AEOD TECHNICAL REVIEW REPORT*

UNITS: Maine Yankee
Haddam Neck
DOCKET NOS: 50-309 and 50-213
LICENSEES: Maine Yankee Atomic Power
Northeast Utilities
NSSS/AE: Combustion Engineering/Stone & Webster
Westinghouse/Stone & Webster

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EVALUATOR/CONTACT: E. Leeds

SUBJECT: EMERGENCY DIESEL GENERATOR COOLING WATER SYSTEM DESIGN DEFICIENCIES AT MAINE YANKEE AND HADDAM NECK

SUMMARY

On June 25, 1985, during a review of systems required for safe shutdown, personnel at Maine Yankee identified a design deficiency that could result in a common mode failure of the cooling water supply for the onsite emergency diesel generators (EDGs). At Maine Yankee, the cooling water supply to the EDGs depended on the proper operation of air-operated temperature control valves and plant personnel determined that a credible single failure could cause a loss of the air supply to these valves, resulting in a loss of cooling water flow to the EDGs. On November 1, 1985, a probabilistic safety study for the Haddam Neck plant identified a previously unrecognized failure sequence that could result in a loss of all cooling water flow to the onsite EDGs due to a single component failure. At Haddam Neck, EDG cooling water flow also depended on proper operation of air-operated supply valves. The probabilistic study found that a single component failure could result in a loss of power to the solenoid air pilot valves that control the position of the cooling water supply valves. A loss of power also resulted in the cooling water valves to both EDGs failing closed. The design deficiencies at Maine Yankee and Haddam Neck were investigated and evaluated to assess their potential applicability to other nuclear plants.

The study found the use of air-operated valves to control the EDG cooling water supply to be unique to the Maine Yankee and Haddam Neck plants. The study also found that the use of an automatic bus transfer (ABT) device at Haddam Neck (to ensure the availability of redundant power supplies to a vital motor control center for emergency core cooling equipment) was also apparently plant unique. However, the interaction and potential adverse impacts of degraded or failed nonsafety-grade air systems on safety-related nuclear plant systems is currently being evaluated on a generic basis in an ongoing AEOD case study on plant air systems. It is suggested, therefore, that the design deficiencies identified at Maine Yankee and Haddam Neck be considered for inclusion in the plant air systems case study.

*This document supports ongoing AEOD and NRC activities and does not represent the position or requirements of the responsible NRC program office.

DISCUSSION

Recently, independent design reviews at Maine Yankee and Haddam Neck identified deficiencies at each plant that could result in common mode failure of the cooling water supply to the onsite EDGs. A sustained interruption or complete loss of cooling water without prompt operator actions would cause the EDGs to overheat and subsequently fail. In view of the significant adverse safety implications associated with the identified design deficiencies, a study was initiated to review the EDG cooling water system configurations at Maine Yankee, Haddam Neck and other early-generation light water reactor plants to determine if the design deficiencies had potential applicability to other nuclear power facilities.

Design Review Experience

1. Maine Yankee

On June 25, 1985, during a design review of the systems required for safe shutdown and accident mitigation, personnel at Yankee Atomic Electric Company identified a deficiency in the cooling water control system for the onsite EDGs (Ref. 1). The design deficiency was such that a single component failure could potentially disable the cooling water supply to both EDGs. At Maine Yankee, two diesel generators provide emergency onsite ac power, with each cooled by a separate component cooling water system. The 'A' EDG heat exchanger is cooled by the "primary" component cooling water (PCCW) system and the 'B' EDG heat exchanger is cooled by the "secondary" component cooling water (SCCW) system. Each EDG cooling water supply is regulated by a separate air-operated temperature control valve. However, both control valves share a common air supply (Figure 1). Because the temperature control valves are designed to fail closed on a loss of air, a single failure in the air supply could have resulted in a loss of cooling water to both EDG heat exchangers.

