Docket Nos. 50-269, 50-270
and 50-287

Mr. J. W. Hampton
Vice President, Oconee Site
Duke Power Company
P. O. Box 1439
Seneca, South Carolina 29679

Dear Mr. Hampton:

SUBJECT: PRELIMINARY ACCIDENT SEQUENCE PRECURSOR (ASP) ANALYSIS OF THE OCONEE LOSS OF POWER EVENT

Enclosed for your information is a preliminary ASP evaluation of the Oconee Unit 2 Loss of Offsite Power (LOOP) event which occurred October 19, 1992. Your input on this analysis would be appreciated, particularly regarding the characterization of the plant equipment status and the analysis assumptions. A copy of the final ASP evaluation will be sent to you after issuance.

If you have questions regarding this matter, contact me at (301) 504-1495.

Sincerely,

Leonard A. Wiens, Project Manager
Project Directorate II-3
Division of Reactor Projects-I/II
Office of Nuclear Reactor Regulation

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ASP Evaluation

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

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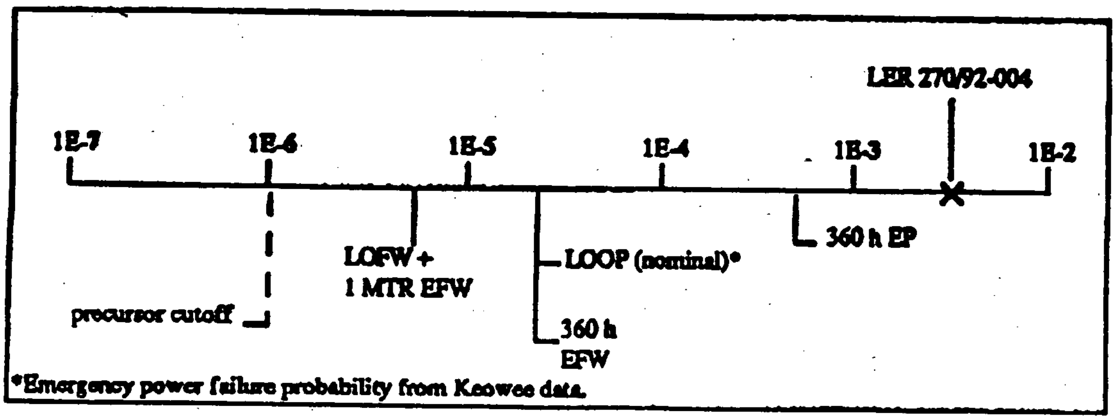
ACCIDENT SEQUENCE PRECURSOR PROGRAM EVENT ANALYSIS

LER No.:	270/92-004
Event Description:	Loss of offsite power with failed emergency power
Date:	October 19, 1992
Plant:	Oconee 2

Summary

Use of a poorly designed switchyard battery replacement procedure resulted in a lockout of the Oconee 230-kV switchyard, a reactor trip and loss of offsite power (LOOP) at Unit 2, and unavailability of power to the startup transformers for Units 1 and 3. An operator error at the Keowee hydro station, the emergency power source for the three Oconee units, caused a loss of all auxiliary power to both hydro units. Auxiliary power was recovered one-half hour later, when an on-call technician arrived at Keowee. If auxiliary power had not been quickly recovered, governor and wicket gate control for the hydro units would have been lost. Problems were also experienced with the emergency feedwater (EFW) system because of water in the turbine-driven pump steam line, instrument air (IA) (which could have resulted in a trip with LOOP on Oconee 1 and 3), the standby shutdown facility (SSF), and numerous unexpected electric power system responses during recovery from the event. The emergency power system, turbine-driven EFW pump, and SSF are the primary features available to protect against core damage due to station blackout following a LOOP.

The conditional core damage probability estimated for this event is 3.0×10^{-3}. The relative significance of this event compared to other postulated events at Oconee is shown below.



LOOP (nominal) = 2.2E-5
LOFW + 1 MTR EFW = 5.3E-6
360 h EFW = 2.2E-5
360 h EP = 5.0E-4

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Event Description

On October 19, 1992, Oconee 2 was operating at 100% power. Keowee Hydro Unit 1 (Keowee 1), one of the emergency power sources for the three Oconee units, was supplying power to the grid via the overhead power path (see Fig. 1). Keowee 2 was shutdown and was aligned to provide emergency power via the underground path. Replacement of the 230-kV switchyard batteries was in progress — battery SY-2 and charger SY-2 were disconnected, switchyard DC buses SY-DC-1 and SY-DC-2 were cross-tied, and charger SY-1 and battery SY-1 were powering both buses (see Fig. 2).

A point had been reached during the battery replacement when charger SY-2 was to be reconnected to its bus and the two buses separated. This alignment was allowed by the battery replacement procedure. Once this was done, bus SY-DC-2 would be powered only by its charger. Battery SY-2, which was normally connected to the bus, would remain unconnected. This highly unusual alignment (which can subject a bus to large voltage fluctuations because of battery charger instability) had been used between October 6-12, 1992, when battery SY-1 was replaced, without any complications. The Oconee 1 Unit Supervisor went to the switchyard relay house with several technicians to perform the procedure steps to reconnect the charger and separate the DC buses. He connected the charger to the bus and then, at 2121 hours, opened the tie breaker to separate the two switchyard DC buses. Within the next several seconds a switchyard lockout, Oconee 2 trip, Keowee 1 normal trip, and emergency start of both Keowee units occurred. The Unit Supervisor suspected that his actions had initiated the event, and "backed out" of the procedure by reclosing the switchyard DC bus tie breakers and opening the breaker from the SY-2 charger.

The 230-kV switchyard lockout was a result of a voltage transient on switchyard DC bus SY-DC-2 caused by charger SY-2. Bus SY-DC-2 powered the breaker failure circuits for all of the 230-kV switchyard breakers. Breaker failure circuitry is designed to actuate an AR relay and trip adjacent breakers after a time delay if a faulted breaker fails to trip. The breaker failure circuitry employed a zener diode as a surge protector in a design which caused current to flow through the breaker AR relay coil when the zener diode conducted (performed its protective function). The relays had been identified as susceptible to spurious operation due to excessive voltages in 1980, but were never modified. The AR relay for power circuit breaker (PCB)-24 was the first to actuate on the Yellow 230-kV Bus. This relay tripped PCB-23 and initiated a Yellow Bus lockout, which tripped PCBs-9, 12, 15, 18, 21, 24, 27, and 30. A lockout also occurred on the Red Bus, and tripped PCBs-4, 7, 10, 13, 16, 19, 22, 26, and 28. PCBs-31 and 33 were tagged open to support maintenance and did not trip. All of the PCBs are shown in Fig. 1.

Actuation of the AR relay in PCB-24 also caused an Oconee 2 generator transformer lockout, which resulted in a turbine and reactor trip. With PCBs-26 and 27 open and the reactor tripped, Oconee 2 had no source of offsite power available. The External Grid Protective System sensed the loss of voltage and frequency on the Yellow and Red Buses [which indicated a LOOP] and generated a Switchyard Isolation signal. This signal tripped PCBs-8, 9 and 17, loadshed Keowee 1, and gave an emergency start signal to both Keowee units. Oconee 1 and 3 continued to operate.

