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ATTACHMENT 3

April 4, 1990

MEMORANDUM TO: Ledyard B. Marsh, Chief
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Division of Systems Safety and Analysis

THRU: George T. Hubbard, Chief
BOP Systems Section
Plant Systems Branch
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FROM: Ann M. Dummer
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SUBJECT: FINAL REPORT ON PRA FOR EQ-TAP TASK 5.b

In 1992, EQ began to attract attention w[illegible] the License Renewal and Environmental Review Project Directorate staff presented their Draft Branch Technical Position (BTP) on EQ for License Renewal to the ACRS and tests performed by Sandia National Laboratories (Sandia) resulted in failures or marginal insulation resistance for some types of qualified cables. The BTP focused on the difference between qualification standards for older and newer plants (IEEE 323/1971 and 1974), advocating re-qualification or upgrade of all EQ components for license renewal. The staff was directed to evaluate the adequacy of EQ, and the BTP for license renewal was nullified by redefining EQ as an "operating reactor issue."

As for all issues facing a potential backfit, the staff performed a PRA for EQ. A potential use of the study was to support the BTP if "old" EQ was found to be inadequate. Probabilistic Safety Assessment Branch (SPSB) staff performed a preliminary risk scoping study which concluded that, if the reliability of environmentally qualified components is reduced by the presence of a harsh environment encountered under accident conditions, the probability of core damage would significantly increase. As a result, the PRA was used in addition to the BTP and the Sandia tests to justify working on EQ as a generic issue.

The scope of the preliminary risk scoping study was limited to core damage prevention, considering internal events only, and to in-containment electric equipment, with emphasis on cables. Highlights of this report are included in Attachment 1. The major objective of the preliminary risk scoping analysis was to identify electric equipment that must function in accident-induced harsh environments and that could be major contributors to core damage. Emphasis was placed on cables because cables are not routinely replaced and receive minimal maintenance, if any. The major conclusions of the preliminary risk scoping analysis are (1) EQ failures could have significant risk impact if electric component reliabilities are reduced in the presence of a harsh environment, (2) the magnitude of the impact on core damage frequency is plant specific, and (3) lack of reliability data bases and limitations in current probabilistic risk assessment models resulted in significant uncertainty in these preliminary results. In the preliminary risk scoping assessment report, the staff made recommendations for further evaluation of the risk impact of EQ.

In parallel with the preliminary risk scoping study, the staff developed a task action plan on EQ which included a task item identified as a "final PRA." Based on the preliminary risk scoping study, the staff had enough concern with the risk significance of EQ to pursue further work. The main intent of the "further work" was to determine whether data existed that could be used to perform a more accurate PRA. Subsequent to the staff's risk scoping study of EQ, Argonne National Laboratory (Argonne), under contract to the NRC, performed additional work on the risk impact of EQ and produced a letter report in October 1993. Highlights of the Argonne study are included in Attachment 2. The objective of this work was (a) to investigate the availability and extent of adequate reliability data for electrical equipment components in harsh environments; (b) to investigate other potential sources of information on reliability data in harsh environments, such as the results of testing programs sponsored by the government or industry; (c) to assess whether this information can be used with PRA techniques to perform a defendable assessment of risk impacts associated with EQ issues; and (d) identify areas where more data are needed as well as approaches of obtaining such data (with special focus given to cable systems).

The literature review performed by Argonne showed that no reliability data bases exist for the performance of electrical components in harsh environments. The investigation of other potential sources of related information included: test data from the TMI-2 accident; work on cable systems sponsored by EPRI; tests performed at Sandia on cables, electrical penetrations, terminal blocks, pressure switches, pressure transmitters, and radiation monitors; and tests performed for NRC for solenoid operated valves. From the review presented in this work, Argonne concluded that the available information cannot be used with PRA techniques to perform a defendable assessment of risk impact associated with EQ issues because there is not enough data to obtain defendable failure rates for the different components of cable systems. This conclusion is also supported by the insights of equipment qualification experts on the use of equipment qualification data to derive quantitative measurements of reliability.

