	1.0	1.0	
BAL	0.28056	0.28056 (100%)	0.0 (0%)	1.0	1.0	
ABL	0.095451	0.09545 (100%)		0.0 (0%)	1.0	1.0
BBL	0.096909	0.09691 (100%)		0.0 (0%)	1.0	1.0

Enhancements: None
These top events map failures of 6.9kV support systems that induce failure of the supported 6.9kV shutdown board(s).

Classification: Low
Enhancement to these top events must be made to the 6.9kV shutdown boards or their support systems. See Sheet 41.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Events A1, A2, B1, B2, A1U2, A2U2, B1U2, and B2U2.

Discussion:

1. These top events model the 480V Shutdown Boards and MOV boards at Watts Bar. These top events include the 6.9kV/480V transformers for each board.
2. Top event A1 includes 480V shutdown board 1A1-A, 6.9kV/480V transformer 1A1-A, and the reactor MOV board 1A1-A, diesel auxiliary board 1A1-A, containment and auxiliary building vent board 1A1-A, and reactor vent board 1A-A. Top event A2 includes 480V shutdown board 1A2-A, 6.9kV/480V transformer 1A2-A, and the reactor MOV board 1A2-A, and diesel auxiliary board 1A2-A. Top event B1 includes 480V shutdown board 1B1-B, 6.9kV/480V transformer 1B1-B, and the reactor MOV board 1B1-B, diesel auxiliary board 1B1-B, containment and auxiliary building vent board 1B1-B, and reactor vent board 1B-B. Top event B2 includes 480V shutdown board 1B2-B, 6.9kV/480V transformer 1B2-B, and the reactor MOV board 1B2-B, and diesel auxiliary board 1B2-B. Top event A1U2 includes 480V shutdown board 2A1-A, 6.9kV/480V transformer 2A1-A, and the reactor MOV board 2A1-A, diesel auxiliary board 2A1-A, containment and auxiliary building vent board 2A1-A, and reactor vent board 2A-A. Top event A2U2 includes 480V shutdown board 2A2-A, 6.9kV/480V transformer 2A2-A, and the reactor MOV board 2A2-A, and diesel auxiliary board 2A2-A. Top event B1U2 includes 480V shutdown board 2B1-B, 6.9kV/480V transformer 2B1-B, and the reactor MOV board 2B1-B, diesel auxiliary board 2B1-B, containment and auxiliary building vent board 2B1-B, and reactor vent board 2B-B. Top event B2U2 includes 480V shutdown board 2B2-B, 6.9kV/480V transformer 2B2-B, and the reactor MOV board 2B2-B, and diesel auxiliary board 2B2-B.
3. These top events are guaranteed to be failed on loss of power to the 6.9kV bus that normally supplies the 480V bus. Top event AA failure fails top events A1 and A2, top event BA failure fails top events B1 and B2, top event AB failure fails top events A1U2 and A2U2, top event BB failure fails top events B1U2 and B2U2.
4. The top event importance factors for these top events are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
A1	0.26510	0.22506 (84.9%)	0.040038 (15.1%)	122.79	0.96020
A2	0.22598	0.22506 (99.6%)	0.000918 (0.4%)	3.4899	0.99930
B1	0.34209	0.27021 (79.0%)	0.071880 (21.0%)	220.12	0.92833
B2	0.27070	0.27021 (99.8%)	0.000489 (0.2%)	2.0672	0.99971
A1U2	0.078610	0.076678 (99.8%)		0.000143 (0.2%)	
0.52976	1.0001				

Enhancement Screening Analysis Sheet

A2U2	0.076964	0.076678 (99.6%)	0.000296 (0.4%)	1.1468	0.99996
B1U2	0.086722	0.086564 (99.8%)	0.001579 (0.2%)	0.56759	1.0001
B2U2	0.088490	0.086564 (97.8%)	0.001926 (2.2%)	7.1900	0.99832

5. No credit is taken in the IPE for the alternate supplies to the 480V shutdown boards and MOV boards. Shutdown boards 1A1-A and 1A2-A can be supplied by alternate 6.9kV/480V transformer 1AA. Shutdown boards 1B1-B and 1B2-B can be supplied by alternate 6.9kV/480V transformer 1BB. Shutdown boards 2A1-A and 2A2-A can be supplied by alternate 6.9kV/480V transformer 2AA. Shutdown boards 2B1-B and 2B2-B can be supplied by alternate 6.9kV/480V transformer 2BB. The MOV boards can be supplied by the other 480V shutdown board (e.g. reactor MOV board 1A1-A, normally supplied by shutdown board 1A1-A, can be supplied by shutdown board 1A2-A.

Enhancements:
Evaluate the capability of the alternate supplies to the shutdown boards and MOV boards. If covered by procedure, consider including the alternate supplies under maintenance conditions for the 6.9kV/480V transformers. If incorporated, this enhancement will reduce the contribution of failure of these 480V shutdown boards to core damage.

Classification: Medium, see analysis sheet 10.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Events A1L, A2L, B1L, B2L, A1U2L, A2U2L, B1U2L, and B2U2L.

Discussion:

1. These top events model the effects of other support systems on the 480V Shutdown Boards and MOV boards at Watts Bar.
2. Top event A1L models 480V shutdown board 1A1-A. Top event A2L models 480V shutdown board 1A2-A. Top event B1L models 480V shutdown board 1B1-B. Top event B2L models 480V shutdown board 1B2-B. Top event A1U2L models 480V shutdown board 2A1-A. Top event A2U2L models 480V shutdown board 2A2-A. Top event B1U2L models 480V shutdown board 2B1-B. Top event B2U2L models 480V shutdown board 2B2-B.
3. These top events are guaranteed to be failed on loss of power to the 6.9kV bus that normally supplies the 480V bus, failure of 480V top event, or failure without recovery of the room cooling for the 6.9kV/480V transformers. Top event AAL failure fails top events A1L and A2L, top event BAL failure fails top events B1L and B2L, top event ABL failure fails top events A1U2L and A2U2L, top event BBL failure fails top events B1U2L and B2U2L. Loss of the room cooling system modeled by top events VT1A and VT1AR fails A1L and A2L. Loss of the room cooling system modeled by top events VT1B and VT1BR fails B1L and B2L. Loss of the room cooling system modeled by top events VT2A and VT2AR fails A1U2L and A2U2L. Loss of the room cooling system modeled by top events VT2B and VT2BR fails B1U2L and B2U2L.
4. The top event importance factors for these top events are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.	
A1L	0.28387	0.28387 (100%)	0.0	1.0000	1.0000	
A2L	0.24477	0.24477 (100%)	0.0	1.0000	1.0000	
B1L	0.35247	0.35247 (100%)	0.0	1.0000	1.0000	
B2L	0.28111	0.28111 (100%)	0.0	1.0000	1.0000	
A1U2L	0.095593	0.095593 (100%)		0.0	1.0000	1.0000
A2U2L	0.095747	0.095747 (100%)		0.0	1.0000	1.0000
B1U2L	0.097067	0.097067 (100%)		0.0	1.0000	1.0000
B2U2L	0.098835	0.098835 (100%)		0.0	1.0000	1.0000

Enhancements: None

Any enhancement to top events A1, A2, B1, B2, A1U2, A2U2, B1U2, and B2U2 will affect these top events.

Enhancement Screening Analysis Sheet

Classification: Medium, see analysis sheet 10.
Enhancement to these top events must be made to the 480V shutdown boards or their support systems.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Events A3 and B3

Discussion:

1. These top events model the 6.9kV and 480V Common Unit Boards for Watts Bar Unit 1.
2. These top events are guaranteed to be failed on loss of off-site power with no recovery by one hour.
3. The top event importance factors for these top events are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
A3	0.20269	0.20260 (99.96%)	9.01E-5 (0.04%)	0.40444	1.0003
B3	0.20269	0.20260 (99.96%)	8.98E-5 (0.04%)	0.40386	1.0003

4. Failure of these top events is dominated by loss of off-site power (161kV) to Watts Bar.

Enhancements: None
These top events are only used by BOP systems in the Watts Bar IPE (e.g. MFW and condensate).

Classification: Low
The risk reduction ratios greater than 1 indicate the relative unimportance of these top events.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event DG

Discussion:

1. This top event models the non-vital 120V AC distribution system 1A. This system provides signal and control power for several of the non-safety-related functions in the IPE.
2. Top event DG is guaranteed to fail if top event A1 fails.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
DG	0.26516	0.26510 (99.98%)	6.11E-5 (0.02%)	0.43376	1.0002

Enhancements: None
Success or failure of this top event has little or no effect on the core damage sequences in the Watts Bar model as indicated by the low risk achievement ratio and the positive risk reduction ratio.

Classification: Low

SUPPORT SYSTEMS
DC POWER

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Events DA, DB, DC, and DD

Discussion:

1. Top events DA, DB, DC, and DD model the vital 125V DC systems at Watts Bar. Top event DA models Train I, DB models Train II, DC models Train III, and DD models Train IV.
2. Top event DA is guaranteed to be failed for the loss of Train I DC initiator LVBB1, top event DB is guaranteed to be failed for the loss of Train II DC initiator LVBB2. These top events are assumed to be unavailable after a station blackout if power is not restored to the battery charger by four hours.
3. The top event importance factors for these top events are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.	
DA	0.009913	0.007467 (75.3%)		0.002446 (24.7%)	28.063	0.99781
DB	0.010715	0.007180 (67.0%)		0.003535 (33.05)	38.704	0.99679
DC	0.011069		0.0	0.011069 (100%)	19.851	0.98906
DD	0.0014581	0.0	0.001458 (100%)	2.6226	0.99867	

4. Failure of DA or DC after a loss of offsite power guarantees failure of power and 6.9kV buses 1A-A and 2A-A due to the loss of the bus strip function, failure of DB or DD after a loss of offsite power guarantees failure of power and 6.9kV buses 1B-B and 2B-B due to the loss of the bus strip function. Failure of DC is assumed to fail the turbine driven AFW pump due to the loss of control power, no credit is taken for the manual switches provided to align control power to DD.