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but with PCBs-17 and 26 open, neither unit would have had a source of offsite power if it had tripped. (This almost happened on Unit 1, as described later.)

Keowee 2 emergency started on the Switchyard Isolation signal. Non-essential Oconee 2 loads were shed and Oconee 2 main feeder buses were reenergized via transformer CT-4. This provided power to essential loads via the underground power path.

The Keowee operator was in the turbine room when the event began. When he returned to the Keowee control room he observed multiple alarms but failed to observe an alarm indicating that an emergency start signal existed. He noted that Keowee 1 was operating with no load, concluded that the hydro unit might be in danger of failing, and manually tripped output breaker ACB-1 (see Fig. 3). With ACB-1 tripped, the Keowee auxiliary buses 1X and 2X attempted to transfer to their alternate power source, transformer CX (which is powered from Oconee 1 switchgear 1TC-4). A bus lockout was received on auxiliary bus 1X (apparently caused by rapid and repeated breaker operations during the event as a result of dirty and misaligned time-delay relay contacts), which prevented ACB-7 from closing. Bus 1X remained deenergized. ACB-8 failed to close (because of a high resistance on a close permissive contact) and auxiliary bus 2X remained deenergized as well. Loss of these two buses resulted in loss of all auxiliary power to the Keowee units. The Keowee control room lights went off, the annunciator panels went dark, and the telephone connection to Oconee and the alarm typer were lost (the computer remained operable). A Keowee main transformer lockout also occurred, which prevented reclosure of ACB-1. At this point, the Keowee operator realized Keowee 2 was starting and that an emergency start had occurred. The Keowee units continued to operate with their control functions supplied by batteries.

Unavailability of Keowee auxiliary power prevented makeup to the hydraulic oil accumulator tanks. These accumulators provide the oil to operate the governor and wicket gates to control turbine speed and generator output. Keowee can operate up to about one hour, depending upon load changes, without auxiliary power before governor and wicket gate control becomes unavailable.

The Oconee 2 turbine-driven EFW pump started automatically following the LOOP and reactor trip. Within a few seconds, EFW flow dropped to zero for 3-5 sec, and then returned to normal. The loss of flow was the result of water in the auxiliary steam supply line to the turbine-driven EFW pump turbine caused by a faulty steam trap. As the turbine-driven pump picked up flow again, power was restored (Keowee 2 start and load) and both motor-driven EFW pumps started as well.

About one min after the LOOP, alarms were received on Oconee 1 and Oconee 2 indicating low pressure in the IA system. The Oconee primary IA compressor is powered from the switchyard and lost power when the Red Bus lockout occurred. The backup IA compressor powered from Unit 2 was load-shed and could not automatically start. While two other backup IA compressors (powered from Oconee 1) did start, they were unable to maintain IA pressure. A diesel-powered IA compressor was locally started at Oconee 3 and a loss of IA was averted. A loss of IA would

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N? B/4 can restore manually

have caused a loss of main feedwater control and loss of control rod drive mechanism cooling at Oconee 1 and resulted in a reactor trip at that unit. If that had occurred, offsite power would not have been available to Unit 1, either.

Several minutes after the loss of auxiliary power at Keowee, the Keowee operator contacted the Duke System Dispatcher in Charlotte via a dedicated phone line, which was still in service. The dispatcher was requested to call the Keowee on-call technician to come to the site. The dispatcher was also able to connect the Oconee control room to Keowee via the dispatcher phone line. The Keowee operator discussed the status of Keowee with the Oconee 2 Unit Supervisor (it appears that the Keowee operator did not adequately describe the ramifications of the loss of auxiliary power), and the Unit Supervisor instructed him not to take any action involving Keowee 2, since it was supplying the Oconee 2 main feeder buses. The Keowee operator then monitored the operation of the hydro units and awaited the arrival of the on-call technician. Meanwhile, because of problems at Keowee, the Oconee Operations Shift Supervisor and the dispatcher decided to try to quickly restore the switchyard. The dispatcher had confirmed that there was no indication of faults or breaker actuations outside the switchyard, and it was decided to skip the lengthy checkout of equipment required by the Loss of Power Abnormal Procedure.

The on-call technician arrived in the Keowee control room at 2150 hours, about 30 min after the event started. The most immediate problem was the restoration of auxiliary power so that hydraulic oil for wicket gate and governor control could be made up to the accumulators. The normal oil level in the accumulator sight-glass is 48 in; when the on-call technician arrived, the level in both accumulators was 4-8 in.

Using the Charlotte dispatcher's phone, the Keowee on-call technician, the dispatcher and the Oconee 2 Unit Supervisor decided to attempt to reset the Keowee main transformer lockout and also have personnel at the Lee Steam Station start a combustion turbine and establish a dedicated line from Lee to Oconee.* The Keowee on-call technician reset the transformer lockout at 2158 hours. This allowed ACB-1 to close automatically which, in turn, allowed Keowee 1 (which had been running with no load) to energize the transformer. The normal supply breaker to the Keowee 2X load center (ACB-6) then closed, restoring auxiliary power to Keowee 2. Auxiliary power to Keowee 1 was restored 8 min later, after resetting a local lockout at breaker ACB-7.

At 2200 hours, the Oconee 1 Unit Supervisor reset the Red and Yellow Bus lockouts from the switchyard. The Red Bus was reenergized from offsite power at 2213 h by closing PCB-10. By 2218 hours, power had been restored to the Unit 2 startup transformer from the Red Bus. Some difficulty was experienced with breaker operation because of the existing Switchyard Isolation signal, which had not been cleared. At 2221 hours, a dedicated line was available from a Lee combustion turbine.

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* Both the dispatcher and the Unit Supervisor were aware of problems at Keowee 20 min earlier, during their first telephone call.

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One result of the breaker operation associated with not clearing the Switchyard Isolation signal was the repowering of the Yellow Bus from Keowee 1. Because Keowee 1 was not synchronized to the grid, a decision was made to shut down Keowee 1 and repower the Yellow Bus from the Red Bus prior to restoring power to the Oconee 1 and Oconee 3 startup transformers.

The single emergency start signal to both Keowee units was reset and Keowee 1 was shut down at 2251 hours. The Yellow Bus deenergized as expected, but Keowee 2 tripped also. The Keowee 2 trip was caused by the undervoltage condition on the Yellow Bus combined with the lack of an emergency start signal; logic determined that Keowee 2 was generating to the grid with no output and tripped the unit. The logic did not consider that Keowee may be supplying power via the underground feeder. The Keowee 2 trip deenergized the underground feeder, the standby buses, and the Oconee 2 main feeder buses. After a 31 sec time delay, the standby breakers tripped open and the startup breakers closed to restore power to the main feeder buses.

The deenergization of the main feeder buses generated a second Keowee emergency start signal. Keowee 1 started, but did not close into the Yellow Bus because a Switchyard Isolation Initiation signal was not generated — the Red Bus was still powered. This response was expected.

