B.14 LER Number 270/92-004, 269/92-011, 269/92-014, 269/92-016, 269/92-019, and 269/93-001

Event Description: Loss of Offsite Power With Failed Emergency Power

Date of Event: October 19, 1992

Plant: Oconee 2

B.14.1 Summary

Use of an inadequate procedure for switchyard battery replacement 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 and two breaker failures 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 0.5 h later, when an on-call technician arrived at Keowee. Problems were also experienced with the emergency feedwater (EFW) system, instrument air (IA) system, and the standby shutdown facility (SSF) during recovery from the event. The emergency power system, the turbine-driven EFW pump, and SSF are the primary features available to protect against core damage from a station blackout following a LOOP.

The conditional core damage probability estimated for this event is 2.1×10^{-4}. The relative significance of this event compared to other postulated events at Oconee is shown below in Fig. B.22.

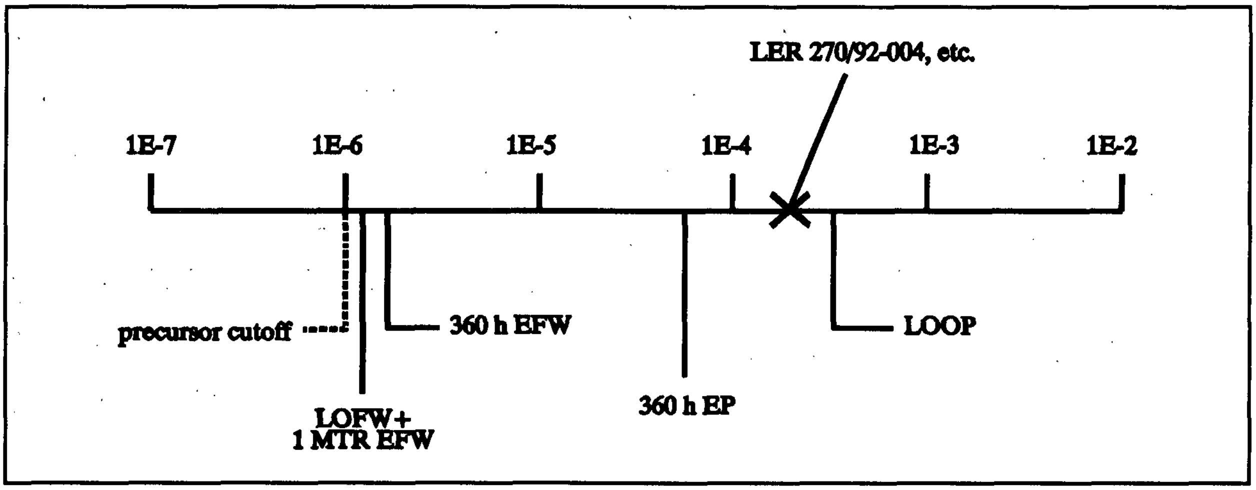

Fig. B.22. Relative event significance of LER 270/92-004, etc., compared with other potential events at Oconee.

B.14.2 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. B.23). Keowee 2 was shut down 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. B.24).

Figure removed during SUNSI review.

Fig. B.23. Emergency power distribution at Oconee
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Fig. B.24. 230-kV switchyard dc power distribution at Oconee
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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 and October 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 procedural 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. The breaker failure circuitry is designed to actuate an auxiliary relay (AR) 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 that 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 being 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. B.23.

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, load-shed Keowee 1, and gave an emergency start signal to both Keowee units. Oconee 1 and 3 continued to operate, but with PCBs-17 and 26 open, neither unit would have had a source of offsite power if Keowee had tripped (manual recovery of offsite power would have been possible). Keowee 2 started on the switchyard isolation signal. Nonessential 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 opened output breaker ACB-1 (see Fig. B.25). When ACB-1 opened, 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). Breaker ACB-7 failed to close,

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Fig. B.25. Keowee Hydro Station ac and dc systems
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apparently because of the spurious actuation of a lockout relay following a series of repetitive breaker operations that occurred as load center 1X lost and regained power during the event. As a result, bus 1X remained deenergized. ACB-8 failed to close because of high resistance on a close permissive contact, which caused auxiliary bus 2X to remain deenergized. The loss of these two buses resulted in the 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. At this point, the Keowee operator determined that Keowee 2 was running in the emergency mode. The Keowee units continued to operate with their control functions supplied by batteries.