The licensee's immediate corrective action was to align the back-up fire water cooling supply to the EDG heat exchangers to allow automatic transfer to fire water cooling in the event of a loss of the air supply. However, leakage past the supply valves allowed untreated fire water to contaminate the PCCW and SCCW systems. The contamination of the PCCW and SCCW systems was determined to be unacceptable by the licensee since both systems utilize demineralized water treated with corrosion inhibitors. Therefore, on June 26, 1985, following a determination that full cooling water flow through the EDG heat exchangers would be acceptable with respect to lube oil and jacket water temperatures, heat exchanger tube erosion, and component cooling flow demand, the temperature control valves were blocked open to provide continuous full flow to the heat exchangers. The fire water temperature control valves were then reisolated to prevent fire water leakage into the PCCW and SCCW systems.

2. Haddam Neck

On November 1, 1985, a probabilistic safety study for the Haddam Neck plant identified a scenario that could result in a loss of cooling water flow to both EDGs by the failure of a single component (Ref. 2). At Haddam Neck, two diesel generators provide onsite emergency ac power. Each EDG has a cooling water supply with an air-operated control valve which opens to allow cooling water to

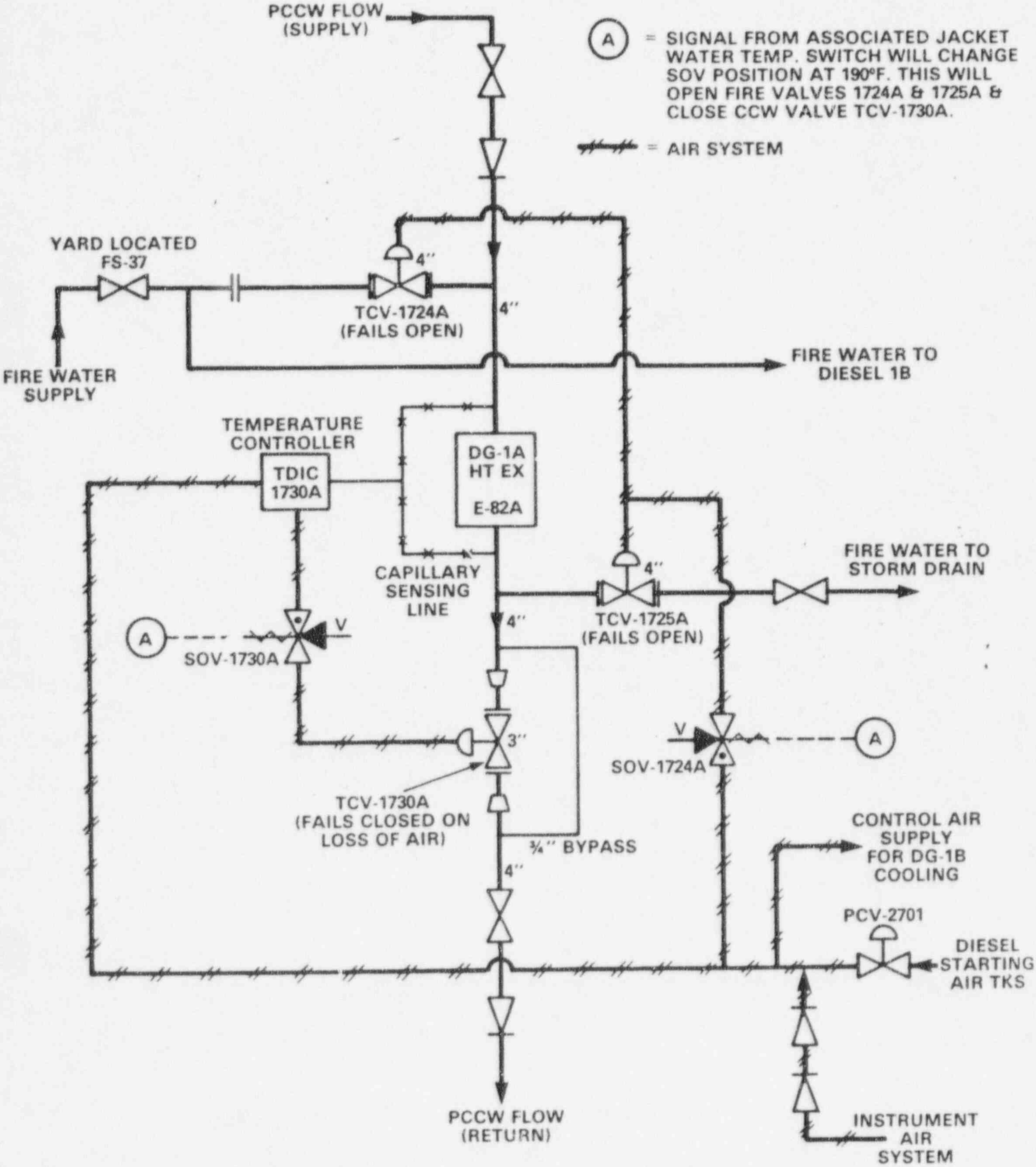

Figure 1 Cooling Water Control Schematic for "A" EDG at Maine Yankee

flow from the service water system to the EDG heat exchanger when the EDG starts. The cooling water supply valves fail open on a loss of air pressure. However, each air-operated cooling water supply valve is positioned by a solenoid air pilot valve. With the solenoid valve energized, air is vented from the air-operator allowing the cooling water supply valve to open. Both solenoid valves receive control power from a common motor control center (MCC). This MCC (MCC-5) can be supplied emergency ac power from either EDG via an ABT (Figure 2). As seen from the figure, the ABT interlocks the output breakers from Bus 5 and Bus 6 so that only one of the two breakers can be shut at any time. If the bus supplying power to MCC-5 