Keowee 2 did not respond as expected. After the trip, it began to slow down. The emergency start signal initiated a restart prior to resetting a speed switch in the field breaker anti-pump circuit. The speed switch and anti-pump circuit prevented the field from energizing and, therefore, kept the generator from functioning.

At 0018 hours the next morning, both Keowee units were shut down. By 0024 hours, Keowee 2 had slowed down enough to reset the speed switch in the field flashing circuit, and had been restarted and realigned to transformer CT-4. At 0041 hours, PCB-8 was closed and the Yellow Bus was reenergized from the Red Bus. The switchyard was restored to its normal alignment by 0057 hours, which also restored power to the startup transformers for Oconee 1 and 3.

It was subsequently determined that the Oconee SSF was degraded as a result of the event. SSF systems provide a backup supply of water to the steam generators and a backup source or reactor coolant pump (RCP) seal injection and reactor coolant makeup sufficient to maintain natural circulation cooling. Normal power to the SSF is fed from Oconee 2 and was lost following the LOOP. The SSF diesel generator was apparently not started to power SSF loads. This deenergized the battery charger in the SSF and resulted in DC and 120 VAC loads being powered from the SSF battery. The potential problems with the SSF were discovered at 0125 hours, 4 h after the event began. Power was restored to the SSF at 0415 hours. The condition of the SSF DC and 120 VAC electrical systems was not described. The utility stated that a spare battery was included in the SSF DC power system and could have been aligned if required.

Numerous equipment inspections, necessary repairs, and procedure modifications took place after the event. A Keowee abnormal procedure was developed to specify operator response following an emergency start. Before this event, no specific procedure existed for verifying or responding to an emergency start of the Keowee units. The Keowee Hydro Station organization was realigned to

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report to the Nuclear Generation Department after the event; it had previously reported to the Hydro Department. In addition, an Oconee operator was assigned to Keowee to stress watchstanding.

A dedicated phone was installed between the Keowee and Oconee control rooms. Previously, a commercial phone line had been used. Protective logic was revised so that the Keowee units would no longer trip due to undervoltage on the main step-up transformer. A special test was performed to confirm (1) the proper response of Keowee hydro to a simulated switchyard isolation signal when aligned to the grid and (2) the implementation of an Oconee "live" bus transfer procedure to repower loads from the switchyard. Generally, the Keowee units performed as expected during the test. The Oconee operators had difficulty controlling Keowee 1 while initially tying it to the grid and while paralleling the overhead path to the grid during system restoration after the test, which resulted in Keowee 1 and 2 tripping. In addition, the Keowee operator was unfamiliar with the response required to several annunciators which alarmed during the test.

Additional Event-Related Information

All three Oconee units have the same generating capacity (850-MWE net) and similar AC power systems (See Fig. 1). Output from the Oconee 1 and 2 generators feed power to the 230-kV switchyard via step-up transformers T1 and T2. The output of Oconee 3 generator feeds the 525-kV switchyard via step-up transformer T3.

The 230-kV and the 525-kV switchyards are divided into two buses designated as the Red Bus and the Yellow Bus. The switchyards are normally operated with both buses energized through a breaker-and-one-half scheme to the grid. The Yellow Bus in the 230-kV switchyard is identified as safety-related. The Keowee hydro station supplies power to the switchyard via an above ground (overhead) path. The overhead path is used to supply power to the Yellow Bus if the grid is lost.

The operating Oconee units normally provide power to their own auxiliary loads through auxiliary transformers 1T, 2T, and 3T. When a unit's generator is unavailable, such as following a reactor trip or during outages, electrical power is automatically supplied from the switchyard through its respective startup transformer CT-1, CT-2, or CT-3. Though Oconee 3 feeds the 525-kV switchyard, the source of power for its startup transformer is through the 230-kV switchyard.

The auxiliary power system for each Oconee unit is designed as a dual-train cascading bus system. There are two 4160 V main feeder buses, MFB1 and MFB2, with each supplying power to three 4160 V load buses TC, TD, and TE. Except for the RCPs, all AC is fed from these three buses. The power to MFB1 and MFB2 is supplied by either the unit's auxiliary transformer through the "N" breakers or the startup transformer through the "E" breakers. In addition, MFB1 and MFB2 for each Oconee unit can be energized from the two standby buses (SB1 and SB2), through the "S" breakers. SB1 and SB2 are common to all three Oconee units and can be energized automatically through transformer CT-4, or manually from CT-5. Transformer CT-5 can be supplied from the Lee steam station through a dedicated line or from the Central substation.

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The Keowee Hydro Station is located approximately three-fourths of a mile east-northeast of the Oconee Nuclear Station. It consists of two hydroelectric generators rated at 87,500 kVA each, which generate at 13.8 kV. The two Keowee hydro units serve the dual functions of generating commercial power to the Duke Power system grid through the Oconee 230-kV switchyard and providing emergency power to the Oconee Station. When a Keowee unit is generating to the grid and an emergency start occurs, it is separated from the 230-kV switchyard and continues to run in standby until needed.

Upon loss of power from an Oconee generating unit and 230-kV switchyard, power is supplied from both Keowee units through two separate and independent paths. One path is a 4000 ft underground 13.8-kV cable feeder to transformer CT-4 which supplies power to the 4160 V standby buses though breakers SK1 and SK2. The underground power path is connected at all times to one hydro unit on a predetermined basis by having either ACB-3 or ACB-4 locked closed. The underground power path and associated transformer are sized to carry full engineered safeguards auxiliaries of one Oconee unit plus auxiliaries for safe shutdown of the other two units. If a Keowee unit is to provide power to an Oconee unit through the underground power path, due to the limited capacity of CT-4, loadshed of non-essential loads from the Oconee units MFBs occurs. The second path from Keowee is a 230-kV transmission line through ACB-1 or ACB-2, via the Yellow Bus, to each Oconee unit's startup transformer.

Keowee auxiliary power (buses 1X and 2X) is required for the AC hydraulic oil pumps, along with other loads. These pumps are used to pressurize the air pre-loaded accumulators that provide hydraulic oil pressure to the governor which controls the position (depending on load) of the wicket gates on the Keowee water turbine. The length of time that the Keowee units can run without AC auxiliaries is limited by the changing load for which the governor must respond. The utility has indicated in several LERs that one hour is the expected maximum time period of Keowee operation without AC auxiliaries.

The normal Keowee configuration at the time of the event had either Keowee 1 or 2 available for generation to the grid using the overhead path (via ACB-1 for Keowee 1 or ACB-2 for Keowee 2). One unit was also aligned to supply the underground path with emergency power (either ACB-3 or ACB-4 closed). The design of the Keowee control circuitry was to provide emergency power to the underground power path from one unit for all emergency start situations while providing power to the overhead path from the other unit only if offsite power was lost.

The Keowee auxiliary buses normally were powered from the overhead path through their respective 1X and 2X transformers, the Keowee main step-up transformer, and the 230 kV switchyard. Normal power was supplied to the 1X bus through ACB-5 and to the 2X bus through ACB-6. These two load centers also had an alternate power source from the CX transformer that receives power from Oconee 1 load center 1TC. Alternate power from the CX transformer for the 1X bus was provided via ACB-7 and alternate power for the 2X bus was provided via ACB-8. An automatic transfer scheme would quickly switch these buses to their alternate power supply on loss of normal power. The transfer scheme was designed to be normal

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seeking so if normal power was restored for about 10 sec, the bus would switch back to the normal supply.

