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Phase 3 SDP Analysis: Arkansas Nuclear One Unit 1 (ANO-1)

Lack of Adequate Procedures for Manual Actions to Achieve Post-Fire Safe Shutdown Following Fire Damage in Fire Zones 98J and 99M

1. Performance Deficiency

The Arkansas Nuclear One Unit 1 (ANO-1) fire zone 98-J (Diesel Generator Corridor) and fire zone 99-M (North Electrical Switchgear Room) did not meet regulatory requirements for separation of electric cables and equipment of redundant trains of systems necessary to achieve post-fire safe shutdown. The licensee did not have adequate procedures for manual actions to achieve post-fire safe shutdown following a fire in fire zones 99-J and 98-M. This condition has existed since the issue was identified as Unresolved Item 50-313;368/0106-02 in the Inspection Report 50-313;368/01-06, August 20, 2001.

2. Fire Scenario

The primary combustibles in the ANO-1fire zones 98-J and 99-M are the safety-related non-qualified IEEE-383 electrical cables routed in open cable trays that are located above numerous potential ignition sources. The height of the lowest cable tray in fire zone 98-J is approximately 6 ft. from the floor; while in the case of fire zone 99-M, the height of the lowest cable tray from the floor is about 8 ft. In fire zone 98-J, the potential ignition sources include a battery charger, 480V motor control centers, 125V DC distribution panels, wall-mounted electrical cabinets, emergency ventilation units, and an emergency chiller unit (VUC4A/C51). The potential ignition sources in fire zone 99-M include an air-cooled transformer (X6), a 120V instrument transformer (X62), 4.16kV switchgear cabinets, 480V motor control centers, a 480V load center, inverter cabinets, and ventilation units. Other potential ignition sources, such as a power cable failure in a tray, or other electrical originated failures (in distribution panels, circuit boards, electrical wiring, internal cable fault, electrical circuit fault in switchgear cabinets, etc.) leading to ignition of the in-situ combustibles (cables), are considered in the fire scenario. Other ignition sources such as hot work (welding) or a limited 100-lb transient combustible source are also possible, but are not considered within the scope of this analysis.

The combustible loading in fire zone 98-J consists of mostly cables in the cable trays. According to licensee-provided information and calculations, the fire duration in fire zone 98-J was estimated to be 2 hours and 15 minutes by considering all available in-situ combustibles and the potential 100-lb transient combustible source. The combustible loading in fire zone 99-M also consists primarily of cable insulation in open cable trays. Considering all available in-situ combustibles and a potential 100-lb transient combustible source, the fire duration in 99-M was estimated to be 30 minutes.

The credible fire scenario is based on postulating that a fire develops from any one of the potential ignition sources, **if undetected and unsuppressed (i.e., no immediate**

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intervention from plant operators), would grow to a rate of heat release of 400 kW (or 380 BTU/s) and ignite the cable insulation of electrical cables resulting in challenging fires. The Diesel Generator Corridor in fire zone 98-J is provided with smoke detection and a partial-coverage automatic water suppression system that is actuated by cross-zoned smoke and in-tray linear heat detectors. The ionization smoke detectors are provided at the ceiling level that only alarms in the Main Control Room (MCR). The line-type heat detectors (trade named Protectowire) are installed on the top of the cables in each cable tray, and also alarm in the MCR. The automatic deluge sprinkler system provides partial protection to the fire zone 98-J, and will activate upon receiving successful cross-zone detection signals from both of the smoke and linear heat detectors. A fire hose reel and portable carbon dioxide extinguishers are located in the vicinity of the fire zone for manual fire fighting purposes when needed. Fire zone 98-J is normally unoccupied except for inspections, shift tours and maintenance activities.

The fire zone 99-M (North Electrical Switchgear Room) is only protected with a smoke detection system. The smoke detectors are provided at the ceiling level which alarm in the MCR. There are no fixed automatic fire suppression systems in this switchgear room. A fire hose reel and portable carbon dioxide extinguishers are also provided in the vicinity of the fire zone for manual fire fighting purposes when needed. Fire zone 99-M is normally unoccupied except for inspections, shift tours and maintenance activities.