Experts interviewed as part of the Argonne work agreed that qualification data cannot be used for reliability because a limited number of samples was tested for qualification. The issue of reliability has not been addressed in current qualification practices. Although qualification tests are intended for design verification and prevention of common cause failures due to harsh environment, such tests focus on successful testing and failures were never reported in qualification reports. Therefore, no conclusion about reliability of components in accident conditions can be made using qualification data because the available data only reflect successful tests and do not reflect all test experience.

When the nonexistence of EQ reliability data was confirmed by Argonne, the staff put PRA work "on hold" until Brookhaven National Laboratory's (BNL) comprehensive EQ literature was completed. The staff hoped this literature review would uncover additional information or data that could be used to continue work in PRA. However, the BNL literature review provided no additional insight into the use of PRA for EQ.

To complete the action plan item on PRA, the staff reviewed the previously discussed activities, with focus on Sandia's 1989 publication, NUREG/CR-5313, "Equipment Qualification (EQ)-Risk Scoping Study." This report was used as a reference in both the staff's preliminary risk scoping study and Argonne's study. A summary of this report is included in Attachment 3. The purpose of this study was to assess whether any historical EQ issues, related to the implementation of the EQ rule, that were subjects of past NRC research appear to have any significant impact on risk. The study provides insights and a systematic framework for examining equipment survivability issues for individual plants. This study also provides an extensive evaluation of risk-important equipment that could be affected by accident environments.

In NUREG/CR-5313, the authors first developed a list of candidate risk significant equipment that must function in accident-induced harsh environments and whose failure would be risk significant. Second, they identified those components (cables, solenoid operators, etc.) for which harsh environment reliabilities might differ substantially from the reliability values based on normal operation conditions employed in past PRAs. These two activities provided a qualitative data base to support risk analysis of the candidate equipment operations in a harsh environment. Risk importance analyses were performed by assessing the impact of completely unreliable and perfectly reliable equipment on risk (risk achievement and risk reduction). This approach circumvented numerous constraints imposed by current EQ and PRA practices. The same approach could be used by licensees for evaluations based on a plant-specific PRA to identify risk important EQ components for condition monitoring. Such an evaluation could either include all systems modeled for the plant-specific PRA or be limited to the components identified in NUREG/CR-5313.

In order to perform a quantitative risk assessment for EQ, it is necessary to have adequate reliability data for equipment operations in harsh environments. The staff, Argonne and BNL searched for such reliability data. They all concluded that available information and data cannot adequately support quantitative risk assessments of EQ issues. The lack of data is due to the fact that qualification tests were not designed to provide reliability data and no reliability testing has been performed for equipment in a harsh environment. Sandia developed a method in NUREG/CR-5313 to evaluate risk significant equipment operations which could be used on a plant-specific basis, but plant-specific analysis is outside the scope of the EQ TAP risk activities. Therefore, no more work should be performed on PRA for the EQ-TAP.

This closes Task 5.b of the EQ Task Action Plan. The insights from the preliminary risk scoping study, the Argonne study, and NUREG/CR-5313 should be reviewed for the Status Review, Task 6 of the EQ Task Action Plan.

Attachments: As stated

"Risk Impact of Environmental Qualification Requirements for Electrical Equipment at Operating Nuclear Power Plants."

Nicholas T. Saltos, SPSB/NRR

March 30, 1993

CONCLUSIONS

- Core damage frequency estimates for both PWR and BWR plants could increase significantly if electrical equipment reliabilities are reduced due to the presence of a harsh environment.
- Current PRA perceptions regarding important risk contributors could change if electrical equipment reliabilities are reduced due to the presence of a harsh environment.
- The magnitude of core damage frequency impact is plant specific.
- Due to the lack of reliability data bases and the limitations in current PRA models, an accurate assessment of the risk associated with harsh environments is not possible at this time.

SPECIFIC EQUIPMENT IDENTIFIED

Electrical components that support risk significant operations in harsh environments:

- Solenoid and motor operators inside containment
- Steam generator level detection circuits in PWRs

These devices/systems, including cables, connectors, penetrations, and transmitters are susceptible to thermal degradation of electronics and age degradation of seals with subsequent moisture intrusion.