ASP Modeling Assumptions and Approach

The event has been modeled as a LOOP at Oconee 2 with failed emergency power and (slightly) degraded emergency feedwater, and as a potential LOOP at Oconee 1 with failed emergency power if that unit had tripped. Unit 3 appears to have been unaffected by the degraded instrument air system, and was not addressed in the analysis.

Recovery of Offsite Power. The LOOP was plant-centered. The probability of non-recovery was estimated as described in ORNL/NRC/LTR-89/11, *Revised LOOP Recovery and PWR Seal LOCA Models*, August 1989. For sequences involving the postulated failure of emergency power, long-term recovery of AC power also considered the potential use of the Lee combustion turbines ($p_{non\text{-}recovery} = 0.12$) and, in some cases, recovery of the Keowee hydro units, as described below. The potential use of the degraded SSF was not considered in the analysis.

Potential Unit 1 Trip. Unit 1 would have tripped if instrument air pressure had not been restored. Oconee's procedure for loss of IA stipulates the starting of a diesel-driven air compressor on low instrument air pressure, and that was done from Oconee 3 (unaffected by the LOOP) during this event. A probability of 0.1 was assumed for failure to restore instrument air pressure prior to a Unit 1 reactor trip. If Unit 1 had tripped, it would also have required emergency power from the Keowee hydro units.

Degraded Turbine-Driven EFW. Flow from the Oconee 2 turbine-driven EFW pump dropped to zero for 3 - 5 sec shortly after the pump started. The utility stated that this was caused by water accumulation in the auxiliary steam line to the pump turbine, the result of a faulty steam trap. While the pump remained operable during this event, greater amounts of water could have caused the pump to trip. The failure probability for the turbine-driven EFW pump in the ASP model for Oconee 2 was increased from 0.05 to 0.1 to reflect this.

Recovery of Keowee Hydro. Although Keowee hydro continued to supply power to Unit 2 after auxiliary power was lost, it was assumed in this analysis that the operable Keowee generator would have failed once the supply of hydraulic oil in the accumulator tanks, used for wicket gate positioning, was consumed. When the Keowee on-call technician arrived, he was able to quickly reset the locked-out and tripped breakers and restore auxiliary power. However, hydraulic oil was almost depleted at the time he arrived. Because of this, the probability of failing to recover auxiliary power to Keowee prior to loss of hydraulic control oil was assumed to be 0.5. Given auxiliary power was not recovered before hydraulic oil was depleted, Keowee hydro was assumed to be failed, but potentially recoverable in the long term ($p_{non\text{-}recovery} = 0.34$) provided a source of auxiliary power existed. This source was from Oconee 1 via the CX transformer. Therefore, if Oconee 1 tripped and auxiliary power was not recovered prior to loss of hydraulic oil, the failure of Keowee was assumed to be non-recoverable.

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Based on the above assumptions, the conditional core damage probability for the event was estimated through a set of calculations as follows:

Case 1. LOOP at Oconee 2. Trip and LOOP at Oconee 1 prevented ($p = 0.9$). Probability of not recovering offsite power in the short term = 0.15 (from ORNL/NRC/LTR-89/11). Probability of turbine-driven EFW pump failure = 0.1. Probability of not recovering AC power in the long term = 0.072 (from ORNL/NRC/LTR-89/11 with loss of emergency power at ~30 min) x 0.12 (failure to provide power from Lee combustion turbines) x 0.34 (failure to recover Keowee hydro after loss of hydraulic oil given auxiliary power available from Oconee 1) = 2.9×10^{-3}.

Case 2. LOOP at Oconee 2. Trip and LOOP at Oconee 1 ($p = 0.1$). Probability of not recovering offsite power in the short term = 0.15. Probability of turbine-driven EFW pump failure (Oconee 2 only) = 0.1. Probability of not recovering AC power in the long term = 0.072 (from ORNL/NRC/LTR-89/11 with loss of emergency power at ~30 min) x 0.12 (failure to provide power from Lee combustion turbines) x 1.0 (failure to recover Keowee hydro after loss of hydraulic oil given auxiliary power not available from Oconee 1) = 8.6×10^{-3}.

The results of sensitivity analyses, which considered a greater likelihood of recovering AC power, the potential for continued Keowee operation, a range of likelihoods for trip of Oconee 1 and 3, and nominal operation of the EFW system, are described in the next section.

Analysis Results

The conditional core damage probability estimated for the event is 3.0×10^{-3} [$0.9 \times 2.8 \times 10^{-3}$ (case 1) + $0.1 \times 3.2 \times 10^{-3}$ (case 2, Oconee 2) + $0.1 \times 2.0 \times 10^{-3}$ (case 2, Oconee 1)]. The dominant core damage sequence, highlighted on the following event tree, involves a LOOP on Oconee 2 only with failure to recover emergency power and failure of the degraded turbine-driven EFW pump.

The conditional probability estimate is strongly influenced by assumptions concerning the impending failure of Keowee upon loss of hydraulic oil, the potential for recovery of Keowee once hydraulic oil is lost, and the availability of the Lee combustion turbines as an alternate source of AC power.

Five sensitivity analyses were performed to determine the impact of selected analysis assumptions on the core damage probability estimated for the event. The assumptions and resulting probability estimates follow.

Assumption	Conditional Probability	Impact (factor)
Probability of failing to provide power from the Lee combustion turbines or the Central Switchyard = 0.04 (instead of 0.12)	2.9×10^{-3}	0.97

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Keowee successfully operates for one hour (instead of one-half hour). A probability of non-recovery of 0.125 was estimated, based on an assumed exponential non-recovery distribution with p = 0.5 at 30 min and a minimum on-site arrival time of 15 min.	7.7×10^{-4}	0.26
Keowee 2 operates successfully with hydraulic oil accumulator tanks empty. The utility contended that this would occur as long as there was no significant change in generating load, and provided a float valve in the bottom of the accumulator tank closed [the base analysis assumed Keowee would fail once hydraulic oil was depleted (~ one-half hour)].	1.5×10^{-5}	0.005
Probability of failing to recover IA pressure before Oconee 1 trip = 0.34 (instead of 0.1)	3.6×10^{-3}	1.2
Probability of failing to recover IA pressure before Oconee 1 trip = 0.04 (instead of 0.1)	2.9×10^{-3}	0.97
Probability of failing to recover IA pressure before Oconee 1 and Oconee 3 trip = 0.1 (instead of Oconee 1 only)	3.2×10^{-3}	1.1
No impact on pump reliability from water in turbine-driven EFW pump steam line (instead of doubling pump failure probability)	1.8×10^{-3}	0.60

As can be seen from the above cases, different assumptions concerning the likelihood of recovering AC power in the long term and the likelihood of a reactor trip from loss of IA have little impact on the conditional probability estimated for the event. Assuming Keowee could operate for up to an hour without auxiliary power reduces the conditional probability by a factor of four - this is to be expected, considering the dominant sequence. Assuming that the water in the EFW pump steam line had no impact on pump reliability reduces the estimated conditional probability by 40 percent - this is also to be expected, considering the dominant core damage sequence.