is deenergized, the ABT automatically opens the deenergized output breaker and closes the alternate bus output breaker (if the alternate bus is energized). The ABT ensures a continuous power supply to MCC-5. Since ac power is required for the solenoid valves to energize (and thereby open the cooling water supply valves), a loss of offsite power coincident with an interruption of emergency power to MCC-5 could cause a simultaneous loss of cooling water flow to both EDG heat exchangers.

The licensee's immediate corrective action was to evaluate the consequences of maintaining the cooling water supply valves in the full open position to ensure cooling water flow to the EDG heat exchangers. Based on this review, the licensee modified the cooling system by blocking open the cooling water supply valves. The licensee is also monitoring the EDG lube oil temperatures daily to ensure the lube oil temperature remains above 85°F in accordance with the EDG manufacturer's specifications.

Analysis and Evaluation

1. Maine Yankee

At Maine Yankee, the 'A' EDG heat exchanger is cooled by the PCCW system and the 'B' EDG heat exchanger is cooled by the SCCW system. When the plant was originally constructed, both EDG heat exchangers relied on the site fire water system for a backup source of cooling water. Fire water cooling to either EDG heat exchanger was designed to be automatically initiated if : (1) EDG jacket water temperature reached 190°F, then fire water cooling supply valves (TCV-1724A and TCV-1725A) would open and the temperature control valve (TCV-1730A) would close (see Figure 1); or (2) a complete loss of the air supply occurred, then the temperature control valve would fail closed and the fire water cooling supply valves would fail open. The licensee isolated the backup fire water cooling supply in late 1981, however, because the fire water leakage past the supply valves was causing contamination of the PCCW and SCCW systems. The licensee believed that isolating the fire water cooling supply was not a safety concern because the temperature control valves that regulate the normal cooling water supply to the EDG heat exchangers are equipped with a seismically qualified, safety-grade backup air supply.