IMPORTANT SEQUENCES

Risk-important core damage sequences and related in-containment components facing harsh environments were identified.

PWRs

- Large and medium LOCAs affect MOVs required to open 15-18 hours into the accident to provide hot leg recirculation.
- Small and transient-induced LOCAs affect SG level detectors which impact AFW operation and affect PORV solenoid and block valve operators; therefore contributing to failure of "feed and bleed" operation after AFW failure.

BWR

- Intermediate and small LOCAs followed by random failure of HPCI affect SRV solenoid operators.
- Transient with loss of suppression pool cooling (TW sequence)* affects SRV and MSIV solenoid operators and MSIV bypass valve motor operators.

*It was subsequently found by Argonne (see Argonne Draft Letter Report "Identification, Characterization, and Evaluation of Risk Important Accident Scenarios Related to EQ Issues," December, 1993) that the TW sequence may not be as significant when credit is taken for high pressure injection with a control rod drive (CRD) pump.

ATTACHMENT 2

"Collection and Evaluation of Existing Reliability Data for Electrical Equipment Performance in a Harsh Environment - A Literature Review,"
N.A. Hanan and C. P. Tzanos
Argonne National Laboratory
October, 1993

This document summarizes EQ test results for a variety of components. The authors reviewed reports on TMI-2 equipment performance; EPRI work on cables; Sandia tests of cables, penetrations, terminal blocks, pressure switches, pressure transmitters, and radiation monitors; and Franklin Research Center testing of solenoid operated valves.

From the TMI-2 work, Argonne concluded that most equipment failures were predominantly a result of moisture intrusion that generally occurred at the electrical penetration to a device.

Based on review of previous test results, the authors identified the following EQ components that could have increased failure rates as a result of an accident harsh environment:

- cables
- electrical penetration assemblies
- pressure switches
- solenoid operated valves

Appendix I summarized expert opinion on the subject of elicitation for severe environment reliability of equipment. The experts interviewed agreed that qualification data cannot be used for reliability because a limited number of samples was tested for qualification. The issue of reliability has not been addressed in current qualification practices. Qualification tests are intended for design verification and prevention of common cause failure due to harsh environment. Since qualification focused on successful testing and documentation of the equipment, failures during qualification testing were never reported in qualification reports. Therefore, no conclusion about reliability of components in accident conditions can be made using qualification data because the available data only reflect successful tests and do not reflect all test experience.

ATTACHMENT 2

NUREG/CR-5313, "Equipment Qualification (EQ)-Risk Scoping Study"

L.D. Bustard et al.
Sandia National Laboratories

January 1989

APPROACH

The authors first developed a list of candidate risk significant equipment that must function in accident-induced harsh environments and whose failure would be risk significant. Second, they identified those components (cables, solenoid operators, etc.) for which harsh environment reliabilities might differ substantially from the reliability values based on normal operation conditions employed in past PRAs. These two activities provided a qualitative data base to justify harsh environment parametric risk achievement analysis for the candidate equipment operations. This project approach circumvented numerous constraints imposed by current EQ and PRA practices.

Historically, equipment qualification has been concerned with loss of coolant accidents (LOCAs), main steam line breaks (MSLBs) and high energy line breaks (HELBs). PRAs, on the other hand, are concerned with a much more diverse set of accident sequences.

Current PRA calculations assume early loss of equipment function during the accident. Equipment failure due to harsh environments may not be immediate, allowing some initial core cooling. For example, in both the TW BWR sequence (transient with loss of suppression pool cooling) and the transient-induced or small break LOCA PWR sequences equipment reliability data for steam, temperature, and pressure conditions would be useful for PRA, but early radiation accident conditions are not assumed for these sequences. However, much of the available [qualification] data that characterizes the accident performance for solenoid and motor operators includes a 200 Mrad radiation exposure prior to simulating the steam/temperature conditions.