A LOOP caused by a similar actuation of breaker failure relays by DC voltage surges occurred at Vermont Yankee on April 23, 1991, during replacement of switchyard batteries (see *Precursors to Potential Severe Core Damage Accidents: 1991, A Status Report*, NUREG/CR-4674, Vol. 16). The LER reporting the Oconee LOOP noted that the Vermont Yankee event had been evaluated by the Duke Power Operating Experience Program (OEP). That evaluation had concluded that the relay models involved, while similar, were not exactly the same and that the zener diode involved did not exist in the equivalent circuit at Oconee. As a result, the OEP review of the Vermont

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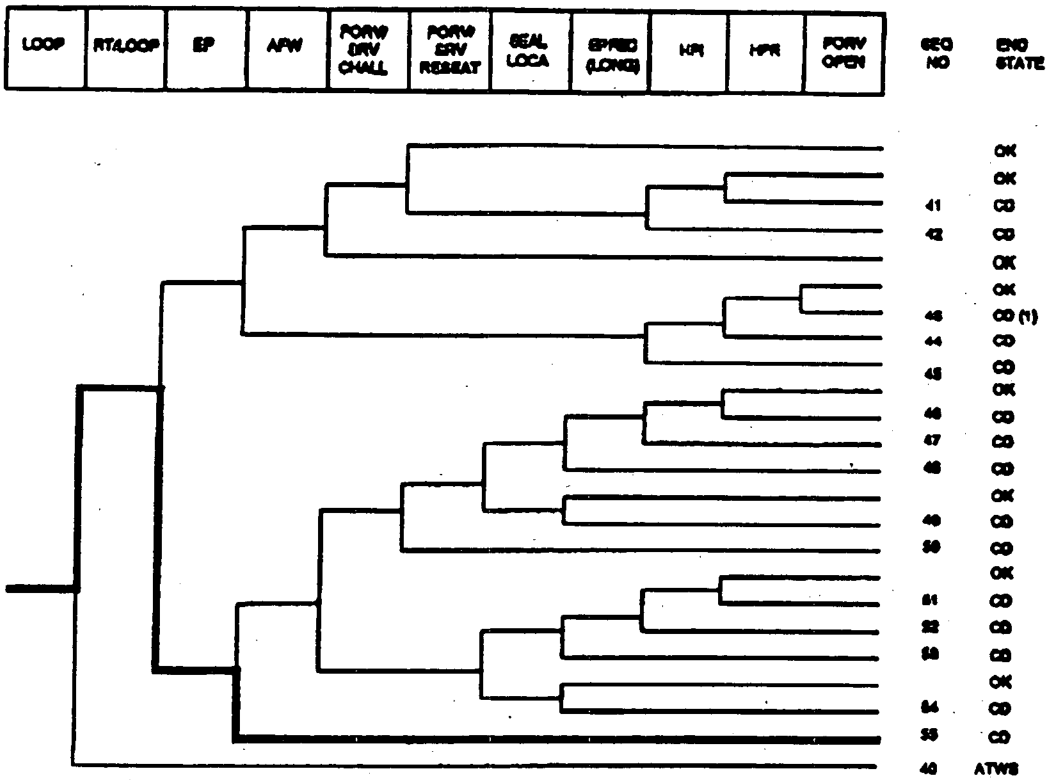
Yankee event concluded that the equivalent portion of the same circuit at Oconee would not fail in the same way. The OEP review did not discover that a different circuit was subject to the same failure mode.

Additional information concerning this event and the post-event Keowee special test is included in NRC Inspection Report Nos. 50-269/92-26, 50-270/92-26, and 50-287/92-26.

PRELIMINARY



(1) OK for Class D

Dominant Core Damage Sequence for LER 270/92-004

PRELIMINARY

230KV SWITCHYARD DC POWER DISTRIBUTION

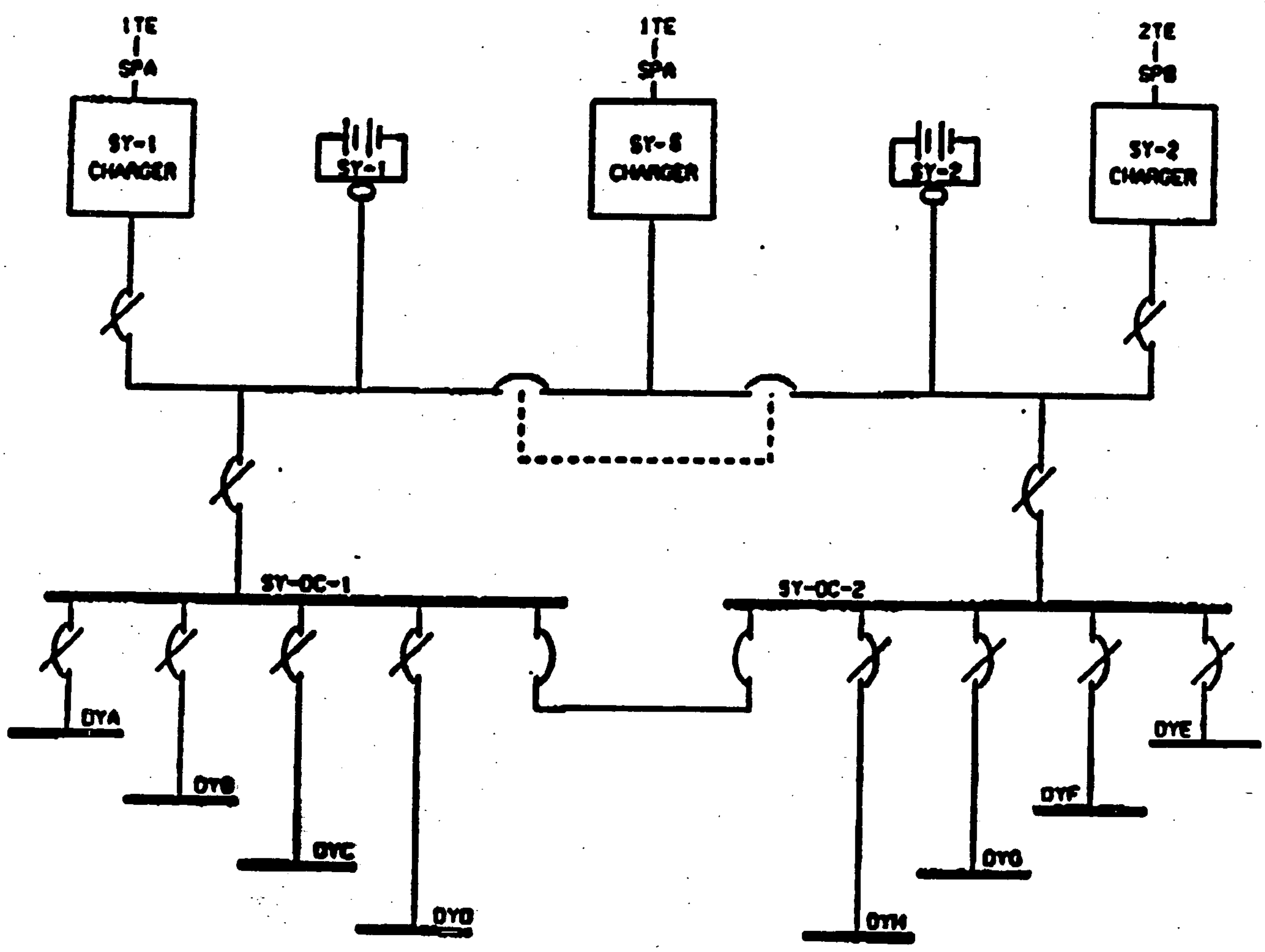


Fig. 2.