The 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 1 h, 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 to 5 sec, and then returned to normal. The loss of flow resulted from water intrusion into the steam supply to the turbine. The water intrusion was 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 1 min after the LOOP, alarms were received at 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 start automatically. 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 started locally at Oconee 3, and a loss of IA was averted. A loss of IA would have caused a loss of main feedwater control and loss of control rod drive mechanism cooling at Oconee 1 and would have resulted in a reactor trip at that unit. If that had occurred, offsite power would have been lost to Unit 1 also.

Several minutes after the loss of auxiliary power at Keowee, the Keowee operator contacted the Duke Power 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 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, and the unit supervisor instructed him not to take any action involving Keowee 2, since it was supplying the Oconee 2 main feeder buses. It appears that the Keowee operator did not adequately describe the ramifications of the loss of auxiliary power. 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 had 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 to 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.[1] The Keowee on-call technician reset the transformer lockout at 2158 hours. This allowed ACB-1 to close automatically, and this closure, 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 a local lockout at breaker ACB-7 was reset.

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 hours 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. 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 also tripped. The Keowee 2 trip was caused by the undervoltage condition on the yellow bus combined with the lack of an emergency start signal; system logic determined that Keowee 2 was generating to the grid with no output and tripped the unit (the system logic does not include Keowee 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 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 onto the yellow bus since a switchyard isolation initiation signal was not generated because the red bus was still energized. This response was expected; however, 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, October 20, 1992, 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, had been restarted, and had been 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 for 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. Oconee personnel

[1]Both the dispatcher and the unit supervisor were aware of problems at Keowee 20 min earlier, during their first telephone call.

confirmed that the SSF diesel generator was not started to power SSF loads. The battery charger in the SSF was de-energized because of the Unit 2 LOOP 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, October 20, 1992, about 4 h after the event began. Power was restored to the SSF at 0415 hours. 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. After the event, the Keowee Hydro Station organization was realigned to report to the Nuclear Generation Department. Previously, it had 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 because of 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. However, 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. In addition, the Keowee operator was unfamiliar with the response required to several annunciators that alarmed during the test.

B.14.3 Additional Event-Related Information

All three Oconee units have the same generating capacity (850 MWe net) and similar ac power systems (see Fig. B.23). 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 the 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, and this 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 the generator for a unit is unavailable, such as following a reactor trip or during outages, electric power is automatically supplied from the switchyard through its respective startup transformer, CT-1, CT-2, or CT-3. Although 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, each of which supplies power to three 4160-V load buses (TC, TD, and TE). Except for the reactor coolant pumps, all ac is fed from these three buses. The power to MFB1 and MFB2 is either supplied by the unit's auxiliary transformer through the N breakers or by 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.

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 that 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 nonessential 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, which are used to pressurize the air preloaded 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 to which the governor must respond. The utility has indicated in several LERs that 1 h is the expected maximum time period of Keowee operation without ac auxiliaries.

The normal Keowee configuration at the time of the event was to have 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 upon loss of normal power. The transfer scheme was

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

A standby shutdown facility (SSF) is located in a separate building on the Oconee site. This facility, which is not normally manned, is capable of providing limited high-pressure injection for reactor coolant system (RCS) makeup and reactor coolant pump (RCP) seal cooling [provided an RCP seal loss-of-coolant accident (LOCA) does not occur]. It can also supply limited steam generator makeup. The facility includes a separate diesel generator which can power SSF loads in the event of a station blackout. SSF systems consist of single trains and are therefore not single-failure-proof.

B.14.4 Modeling Assumptions

The event was modeled as a plant-centered LOOP with failed emergency power and (slightly) degraded EFW. Potential sequences associated with the event are described in Appendix A, sect. A.3.1, PWR LOOP. These sequences were modified to address the Oconee-specific SSF, as described later in this section, and shown on the event tree included with this analysis documentation. The plant response observed during the event impacted the following branches on the event tree:

Loss of Offsite Power. The LOOP was caused by the lockout of the 230-kV switchyard. Potential short-term (~30 min) recovery of offsite power was considered in the analysis (bus lockouts were reset 39 min after the LOOP and the switchyard was repowered 52 min after the LOOP). The probability of not recovering offsite power in the short term was estimated to be 0.15, as described in ORNL/NRC/LTR-89/11R1, *Revised LOOP Recovery and Seal LOCA Models*, October 1993.