Enhancements: None

The probabilistic importance of the guaranteed failed fraction for top events DA and DB is due to the loss of DC power initiators LVBB1 and LVBB2. The initiating event frequency used for these initiators is based on a system unavailability quantification, and is similar to historical data. The probabilistic importance of top event DC is due primarily to the guaranteed failure of the turbine driven AFW pump assumed for a loss of this DC bus. Sheet 68 and analysis sheet 5 discuss this dependency.

The maximum reduction in core damage frequency using the risk reduction ratio is:

Enhancement Screening Analysis Sheet

8.04E-05 * ((1-.99781) + (1-.99679) + (1-.98906) + (1-.99867))

or 1.42E-06, 62% due to top event DC.

Increasing battery capacity to allow longer recovery times for off-site power is not reflected in these calculations. The benefit from extending battery life in increasing the likelihood of offsite power recovery is less than 10% for a change from 4 hours to 8 hours (NSAC-147).

Classification: Low

SUPPORT SYSTEMS
ACTUATION SYSTEMS

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event OS

Discussion:

1. Top event OS models the operator actions taken after a failure of the ESFAS function.
2. OS is not guaranteed to be failed as a result of any boundary condition.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
OS	0.026501		0.0	0.026501 (100%)	9.4437

0.97367

4. Failure of top event OS after failure of either or both trains of ESFAS is assumed to result in failure of the equipment that receives automatic start signals from the ESFAS.

Enhancements: None

1. The emergency response procedures guide the operators to back-up the automatic actuation signals. The failure of this top event is dominated by the frequency of error assigned to the operators based on operator interviews.
2. The change in core damage frequency from enhancements to this function are calculated using the risk reduction ratio. The maximum change in core damage frequency is, 8.04E-05 * (1 - .97367), or 2.1E-06 per reactor year. No significant improvement is expected in the frequency of operator error after failure of ESFAS, so no further analysis is performed.

Classification: Low

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top events ZA and ZB.

Discussion:

1. Top events ZA and ZB model trains A and B of the ESFAS. The ESFAS processes plant parameters and develops actuation signals for plant equipment in response to RCS, containment, steam generator, etc. conditions.
2. Top event ZA is guaranteed to be failed if 120V AC vital channel I-1 is failed due the loss of power to the output relays. Top event ZB is guaranteed to be failed if 120V AC vital channel II-1 is failed due the loss of power to the output relays.
3. The top event importance factors for these top events are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
ZA	0.034435	0.005080 (14.8%)	0.029354 (85.2%)	3.4970	0.97886
ZB	0.034648	0.005151 (14.9%)	0.029498 (85.1)	1.3162	0.97852

4. Failure of top event ZA and/or ZB in conjunction with failure of the operator actions modeled in top event OS is assumed to result in failure of the equipment that receives automatic start signals from the ESFAS.

Enhancements: None

1. Failure of these top events is dominated by failure of the output relays required for equipment actuation (master and slave relays).
2. The model conservatively assumes that failure of any required relay in a train fails the entire train.
3. The maximum change in core damage frequency associated with these top events can be determined from the risk reduction ratio of top event OS. The maximum change in core damage frequency is 2.1E-06 per reactor year (sheet 50). No enhancements are identified that would significantly change the failure frequency of these top events.

Classification: Low

A system model revision that accurately reflects the relay combinations that result in failure could reduce the failure frequency of these top events and reduce their importance.

SUPPORT SYSTEMS
ERCW SYSTEM

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Events AE and BE

Discussion:

1. These top events model the ERCW supply trains A and B. Top event AE models train A and top event BE models train B. Each train includes four ERCW pumps, two powered from Unit 1 6.9kV shutdown boards and two powered from Unit 2 6.9kV shutdown boards.
2. These top events are guaranteed to be failed on loss of power to the pumps, or the flood initiator FLPH1A or loss of train A ERCW for top event AE, flood initiator FLPH1B or loss of train B ERCW for top event BE, and the total loss of ERCW initiator, ERCWTL.
3. The top event importance factors for these top events are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
AE	0.16088	0.13788 (85.7%)	0.022991 (14.3%)	1427.0	0.97802
BE	0.16681	0.14190 (85.7%)	0.023907 (14.3%)	72.060	0.97781

4. Failure of these top events affect almost all other top events in the IPE.

Enhancements: None
No enhancements are identified for these top events. The maximum change using the risk reduction ratios is

8.04E-05 * ((1-.97802) + (1 - .97781))

or 3.55E-06 per reactor year. Eight ERCW pumps are installed, the success criterion requires 2 of 4 pumps per header and only one header. Reduced criteria for the LOSP initiator of one pump per header based on plant specific analysis is also included in the IPE model. Failure of the pumps is dominated by historical failure data collected from the nuclear industry.

Classification: Medium

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Events CE, DE, EE, and FE

Discussion:

1. These top events model the ERCW supply headers at Watts Bar. Top Event CE models header 1A-A, DE models header 1B-B, EE models header 2A-A, and FE models header 2B-B.
2. Top event CE is guaranteed to be failed if top event AE fails. Top event DE fails if top event BE fails or if top events MDE and EE fail. Top event EE fails if top event AE fails. Top event FE fails if top event BE fails.
3. The top event importance factors for these top events are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
CE	0.20979	0.16089 (76.7%)	0.048898 (23.3%)	100.81	0.95127
DE	0.23251	0.17565 (75.6%)	0.056851 (24.4%)	138.56	0.94330
EE	0.16324	0.16088 (98.6%)	0.023690 (1.4%)	13.461	0.99778
FE	0.16701	0.16681 (99.9%)	2.076E-4 (0.01%)	1.3369	0.99991

4. Failure of headers 2A-A and 2B-B is dominated by failure of the ERCW pump trains modeled by top events AE and BE. Failure of headers 1A-A and 1B-B is dominated by failure of the ERCW pump trains modeled by top events AE and BE and by maintenance on the header self-cleaning strainer given one of the loss of ERCW header initiators (FLPH1A, FLPH1B, ERCWA, or ERCWB).
4. The individual ERCW headers are capable of being cross-tied to other headers. Headers 1A-A and 2B-B are cross-tied and headers 1B-B and 2A-A are cross-tied. The 1B-B to 2A-A cross-tie is modeled under top event CCSR and top event MDE. The 1A-A to 2B-B cross-tie is not modeled in the IPE.

Enhancements:

1. The risk achievement ratios for top events CE and DE indicate the importance of ERCW to the plant safety systems. Failure of these top events is dominated by failure of the ERCW supply and by maintenance of the self-cleaning strainer for the ERCW initiators.
2. Collection and evaluation of the maintenance data from Sequoyah for the ERCW self-cleaning strainers may allow a reduction in the unavailability of these strainers due to maintenance.

Classification: Medium, see analysis sheet 11.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event MDE

Discussion:

1. Top event MDE models the maintenance of the ERCW header self-cleaning strainers. All strainer maintenance is assigned to ERCW header 1B-B in order to simplify the modeling of the operator actions necessary to cross-tie ERCW headers that result from maintenance of an ERCW strainer. For those initiators that model failure of an ERCW header, ERCWA, ERCWB, FLPH1A, and FLPH1B, strainer maintenance is assigned to the remaining unit 1 ERCW header and top event MDE is guaranteed to be successful.
2. Top event MDE is not guaranteed to be failed for any boundary conditions.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
MDE	0.011191		0.0	0.011191 (100%)	2.3786

0.99315

4. Failure of top event MDE is dominated by the unavailability assigned to maintenance of the self cleaning strainers.

Enhancements: None
This top event is a modeling convenience only.

Classification: Medium, see analysis sheet 11.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event DSLR

Discussion:

1. Top event DSLR models the realignment of ERCW to an EDG that has insufficient cooling following a LOSP.
2. ERCW cooling to the EDGs is supplied automatically by two of the four ERCW supply headers, ERCW header 1A-A (top event CE) supplies EDGs 1A-A and 2A-A while ERCW header 1B-B (top event DE) supplies EDGs 1B-B and 2B-B. An alternate ERCW supply to the EDGs is available from the opposite ERCW header, ERCW header 2B-B (top event FE) backs up ERCW header 1A-A and ERCW header 2A-A (top event EE) backs up ERCW header 1B-B. Alignment of the alternate ERCW supply requires operator action. The operator action is described in LOSP emergency operating procedure.
3. This top event is guaranteed to be failed if the opposite ERCW header is unavailable.
4. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
DSLR	0.028408	0.026490 (93.2%)		0.00199 (6.8%)	
0.99656	1.0001				

5. Failure of this top event is dominated by failure of the ERCW headers.

Enhancements: None
The positive risk reduction ratio indicates low importance of this top event because failure of an ERCW header dominates the failure of this top event.

Classification: Low

SUPPORT SYSTEMS
COMPONENT COOLING SYSTEMS
(and RCP Seals)

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Events AC and BC

Discussion:

1. These top events model the CCS system. Top event AC models CCS train A (pumps 1A-A and 1B-B) in Unit 1, top event BC models CCS train B (pump C).
2. These top events are guaranteed to be failed on loss of power to the pumps, or the loss of train A CCS initiator, CCSA, for top event AC or loss of the CCS system initiator, CCSTL, or loss of cooling to the CCS heat exchangers.
3. The top event importance factors for these top events are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
AC	0.43013	0.31192 (72.5%)	0.011821 (27.5%)	110.91	0.88303
BC	0.19975	0.16611 (83.2%)	0.033644 (16.8%)	8.2582	0.96983

4. The difference in the importance ratios calculated for these two top events is due to the importance of the thermal barrier cooling system supplied by CCS Train A. All other important cooling loads are divided on a train basis.