In the fire scenario development, it is assumed that a credible fire starts from a specific ignition source (e.g., transformers, electrical cabinets, 4.16kV switchgear, 480 V motor control centers, 480V load center, 125V DC distribution panels, or cables) and has sufficient flame spread (i.e., flame height and radius) to ignite a cable tray closest to the ignition source. The SPLB fire hazards and fire modeling analyses (see ADAMS Accession #ML021490005, #ML021990405) postulated that energetic electrical faults in electrical cabinets, producing a fire with heat release rate (HRR) of 400kW or greater, can lead to fire growth and subsequent fire damage to target cables depending on the ventilation conditions in the compartment. Two different cases of fire compartment conditions were considered to define the fire damaging scenarios for the two fire zones: (1) vent open and closed in Fire Zone 98-J, and (2) door open and closed in Fire Zone 99-M.

The CFAST (Consolidated Model of Fire Growth and Smoke Transport) computer code was used to model the fire growth of fire involving electrical cabinet and equipment that would lead to a challenging fire in the fire zones 98-J and 99-M. In each of the fire scenarios, a range of HRR curves from 200 kW to 500 kW were used as input to the CFAST fire modeling analyses because no direct data on the burning of the specific electrical ignition sources at full or intermediate scale were available. As documented in NUREG/CR-4527, the selected range of HRR curves were developed for electrical cabinet fires from full-scale fire tests conducted on electrical cabinets in a large (e.g., actual control room size) enclosure. In the fire modeling analyses, the fire was assumed to develop with a "t^2 fast fire growth rate" due to the electrically energized fire environment. It is also assumed that there is complete combustion and an ample supply of oxygen for the fire with the given HRR.

Basis for HRR?

Basis?

In modeling the fire growth and damage potential, results of SPLB fire modeling analyses show that fires with HRR of 400kW could damage the overhead cables in fire zone 98-J with open vent conditions, and in fire zone 99-M with closed door conditions. In the fire

scenario for fire zone 98-J with open vent conditions, the smoke layer temperature reaches 425 °F in approximately **19 minutes**. In the case of fire zone 99-M with closed door conditions, the smoke layer temperature reaches 425 °F in approximately **10 minutes**. The limiting temperature of 425 °F was used in the fire modeling analyses because this temperature condition can cause failure of non-IEEE-383 rated cables. The results of the fire modeling analyses also indicate that fires with HRR of 200 kW and 300 kW in the two fire zones tend to become ventilation limited and decay with time. A fire with HRR of 200kW could only result in a maximum smoke layer temperature of 305 °F in about one hour for the fire zone 98-J with open vent conditions. This result indicates that the overhead cables may remain undamaged in fire zone 98-J for an hour under the postulated conditions.

Based on results of the fire hazards analysis, SPLB fire protection staff also postulated a fire scenario involving a lube oil spill fire resulting from a breach or leak in the lube oil system for the emergency chiller chilled water pump located in fire zone 98-J. The fire modeling analysis for this scenario indicates that a single gallon of lube oil spill, if ignited, could form a pool fire with a diameter of approximately 1.5 feet, flame height of 6 feet, and burn duration of 7.5 minutes. The flame height of the postulated pool fire is sufficiently high to impinge on the cable insulation of the non-IEEE-383 rated cables on the lowest cable tray that is located about 6 feet from the floor. It was concluded that the turbulent diffusion flame impingement on the cables would cause potential ignition and flame spread along the cable trays, and thereby further increases the HRR in the fire zone 98-J.

3. Assumptions

(a) Fire Barriers - In fire zone 98-J, the walls and doors are 3-hour rated fire barriers. A one-hour rated barrier surrounds the Red train AC instrumentation power supply cables, while other Red train power cables in fire zone 98-J are unprotected. The Red train redundant cables are not separated from the Green train cables by a minimum of 20 feet distance free of intervening combustibles. In fire zone 99-M, the Red train cables are not protected with one-hour rated barrier, and are not separated from the Green train cables by a minimum of 20 feet distance free of intervening combustibles. As such, the cables in both fire zones could be damaged by a floor based fire.

(b) Automatic Fire Suppression - The East portion of fire zone 98-J is protected by a cross-zoned, pre-action deluge system that is actuated by cross-zoned smoke and in-tray linear heat detectors. Periodic surveillance is performed on the cable tray detection system and room smoke detection system to ensure that the suppression system remains operable. The sprinkler heads in the corridor are open heads, and water will be available as soon as the sprinkler valve opens in approximately 5 seconds (according to manufacturer's information). The suppression system response time is assumed to be approximately 7 minutes because the actuation time for the line-type heat detection system to sense a temperature of 190 °F was estimated to be less than 7 minutes. Therefore, the raceways that required more than 10 minutes to sustain damage can be assumed to be protected by the suppression system. The probability of pre-action sprinkler system being unavailable is assumed to be 0.05 for the normal operating state based on the EPRI database (EPRI FIVE report, page 10.3-7). This unavailability value include the consideration for failure of the system to operate on demand and the system being out of service at the time of a fire

(due to shut control valve, etc.). In fire zone 99-M, no automatic fire suppression system is provided.