Emergency Power. Although Keowee Hydro continued to supply power to Unit 2 after auxiliary power was lost, it was assumed in the 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 by the time he arrived.

The probability of the on-call technician failing to arrive on-site and recover auxiliary power to Keowee Hydro prior to the loss of hydraulic oil was estimated to be 0.64. Since there is no published data available that could be used to estimate such a value, it was developed assuming the probability of repair (dominated by travel time in this case) was log-normally distributed with the observed arrival time (29 min) the most probable value (mode) of the distribution. The 95th percentile was assumed to be 1 h, based on a 1 h response requirement for on-call technicians in Keowee procedures. All time once the on-call technician arrived at Keowee was assumed to be required for restoration of the first hydro unit. Additionally, since hydraulic fluid was nearly depleted when the on-call technician arrived, the time at which the Keowee hydro units would fail was assumed to be the time required for recovery during this event (37 min). The actual Keowee time-to-failure given the loss of auxiliary power is poorly understood — the licensee has stated in several LERs that it could be as long as 1 h in some cases (this possibility is addressed in a sensitivity analysis).

The Central Switchyard was also available as an alternate source of power to the standby buses. A probability of 0.12 (ASP non-recovery class R3, see Appendix A, sect. A.1) was assumed for failing to recover power from the Central Switchyard via transformer CT-5. This value was chosen because recovery appeared possible in the required time period from the control room. However, because of the LOOP and the problems with Keowee, recovery was considered to be non-routine and burdened.

Auxiliary Feedwater. Flow from the Oconee 2 turbine-driven EFW pump dropped to zero for 3 to 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, resulting from a faulty steam trap. While the pump remained operable during this event, greater amounts of water could have caused the pump to trip; therefore, the unavailability 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 Electric Power in the Long term. The probability of not recovering offsite power prior to battery depletion and RCP seal LOCA, given that offsite power was not recovered in the short term and Keowee Hydro failed at 37 min, was estimated to be 0.056. This is the probability of not recovering offsite power at 1.6 h (the 37 min failure time for Keowee plus the 1 h Oconee battery depletion time) given it was not recovered at 0.5 h (nonrecovery at 0.5 h is addressed in the LOOP nonrecovery) for plant-centered LOOP class I1, as described in ORNL/NRC/LTR-89/11, *Revised LOOP Recovery and Seal LOCA Models*, August 1989 (see Table B.7 for Weibull distribution parameters used for this estimate). The overall probability of not recovering offsite power through recovery of the Oconee switchyard or through the use of the Central switchyard via CT-5 was estimated to be 0.001.

Table B.7. Oconee Loss of Offsite Power Sensitivity Analyses

Assumption	Conditional Probability	Impact (factor)
Probability of failing to provide power from the central switchyard = 0.04 (instead of 0.12)	7.2×10^{-5}	0.34
Keowee successfully operates for 1 h (instead of 0.5 h). Estimated probability of nonrecovery of 0.05 (see Sect. B.14.4)	1.7×10^{-5}	0.08
Oconee 1 trips due to reduced instrument air (IA) pressure. Complications from the two-unit LOOP prevents recovery of Keowee; *p* (loss of IA) = 0.1 assumed	2.5×10^{-4}	1.19
No impact on pump reliability from water in turbine-driven EFW pump steam line (instead of doubling pump failure probability)	1.8×10^{-4}	0.86
Probability of SSF failure = 0.4 (instead of 0.2) because of the long-term unavailability of normal power	4.2×10^{-4}	2.0

The use of the SSF as an alternate source of reactor coolant system (RCS) and steam generator (SG) makeup was also addressed in the analysis. This was done by identifying core damage sequences that could be recovered through the use of the SSF (sequences with failed SG makeup or RCP seal cooling and without loss of inventory), and modifying the event tree model described in Appendix A to include its consideration. The revised event tree for Oconee is included with this analysis. A combined operator and equipment failure probability of 0.2 was used for the SSF. This probability is consistent with values developed in the Oconee PRA (NSAC-60) and in licensee analyses of this event.