CONCLUSIONS

- From a PRA perspective, the EQ issue of whether correct accident acceleration techniques have been used is not risk significant. Also not risk significant are: simultaneous versus sequential accident simulations, presence of oxygen in the test chamber, simulation of beta with gamma.

- From a PRA perspective, much safety-related equipment inside containment need not function in an accident radiation environment; the remaining equipment needs to function during radiation conditions for a few hours to a few days.

- Hydrogen control equipment inside containment would be exposed to risk significant radiation conditions substantially less than currently employed during EQ testing.

- Currently the importance of the accident radiation dose is overemphasized. The current overconservatism in assumed radiation during EQ-testing may actually impact risk adversely (see SG level detector example).

- For the steam generator level transmitters the authors note that PRAs do not model the transmitter harsh environment reliability in determining the auxiliary feedwater system reliability. Degraded transmitter o-rings may produce a common-cause susceptibility to moisture degradation.

The following issues have potential applicability to safety-related components with potential risk significance. Additional investigation may by warranted:

1. Adequate sealing/protection of safety-related circuits from moisture intrusion/condensation effects.
2. Choice of ambient environments as a basis for equipment qualification.
3. Humidity aging effects.
4. Choice of accident environments for equipment qualification.
5. Use of alternative test approaches (multiple sample reliability assessment and/or fragility testing) to complement current qualification type testing.
6. Accelerated aging methods for nuclear station batteries.

PREVIOUS WORK

The authors evaluated a number of previous studies on PRA and/or EQ and developed the following "Historical PRA Insights:"

NUREG 1150, "Reactor Risk Reference Document," draft February 1987
The intersection of an elevated environment and a significant risk reduction interval or risk increase interval provides the possibility of a significant EQ impact on PRA results. Systems designed to mitigate consequences of an accident (i.e., containment integrity systems and fission product scrubbing mechanisms) which are of less importance to core damage potential than risk mitigation are the very systems which could see the most severe environmental conditions after the onset of core damage. Calculations based on single component failures do not provide a complete perspective regarding the potential for common-cause equipment failure to impact risk.

NUREG/CR 4144, "Importance Ranking Based on Aging Considerations"
Components within safety systems that had many moving parts were the most risk significant components susceptible to aging effects. These included MOVs in the emergency injection systems and sources of emergency power and signal processing.

NSAC/36, "Importance Ranking in Equipment Qualification"
This industry document concluded that actions such as plant modifications or operating procedure changes may be a more cost effective method for achieving risk reduction than proving qualification for safety-systems of an older plant.

NUREG/CR-3762, "Identification of Equipment and Components Predicted as Significant Contributors to Core Damage"
The purpose of this study was to identify components predicted to be significant contributors to dominant severe accident sequences. Equipment identified by this screening process includes power operated relief valves (PORVs), motor-operated valves (MOVs), solenoid operated valves (SOVs), main steam isolation valves (MSIVs), electrical cables, connectors, and limit switches.

NUREG/CR-4537, "Electrical Equipment Performance in Accidents"
This study as designed to determine the performance of safety related equipment under severe accident conditions. The results of the study indicated that safety relief valve actuation assemblies and main steam isolation valve solenoid control assemblies are risk significant equipment items with the potential of seeing environmental stress in excess of qualification levels.

SPECIFIC EQUIPMENT AND SEQUENCES

Steam Generator Level Detectors and PORVs and Associated Block Valves

NRC requirements that EQ testing be based on "instantaneous release" of part of the core inventory have potentially increased the feedwater-related scram rates for PWRs. The impact of this NRC requirement on PWR feedwater scram rate should be further investigated to provide a basis for possible modification of the NRC requirement.

Steam generator level transmitters are an example of equipment currently qualified for accident radiation conditions even though PRA does not model their use after core melt. From a PRA perspective if auxiliary feedwater to the steam generators is being used to maintain core cooling, then the steam generators must boil dry prior to core melt. Thus the transmitters are not needed after core melt when the accident radiation conditions would occur.