Normally, each EDG temperature control valve receives its air supply from the instrument air system, which is a nonsafety-grade system. The instrument air system consists of three motor-driven air compressors powered from vital buses. Additionally, the temperature control valves and the fire water cooling supply valves must remain operable during all postulated accidents. Therefore, the instrument air system has a back-up tie-in from the diesel air starting system

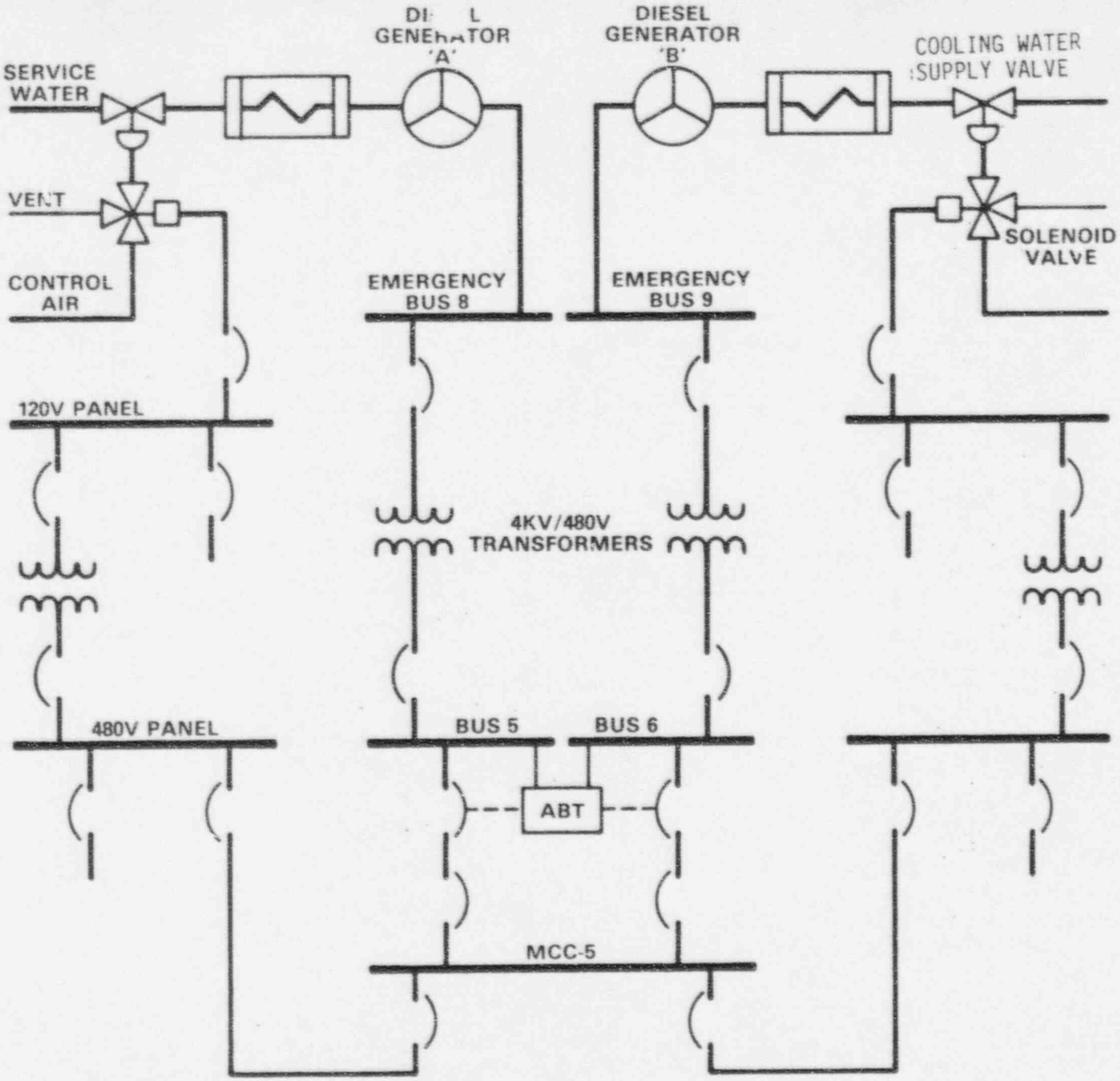

Figure 2 Emergency Electric Distribution for MCC-5 at Haddam Neck

which is a seismically qualified, safety-grade system. The instrument air system supplies air at 95 psi to both the temperature control valves and the fire water cooling supply valves through a common piping header. The diesel air starting system is a 200 psi system which supplies a back-up source of air to the valves through a single regulating valve, PCV-2701, which is connected to a common piping header (see Figure 1). If instrument air system pressure drops below 40 psi, the regulating valve will open and regulate the back-up air system pressure to maintain 95 psi air pressure in the header.