Enhancements:

1. A significant fraction of the failure of CCS train A is caused by loss of cooling water to the CCS heat exchanger A. This cooling water is supplied by ERCW header 1B-B. Loss of this ERCW header leads to a failure of train B ECCS and CS pumps due to the loss of pump room cooling and failure of train A ECCS pumps due a loss of oil and seal cooling. With no operator action, loss of this ERCW header leads to core damage due to loss of RCP seal cooling and failure of the injection systems necessary for RCS make-up. Two operator actions are included in the IPE model; cross-tieing ERCW header 2A-A to the CCS heat exchanger A, and aligning ERCW to CVCS pump 1A-A to provide oil cooling. Aligning the A train ERCW header to the A train CCS heat exchanger would decrease the frequency of challenge to the operators from loss of a single ERCW header.
2. The maximum change in core damage frequency associated with this enhancement to top event AC is determined using the risk reduction ratio for top event DE which is the normal cooling source. The change in core damage frequency is, 8.04E-05 * (1-.94330), or 4.6E-06 per reactor year.
3. The change in core damage frequency associated with providing alternate ERCW cooling to centrifugal charging pump 1B-B is shown in analysis sheet 14. No other enhancements were identified for top event BC.

Classification: Medium, see analysis sheet 14 for RCP Seal LOCA concerns.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event CCPR

Discussion:

1. This top event models the operator actions taken to supply ERCW to charging pump 1A-A after a loss of CCS train A to the pump gear and bearing oil coolers. ERCW is supplied by header 1A-A.
2. This top event is guaranteed to be failed if power is lost to CVCS pumps 1A-A and 1B-B or if ERCW header 1A-A is unavailable.
2. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
CCPR	0.38448	0.24918 (64.8%)	0.13530 (35.2%)	2.0125	0.88134

Enhancements:

1. Addition of ERCW back-up to CVCS pump 1B-B has been previously discussed.
2. Cross-tie of CCS headers and the effects of the ERCW header alignment have been previously discussed.

Classification: Medium, see analysis sheet 14.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event CCSR

Discussion:

1. This top event models the operator actions and/or automatic actions necessary to align ERCW header 2A-A to CCS heat exchanger 1A. This heat exchanger is normally supplied by ERCW header 1B-B. Upon loss of off-site power and loss of power to shutdown board 1B1-B, this alignment is automatic. Upon loss of flow in ERCW header 1B-B for other causes, operator action is necessary to complete this alignment.
2. This top event is guaranteed to be failed if power is unavailable to CVCS pumps 1A-A and 1B-B or if ERCW header 2A-A is failed.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
CCSR	0.26778	0.26559 (99.2%)	0.00219 (0.8%)	2.3017	0.99793

Enhancements:

1. The effects of the ERCW header alignment to CCS heat exchanger 1A has been previously discussed.

Classification: Medium, see analysis sheet 14.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event TB

Discussion:

1. This top event models the operation of the thermal barrier cooling water system.
2. This system provides cooling water to the RCP thermal barrier heat exchangers. The TB system is supplied from the component cooling system, train A. Water from the RCP thermal barrier heat exchangers returns to the CCS pumps.
3. The TB system is isolated from the RCP on a containment Phase B (high-high pressure) signal.
4. This system is guaranteed to be failed on loss of CCS train A, power to the TB Booster pumps (A1 and B1) or TBBPs ventilation failures, and by external system boundary conditions, (Phase B containment isolation signal).
5. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
TB	0.77621	0.74743 (96.6%)	0.026779 (0.4%)	1.3743	.97523

6. Failure of this top event affects top event SE.

Enhancements:

1. Cross-tie of the CCS trains A and B would reduce the importance of this top event. The cross-tie lines and valves are already installed, however, the MOVs are normally de-energized and closed for Appendix R concerns. The AOI for loss of CCS would have to be modified to describe the steps and limitations necessary for use of this cross-tie.
2. A flood-mode cross-tie to the ERCW system is already permanently installed at WBN. No credit is taken for this cross-tie in the IPE. If the loss of CCS AOI were modified to credit this source of cooling water to the RCP thermal barriers, a decrease in the importance of this top event would occur.
3. Providing a second TB source of cooling water from CCS Train B would reduce the frequency of challenge of the RCP seals from loss of CCS Train A. This source of water would be manually aligned and could consist of spool pieces, etc., that can be quickly made up to restore cooling water to the RCP thermal barrier heat exchangers. A flow of approximately 160 gpm (design) would be required.

Classification: Medium, see analysis sheet 14.
Quickly restoring flow to the RCP thermal barrier heat exchangers will mitigate or reduce likelihood of failure of the RCP seals.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event SE

Discussion:

1. This top event models the challenge to RCP seal integrity from loss of cooling to the RCP seals from the charging system and to the thermal barrier heat exchangers from the thermal barrier cooling system.
2. Enhancements to top event TB will affect the importance of this top event (e.g. any enhancement that improves Top Event TB will also improve top event SE)
3. Failure of this top event is caused by failure of the thermal barrier cooling system and failure of CVCS RCP seal injection. This top event is guaranteed to be failed is a non-isolable small LOCA occurs or if the thermal barrier cooling system fails and both coolant charging pumps fail. The IPE model does not take credit for the positive displacement charging pump because the support systems for this pump are same as the support systems for the centrifugal charging pumps.
4. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
SE	0.77267	.76049 (98.4%)	0.012182 (1.6%)	3.4899	.98783

Enhancements:
None outside of those enhancements identified for top event TB.

Classification: Medium, see analysis sheet 14.
If enhancements are made to the thermal barrier cooling system, top event TB, the importance of this top event will be reduced.

SUPPORT SYSTEMS
VENTILATION AND MISCELLANEOUS SUPPORT SYSTEMS

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Events V1 and V2

Discussion:

1. Top events V1 and V2 model the ventilation systems that supply the 6.9kV Shutdown Board Rooms.
2. Top event V1 is guaranteed to be failed if the 480V shutdown boards modeled by top events A2 and A2U2 are failed. Top event V2 is guaranteed to be failed if the 480V shutdown boards modeled by top events B2 and B2U2 are failed.
3. The top event importance factors for these top events are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
V1	0.062685	0.06229 (99.37%)		3.96E-4 (0.03%)	
0.15445	1.0003				
V2	0.061554	0.06153 (99.95%)		2.83E-5 (0.05%)	
0.14309	1.0000				

4. Failure of these top events is dominated by failure of power to the fans.

Enhancements: None
Failure of these top events is dominated by failure of the fan support systems. Failure of the support systems is dominated by failure of the shutdown boards that the fans cool. Recovery top events V1R and V2R serve to reduce the importance of these top events.

Classification: Low

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Events V1R and V2R

Discussion:

1. Top events V1R and V2R model the operator actions necessary to restore cooling to the 6.9kV shutdown board rooms after the normal ventilation systems fail.
2. Top event V1R is guaranteed to be failed is top events AA and AB fail, AA and AB are the buses cooled by the ventilation system modeled in top event V1. Top event V2R is guaranteed to be failed is top events BA and BB fail, BA and BB are the buses cooled by the ventilation system modeled in top event V2.
3. The top event importance factors for these top events are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
V1R	0.062289	0.062289 (100%)		0.0	0.99960
1.0000					
V2R	0.061526	0.061526 (100%)		0.0	0.99997
1.0000					

4.

Enhancements: None
Guaranteed failure of this top event reflects the situation when cooling is not required due to the failure of the cooled 6.9kV shutdown boards.

Classification: Low

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top events VT1A, VT1B, VT2A, and VT2B.

Discussion:

1. These top events model the room ventilation systems for the 6.9kV/480V shutdown board transformers. Four ventilation system are provided, one for each major power train.
2. These top events are guaranteed to be failed if power is lost to the room exhaust fans. Power to the fans is provided by Vent boards supplied by the associated transformers.
3. The top event importance factors for these top events are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
VT1A	0.26516	0.26510 (99.98%)	6.38E-5 (0.02%)	0.44598	1.0002
VT1B	0.34214	0.34209 (99.99%)	4.58E-5 (0.01%)	0.48381	1.0002
VT2A	0.076840	0.07681 (99.96%)	3.01E-5 (0.04%)	0.17003	1.0003
VT2B	0.086769	0.08672 (99.95%)	4.69E-5 (0.05%)	0.21977	1.0002

4. Recovery from failure of these top events is included in top events VT1AR, VT1BR, VT2AR, and VT2BR. The importance of the recovery top events is less than 5E-04.
5. Failure of these top events is dominated by failure of power to the fans.

Enhancements: None
Recovery is already modeled in the IPE and reduces the importance of these events to less than 5E-04.

Classification: Low

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Events VINV1 and VINV2

Discussion:

1. Top events VINV1 and VINV2 model the ventilation supply to the 120V vital inverters for channels I and II (VINV1) and channels III and IV (VINV2).
2. These top events are guaranteed to be failed on loss of power to the associated ventilation system, top event B2 for VINV1 and B2U2 for VINV2.
3. The top event importance factors for these top events are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
VINV1	0.27070	0.27070 (100%)	0.0	0.27134	1.0001
VINV2	0.089568	0.088490 (98.8%)		0.0010781	(1.2%)
0.18989	1.0006				

4. Recovery from failure of these top events is included in top events VNV1R and VNV2R. The importance of the recovery top events is approximately 5E-04.
5. Failure of these top events is dominated by failure of power to the fans.

Enhancements: None
Recovery is already modeled in the IPE and reduces the importance of these events to approximately than 5E-04.

Classification: Low

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Events PA and PB

Discussion:

1. Top events PA and PB model the Auxiliary Control Air (ACA) trains A and B.
2. Top event PA is guaranteed to be failed if top events DAAC or PD fail and A1U2L or CE or GE fail. Top event PB is guaranteed to be failed if top events DBAC or PD fail and B1U2L or DE or HE fail.
3. The top event importance factors for these top events are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
PA	0.21414	0.20611 (92.3%)	0.00802 (7.7%)	1.7630	0.99667
PB	0.17196	0.16326 (94.9%)	0.00871 (5.1%)	1.5725	0.99637

4. Failure of these top events is dominated by failure of support systems, AC power and cooling water.

Enhancements:
The backup source of control air (accumulators or N2) described previously in relation to the AFW LCVs will significantly affect the importance of these top events.