(b) Fire Detection and Manual Fire Suppression - Both fire zones 98-J and 99-M are equipped with ionization detection systems that will detect fires in the incipient stages and provide alarm conditions in the Main Control Room (MCR). Alarms from the ionization detection system would result in the dispatch of an operator to investigate any of the two fire zones. The central fire brigade locker is located one elevation above the fire zones 98-J and 99-M, and therefore, the travel time of the fire brigade from the locker to the fire scene is considered to be reasonably short.

Based on recent fire drills performed on fire zone 100-N, which is adjacent to fire zone 99-M, the response times of the entire fire brigade arriving at the fire zone averaged less than 10 minutes. There are two access points to the fire zones, which are easily accessible by the fire brigade response team. Based on these factors, it was assumed that any fire scenario requiring greater than 20 minutes to sustain cable damage may be suppressed by the fire brigade.

The fire-induced core damage frequency equation for the fire zones can be defined as follows:

$$F_{CDF} = F_i * S_f * P1 * P2 * P3$$

where F_i = Fire ignition frequency of ignition source
S_f = Severity factor for a challenging fire
P1 = Probability of automatic fire suppression system being unavailable
P2 = Failure probability of manual suppression by fire brigade
P3 = Conditional core damage probability, with or without recovery actions

4: Fire Ignition Frequencies

The various ignition sources in the fire zones 98-J and 99-M respectively, and their associated fire ignition frequency estimates, as calculated using the EPRI FIVE methodology and listed on the Ignition Source Data Sheet (ISDS) for the two ANO-1 fire zones, are shown below:

Fire Zone 98-J Ignition Sources	Generic Frequency	WF_L	WF_i	ISDS Ignition Frequency
Electrical Cabinets	1.9 E-2	1	1.01 E-1	1.9 E-3
Battery Charger	4.0 E-3	2	9.52 E-2	7.6 E-4
Ventilation Subsystems	9.5 E-3	2	1.12 E-2	2.1 E-4
Fire Protection Panels	2.4 E-3	2	2.33 E-2	1.1 E-4
Emergency Chiller Pump	9.5 E-3	2	2.80 E-3	5.3 E-5

Fire Zone 99-M Ignition Sources	Generic Frequency	WF_L	WF_I	ISDS Ignition Frequency
Electrical Cabinets	1.5 E-2	0.25	1.0	3.8 E-3
Transformers	7.9 E-3	2	2.04 E-2	3.2 E-4
Ventilation Subsystems	9.5 E-3	2	5.60 E-3	1.1 E-4

The ISDS ignition frequency estimates of each identified ignition source were derived based on adjusting the generic fire ignition frequencies by a location weighting factor (WF_L) and an ignition source weighting factor (WF_I). The generic fire ignition frequencies used in this analysis were based on the EPRI database (EPRI Fire PRA Implementation Guide, pages 4-7 & 4-8, Table 4.2). A comparison of the generic fire ignition frequency estimates against the NRC updated fire events database (Houghton, RES) showed that the generic frequency estimates were generally higher, ~~by an order of magnitude.~~

With the exception of the electrical cabinets, all of the above listed sources were considered as "Plant Wide " components and therefore, were assigned a $WF_L = 2$ (i.e., number of units per site). For fire zone 98-J in the auxiliary building, the electrical cabinets were assigned $WF_L = 1$ because of the number of units per site divided by the number of auxiliary buildings. For fire zone 99-M (which is a switchgear room), the electrical cabinets were assigned $WF_L = 0.25$ because of 2 units per site divided by 8 switchgear rooms.

The weighting factor, WF_I, for plant-wide components is obtained by dividing the number of components in the specified room by the total number of components in the plant. In fire zone 98-J, $WF_I = 0.101$ is derived for the electrical cabinets by dividing 147 cabinets in the corridor by the total number of 1452 cabinets in the auxiliary building. Similarly, the WF_I factors for the other ignition sources in both fire zones 98-J and 99-M were derived from plant-specific data (as provided in ANO-1 licensee response package). In fire zone 98-J, there are 4 ventilation subsystems, whereas there are two ventilation units in fire zone 99-M. In fire zone 98-J, there are 2 fire protection panels, whereas there are none in fire zone 99-M. In fire zone 98-J, there are no transformers, whereas there are two transformers in fire zone 99-M. In fire zone 98-J, there are 2 battery chargers, whereas there are none in fire zone 99-M. Based on licensee Calculation 85-E-0053-47, the total number of ventilation subsystems is 357, the total number of fire protection panels is 86, the total number of transformers is 98, and the total number of battery chargers is 21 (increased from 19 due to recent modifications).