The SSF was without power from Oconee 2 (its normal power source) for over 4 h following the LOOP, which resulted in loss of power to the SSF battery chargers. However, since no undervoltage alarms resulted from the unavailability of normal power, and because a spare battery was available in the SSF, the SSF failure probability was not modified in the base analysis (an increase in failure probability was considered in a sensitivity analysis).

The results of sensitivity analyses — that considered a greater likelihood of recovering ac power, the potential for Keowee operation for 1 h after loss of auxiliary power, the potential for trip of Oconee 1 due to a loss of instrument air initiated by the LOOP, nominal operation of the EFW system, and a increased failure probability for the SSF because of the long-term unavailablity of normal power - are described in the next section.

B.14.5 Analysis Results

The conditional core damage probability estimated for the event is 2.1×10^{-4}. The dominant core damage sequence, highlighted on the event tree in Fig. B.26, involves the observed LOOP with failure to recover emergency power, failure to utilize the SSF for RCS and SG makeup, and failure to recover ac power before battery depletion.

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 ac power via transformer CT-5.

Five sensitivity analyses were performed to determine the impact of selected assumptions on the core damage probability estimated for the event. The assumptions and resulting probability estimates are shown in Table B.7. As can be seen from these cases, more optimistic assumptions concerning the likelihood of recovering ac power using the central switchyard and longer Keowee operations without auxiliary power reduce the conditional probability by up to a factor of 12. This is to be expected, considering the dominant sequence. Assuming a possible Oconee 1 trip following a loss of IA increases the core damage probability by 19% to 2.5×10^{-4}. This value includes probabilities for Units 1 and 2. Assuming that the water in the EFW pump steam line had no impact on pump reliability reduces the estimated conditional probability by 14%. Increasing the SSF failure probability by a factor of two doubles the conditional probability. This is also to be expected considering the dominant sequences.