PRELIMINARY

PRELIMINARY

KEOWEE HYDRO STATION AC & DC SYSTEMS

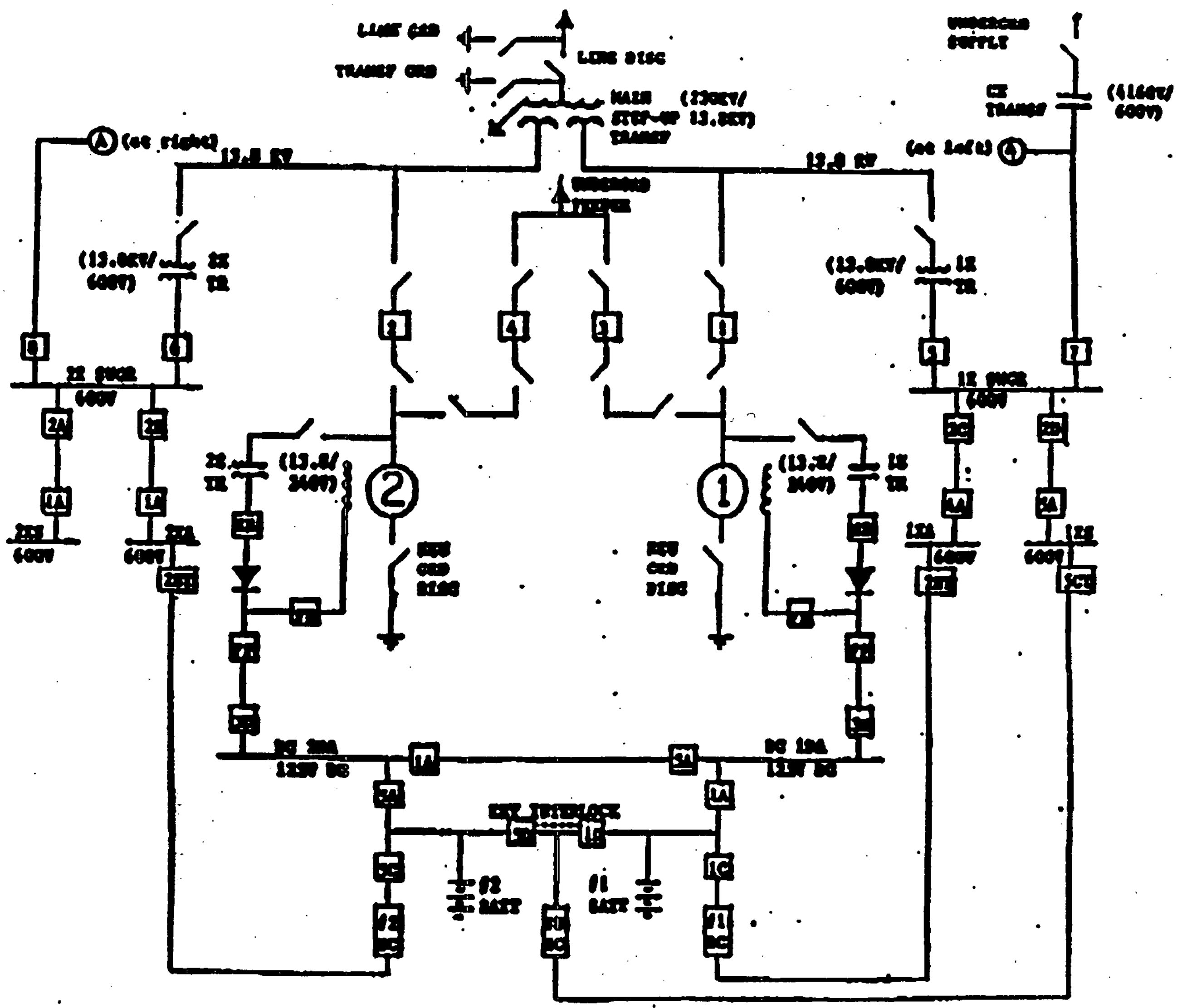


Fig. 3.