During a review of the systems required for safe shutdown and accident mitigation, personnel at the Yankee Atomic Electric Company found that the single failure of the back-up air supply regulating valve (PCV-2701) coincident with a loss of offsite power could result in the loss of cooling water to both EDG heat exchangers. Following a loss of offsite power, the instrument air system compressors would lose power, resulting in a loss of the normal (instrument) air supply to the temperature control valves. A failure of the backup air supply regulating valve would then result in a complete loss of air to the temperature control valves. With a loss of air pressure the temperature control valves would fail closed and the fire water control valves would fail open to allow backup fire water cooling to the heat exchangers. However, because the fire water cooling supply system had been isolated, a loss of the normal and backup air supplies to the temperature control valves would result in a complete loss of cooling water to both EDG heat exchangers.

The licensee's corrective action consisted of blocking open the temperature control valves to provide continuous full cooling flow to both EDG heat exchangers. The temperature control valves were originally designed to be positioned by a temperature controller to maintain a 25°F delta-temperature across each EDG heat exchanger (see Figure 1). This arrangement was used to balance the component cooling water flow demand. However, the licensee determined that full cooling flow through the heat exchangers was acceptable in regard to the cooling loads of the PCCW and SCCW systems. Additionally, full cooling flow to the heat exchangers did not impact on the EDG lube oil and jacket water temperatures because each EDG has an internal "thermostat" to specifically regulate the lube oil and jacket water temperatures. Finally, the licensee determined that full cooling flow would not adversely increase the rate of heat exchanger tube erosion. Therefore, blocking the temperature control valves open was acceptable and would eliminate the possibility of a loss of air supply causing a loss of cooling water to both EDG heat exchangers.

2. Haddam Neck

At Haddam Neck, control air pressure overcomes an internal spring force to shut the cooling water supply valves for the EDG heat exchangers. When control air pressure is lost, the cooling water supply valves will "fail safe," i.e., the spring force will open the valves to ensure a cooling water supply to the EDG heat exchangers. The air supply to each cooling water supply valve is controlled by a three-way solenoid air pilot valve. When an EDG is not running, its associated solenoid valve is deenergized, allowing control air pressure to be supplied to the air actuator of the cooling water supply valve keeping the supply valve closed. When an EDG starts, the solenoid valve is energized and repositions, venting air from the air actuator. The spring force will then open the cooling water supply valve allowing cooling water flow to the EDG heat exchanger. The control air system at Haddam Neck uses large accumulators which maintain air pressure in the event that the compressors are lost. However, if electrical power to the solenoid valves is lost, the solenoid valves will not reposition. In such an event, with air pressure available, the cooling water supply valves will remain closed. Therefore, a loss of electrical power to the solenoid valves would result in a loss of cooling water flow to the EDG heat exchangers.