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*

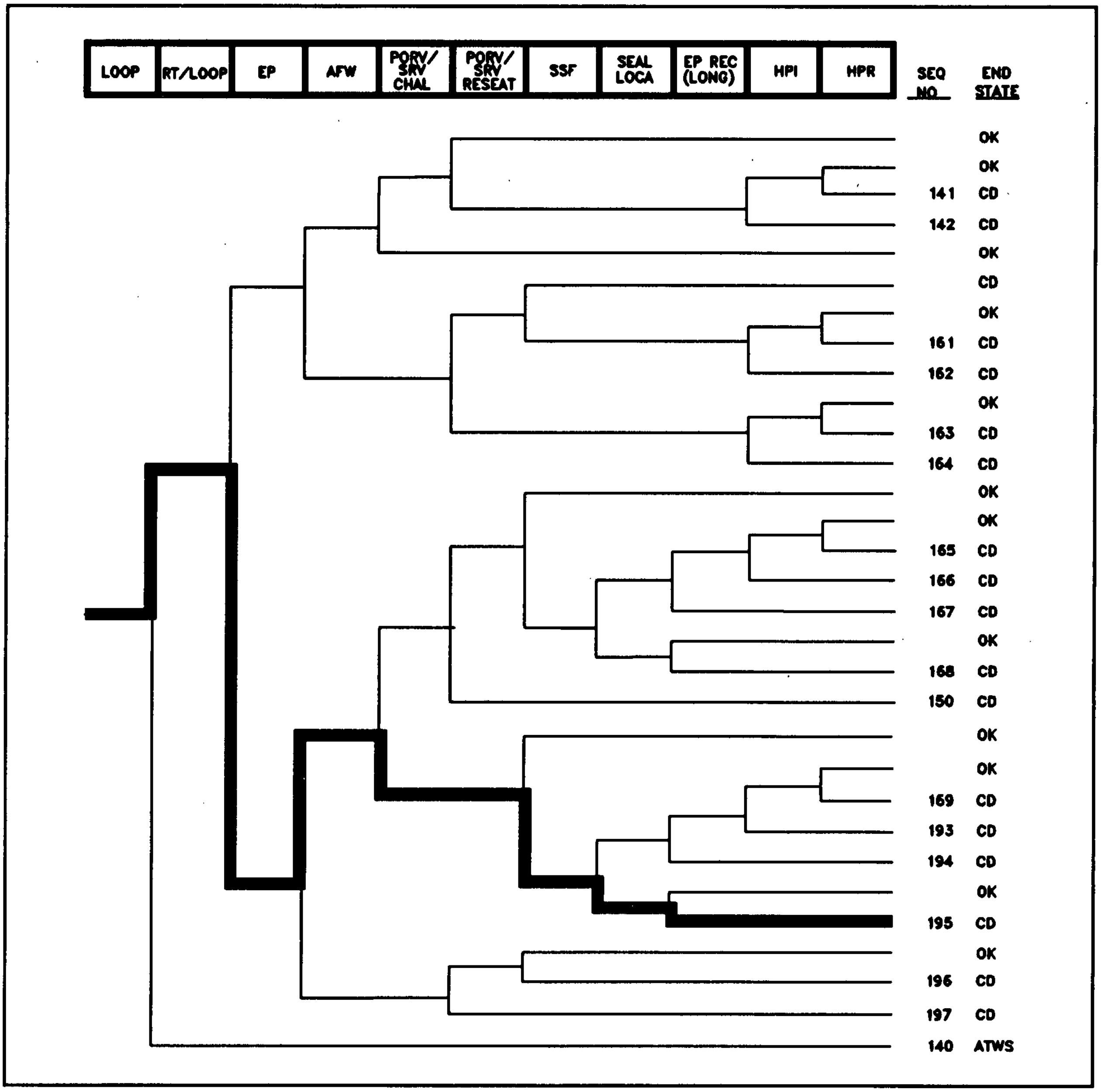

Fig. B.26. Dominant core damage sequences for LER 270/92-004

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 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 special test at Keowee is included in NRC Augmented Inspection Team (AIT) report no. 50-269/92-26, 50-270/92-26, and 50-287/92-26. A number of other LERs reported problems with Keowee during 1992 and early 1993. Two of these events describe periods in which both Keowee units were unavailable and are documented separately as precursors. Additionally, the following events were related to this event and also occurred at Keowee or Oconee:

269/91-012 Incorrect relief value setpoints resulted in inoperability of each Oconee unit SSF reactor coolant makeup system since initial installation in 1981.

269/92-011 Potential single failure could tie both Keowee units together out of phase.

269/92-014 Unavailability of Keowee 2 to supply power to the overhead path because of a failed relay.

269/92-016 Potential single failure (bus fault) could result in the unavailability of both Keowee units, due to the protective relaying that would occur while clearing the fault.

269/92-019 Potential single failure (bus fault) could lock out both Keowee units from the overhead path and also lock out the auxiliary power normal and alternate feeder breakers for both units.

269/93-001 Potential for a Keowee unit trip on overspeed if that unit was generating power to the grid and an emergency start signal was initiated.

CONDITIONAL CORE DAMAGE PROBABILITY CALCULATIONS

Event Identifier: 270/92-004
Event Description: Loss of offsite power with failed emergency power
Event Date: October 19, 1992
Plant: Oconee 2

INITIATING EVENT

NON-RECOVERABLE INITIATING EVENT PROBABILITIES

LOOP(PLANT_CENT)	1.5E-01

SEQUENCE CONDITIONAL PROBABILITY SUMS

End State/Initiator	Probability
CD	
LOOP(PLANT_CENT)	2.1E-04
Total	2.1E-04
ATWS	
LOOP(PLANT_CENT)	0.0E+00
Total	0.0E+00

SEQUENCE CONDITIONAL PROBABILITIES (PROBABILITY ORDER)

	Sequence	End State	Prob	N Rec**
195	loop(plant_cent) -rt/loop EMERG.POWER(PLANT_CENT) -AFW/EMERG.POWER -porv.or.srv.chall(loop) ssf -seal.loca(plant_cent) EP.REC(PLANT_CENT)	CD	1.1E-04	9.4E-02
196	loop(plant_cent) -rt/loop EMERG.POWER(PLANT_CENT) AFW/EMERG.POWER -porv.or.srv.reseat/emerg.power ssf	CD	7.8E-05	3.3E-02
168	loop(plant_cent) -rt/loop EMERG.POWER(PLANT_CENT) -AFW/EMERG.POWER porv.or.srv.chall(loop) -porv.or.srv.reseat/emerg.power ssf -seal.loca(plant_cent) EP.REC(PLANT_CENT)	CD	9.9E-06	9.4E-02
150	loop(plant_cent) -rt/loop EMERG.POWER(PLANT_CENT) -AFW/EMERG.POWER porv.or.srv.chall(loop) porv.or.srv.reseat/emerg.power	CD	8.9E-06	9.4E-02
197	loop(plant_cent) -rt/loop EMERG.POWER(PLANT_CENT) AFW/EMERG.POWER porv.or.srv.reseat/emerg.power	CD	3.9E-06	3.3E-02