PRELIMINARY

PRELIMINARY

EMERGENCY POWER DISTRIBUTION

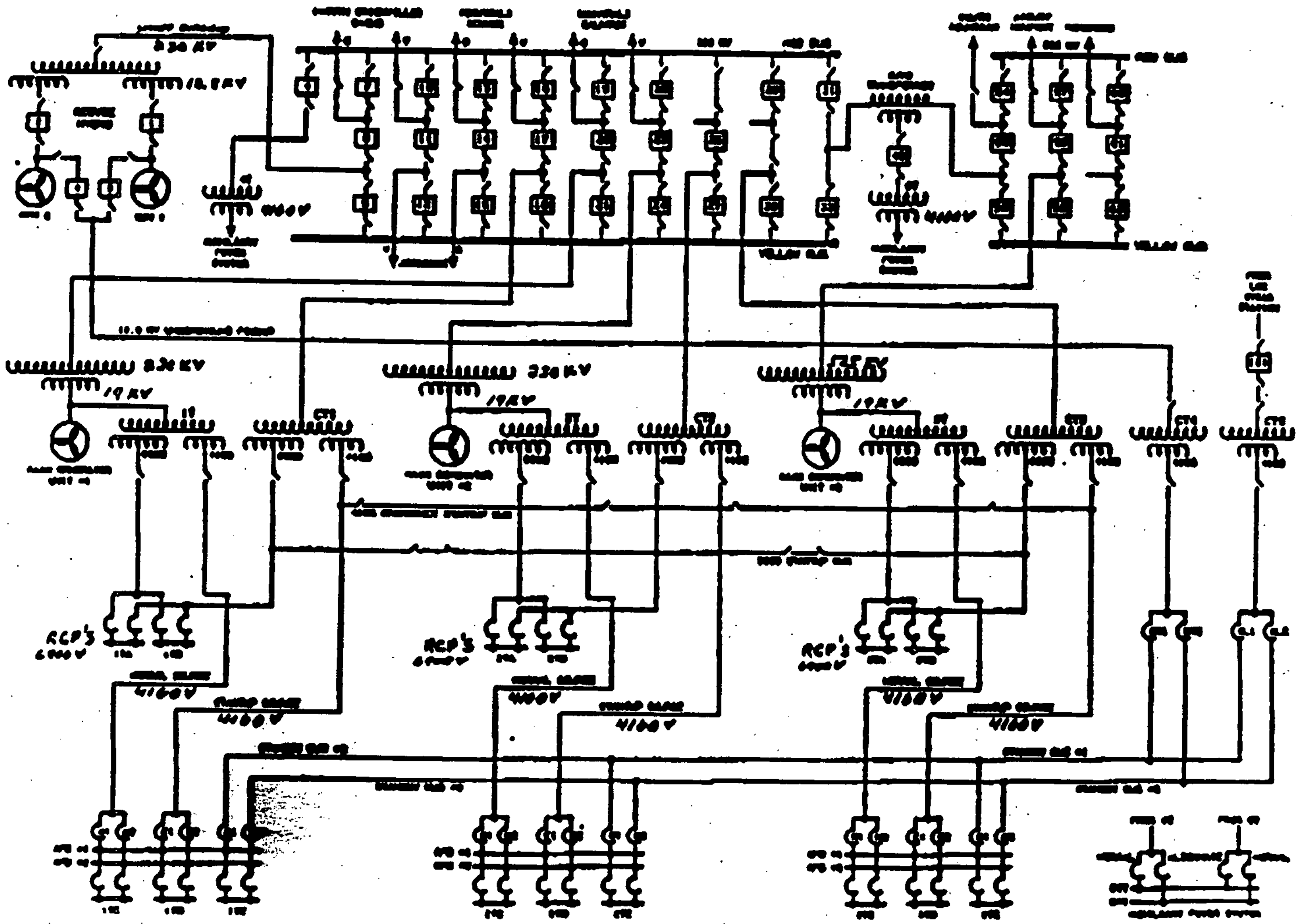


Fig. 1.

PRELIMINARY

CONDITIONAL CORE DAMAGE PROBABILITY CALCULATIONS

Event Identifier: 270/92-004
Event Description: LOOP and emergency power failure (case 1)
Event Date: 10/19/92
Plant: Oconee 2

INITIATING EVENT

NON-RECOVERABLE INITIATING EVENT PROBABILITIES

LOOP	1.5E-01

SEQUENCE CONDITIONAL PROBABILITY SUMS

End State/Initiator	Probability
CD	
LOOP	2.8E-03
Total	2.8E-03
ATWS	
LOOP	0.0E+00
Total	0.0E+00

SEQUENCE CONDITIONAL PROBABILITIES (PROBABILITY ORDER)

	Sequence	End State	Prob	N Rec**
55	LOOP -rt/loop EMERG.POWER AFW/EMERG.POWER	CD	2.6E-03	2.6E-02
54	LOOP -rt/loop EMERG.POWER -AFW/EMERG.POWER -porv.or.srv.chall -seal.loca EP.REC	CD	1.9E-04	7.3E-02

** non-recovery credit for edited case

SEQUENCE CONDITIONAL PROBABILITIES (SEQUENCE ORDER)

	Sequence	End State	Prob	N Rec**
54	LOOP -rt/loop EMERG.POWER -AFW/EMERG.POWER -porv.or.srv.chall -seal.loca EP.REC	CD	1.9E-04	7.3E-02
55	LOOP -rt/loop EMERG.POWER AFW/EMERG.POWER	CD	2.6E-03	2.6E-02

** non-recovery credit for edited case

SEQUENCE MODEL: c:\asp\1989\pwrdseal.cmp
BRANCH MODEL: c:\asp\1989\oconee2.sll
PROBABILITY FILE: c:\asp\1989\pwr_bsll.pro

No Recovery Limit

BRANCH FREQUENCIES/PROBABILITIES

Branch	System	Non-Recov	Opr Fail
trans	2.6E-04	1.0E+00	

Event Identifier: 270/92-004

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LOOP	1.6E-08 > 1.6E-08	2.4E-01 > 1.5E-01	
Branch Model: INITOR			
Initiator Freq:	1.6E-08		
loca	2.4E-06	4.3E-01	
rt	2.8E-04	1.2E-01	
rt/loop	0.0E+00	1.0E+00	
EMERG.POWER	2.8E-04 > 1.0E+00	8.0E-01 > 5.0E-01	
Branch Model: 1.OF.2+ser			
Train 1 Cond Prob:	2.3E-03 > Failed		
Train 2 Cond Prob:	4.7E-02 > Failed		
Serial Component Prob:	1.4E-04		
AFW	3.8E-04 > 4.8E-04	2.6E-01	
Branch Model: 1.OF.3+ser			
Train 1 Cond Prob:	2.0E-02		
Train 2 Cond Prob:	1.0E-01		
Train 3 Cond Prob:	5.0E-02 > 1.0E-01		
Serial Component Prob:	2.8E-04		
AFW/EMERG.POWER	5.0E-02 > 1.0E-01	3.4E-01	
Branch Model: 1.OF.1			
Train 1 Cond Prob:	5.0E-02 > 1.0E-01		
afw	2.0E-01	3.4E-01	
porv.or.srv.chall	8.0E-02	1.0E+00	
porv.or.srv.reseat	1.0E-02	1.1E-02	
porv.or.srv.reseat/emerg.power	1.0E-02	1.0E+00	
seal.loca	0.0E+00	1.0E+00	
ep.rec(sl)	0.0E+00	1.0E+00	
EP.REC	4.5E-01 > 2.9E-03	1.0E+00	
Branch Model: 1.OF.1			
Train 1 Cond Prob:	4.5E-01 > 2.9E-03		
hpi	3.0E-04	8.4E-01	
hpi(f/b)	3.0E-04	8.4E-01	1.0E-02
hpr/-hpi	1.5E-04	1.0E+00	1.0E-03

* branch model file
** forced

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Event Identifier: 270/92-004

PRELIMINARY

PRELIMINARY

CONDITIONAL CORE DAMAGE PROBABILITY CALCULATIONS

Event Identifier: 270/92-004
Event Description: LOOP and emergency power failure (case 2)
Event Date: 10/19/92
Plant: Oconee 2

INITIATING EVENT

NON-RECOVERABLE INITIATING EVENT PROBABILITIES

LOOP	1.5E-01

SEQUENCE CONDITIONAL PROBABILITY SUMS

End State/Initiator	Probability
CD	
LOOP	3.2E-03
Total	3.2E-03
ATWS	
LOOP	0.0E+00
Total	0.0E+00

SEQUENCE CONDITIONAL PROBABILITIES (PROBABILITY ORDER)

	Sequence	End State	Prob	N Rec**
55	LOOP -rt/loop EMERG.POWER AFW/EMERG.POWER	CD	2.6E-03	2.6E-02
54	LOOP -rt/loop EMERG.POWER -AFW/EMERG.POWER -porv.or.srv.chall -seal.loca EP.REC	CD	5.7E-04	7.3E-02

** non-recovery credit for edited case

SEQUENCE CONDITIONAL PROBABILITIES (SEQUENCE ORDER)