Classification: Low, see analysis sheet 9.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event PD

Discussion:

1. Top event PD models the non-essential control air system supply system.
2. Four plant air compressors are provided, two plant air compressors are powered by buses supplied by the EDGs. operator action is necessary to start these air compressors after a loss of off-site power.
2. Top event PD is guaranteed to fail if top event PE fails (loss of cooling), or if top event A3 fails and DC train B (DB), or 480V AC top B1 (B1L), or 480V AC top A2 (A2L) fail.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
PD	0.33171	0.32107 (96.8%)	0.010634 (3.2%)	4.1696	0.99695

4. Failure of this system is dominated by failure of support systems or imposed boundary conditions.

Enhancements: None
The backup source of control air (accumulators or N2) described previously in relation to the AFW LCVs will significantly affect the importance of this top event.

Classification: Low, see analysis sheet 9.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event PE

Discussion:

1. Top event PE models the backup ERCW supply to the plant air compressors (modeled by top event PD).
2. Top event PE is guaranteed failed if top events CE and DE fail.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
PE	0.14719	0.14719 (100%)	0.0	0.14784	1.0000

Enhancements: None
Failure of this system is dominated by support system failures, primarily failure of the cooling water support systems. Risk reduction ratio of 1 indicates low importance of this top event.

Classification: Low, see analysis sheet 9.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event RW

Discussion:

1. Top event RW models the RWST as a source of borated water for the ECCS and CS pumps.
2. The RWST contains no active components; however the function is guaranteed to be failed for FLAB2.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
RW	2.84E-4	9.33E-5 (32.8%)	1.91E-4 (67.2%)	310.41	0.99981

Enhancements: None
Failure of the RWST is an extremely unlikely although important event as indicated by the risk achievement worth and the low probabilistic importance.

Classification: Low

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event MU

Discussion:

1. Top event MU models the operator actions and equipment necessary to refill the RWST during Small LOCA (SLOCA), Steam Line Break Inside Containment (SLBIC), and Steam Generator Tube Rupture (SGTR) initiating events. This top event is needed in those sequences where the low pressure pumps have failed (SLOCA, SLBIC) or where RCS inventory is bypassing the containment and passing through the steam generator PORV or safety valves (SGTR).
2. Top event MU is assumed to failed if the RWST has failed or if primary make-up or CVCS boron blending is unavailable (top events PD or DA or A1L or A1U2 and B1U2 or DAAC and (DBAC or B1L) fail).
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
MU	0.62115	0.43208 (69.6%)	0.18907 (30.4%)	2.3716	0.88572

4. Failure of top event MU is dominated by failure of the operators given the short time available for recovery.

Enhancements: None for this top event
The maximum change in core damage frequency possible is calculated using the risk reduction ratio, 8.04E-05 * (1 - .88572), or 9.2E-06 per reactor year. Increasing the time available for operator action by reducing the draw-down rate from the RWST will result in a decrease in core damage frequency. Assuming a 50% decrease in operator failure likelihood, the maximum change in core damage frequency is 4.6E-06 per reactor year.

Classification: Medium, see analysis sheet 1 for the effect on top event RR.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event CTMU

Discussion:

1. Top event CTMU models the operator actions and equipment necessary to provide make-up to the CST during an initiating event with reactor trip failure.
2. Top event CTMU is guaranteed to be failed if the off-site grid is failed, top event OG.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
CTMU	0.25267	0.23659 (93.6%)	0.016081 (6.4%)	0.88832	1.0028

Enhancements: None
The risk reduction ratio indicates the low importance associated with this top event. This is due to the low frequency of failure of top event CTMU after an ATWS event.

Classification: Low

SUPPORT SYSTEMS
REACTIVITY CONTROL

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event RT

Discussion:

1. Top event RT models the reactor trip function in response to a plant initiating event.
2. The reactor trip function is guaranteed to be successful for the reactor trip initiator. With failure of off-site power, the reactor trip function models the RCCAs only.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
RT	0.047088		0.0	0.047088 (100%)	1485.5

0.95296

4. Reactor trip failure is dominated by common cause failure of the reactor trip breakers to trip.

Enhancements:

1. The capability to quickly trip the RCCA motor generators sets from the control room has been previously identified.
2. Collection of new failure data could reduce the failure frequency and common cause failure frequency for the reactor trip breakers. The maximum change in core damage frequency based on the risk reduction ratio is

   8.04E-05 * (1-.95296)

   or 3.8E-06 per reactor year. A 50% reduction in breaker failure rate would result in a change in core damage frequency of 1.9E-06 per reactor year.

Classification: Medium, see analysis sheet 13.
See top event PL, sheet 73, for suggested model refinements.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event EB

Discussion:

1. Top event EB models the operator actions and equipment necessary to ensure the reactor is subcritical after an ATWS event.
2. Failure of this function is dominated by the failure of the operator action modeled and by equipment failure given operator success.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
EB	0.011387	0.98891	0.0	0.011387 (100%)	2.2292

4. Failure of this top event is assumed to eventually lead to core damage because of the failure to restore lost RCS inventory.

Enhancements:

1. The operator action frequency of failure is based on taking action outside the control room (tripping the control rod MG sets) or initiating emergency boration. These actions must be started within 10 minutes.
2. The capability to operate the MG set breakers from the control room has been previously identified.

Classification: Medium, see analysis sheet 13.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event PL

Discussion:

1. Top event PL is used to determine the reactor power conditions at the time of an ATWS event.
2. Success of this top event indicates reactor power at the time of the ATWS event is <40%. This guarantees success of top event SR.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
PL	0.042768		0.0	0.042768 (100%)	1.0175

0.96569

4. Failure of this top event indicates reactor power is >40% at the time of the ATWS challenge, which requires questions be asked of the AMSAC system (top event AM) and main feedwater system (FW).

Enhancements: None

The data used to quantify this top event is based on historical evidence from operating power plants. The top event function is based on analysis in WCAP-11993.

Classification: Medium

A reactor power of less than 40% for those initiators which guarantee success of the turbine trip function is not currently modeled. Guaranteeing success of this top event for initiators TTIE, LOCV, LOSP, and AMSIV (and possibly EXMFW which results in a turbine trip) would reduce the importance of this top event. A quick hand calculation indicates the maximum change in core damage frequency would be approximately 3E-07 per reactor year.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event SR

Discussion:

1. Top event SR models the RCS relief function after a reactor trip failure (ATWS).
2. This top event includes the three pressurizer safety valves and one or two of the pressurizer PORVs.
3. This top event is guaranteed to be failed if turbine trip or AMSAC fail (top events TT or AM) and AFW flow is less than 50% and power level is greater than 40% (top event PL) and main feedwater is not available (top event MF).
4. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
SR	0.033658	0.016084 (47.8%)		0.017575 (52.2%)	1.4112

0.98257

5. Failure of this top event leads to a low pressure core damage event because of the assumed failure of the reactor pressure vessel.
6. Failure of this top event is dominated by failure of the PORVs, due either to mechanical failure to open or isolated due to maintenance.

Enhancements: None

1. The quantification of the failure of this top event is based on calculations performed in support of WCAP-11993. Additional analysis would not significantly affect the success requirements for this top event.
2. Given the success requirements, no significant change in top event frequency of failure can be expected without extensive data collection.
3. Trip of the control rod motor generator sets from the control room could decrease the probabilistic importance of this top event.
4. The maximum change in core damage frequency possible is determined using the risk reduction ration, 8.04E-05 * (1-.98257), or 1.4E-06 per reactor year.

Classification: Medium

See sheet 73 for changes in the quantification for top event PL that could affect the importance of this top event.

SUPPORT SYSTEMS
DECAY HEAT REMOVAL

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event TP

Discussion:

1. This top event models the turbine driven AFW pump and associated auxiliary systems.
2. This pump is guaranteed to be failed on loss of 120V Vital AC Channel III or 125V DC Vital Bus III. No credit is taken for the manual cross-tie switches in the pump room.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
TP	0.13494	0.039322 (29.1%)	0.095617 (70.9%)	1.5426	0.95698

4. For most initiating events, this top event is a back-up to the motor-driven AFW pumps and is backed up by recovery of the main feedwater system. For Station Blackout events, this pump is the only means of maintaining secondary decay heat removal.

Enhancements:

1. Failure of this top event is dominated by historical failure data from the nuclear power industry. Collection and evaluation of data from Sequoyah could result in a decrease in the likelihood of failure of this top event.
2. Inclusion of the operator actions to shift control power to alternate sources, which is covered by plant abnormal operating instructions, would reduce the probabilistic importance of this top event, and would significantly enhance the capability of this top event for LOSP/SBO sequences.

Classification: Medium, see analysis sheet 5 for the effects of including the manual switch, see analysis sheet 9 for the effects of plant instrument air on the level control valves.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event TPR

Discussion:

1. This top event models the actions taken by the operator to restart a tripped turbine driven AFW pump.
2. Top event TPR is guaranteed to be failed if the turbine driven pump support systems fail.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
TPR	0.12748	0.039322 (30.9%)	0.088156 (69.1%)	1.0135	0.94320

4. Failure of this top event is dominated by the failure of the operator action to restart the turbine driven AFW pump and the likelihood of having a recoverable start failure.

Enhancements: None
This top event models the likelihood of recovery of start failures of the turbine driven AFW pump and is based on historical data from operating nuclear power plants.

Classification: Medium

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Events MA and MB

Discussion:

1. These top events model the train A and train B motor driven AFW pumps. Top event MA models pump 1A-A and top event MB models pump 1B-B.
2. Guaranteed failure of these top events is caused by loss of power to the pump motor, top events AA or DA and BA or DB, loss of air to the air-operated pressure control valves (PCVs) and level control valves (LCVs), top events PA and PB, or failure of the actuation system, top events ZA and ZB.
3. The top event importance factors for these top events are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
MA	0.41849	0.40759 (97.4%)	0.010906 (2.6%)	1.7602	0.99337
MB	0.42846	0.41474 (96.8%)	0.013726 (3.2%)	1.7567	0.99040

4. Failure of these top events is dominated by loss of power to the pump motors and by loss of air to the PCVs and LCVs.

Enhancements:

1. The LCVs for the motor-driven AFW pumps fail open on loss of air, however, the pump discharge PCVs fail closed. Abnormal operating procedures for loss of air direct the operators in the control of these LCVs and PCVs and the LCVs for the turbine driven AFW pump. No credit is taken in the IPE for the operator actions that would occur to restore flow from the AFW motor-driven AFW pumps in the event of loss of control air
2. Addition of air reservoirs to the PCVs would allow operation of the motor-driven AFW pumps for some period of time after an event that results in a loss of control air to the PCVs. This would allow inclusion of operator recovery actions into the system model for the motor-driven AFW pumps.