The solenoid air pilot valves for both EDGs are supplied electrical power from MCC-5. This MCC normally is supplied by offsite power though emergency Buses 8 and 9. The MCC is supplied with emergency ac power from either EDG via an ABT (Figure 2) in the event that offsite power is unavailable. The scenario identified by the licensee, which could lead to a loss of cooling water to both EDGs, involves a postulated loss of offsite power and the coincident failure of the ABT for MCC-5. The ABT failure sequence is as follows: Initially, offsite power is assumed to be supplying Buses 5 and 6 and the preferred source selector switch for the ABT is assumed to be set for Bus 5. In this alignment, Bus 5 is supplying power to MCC-5 (the Bus 5 output breaker is shut). The scenario begins with a loss of offsite power which results in a loss of power to emergency Buses 8 and 9 and consequently to Buses 5 and 6. As soon as the electrical frequency associated with Bus 5 decreases by a predetermined amount, the ABT, as designed, would open the Bus 5 output breaker. However, since the electrical frequency associated with Bus 6 would also decrease by the same amount, the ABT will not shut the bus 6 output breaker. Thus, MCC-5 would be deenergized with both Bus 5 and Bus 6 output breakers open. However, the EDGs start following a loss of offsite power and begin to load 10 to 13 seconds later. When the EDGs reenergize Buses 5 and 6, the ABT would sense that the selected source (Bus 5) had electrical power and would attempt to shut the Bus 5 output breaker. It is postulated that the Bus 5 output breaker fails to close (single failure). By design, the ABT would continue to attempt to shut the selected source (Bus 5) output breaker as long as the bus had electrical power. The ABT will not transfer and shut the alternate source (Bus 6) output breaker unless electrical power to Bus 5 is interrupted or an operator selects bus 6 with the ABT's preferred source selector switch. Thus, MCC-5 would be deenergized with neither Bus 5 nor Bus 6 supplying power. In this situation, the EDG cooling water supply valves would remain closed since the solenoid valves would have no power to reposition to vent air from the cooling water supply valve air actuators.

To fully evaluate the significance of this failure mode, background information regarding MCC-5 is presented. MCC-5 is a single 480 volt distribution bus which powers many vital loads (such as the motor-operated injection valves) for both safeguards trains. However, MCC-5 is not a single failure proof power distribution center. Furthermore, MCC-5 was not originally required to meet the single failure criterion. This fact had been identified and determined to be acceptable by the then Atomic Energy Commission in the safety evaluation for the plant's operating license. Subsequently, the use of an ABT (to provide redundant power supplies to MCC-5) was discussed at an Advisory Committee on Reactor Safeguards (ACRS) subcommittee meeting held in Washington, D.C. on April 7, 1983 (Ref. 3). The meeting was held to review the results of Phase II of the Systematic Evaluation Program as applied to the Haddam Neck plant. Questions raised by the subcommittee prompted an analysis to evaluate the availability of power for vital equipment powered from MCC-5. The analysis, performed in 1983 and utilizing probabilistic risk assessment (PRA) techniques, determined that the frequency of a loss of power to MCC-5 is 9E-4/yr (Ref. 4). This frequency was based on the yearly testing interval at Haddam Neck for the ABT and associated breakers. If a monthly test interval is assumed for these components, the frequency drops to 7.3E-4/yr. The analysis also determined that the frequency of a total station blackout, a loss of offsite power coincident with the failure of both EDGs, is 7.2E-4/yr. Therefore, it appeared that the probability of losing power to MCC-5 was of the same order of magnitude as a total station blackout.

The failure scenario for the ABT identified in the new probabilistic safety study completed by Northeast Utilities (the licensee) significantly affects the probabilistic frequency for a loss of power to MCC-5 (Ref. 5). The scenario presented in the new study (previously discussed in this report) was not identified in the 1983 PRA.

Based on the new scenario, the frequency of a loss of power to MCC-5 is calculated as follows:

$$F(MCC\text{-}5) = F(LOSP) * P(BKR)$$

where:

F(MCC-5) = frequency of a loss of power to MCC-5
F(LOSP) = loss of offsite power frequency
P(BKR) = probability of a breaker failing to close

For Haddam Neck, F(LOSP) is assumed to be .2/yr and P(BKR), based on its yearly testing interval, is approximately 1.0E-2. Therefore, F(MCC-5), the frequency of a loss of power to MCC-5, becomes 2.0E-3 (Ref. 5). The current PRA indicates that the frequency of a loss of power to MCC-5 is an order of magnitude greater than the probability of a loss of offsite power coincident with a failure of both EDGs for other causes. Thus, a loss of power to the solenoid valves controlling the EDG cooling water supply valves was determined to be a significant safety concern.