** non-recovery credit for edited case

SEQUENCE CONDITIONAL PROBABILITIES (SEQUENCE ORDER)

	Sequence	End State	Prob	N Rec**
168	loop(plant_cent) -rt/loop EMERG.POWER(PLANT_CENT) -AFW/EMERG.POWER porv.or.srv.chall(loop) -porv.or.srv.reseat/emerg.power ssf -seal.loca(plant_cent) EP.REC(PLANT_CENT)	CD	9.9E-06	9.4E-02
150	loop(plant_cent) -rt/loop EMERG.POWER(PLANT_CENT) -AFW/EMERG.POWER porv.or.srv.chall(loop) porv.or.srv.reseat/emerg.power	CD	8.9E-06	9.4E-02

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195	loop(plant_cent) -rt/loop EMERG.POWER(PLANT_CENT) -AFW/EMERG.POWER -porv.or.srv.chall(loop) ssf -seal.loca(plant_cent) EP.REC (PLANT_CENT)	CD	1.1E-04	9.4E-02
196	loop(plant_cent) -rt/loop EMERG.POWER(PLANT_CENT) AFW/EMERG.POWER -porv.or.srv.reseat/emerg.power ssf	CD	7.8E-05	3.3E-02
197	loop(plant_cent) -rt/loop EMERG.POWER(PLANT_CENT) AFW/EMERG.POWER porv.or.srv.reseat/emerg.power	CD	3.9E-06	3.3E-02

** non-recovery credit for edited case

SEQUENCE MODEL: c:\asp\1989\oconseal.cmp
BRANCH MODEL: c:\asp\1989\oconee2.ssf
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	
loop(plant_cent)	1.3E-05	1.5E-01[1]	
loop(grid)	1.6E-06	4.8E-01	
loop(weather)	1.1E-06	9.3E-01	
loca	2.4E-06	4.3E-01	
rt	2.8E-04	1.2E-01	
rt/loop	0.0E+00	1.0E+00	
EMERG.POWER(PLANT_CENT)	3.0E-04 > 1.2E-01	8.0E-01 > 6.4E-01[2]	
Branch Model: 1.OF.3			
Train 1 Cond Prob:	5.0E-02 > Failed[3]		
Train 2 Cond Prob:	5.0E-02 > Failed[3]		
Train 3 Cond Prob:	1.2E-01		
emerg.power(grid)	2.5E-03	8.0E-01	
emerg.power(weather)	2.5E-03	8.0E-01	
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[4]		
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[4]		
mfw	2.0E-01	3.4E-01	
porv.or.srv.chall	8.0E-02	1.0E+00	
porv.or.srv.chall(loop)	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	
ssf	2.0E-01	1.0E+00	
seal.loca(plant_cent)	0.0E+00	1.0E+00	
seal.loca(grid)	0.0E+00	1.0E+00	
seal.loca(weather)	0.0E+00	1.0E+00	

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ep.rec(sl)(plant_cent)	0.0E+00	1.0E+00	
ep.rec(sl)(grid)	0.0E+00	1.0E+00	
ep.rec(sl)(weather)	0.0E+00	1.0E+00	
EP.REC(PLANT_CENT)	2.3E-01 > 5.6E-02	1.0E+00	
Branch Model: 1.OF.1			
Train 1 Cond Prob:	2.3E-01 > 5.6E-02[1]		
ep.rec(grid)	5.3E-02	1.0E+00	
ep.rec(weather)	8.6E-01	1.0E+00	
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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Notes:

[1] See Modeling Assumptions for development of this non-recovery value.
[2] This non-recovery value addresses the potential for recovery of Keowee and the potential use of transformer CT5.
[3] Keowee 1 and 2 are assumed failed if auxiliary power is not recovered.
[4] The failure probability for the turbine-driven EFW pump was increased to address the potential for trip because of water in the steam line.