Classification: Low, see analysis sheet 9.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event AF

Discussion:

1. Top event AF models the AFW supply lines to the four steam generators. Each steam generator can receive AFW flow from one motor driven AFW pump and the turbine driven AFW pump.
2. Top event AF is bypassed (guaranteed to be failed) in the general transient event tree if the three AFW pumps have failed.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
AF	0.014381	3.04E-4 (2.1%)		0.014077 (97.9%)	54.236

0.99310

Enhancements:
In the current design, the turbine driven AFW pump LCVs to the steam generators fail closed on loss of air. The motor driven AFW pump LCVs fail open on loss of air, however the PCVs fail closed. With a station black-out, operator action is required within a short period of time, approximately 20 minutes, to locally control the turbine driven AFW pump LCVs to allow the restoration of flow to the steam generators. The addition of a back-up source of control air to the LCVs has been previously identified.

Classification: Low, see analysis sheet 9.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event MS

Discussion:

1. This top event models the operation of the MSIVs in response to low steam line pressure, high negative steam pressure rate with pressurizer pressure low, or high-high containment pressure.
2. Success of this top event guarantees failure of the main feedwater system because the MSIVs are closed.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
MS	0.35645	0.35465 (100%)	0.0	0.41536	1.0001

5. Failure of this top event is dominated by support system failures or by the initiating event.

Enhancements: None

A risk reduction ratio greater than 1 is an indication of the effect of this top event on core damage frequency. Failure of this top event for most initiators indicates that the MSIVs remain open, which allows questions to be asked of the main feedwater system.

Classification: Low

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event CD

Discussion:

1. This top event models secondary heat removal by the condenser and return of condensate by the condensate system.
2. This top event is bypassed if top event MS is successful (MSIVs closed). This top event is guaranteed to be failed if off-site power is unavailable, if the initiator is a result of loss of the condenser function, or if support systems fail (plant air, DC power, or 6.9kV shutdown board 1A-A).
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
CD	0.066184	0.063179 (95.5%)		0.003005 (4.5%)	1.0793

0.99936

4. Failure of this top event guarantees failure of secondary heat removal using the main feedwater system.
5. Failure of this top event is dominated by boundary conditions and by failures in support systems.

Enhancements: None

1. Failure of this top event is controlled by boundary conditions and support system failures.
2. Use of the condensate system without the use of the condenser as a heat sink is not included in the Watts Bar IPE.

Classification: Low, see analysis sheet 2.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event FW

Discussion:

1. This top event models the availability of main feedwater for ATWS events.
2. This top event is guaranteed to be failed for those initiating events that are initiated by a loss of main feedwater or if the condensate system (top event CD) is failed.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
FW	0.031444	0.031408 (99.89%)		3.64E-5 (0.11%)	
0.99985	1.0000				

4. Failure of this top event indicates that the main feedwater system is not available to supply the steam generators after an ATWS event which increases the likelihood of a pressure challenge to the RCS.

Enhancements: None
Failure of this top event is dominated by the boundary conditions which guarantee failure of the top event.

Classification: Low

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event MF

Discussion:

1. Top event MF models the equipment necessary to restore the main feedwater system to operation after a plant initiating event. This top event is only questioned after a loss of AFW with reactor scram success.
2. Top event MF is guaranteed to be failed for all initiators that directly affect the MFW system (TLMFW, EXMFW, LOCV, and LOSP), and by the main feedwater system support systems (CD, etc.).
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
MF	0.099889	0.096144 (96.3%)		0.0037456 (3.7%)	1.1403

0.99656

4. Failure of top event MF is dominated by failure of MFW support systems and by the initiators that affect the MFW system.

Enhancements: None

1. The IPE model conservatively assumes that main feedwater will always be tripped after any initiating event due to the low T_{avg} isolation signal (due to W ERG philosophy).
2. This top event models the equipment necessary to restore main feedwater for a limited number of plant sequences.
3. Because failure of this system is dominated by failure of support systems or by imposed boundary conditions, very little benefit will be achieved by enhancements to the equipment modeled by this top event.

Classification: Low, see analysis sheet 2

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event PR

Discussion:

1. This top event models RCS pressure relief via the pressurizer PORVs and safety valves in response to a pressure challenge to the RCS. The success criteria requires successful opening and successful reclosing (or isolation for PORVs) after a steam or water challenge.
2. Top event PR is guaranteed to be failed with an isolable SLOCA and failure of top event B1L or if top event RT fails, or if a water challenge exists (top event WC fails) with failure of the AFW system.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
PR	0.16338	0.15659 (95.8%)	0.00679 (4.2%)	8.4521	0.99328

4. Failure of top event PR is dominated by boundary conditions and support system failures.
5. The IPE model assumes that steam challenge to the pressurizer PORVs occurs whenever the support systems for pressurizer spray or S/G atmospheric dump valves are not available.

Enhancements:
The maximum change possible is determined by using the risk reduction ratio,

8.04E-05 * (1-.99328)

or 5.4E-07 per reactor year.

Classification: Low

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event OB

Discussion:

1. Top event OB models the operator actions taken to establish feed and bleed cooling of the RCS after a loss of secondary cooling. The pressurizer PORVs are also modeled in this top event.
2. This top event is guaranteed to be failed if the charging pumps and the safety injection pumps have failed or if DC trains I and II (top events DA and DB) have failed.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
OB	0.006154	2.77E-04 (4.5%)		0.005878 (95.5%)	1.4476

0.99474

4. Failure of this top event is assumed to lead to core damage because of the loss of RCS decay heat removal.
5. Failure of this top event is dominated by failure of the operator action.

Enhancements: None
Failure of this top event is dominated by operator failure. Given the time constraints, and the scenarios that question this top event, no significant change in the likelihood of operator error is likely. The maximum change possible is determined by using the risk reduction ratio, 8.04E-05 * (1-.99474) or 4.2E-07 per reactor year.

Classification: Low

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event DS

Discussion:

1. Top event DS models the operator actions and equipment necessary to depressurize the secondary plant using steam generator PORVs or condenser bypass valves. This function is important for station black-out and SGTR sequences.
2. Top event DS is guaranteed to be failed if there is a station black-out and AFW is not successful or if a SGTR occurs and no feedwater is available to the steam generators, or on loss of plant air trains PA and PB.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
DS	0.63062	0.57561 (91.3%)	0.055001 (8.7%)	13.050	0.95723

4.

Enhancements:
The addition of accumulators or a backup source of instrument air for the steam generator PORVs will reduce the importance of this top event.

Classification: Low, see analysis sheet 9.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event DP

Discussion:

1. Top event DP models the equipment necessary to depressurize the RCS to the RHR entry conditions. The operator actions necessary for this depressurization are included in top event DS.
2. Top event DP is not asked if AFW to the steam generators has failed.
2. Top event DP is guaranteed to be failed if top event DS fails or if top events DA and DB fail and (OG fails or Channel IV Vital AC fails or Train A CCS fails or ACA Trains A and B fail).
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
DP	0.63254	0.63063 (99.7%)	0.001911 (0.03%)	0.96045	1.0005

Enhancements: None
The frequency of failure of this top event with top event DS successful is extremely small. A risk reduction ratio greater than one indicates the low overall importance of this top event.

Classification: Low

SUPPORT SYSTEMS
RCS INJECTION/RECIRCULATION

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event VS

Discussion:

1. Top event VS models the suction supply to the centrifugal charging pumps. For most general transients, suction is from the volume control tank, for all LOCAs, suction is from the RWST.
2. This top event is guaranteed to be failed if the initiator generates an SI signal, and the power or the actuation signal to the suction valves fail or the RWST fails.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
VS	0.009284	0.0079729 (85.9%)		0.001312 (14.1%)	1.7044

0.99899

4. Failure of this top event fails the centrifugal charging pump top events VA and VB.

Enhancements: None
Failure of this top event is dominated by failures induced by boundary conditions.

Classification: Low

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Events VA and VB

Discussion:

1. These top events model the CVCS pumps 1A-A and 1B-B. Pump 1A-A is assumed to operating for purposes of analysis in the IPE.
2. These top events are guaranteed to be failed on loss of power to the pumps or room cooler, loss of cooling to the oil coolers or room coolers, and for pump 1B-B failure of the actuation system.
3. The top event importance factors for these top events are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
VA	0.56302	0.54797 (97.3%)	0.015050 (2.7%)	2.8858	0.98755
VB	0.60449	0.60110 (99.4%)	0.003393 (0.6%)	1.1782	0.99894

4. Failure of top events VA and VB is dominated by failures in the support systems for these pumps.

Enhancements:

1. ERCW back-up to CVCS pump 1A-A is included in the IPE model in top event CCPR. The addition of ERCW to CVCS pump 1B-B is previously described.
2. The current system analysis assumes that loss of cooling water to the CVCS pump room coolers, or failure of the coolers will fail the associated pump.
3. Evaluation of pump room cooling requirements may allow the removal of the dependency of these pumps on pump room cooling.

Classification: Medium, see analysis sheet 6.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event VC

Discussion:

1. Top event VC models the common piping and valves in the discharge of CVCS pumps 1A-A and 1B-B. It includes the normally closed MOVs that isolate the CVCS pumps from the CVCS high pressure injection piping.
2. Guaranteed failure of this top event occurs on loss of power to the MOVs, failure of the actuation signal to the MOVs, failure of the CVCS pumps modeled in VA and VB, or failure of the supply to the CVCS modeled in top event VS.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
VC	0.57949	0.57759 (99.94%)	3.53E-4 (0.06%)	1.0188	1.0002

4. Failure of top event VC is dominated by failure of the CVCS pumps (top events VA and VB) and failure of power to the MOVs.