The ignition frequency of the emergency chiller pump was derived using the generic frequency for the ventilation subsystems because there was no plant-specific ignition frequency data. The WF_I factor for the emergency chiller pump was based on a single ventilation subsystem in the fire zone. Therefore, $WF_I = 1/357 =$ ~~2.8 E-3~~ was used in deriving the ignition frequency for the emergency chiller pump. The emergency chiller unit in fire zone 98-J is a standby component and its operability is demonstrated on a monthly basis by a surveillance test with duration of less than 30 minutes. The test is performed by Operations personnel who are trained fire brigade members.

5: Conditional Core Damage Probability (CCDP)

In the various fire scenarios considered (i.e., each scenario initiated by a different ignition source), conditional core damage probabilities (CCDPs) were calculated for the two fire zones using the ANO-1 IPEEE fire risk model for two cases: (a) no operator recovery actions were credited, and (b) credit for operator actions to recover the Emergency Feedwater (EFW) system and other required actions for safe shutdown. In both cases, the CCDP calculations were performed for two conditions: (i) one Red equipment train is available to perform mitigating functions, and (ii) both Red and Green equipment trains are unavailable due to the severe, challenging fire. In the event that both redundant equipment trains in a fire zone are affected by fire, the CCDPs would be dominated by operator actions to achieve safe shutdown outside of the main control room.

In the licensee's PSA analyses to estimate the CCDPs with no operator recovery actions (ANO-1 Calculations 02-E-0004-01 and 02-E-0004-02), the following operator recovery actions were not credited (i.e., set to logical TRUE in the cutsets of the risk model):

1. Operator fails to isolate ICW after automatic SW isolation fails on ES
2. Operator fails to start and control EFW pump P-7A manually when offsite power is available
3. Operator fails to start and control EFW pump P-7B from control room when offsite power is available
4. Operator fails to open breaker locally at A1 from the unit auxiliary transformer and close the breaker from startup transformer SUT1
5. Operator fails to manually close breaker 152-308 or 152-408 for EDG recovery
6. Operator fails to de-energize CV-2646 and CV-2648 (with consideration of hot-short probability for CV-2646 or CV-2648)

As shown in the ANO-1 Calculations 02-E-0004-01 and 02-E-0004-02, the CCDPs calculated for the two fire zones for the different fire scenarios are provided below:

Fire Zone 98-J East Area	CCDP with No Operator Recovery	CCDP with Operator Recovery
All Redundant Cable Trains Failed	1.13 E-2	2.18 E-4
Red Train Protected	8.10 E-3	1.97 E-4

How was CCDP derived what does this mean if fire then this is result?

Fire Zone 98-J West 1 Area	CCDP with No Operator Recovery	CCDP with Operator Recovery
All Redundant Cable Trains Failed	5.38 E-4	1.39 E-4
Red Train Protected	5.38 E-4	1.39 E-4

Fire a Fire/Fail / CCDP

CCDP

Fire Zone 98-J West 2 Area	CCDP with No Operator Recovery	CCDP with Operator Recovery
All Redundant Cable Trains Failed	2.49 E-3	1.85 E-4
Red Train Protected	5.38 E-4	1.26 E-4

Fire Zone 99-M	CCDP with No Operator Recovery	CCDP with Operator Recovery
All Redundant Cable Trains Failed	5.76 E-2	1.27 E-3
Red Train Protected	7.96 E-3	8.32 E-4

Fire Zone 98-J Ignition Sources

	F_I	S_I	P1	P2	P3	F_{CDF}
Electrical Cabinets	1.9 E-3	0.75	0.05	0.5	9.2E-3	3.3E-7
Battery Chargers	7.6 E-4	0.75	0.05	0.5	9.2E-3	1.3E-7
Ventilation Subsystems	2.1 E-4	0.08	0.05	0.5	9.2E-3	3.0E-9
Fire Protection Panels	1.1 E-4	0.12	0.05	0.5	9.2E-3	3.0E-9
Emergency Chiller Pump	5.3E-5	0.08	0.05	0.5	1.4E-2	1.0E-9
Total CDF						4.7E-7