For many plants these same steam generator level detectors are used to initiate a feedwater trip during normal operation. The setpoints for allowable variation in the steam generator level during normal operation are partially based on the accident accuracy of the steam generator level transmitters. Manufacturers' tests indicate that the dominant contribution to transmitter inaccuracy is caused by the accident radiation exposure. For example, Barton specified for its transmitters a 3% inaccuracy during steam/thermal exposures but a 10% inaccuracy during radiation exposures. Hence, NRC's instantaneous radiation release requirement currently controls feedwater trip setpoints. Eliminating this regulatory requirement might allow greater flexibility during plant operation with respect to steam generator level. This might reduce the number of feedwater trips that act as initiating events for PRA accident sequences.

The primary environments of concern are small break steam and temperature conditions. Chemical sprays, radiation, and hydrogen burn conditions are not applicable from a PRA perspective since they occur after initiation of core damage. Poor sealing against moisture intrusion would have to be considered a primary concern. SOV and MOVs would only be required to function for a few hours of high dose rate exposures. Confirming calculations regarding actual equipment radiation exposure conditions may be warranted.

BWR SRVs and MSIVs

In the TW sequence (transient with loss of suppression pool cooling), containment cooling can be restored by opening the MSIVs in the harsh environment caused by high suppression pool temperatures and pressures. Environmentally-induced failure of the MSIVs leading to failure to restore the power conversion system is currently not modelled by PRA analysis. Even though the environments surrounding the MSIVs have worsened as the TW sequence progresses, PRAs currently calculate that recovery becomes more probable (i.e., PRAs currently do not account for environmental failures of the MSIVs). Of primary concern for the MSIVs would be the solenoid operators, the limit switches, the cabling, the electrical connections and seals, the electrical penetrations, and the motor operated bypass valve operator and controls.

To obtain a bounding estimate for the potential impact of MSIV failure on core damage frequency, the authors assumed non-recovery of the power conversion system for those sequences which could produce a harsh environment in containment. This resulted in, at most, a factor of two increase in base case core damage frequency in the plants analyzed.

Of concern for the SRVs would be the solenoid operators, the cabling, the connections, the electrical penetrations, and the valve position indication devices. There is a potential impact on equipment operability from humidity effects, connection interfaces, and sealing techniques. In addition, there is evidence that accident equipment reliability differs from normal operation equipment reliability. Therefore, RELIABILITY testing of solenoids under accident conditions may be worthwhile.

HPCI, RCIC, and HPCS pumps

In BWRs, the HPCI, RCIC, and HPCS pumps are located outside containment. PRAs currently assume failure of these pumps when suppression pool temperatures exceed 210-240°F.

For BWR/4s, for non-station blackout sequences, operability of HPCI/RCIC pumps during high suppression pool temperature conditions is only risk significant if the harsh suppression pool conditions concurrently impact the reliability of the MSIVs and the SRVs. Core damage frequency contributions from TW sequences (transient with loss of suppression pool cooling) can become significant and substantially alter current PRA perceptions regarding the risk significance of the TW sequence when all these systems (HPCI/RCIC, SRV and MSIV) are affected by common-cause high suppression pool/containment temperatures.

The current design basis EQ requirements for HPCI or HPCS pumps generally lack PRA significance. Demonstration that HPCI, RCIC, and HPCS pumps would be reliable when they pump high temperature water from the suppression pool (water temperatures up to 385°F) could substantially reduce core damage frequencies for some plants.

PWR Containment Fans

The authors recommend additional PRA analyses to determine whether PWR containment fan operation is sufficiently risk significant to warrant substantial equipment qualification attention. Fan coolers are assumed to fail either because of cable failure in the harsh radiation and steam conditions or because of clogging by core debris and aerosols. If fan operation is deemed to be sufficiently risk significant, then consideration of humidity aging effects and appropriate lubrication and maintenance activities may be appropriate.

BWR and PWR High Range Radiation Monitors

The high range radiation monitor would detect the loss of the UO_2 ceramic barrier via an increased signal for radiation levels within containment. The high range radiation monitor is one of the few signals available to the operator to indicate loss of ceramic integrity. Containment area radiation levels of the order 1E+3 R/h or greater would suggest that the fuel ceramic barrier is being lost via core melting.