Enhancements: None
Any enhancement to the CVCS pumps (top events VA and VB) will affect the importance of this top event. Failure is dominated by imposed boundary conditions.

Classification: Low

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Events S1 and S2

Discussion:

1. These top events model trains A and B of the safety injection system.
2. Top events S1 and S2 are guaranteed to be failed if power fails to the SI pumps, the mini-flow valves or the room coolers, or CCS cooling to the seal and oil coolers fail or cooling to the room coolers fail or the actuation signal fails, or the RWST is unavailable.
3. The top event importance factors for these top events are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
S1	0.60103	0.59588 (99.1%)	0.005158 (0.9%)	1.0652	0.99927
S2	0.61579	0.60918 (98.9%)	0.006613 (1.1%)	1.0956	0.99753

Enhancements:

1. The current system analysis assumes that loss of cooling water to the SI pump room coolers, or failure of the coolers will fail the associated pump.
2. Evaluation of pump room cooling requirements may allow the removal of the dependency of these pumps on pump room cooling.

Classification: Medium, see analysis sheet 6.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event SI

Discussion:

1. Top event SI models the injection piping and valves of the safety injection pumps.
2. Top event SI is guaranteed to be failed if top events S1 and S2 fail or if top event RW fails.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
SI	0.57819	0.57777 (99.3%)	4.20E-4 (0.7%)	1.0423	0.99996

4. Failure of this top event is dominated by failures in the high pressure safety injection pumps modeled by top events S1 and S2.

Enhancements: None
Any enhancement to the SI pumps will affect the importance of this top event. Failure is dominated by imposed boundary conditions.

Classification: Low

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Events RA and RB

Discussion:

1. These top events models trains A and B of the RHR system. Included are the pumps, the mini-flow isolation valves, the suction isolation valves, and the piping from the RWST supply to the injection point.
2. Top event RA fails on loss of power to the pump, the mini-flow valve, or the room cooler, loss of cooling to the room cooler, loss of pump seal cooling, or failure of the actuation system. Top event RB fails on loss of power to the pump, the mini-flow valve, or the room cooler, loss of cooling to the room cooler, loss of pump seal cooling, or failure of the actuation system.
3. The top event importance factors for these top events are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
RA	0.67666	0.59588 (88.1%)	0.080787 (11.9%)	5.3020	.92486
RB	0.68950	0.60918 (88.4%)	0.080327 (11.6%)	2.8073	.92618

4. Failure of these top events is dominated by the miniflow isolation valve failure (30%), failure of the RHR pumps to operate (28%), and maintenance on the RHR pumps, fans, or MOVs (25%).

Enhancements:

1. The current system analysis assumes that loss of cooling water to the RHR pump room coolers, or failure of the coolers will fail the RHR pump. In addition, loss of seal cooling is assumed to fail the pump.
2. Evaluation of pump room cooling requirements may allow the removal of the dependency of these pumps on pump room cooling.
3. Failure of the seal cooling system should not affect the operation of the RHR pumps as they are modeled in the IPE. However, removal of the seal cooling requirement from the RHR pumps will not significantly affect core damage as the CCS system is necessary for core decay heat removal.
4. The maximum change in core damage frequency possible based on the risk reduction ratio is

   8.04E-05 * ((1-0.92486) + (1-0.92618))

   or 1.2E-05 per reactor year.

Enhancement Screening Analysis Sheet

5. The data used for the quantification of these top events and the system models were reviewed in the Level I update to the IPE, no further data enhancements are believed possible.

Classification: Medium, see analysis sheet 6.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top events RVA and RVB

Discussion:

1. Top events RVA and RVB model the MOVs associated with switchover from RWST suction to containment sump suction for the ECCS.
2. These top events are guaranteed to be failed on loss of power to the MOVs, or failure of the automatic switchover signal modeled by top event RL.
3. The top event importance factors for these top events are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
RVA	0.30532	0.28320 (92.8%)	0.022117 (7.2%)	2.6251	0.98447
RVB	0.37892	0.35140 (92.7%)	0.027517 (7.3%)	2.6120	0.98201

4. Failure of these top events individually is dominated by loss of power or loss of the associated RHR pump train. Failure of RVA and RVB together is dominated by common cause failure of the MOVs to open.

Enhancements: None

The maximum change in core damage frequency calculated using the risk reduction ratio is:

8.04E-05 * ((1-.98447) + (1-.98201))

or, 2.7E-06 per reactor year. Assuming a reduction in the MOV failure rate of 50%, the maximum change in core damage frequency is 1.34E-06, approximately 1.6% of core damage frequency.

Classification: Low

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event RR

Discussion:

1. Top event RR models the semi-automatic switchover to containment sump recirculation.
2. The switchover starts when the automatic signal, modeled by top event RL, is sent to close the RWST to RHR pump suction valves and open the containment sump to RHR pump suction valves.
3. Operator action is necessary to complete the switchover to high pressure or low pressure recirculation. This operator action is included in top event RR.
4. High pressure recirculation requires the opening of the RHR to SI and CVCS cross-tie MOVs, closing the RHR train cross-tie MOVs, and ensuring that the SI pump and CVCS pump mini-flow isolation valves are closed.
5. The guaranteed failed split fraction is dominated by failure of support systems, including power to the MOVs and failure of the RHR Pump trains.
6. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
RR	0.86341	0.68208 (79.0%)	0.18133 (21%)	87.899	.81872

7. Operator error in the control room contributes approximately 10% and common cause failure of MOVs in parallel paths to open contributes approximately 80% to the top event frequency of failure for the non-guaranteed failure split fractions.
8. Success of this top event would allow some of the current core damage sequences to go to the successful end-state by allowing questions of the high pressure and low pressure recirculation top events.

Enhancements:

1. No operator action to recover failure of MOVs is modeled in the IPE. A change in the containment spray actuation setpoint could allow more time for operator action to locally operate failed MOVs. The change in the setpoint has been previously discussed.
2. The emergency operating procedures guide the operators in the establishment of a flow path for recirculation after a LOCA initiating event, including operation of MOVs locally.

Classification: Medium, see analysis sheet 1.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event LCL

Discussion:

1. Top event LCL models the RCS accumulators for the Large LOCA initiating event.
2. This top event requires three of three accumulators inject into the intact RCS loops. No support system or boundary conditions affect this top event.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
LCL	0.010191		0.0	0.010191 (100%)	3.5405

0.98990

Enhancements: None

1. Failure of this top event is caused by failure of the check valves on the accumulator discharge.
2. Changing the success criteria of the accumulator function would have to be justified by supporting analysis (probably by Westinghouse as this function is a licensing requirement).
3. The benefit from the relaxation of this success criteria is small (1% core damage frequency).

Classification: Low

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event SL

Discussion:

1. Top event SL models the isolation of the secondary side of the steam generator in response to a steam generator tube rupture.
2. The steam generator MSIV, the PORV, steam generator blowdown, feedwater supply and one safety valve are included in this model for this top event.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
SL	0.011017	0.004090 (37.1%)		0.006927 (62.9%)	1.4079

0.99413

4. Failure of this top event is dominated by failure of the safety relief valve to reseat and failure of the PORV to reseat and operator failure to isolate the PORV.

Enhancements:

1. This analysis assumes that one safety valve and one steam generator PORV are challenged as a result of a SGTR. If realistic analysis shows that the PORV can pass the RCS flow from the tube rupture, then the safety valve can be removed from the model. This would reduce the frequency of failure of the top event by 30% and the importance of the event by an equivalent amount.
2. The maximum change possible is determined by using the risk reduction ratio, 8.04E-05 * (1-.99413) or 4.7E-07 per reactor year.

Classification: Low
Core damage frequency change less than 1%.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event RD

Discussion:

1. Top event RD models the operator actions and equipment necessary to establish and maintain normal RHR cooldown. This top event is only questioned for SGTR events if top event SL has failed.
2. This top event is guaranteed to be failed if the RHR pumps fail, no hot leg or cold leg path can be established, or if RCS depressurization fails.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
RD	0.054356	0.051877 (95.4%)	0.002480 (4.6%)	1.2054	0.99752

4. Failure of this top event leads to a requirement for continuous make-up to the RWST.

Enhancements: None
Failure of this top event is dominated by boundary conditions or by failures in support systems. The boundary conditions that affect this top event are DS, DP, PR, SE, and RT, all of which have been previously discussed.

Classification: Low

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event RH

Discussion:

1. Top event RH models the operator actions and equipment necessary to establish hot leg recirculation during Large and Medium LOCA initiating events. The plant emergency procedures require this action to be completed at 15 hours after the initiating event.
2. This top event is guaranteed to be failed if the power is lost to the hot leg isolation MOVs, or if the RHR trains are unavailable (top events RA and RVA and RB and RVB).
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
RH	0.022431	0.007583 (33.8%)	0.014848 (66.2%)	0.98526	0.98526

4. Failure of this top event dominated by failure of the hot leg MOVs to operate.

Enhancements: None

Failure of this top event is dominated by the valve failure rate data used in the quantification process. This data was reviewed during the Level I update. No operator action to operate the MOVs locally is included in the IPE model.

Classification: Low

SUPPORT SYSTEMS
CONTAINMENT FUNCTIONS

NOTE: The importance ratios used in the screening analysis do not evaluate the effects of the containment functions evaluated on the following pages on plant damage state and release after core damage.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Events CSA and CSB

Discussion:

1. These top events models trains A and B of the Containment Spray system in the injection mode.
2. Top event CSA fails on loss of power to the pump, the isolation MOV, or power to the room coolers, loss of cooling to the heat exchanger or room cooler, failure of the room cooler, or loss of CCS to the seal and oil coolers. Top event CSB fails on loss of power to the pump, the isolation MOV, or power to the room coolers, loss of cooling to the heat exchanger or room cooler, failure of the room cooler, or loss of CCS to the seal and oil coolers.
3. The top event importance factors for these top events are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
CSA	0.64817	0.64217 (99.1%)	0.005992 (0.03%)	0.94073	1.0012
CSB	0.66220	0.65684 (99.2%)	0.005361 (0.08%)	0.92656	1.0015

Enhancements:

1. The current system analysis assumes that loss of cooling water to the CS pump room coolers, or failure of the coolers will fail the CS pump.
2. Evaluation of pump room cooling requirements may allow the removal of the dependency of these pumps on pump room cooling.