Fire Zone 99-M Ignition Sources

	F_I	S_I	P1	P2	P3	F_{CDF}
Electrical Cabinets	3.8 E-3	0.12	1.0	0.5	5.8E-2	1.3E-5
Transformers	3.2 E-4	0.10	1.0	0.5	5.8E-2	9.3E-7
Ventilation Subsystems	1.1 E-4	0.08	1.0	0.5	5.8E-2	2.6E-7

6. Integrated Assessment of Fire-Induced Core Damage Frequency

The fire-induced CDF estimate for fire in the fire zones 98-J and 99-M with no operator recovery actions is calculated as shown below:

estimate of 9.2E-3 (summed over all portions of fire zone 98-J) was used in the risk analysis of the fire scenarios involving these ignition sources. In the case of the fire scenario involving the emergency chiller pump, the pool fire with a flame height of 6 feet and burn duration of 7.5 minutes was postulated to impinge on the cable insulation of the non-IEEE-383 rated cables on the lowest cable tray that is located about 6 feet from the floor. It was concluded that the turbulent diffusion flame impingement on the cables would cause potential ignition and flame spread along the cable trays, and thereby further increases the HRR in the fire zone 98-J. It is likely that a fire from this pool fire may damage both equipment trains at the same time. Therefore, the CCDP estimate of 1.4E-2 (summed over all portions of fire zone 98-J) was used in the risk analysis of this fire scenario.

For the fire scenarios in fire zone 99-M involving ignition of the electrical cabinets, transformers, and ventilation systems, it is assumed that both equipment trains would not be available to perform mitigating functions because the Red train cables are not protected with one-hour rated barrier, and are not separated from the Green train cables by a minimum of 20 feet distance free of intervening combustibles. Therefore, the CCDP estimate of 5.8 E-2 was used in the risk analysis of the fire scenarios in fire zone 98-M.

7: Incremental Fire-Induced CDF

The baseline CDF (conforming case) for the fire scenarios in the fire zones 98-J and 99-M with credit of operator recovery actions is calculated by assuming the manual suppression failure probability of 0.1. This value is used for the manual suppression capability because it is considered to be appropriate for the entire population of fires, including severe fires, arising from an ignition source. The fire protection SDP methodology, which uses the entire population of fires as the basis to derive an ignition frequency, also uses the probability value of 0.1, in general, for the failure probability of nondegraded manual suppression capability. The baseline CDF with credit of operator recovery actions for the conforming case analyses are shown below:

Fire Zone 98-J Ignition Sources	F_I	P1	P2	P3	F_{CDF}
Electrical Cabinets	1.9 E-3	0.05	0.1	4.6E-4	4.0E-9
Battery Charger	7.6 E-4	0.05	0.1	4.6E-4	1.0E-9
Ventilation Subsystems	2.1 E-4	0.05	0.1	4.6E-4	5.0E-10
Fire Protection Panels	1.1 E-4	0.05	0.1	4.6E-4	3.0E-10
Emergency Chiller Pump	5.3E-5	0.05	0.1	5.4E-4	1.0E-10
Total CDF					6.0E-9

Fire Zone 99-M Ignition Sources	F_I	P1	P2	P3	F_{CDF}	w/o credit (5.76 E-3)
Electrical Cabinets	3.8 E-3	1.0	0.1	1.3E-3	4.9E-7	2.19 E-5
Transformers	3.2 E-4	1.0	0.1	1.3E-3	4.1E-8	1.84 E-6
Ventilation Subsystems	1.1 E-4	1.0	0.1	1.3E-3	1.4E-8	6.35 E-7
Total CDF					5.5E-7	2.43 E-5

Therefore, the incremental CDF changes due to taking credit for operator recovery actions for fire scenarios in fire zones 98-J and 99-M are estimated as follows:

A. Fire zone 98-J: (4.7E-7) - (6.9E-9) = 4.6E-7

B. Fire zone 99-M: (1.4E-5) - (5.5E-7) = 1.3E-5

[no credit for op. recov. actions]

CONCLUSION: The change in CDF due to taking credit for operator recovery actions for fire scenarios in fire zone 98-J is 4.6E-7, and the significance characterization is GREEN. The change in CDF due to taking credit for operator recovery actions for fire scenarios in fire zone 99-M is 1.3E-5, and the significance characterization is [redacted] Ex 5