The licensee blocked the EDG cooling water supply valves open by removing the control air lines which provide the air pressure necessary to hold the valves closed. This eliminates the potential for a loss of electrical power to MCC-5 to cause a loss of cooling water to the EDG heat exchangers. However, redundant and nonredundant equipment necessary for safety injection is still powered from MCC-5. A coincident loss of MCC-5 during a postulated loss of coolant accident (LOCA) would prevent initiation of safety injection and could lead to core damage. The resident inspector at Haddam Neck has raised this concern with the licensee (Ref. 6). The licensee stated that the probability of a LOCA with a loss of offsite power and coincident loss of MCC-5 is sufficiently low that immediate corrective action is not required. Region 1 has requested the Office of Nuclear Reactor Regulation (NRR) to review the potential concerns resulting from the new higher probability scenario for a loss of MCC-5 (Ref. 7). The region has also requested NRR to take the lead responsibility for reviewing the recently completed probabilistic safety study and for determining whether the

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*The frequency of a loss of a single ac bus is small enough so that the loss of offsite power will dominate the frequency for a loss of power to the buses.

licensee's plan of action regarding potential MCC-5 failure consequences during a postulated LOCA or main steam line break is acceptable.

Generic Applicability

To generically assess the extent to which air-operated valves are used in EDG cooling water systems, the EDG cooling systems at eight operating plants were reviewed. Because Stone and Webster (S&W) was the architect engineer (A/E) for both Maine Yankee and Haddam Neck, the review included four S&W plants: North Anna, Surry, Beaver Valley and Fitzpatrick. The other plants included in the review were licensed some time before or after Maine Yankee and Haddam Neck. These were: Ginna, Oyster Creek, Quad Cities and Fort Calhoun. None of the plants examined used air-operated valves in their EDG cooling water systems (Ref. 8). Six of the plants used manually operated valves which were locked open to permit full cooling water flow through the EDG heat exchangers. One plant used a motor-operated valve for cooling water control and one plant uses air-cooled EDGs. For additional independent verification, Reference 9 was reviewed to assess whether significant EDG failure operating experiences were reported to have been caused by air-operated valve problems associated with the EDG cooling supply. The review of Reference 9 revealed no evidence of other plants utilizing air-operated valves in their EDG cooling water control systems. Due to the absence of data involving the loss of EDG cooling water (Ref. 9) caused by air-operated valve problems, it was concluded that the deficiencies associated with the design of the EDG cooling water systems at Maine Yankee and Haddam Neck were unique to those plants. Therefore, this issue does not appear to be a generic concern.

Similarly, the issue of using an ABT to provide redundant power supplies for ECCS equipment was examined to assess its generic applicability. Historically, the Nuclear Regulatory Commission has required that ECCS equipment be supplied by separate and redundant power sources. Exceptions to these requirements (e.g., MCC-5 at Haddam Neck) appear to have been accepted by the AEC on a case-by-case basis for some of the earlier licensed plants. To determine if any other operating plants have vital motor control centers or load centers which receive normal and alternate power supplies through an ABT device, the design of six plants licensed in the 1960s and early 1970s were reviewed. They were: Quad Cities, Ginna, Zion, Oconee, Oyster Creek and Fitzpatrick. None of these plants were found to have an ABT arrangement similar to the design for MCC-5 at Haddam Neck (Ref. 10). Therefore, it appears that this arrangement is also unique to Haddam Neck and is, therefore, not a generic concern.

FINDINGS AND CONCLUSIONS

Both of the design deficiencies evaluated in this study identified the potential for a failure in a nonsafety-related system to adversely affect the onsite safety-related EDG systems. Specifically, at Maine Yankee, the loss of the nonsafety-related air supply to the temperature control valves could have resulted in a loss of cooling water flow to the EDG heat exchangers. At Haddam Neck, an interruption of power to the solenoid air pilot valves (which control the position of the EDG cooling water supply valves) could have resulted in a loss of cooling water flow to the EDG heat exchangers. A sustained interruption or complete loss of cooling water would cause the EDGs to overheat and subsequently fail without prompt operator actions. The corrective action taken at both plants was virtually identical, uncomplicated and adequate - the air-operated valves controlling the cooling water supply to the EDG heat exchangers were blocked open. Blocking the valves open, in effect, eliminated the potential adverse interaction between the safety-related system (i.e., the EDG cooling water system) and the nonsafety-related system (i.e., the air supply system). However, a review of the EDG cooling water system designs at eight nuclear plants has led to the conclusion that the use of air-operated valves in EDG cooling water systems is unique to the Maine Yankee and Haddam Neck plants and that this issue is, therefore, not a generic concern.