Classification: Medium, see analysis sheet 6.
The risk achievement and risk reduction ratios indicate an adverse effects on core damage frequency from operation of these pumps. At Watts Bar, any size LOCA is assumed to require operation of the containment spray system which leads to an early demand for recirculation switchover.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event CH

Discussion:

1. This top event models the switch to containment spray recirculation in the long-term cooling mode of the containment. It includes the CS heat exchangers and establishment of cooling water to heat exchangers which requires operator action.
2. The guaranteed failed split fraction is dominated by loss of the containment spray system in the injection mode.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
CH	0.63786	0.63350 (99.3%)	0.004362 (0.07%)	0.98305	0.99953

Enhancements: None
Any enhancement to the containment spray system will reduce the importance of this top event. Failure of this top event is dominated by failure due to boundary conditions.

Classification: Low

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event HH

Discussion:

1. Top event HH models the H2 ignitors at Watts Bar.
2. Top event HH is guaranteed to be failed if power is lost to the ignitor trains, e.g., top events A1L and B1L fail.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
HH	0.20540	0.20420 (99.4%)	0.01145 (0.6%)	0.60169	1.0012

Enhancements: None
Alternate power supplies have been previously identified as a possible enhancement (SAMDA Alternative 6).

Classification: Low
A risk reduction ratio greater than 1 indicates unimportance of this top event in terms of core damage frequency This system affects the assignment of plant damage states.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event AR

Discussion:

1. Top event AR models the containment air return fans. The containment air return fans are required to get the full benefit of the ice contained in the ice condenser at Watts Bar.
2. Top event AR is guaranteed to be failed if trains A and B fail. Train A fails if power is lost (top event A1 or DA) or no actuation signal is received (top event ZA). Train B fails if power is lost (top event B1 or DB) or no actuation signal is received (top event ZB). Operator action to backup the automatic start signal is not included in this top event.
3.. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
AR	0.21725	0.21652 (99.66%)	7.28E-4 (0.04%)	0.39264	1.0009

Enhancements: None
Failure of this system is dominated by support system failures. The risk reduction ratio for this top event indicates its low importance in terms of core damage frequency.

Classification: Low
Consider the addition of operator recovery modeled by top event OS to the RISKMAN quantification rules for this top event.

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event RS

Discussion:

1. Top event RS models containment spray using the RHR pumps and serves as a back-up to the containment spray system.
2. Failure of this top event is guaranteed if recirculation (top event RR) fails, or if either of the two RHR pump trains fail.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
RS	0.010835	0.010611 (97.9%)		2.24E-4 (2.1%)	
0.95430	1.0002				

Enhancements: None
Failure of this top event is dominated by the boundary conditions which guarantee failure of the top event.

Classification: Low

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event OT

Discussion:

1. Top event OT models the operator actions taken to reduce containment spray flow for the small LOCAs represented by an RCP seal LOCA.
2. Operator termination of containment spray is important in determining the time to recirculation switchover. Note, no credit is taken in the current model for this top event (e.g. the time to recirculation is always based on the time to empty the RWST with the spray pumps operating).
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
OT	0.051804	0.051606 (99.62%)		1.97E-4 (0.38%)	
0.85993	1.0002				

4. Failure of this top event is dominated by guaranteed failure imposed by the boundary conditions.

Enhancements: None

1. Failure of this top event is dominated by the imposed boundary conditions.

Classification: Low

Enhancement Screening Analysis Sheet

Source: RISKMAN Results

Description: Top Event CI

Discussion:

1. Top event CI models the containment isolation function for containments penetrations other than the purge lines.
2. This top event is guaranteed to be failed if the actuation signal fails or if power is lost to the letdown isolation valves with off-site power available.
3. The top event importance factors for this top event are:

	Top Imp	GF Frac	Non-GF Imp	Risk Ach.	Risk Red.
CI	0.049852	0.025150 (50.4%)		0.024702 (49.6%)	
0.67815	1.0039				

4. Failure of this top event is dominated by the operator failure likelihood during station black-out conditions and by the failure of necessary support systems.

Enhancements:

1. The operator failure likelihood is based on existing plant procedures and the confusion that would exist during a station black-out condition.
2. Allowing operator recovery for failures in support systems other than station black-out would reduce the likelihood of failure of this top event and its importance.

Classification: Low

Appendix C

WATTS BAR DOSE CONVERSION FACTORS

DETERMINATION OF WBN DOSE CONVERSION FACTORS

In order to assess the value-impact of potential enhancements, it is necessary to estimate the change in population radiation dose resulting from change in plant safety characteristics. However, the Watts Bar (WBN) IPE is only a Level 2 PRA and does not include calculation of offsite effects from severe accidents. It was therefore necessary to develop site-specific dose conversion factors for the WBN site. This was accomplished through a simplified process utilizing the NUREG-1150 results for Sequoyah (SQN). This appendix describes the methodology used to develop WBN-specific dose conversion factors for use in the value impact analysis.

C.1 SOURCE TERM CONSIDERATIONS

NUREG-1150, Section 5.4 discusses the radioactivity source term analysis for SQN. This section identifies plant characteristics that are key attributes for defining accident source terms. For SQN, these characteristics are the ice condenser containment, the reactor cavity configuration, and the containment spray system. SQN and WBN are similar Westinghouse ice condenser units, and the key attributes for defining source terms are essentially identical between the two plants. The other primary design aspect for a commercial light water reactor which influences the source term is the reactor core thermal rating. This rating is approximately 3400 MW for both plants. Based on these aspects, the source terms identified in NUREG-1150 for SQN are directly applicable to WBN.

It should be noted that various source term classifications are identified and used for SQN in NUREG-1150. These classifications, called accident progression bins, customize the source terms for a particular event based on the timing and severity of a postulated core damage event with containment degradation. The timing and probability of a particular sequence is based on the results of the plant-specific PRA. The appropriate NUREG-1150 source term classes for the dominant WBN severe accident events are selected based on the accident sequences identified in the WBN IPE. Table C-1 provides a matrix which translates the Key Release Categories (KRCs) from the WBN IPE to the NUREG-1150 Accident Progression Bins (APBs).

C.2 Applicability of SQN Dose Conversion Factors

The person-rem dose is the product of the radiation dose seen in a given area and the exposed population in that area. A simplified typical formula for calculating offsite dose is provided below and is based on equations in Chapter 15 of the WBN Final Safety Analysis Report (FSAR).

*Dose = (Constant) * (χ/Q) * ((Sum of activity for various isotopes) * (Sum of energy released form the decay of each isotope))*

TABLE C-1

CONVERSION MATRIX FOR IPE KEY RELEASE CATEGORIES (KRCs) TO NUREG-1150 ACCIDENT PROGRESSION BINS (APBs)

WBN IPE KEY RELEASE CATEGORIES	NUREG-1150 ACCIDENT PROGRESSION BINS (APBs)									
	1	2	3	4	5	6	7	8	9[1]	10
R01			●							
R01DI			●							
RO1I			●							
R01IF			●							
R01SI	●									
R01SIF	●									
R01SUI	●									
R01SUIF	●									
R01UI			●							
R01UIF			●							
R02IF			●							
R03				●						
R03I		●								
R03IF		●								
R03SI	●									
R03SIF	●									
R03SUI	●									
R03SUIF	●									
R03UI				●						
R03UIF				●						
R04		●								

WBN IPE KEY RELEASE CATEGORIES	NUREG-1150 ACCIDENT PROGRESSION BINS (APBs)									
	1	2	3	4	5	6	7	8	9[1]	10
R04IF				●						
R04UIF				●						
R05SLI	●									
R05SLIF	●									
R05SLUI	●									
R05SLUIF			●							
R07SLUI	●									
R07SLUIF	●									
R09I					●					
R09UI					●					
R11I					●					
R11IF					●					
R11UI					●					
R17L					●					
R17LU					●					
R17U						●				
R18							●			
R19							●			
R20							●			
R21								●		
R22										●

NOTES:

(1) The frequency of KRCs which would have contributed to this APB was found to be less than 1×10^{-8} per year. Therefore, no KRCs were assigned to this APB.

Based on this equation, the dose is linearly proportional to the atmospheric dispersion factor *(χ/Q)*. The person-rem dose or a person-rem dose conversion factor is linearly proportional to both the atmospheric dispersion factor and the population.

The population and population distributions of the two sites are described in Section 3.1.3 of the respective FSARs (References 5 and 6) of each site. Similar to the risk estimates described in NUREG-0775 and NUREG-0964 (References 7 and 8, respectively), the population within 50 miles of the plant will define the population base of consideration for TVA's evaluation of selected potential plant enhancements. For the purpose of this justification, the population based on the latest census information (circa 1980) from each plant's FSAR will be utilized. The population distribution within 50 miles of each site is as follows in Table C-2 below.

Table C-2

Miles From Site	Population - SQN*	Population - WBN*
0 - 10 (Zone 1)	32,710	12,335
10 - 20 (Zone 2)	320,675	63,445
20 - 30 (Zone 3)	132,795	117,660
30 - 40 (Zone 4)	147,490	144,975
40 - 50 (Zone 5)	102,600	411,040
TOTAL	736,270	749,455

* SQN data taken from Table 2.1.3-8 of the SQN FSAR and WBN data taken from Table 2.1-11 of the WBN FSAR. It should be noted that the 1990 general census population data has been received by TVA; however, the disaggregation by geographical boundaries has not been received. The actual 1990 census general population data is less than the projected 1990 population data in the WBN FSAR Table 2.1-12.