	Sequence	End State	Prob	N Rec**
54	LOOP -rt/loop EMERG.POWER -AFW/EMERG.POWER -porv.or.srv.chall -seal.loca EP.REC	CD	5.7E-04	7.3E-02
55	LOOP -rt/loop EMERG.POWER AFW/EMERG.POWER	CD	2.6E-03	2.6E-02

** non-recovery credit for edited case

SEQUENCE MODEL: c:\asp\1989\pwrdseal.cmp
BRANCH MODEL: c:\asp\1989\oconee2.sll
PROBABILITY FILE: c:\asp\1989\pwr_bsl1.pro

No Recovery Limit

BRANCH FREQUENCIES/PROBABILITIES

Branch	System	Non-Recov	Opr Fail
trans	2.6E-04	1.0E+00	

Event Identifier: 270/92-004

PRELIMINARY

LOOP	1.6E-05 > 1.6E-06	2.4E-01 > 1.5E-01	
Branch Model: [illegible]			
Initiator Freq:	1.6E-05		
loca	2.4E-06	4.3E-01	
rt	2.8E-04	1.2E-01	
rt/loop	0.0E+00	1.0E+00	
EMERG.POWER	2.5E-04 > 1.0E+00	8.0E-01 > 5.0E-01	
Branch Model: 1.OF.2+ser			
Train 1 Cond Prob:	2.3E-03 > Failed		
Train 2 Cond Prob:	4.7E-02 > Failed		
Serial Component Prob:	1.4E-04		
AFW	3.8E-04 > 4.8E-04	2.6E-01	
Branch Model: 1.OF.3+ser			
Train 1 Cond Prob:	2.0E-02		
Train 2 Cond Prob:	1.0E-01		
Train 3 Cond Prob:	5.0E-02 > 1.0E-01		
Serial Component Prob:	2.8E-04		
AFW/EMERG.POWER	5.0E-02 > 1.0E-01	3.4E-01	
Branch Model: 1.OF.1			
Train 1 Cond Prob:	5.0E-02 > 1.0E-01		
afw	2.0E-01	3.4E-01	
porv.or.srv.chall	8.0E-02	1.0E+00	
porv.or.srv.reseat	1.0E-02	1.1E-02	
porv.or.srv.reseat/emerg.power	1.0E-02	1.0E+00	
seal.loca	0.0E+00	1.0E+00	
ep.rec(sl)	0.0E+00	1.0E+00	
EP.REC	4.5E-01 > 8.6E-03	1.0E+00	
Branch Model: 1.OF.1			
Train 1 Cond Prob:	4.5E-01 > 8.6E-03		
hpi	3.0E-04	8.4E-01	
hpi(f/b)	3.0E-04	8.4E-01	1.0E-02
hpr/-hpi	1.5E-04	1.0E+00	1.0E-03

* branch model file
** forced

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Event Identifier: 270/92-004

PRELIMINARY

PRELIMINARY

CONDITIONAL CORE DAMAGE PROBABILITY CALCULATIONS

Event Identifier: 270/92-004
Event Description: LOOP with emergency power failure at Oconee 2 (case 2)
Event Date: 10/19/92
Plant: Oconee 1

INITIATING EVENT

NON-RECOVERABLE INITIATING EVENT PROBABILITIES

LOOP	1.5E-01

SEQUENCE CONDITIONAL PROBABILITY SUMS

End State/Initiator	Probability
CD	
LOOP	2.0E-03
Total	2.0E-03
ATWS	
LOOP	0.0E+00
Total	0.0E+00

SEQUENCE CONDITIONAL PROBABILITIES (PROBABILITY ORDER)

	Sequence	End State	Prob	N Rec**
55	LOOP -rt/loop EMERG.POWER afw/emerg.power	CD	1.3E-03	2.6E-02
54	LOOP -rt/loop EMERG.POWER -afw/emerg.power -porv.or.srv.chall -seal.loca EP.REC	CD	5.8E-04	7.4E-02
50	LOOP -rt/loop EMERG.POWER -afw/emerg.power porv.or.srv.chall porv.or.srv.reseat/emerg.power	CD	5.9E-05	7.4E-02
49	LOOP -rt/loop EMERG.POWER -afw/emerg.power porv.or.srv.chall -porv.or.srv.reseat/emerg.power -seal.loca EP.REC	CD	5.0E-05	7.4E-02

** non-recovery credit for edited case

SEQUENCE CONDITIONAL PROBABILITIES (SEQUENCE ORDER)

	Sequence	End State	Prob	N Rec**
49	LOOP -rt/loop EMERG.POWER -afw/emerg.power porv.or.srv.chall -porv.or.srv.reseat/emerg.power -seal.loca EP.REC	CD	5.0E-05	7.4E-02
50	LOOP -rt/loop EMERG.POWER -afw/emerg.power porv.or.srv.chall porv.or.srv.reseat/emerg.power	CD	5.9E-05	7.4E-02
54	LOOP -rt/loop EMERG.POWER -afw/emerg.power -porv.or.srv.chall -seal.loca EP.REC	CD	5.8E-04	7.4E-02
55	LOOP -rt/loop EMERG.POWER afw/emerg.power	CD	1.3E-03	2.6E-02

** non-recovery credit for edited case

SEQUENCE MODEL: c:\asp\1989\pwrdseal.cmp
BRANCH MODEL: c:\asp\1989\oconee1.all
PROBABILITY FILE: c:\asp\1989\pwr_bel1.pro

Event Identifier: 270/92-004

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No Recovery Limit

BRANCH FREQUENCIES/PROBABILITIES

Branch	System	Non-Recov	Opr Fail
trans	6.4E-05	1.0E+00	
LOOP	1.6E-05 > 1.6E-05	2.4E-01 > 1.5E-01	
Branch Model: INITOR			
Initiator Freq:	1.6E-05		
loca	2.4E-06	4.3E-01	
rt	2.8E-04	1.2E-01	
rt/loop	0.0E+00	1.0E+00	
EMERG.POWER	2.5E-04 > 1.0E+00	8.0E-01 > 5.0E-01	
Branch Model: 1.OF.2+ser			
Train 1 Cond Prob:	2.3E-03 > Failed		
Train 2 Cond Prob:	4.7E-02 > Failed		
Serial Component Prob:	1.4E-04		
afw	3.8E-04	2.6E-01	
afw/emerg.power	5.0E-02	3.4E-01	
mfw	2.0E-01	3.4E-01	
porv.or.srv.chall	8.0E-02	1.0E+00	
porv.or.srv.reseat	1.0E-02	1.1E-02	
porv.or.srv.reseat/emerg.power	1.0E-02	1.0E+00	
seal.loca	0.0E+00	1.0E+00	
ep.rec(sl)	0.0E+00	1.0E+00	
EP.REC	4.5E-01 > 8.6E-03	1.0E+00	
Branch Model: 1.OF.1			
Train 1 Cond Prob:	4.5E-01 > 8.6E-03		
hpi	3.0E-04	8.4E-01	
hpi(f/b)	3.0E-04	8.4E-01	1.0E-02
hpr/-hpi	1.5E-04	1.0E+00	1.0E-03

* branch model file
** forced

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Event Identifier: 270/92-004

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