At Haddam Neck, the use of an ABT to provide redundant power supplies to MCC-5 was initially reviewed in the licensing process for the original plant design and was again accepted during the Systematic Evaluation Program review of existing plant system configurations. However, a recently completed probabilistic safety study identified a previously unrecognized failure mechanism for the ABT which significantly affects the probabilistic frequency for a loss of power to MCC-5. The licensee found that a loss of MCC-5 would cause the loss of cooling water to both EDGs and took appropriate corrective actions. However, significant redundant and nonredundant equipment necessary for safety injection is also powered from MCC-5. A coincident loss of MCC-5 during a postulated LOCA would prevent initiation of safety injection and could lead to core damage. Region 1 has requested that NRR take lead responsibility to review the recently completed probabilistic safety study and determine whether the licensee's plan of action regarding potential MCC-5 failure consequences during a postulated LOCA or main steam line break is acceptable. A review to generically assess the use of ABTs to provide redundant sources of power to ECCS equipment concluded that this type of arrangement is unique to Haddam Neck and is, therefore, also not a generic concern.

SUGGESTIONS

At both Maine Yankee and Haddam Neck, the cooling water supply to the EDG heat exchangers is dependent on the proper operation of air-operated control valves. The interaction and impact of nonsafety-grade air systems on other nuclear plant systems is currently being evaluated on a generic basis by an AEOD case study on plant air systems. Therefore, it is suggested that the design deficiencies identified at Maine Yankee and Haddam Neck be included in the plant air systems case study.

The use of an ABT to provide redundant power supplies to emergency core cooling system equipment appears to be unique to the Haddam Neck plant. Since Region I has requested that NRR review the ABT issue at Haddam Neck, it is suggested that no further AEOD review on this subject be taken at this time.

REFERENCES

1. Licensee Event Report 85-006, Maine Yankee Atomic Power Plant, Docket No. 50-309, June 25, 1985.

2. Licensee Event Report 85-029, Haddam Neck Plant, Docket No. 50-213, November 1, 1985.

3. Letter from J. C. Ebersole, ACRS, to N. J. Palladino, Chairman, NRC, Subject: ACRS Report on the Systematic Evaluation Program Review of the Haddam Neck Plant, May 17, 1985.

4. D. Gallagher and others, "Review and Assessment of Various Automatic Bus Transfer Designs for Haddam Neck," performed for USNRC by Science Applications, Inc. May, 1983.

5. Telecommunications between E. Leeds and F. Akstulewicz, NRC, and M. Bain, J. Bickle and D. Dube, Northeast Utilities, February 13, 1986.

6. NRC Inspection Report No. 50-213/85-21, January 5, 1986.

7. Memorandum from R. W. Starostecki, NRC, to F. Miraglia, NRC, Subject: Increased Potential for Loss of Offsite AC Power Leading to Loss of Emergency Core Cooling, February 18, 1986.

8. Telecommunications between E. Leeds (AEOD) and the resident inspectors at North Anna, Surry, Beaver Valley, Fort Calhoun, Ginna, Oyster Creek, Quad Cities and Fitzpatrick, April 10, 1986.

9. NUREG/CR-2989, "Reliability of Emergency AC Power Systems at Nuclear Power Plants," by R. E. Battle and D. J. Campbell, July, 1983.

10. Telecommunications between E. Leeds (AEOD) and the resident inspectors at Quad Cities, Ginna, Zion, Oconee, Oyster Creek and Fitzpatrick, April 10, 1986.