Note that credit for evacuation, relocation, and sheltering for the surrounding population is taken to reduce the dose to the public. The credit allowed in NUREG-1150 was based on several factors such as the magnitude of the population affected and emergency preparedness program of the subject utility. Since the same emergency preparedness program is (or will be) in effect at WBN and SQN and, to a large extent, the same population will be affected, it is appropriate to allow the same credit at both plants. It should be noted that the population density around WBN is significantly lower than SQN in Zones 1 through 3. This is due to the proximity of SQN to the Chattanooga metropolitan area and the relative remoteness of WBN to immediate large population centers.

Atmospheric dispersion factors based on a yearly average as predicted by a MESOPUFF II model (Reference 9) are used to compare the expected dispersion of a release from either WBN or SQN. While these atmospheric dispersion factors have been developed for predicting offsite doses due to routine releases, they provide a logical basis for

comparing the dispersion of a severe accident release from either WBN or SQN. Point estimates of the atmospheric dispersion factor at 5, 15, 25, 35 and 45 miles from each site in the south direction have been selected for evaluating the appropriateness of using the SQN dose conversion factors from NUREG-1150 at WBN. The southern direction was chosen because the major population center within 50 miles of either site is Chattanooga, which is south to south-west of the two sites.

Plots of χ/Q distribution up to 80 Km (50 miles) from each site are provided as Figures C-1 and C-2 for SQN and WBN, respectively. These plots show that the χ/Q distribution around each site is reasonably symmetric and concentric about the site, with a slight bias in the north and south directions due to the Tennessee River and local mountains that have this same orientation.

The point estimate χ/Q values taken from the data used to generate these figures are provided in Table C-3 below.

Table C-3

Miles From Site	SQN χ/Q	WBN χ/Q
5 (Zone 1)	3.6E-07	2.5E-07
15 (Zone 2)	5.4E-08	2.7E-08
25 (Zone 3)	1.6E-08	9.4E-09
35 (Zone 4)	6.4E-09	4.6E-09
45 (Zone 5)	3.5E-09	3.2E-09

The sum of the product of each population zone and its corresponding χ/Q value provides a basis for comparing the dose conversion factors that would be appropriate for each site. This comparison is shown in Table C-4 below.

Table C-4

Zone	SQN Pop. *χ/Q	WBN Pop. *χ/Q
1	1.2E-02	3.1E-03
2	1.7E-02	1.7E-03
3	2.1E-03	1.1E-03
4	9.4E-04	6.7E-04
5	3.6E-04	1.3E-03
SUM	3.2E-02	7.9E-03

Comparing the sums of the two columns in Table C-4, it can be seen that the value for SQN is approximately a factor of 4 greater than WBN. This factor (0.247) is applied to the SQN dose dose conversion factors to provide offsite dose estimates for WBN in this analysis.

C.3 Calculation of WBN Dose Conversion Factors

The dose conversion factors which will be used for evaluating candidate WBN potential plant enhancements are based on the 50-mile population doses calculated for the Summary Accident Progression Bins (APBs) in NUREG-1150. The characteristics that are used to define an APB are based on the primary accident progression attributes that influence a source term, e.g., the timing and failure mode of the reactor pressure vessel and containment. The manipulation of the data contained in NUREG-1150 and NUREG/CR-4551 (Reference 10) into a format that can be readily applied at WBN is shown in Table C-5 and is explained below.

Columns 1 and 2 of Table C-5 identifies the Summary APB Categories identified in NUREG/CR-4551.

The NUREG-1150 risk assessment for SQN produced a distribution of values for the population doses at 50-miles, and the mean population dose risk calculated for SQN in NUREG/CR-4551 is 12 person-rem per reactor-year. From this mean dose risk, dose risk associated with each APB can be estimated. The data used to calculate the APB specific doses are shown in Columns 3 through 5 of Table C-4.

Column 3 shows the percentage of the mean dose associated with each APB category. These percentages are based on the Fractional Contribution to Mean Risk (FCMR) methodology as defined in NUREG/CR-4551. The FCMR methodology is a statistical technique to determine the average result over the entire distribution of results. Column 4 shows the dose risk frequency determined by applying the Column 3 percentages to the dose of 12 person-rem per reactor-year. Column 5 provides an estimate of the distribution of the SQN-specific event frequencies for each summary APB category. Dividing the dose risk frequencies shown in Column 4 by the event frequencies in Column 5, a frequency independent dose associated with a given APB category can be produced. This frequency independent dose is a representative estimate of the dose that would result from a representative release of a given APB for any plant that has meteorology, a population density, an emergency preparedness plan, etc., similar to SQN. These doses are shown in Column 6. The population dose for each APB at WBN can be estimated by multiplying the dose shown in Column 6 by the WBN by the (0.247) dose correction factor for WBN population *(χ/Q) characteristics described in Table C-3. The resulting population doses are shown in Column 7. The values shown in Column 7 provide the baseline dose that is used to screen candidate potential plant enhancements.

Table C-4

SUMMARY OF ACCIDENT PROGRESSION BINS (APB) AND 50-MILE POPULATION DOSES

APB ID No. (1)	Summary APB Category (2)	SQN NUREG/CR-4551 Population Dose Percentage - FCMR (3)	SQN NUREG/CR-4551 Mean Population Dose of Summary APBs (person-rem/rx-yr) (4)	SQN NUREG/CR-4551 Mean Probability Estimates of Summary APBs (/rx-yr) (5)	Representative SQN Population Dose (person-rem) (6)	Representative WBN Population Dose (person-rem) (7)
1	VB, early CF (during CD)	3.7	0.44	2.79E-7	1.58E+6	3.90E+5
2	VB, alpha, early CF (at VB)	0.7	8.42-2	1.12E-7	7.50E+5	1.85E+5
3	VB > 200 psi, early CF (at VB)	21.0	2.52	1.95E-6	1.29E+6	3.18E+5
4	VB < 200 psi, early CF (at VB)	14.7	1.76	1.28E-6	1.38E+6	3.41E+5
5	VB, late CF	4.9	0.59	2.12E-6	2.78E+5	6.86E+4
6	VB, BMT, very late CF	6.9	0.83	9.54E-6	8.68E+4	2.14E+4
7	Bypass	42.9	5.15	3.12E-6	1.65E+6	4.07E+5
8	VB, No CF	0.1	1.2-2	1.50E-5	8.00E+2	1.98E+2
9	No VB, early CF (during CD)	5.0	0.6	6.14E-7	9.77E+5	2.41E+5
10	No VB	0.1	1.2-2	2.07E-5	5.80E+2	1.43E+2

Notes:
(1),(2) Summary APB Categories taken directly from NUREG/CR-4551.
(3) Values taken from Table 5.1-3 of Reference 10.
(4) Product of the mean 50-mile population dose shown in Table 5.1-1 of Reference 10, i.e., 12 person-rem per reactor-year, and the percentages in Column 3.
(5) Values calculated by multiplying the weighted average contribution of the APBs (shown in Figure 2.5-3 of Reference 10, with the SQN mean core damage frequency of 5.58E-05).
(6) Calculated by dividing Column 4 by Column 5.
(7) Calculated by multiplying Column 6 by the dose correction factor for WBN (0.247).

Figure C-1

Sequoyah Nuclear Plant Chi/Qs (in 10^{-9} s/m^3)
MESOPUFF2 run started at year 88, day 1, hour 0 and continued for 8784 hours
Based on 2 puffs per hour with minimum sampling rate of 2 per hour

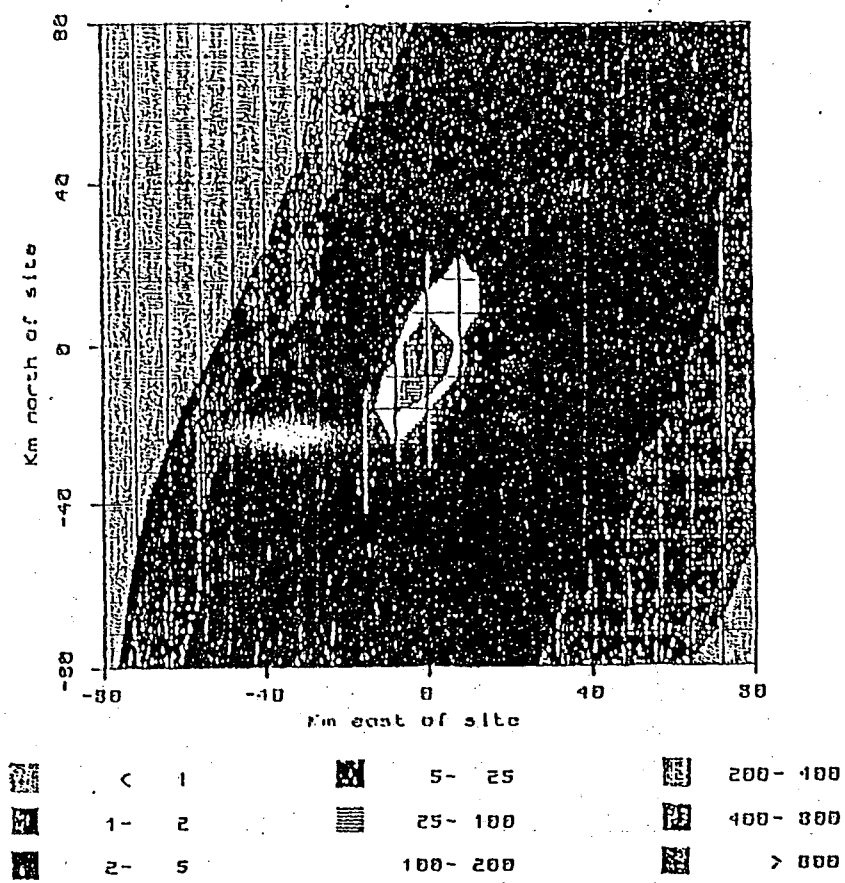

Figure C-2

Watts Bar Nuclear Plant Chi/Qs (in 10^{-9} s/m^3)
MESOPUFF2 run started at year 78, day 1, hour 1 and continued for 8759 hours
Based on 2 puffs per hour with minimum sampling rate of 2 per hour