The largest risk impact due to operation of High Range Radiation Monitors is for the early release accident sequences. For early release scenarios, containment failure follows core melt by at most a few hours. There does not appear to be a risk basis for requiring a factor of two accuracy for the radiation monitor in the full range of 1 R/h to 1E+7 R/h. Radiation monitor signals in the low ranges are below those that indicate significant core melt and hence would likely not initiate emergency response decision making.

This closes Task 5.b of the EQ Task Action Plan. The insights from the preliminary risk scoping study, the Argonne study, and NUREG/CR-5313 should be reviewed for the Status Review, Task 6 of the EQ Task Action Plan.

Attachments: As stated

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Ledyard B. Marsh

This closes Task 5.b of the EQ Task Action Plan. The insights from the preliminary risk scoping study, the Argonne study, and NUREG/CR-5313 should be reviewed for the Status Review, Task 6 of the EQ Task Action Plan.

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ATTACHMENT 4

POSSIBLE USES OF PROBABILISTIC RISK ASSESSMENT TO GAIN RISK INSIGHTS ON ENVIRONMENTAL QUALIFICATION

BY

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There are two potential uses of probabilistic risk assessment (PRA) to gain risk insights in to environmental qualification (EQ). One use of PRA would be to use it to categorize and prioritize equipment with respect to its being on a condition monitoring list. While all the potentially vulnerable equipment may not typically be modeled in the PRA directly (instrumentation for example), it would be relatively easy to find the right "hooks" (basic events or gates) in the model with which to associate the relevant equipment. For this purpose, the aim would be to identify equipment that has aged or deteriorated so that it no longer would survive the environment for which it is qualified. In this case the categorization or ranking would be performed using the scenarios for which the equipment is required rather than those for which the EQ stresses are exceeded.

Another use is to use the PRA to explore the appropriateness of the EQ design basis accident scenarios. To do this requires using the PRA to identify whether there are realistic scenarios that can result in the environment becoming harsher than that assumed in the EQ tests. Or, put another way, are the EQ test design basis accidents bounding in terms of the environmental stresses expected in the range of scenarios identified by the PRA. One example of this would be concerns associated with flooding, i.e., equipment designed for steam and high temperature environments becoming submerged because, for example, of containment flooding in BWRs. To address this issue it would be necessary to identify whether there were any sequences in which EQ equipment were to become submerged, and whether any credit is taken for their operability.

There are two issues to look at; the role of the equipment in preventing core damage, and the role of the equipment in determining the containment failure probability and therefore the radionuclide release and public risk. The flooding example above is likely to be more of an issue for risk than core damage, because it only becomes a concern when a lot of water is put into containment, either directly (containment flooding in a BWR) or indirectly (for a PWR as an example, through a hole in the RCS, followed by failure to go to sump recirculation, necessitating maintenance of cooling by refilling the RWST).

It is likely to be the case that it would not be possible to use many PRAs directly without modification. Many BWR PRAs do not model containment flooding as a core damage prevention strategy, but they may include it in the

Level 2 portion of the PRA. Also, for PWRs, there are few examples in which the PRAs model RWST refill as a prevention strategy. These are typically very low frequency scenarios, and, in addition, it is likely that the impact on risk may be minimal since they take a long time to develop, and are probably not LERF contributors.

It should be noted further that, for the assessment to be appropriate, the PRA model should reflect the way the plant would be operated in accordance with the EOPs, and standard plant practices. In PRA a particular success strategy is typically adopted for representation in the event tree. So, for some Westinghouse PWRs PRAs, for small LOCAs, the success path is that the operators cooldown and depressurize the reactor (using AFW as the heat sink) to establish RHR, and minimize the break flow. Many PRAs, however, model the sequence of events as continuation of SI until the RWST is depleted, followed by switch over to high pressure recirculation, and heat removal via the RHR heat exchangers. In either case, the AFW would not be required for more than a few hours, and EQ concerns about the steam generator level sensors may be minimal.