Insights From 44 Years Of NRC Fire Protection Inspections

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Abstract: Following the fire at Browns Ferry Unit 1 on March 22, 1975, the U.S. NRC issued *"Appendix R to Part 50 - Fire Protection Program for Nuclear Power Facilities Operating Prior to January 1, 1979"* with significant new requirements for fire protection and protection of safe shutdown equipment. Over the more than four decades since "Appendix R" was published, this document has become a model for governments around the world to set baseline requirements for nuclear fire protection. These basic requirements also formed the foundation for all the US plant Fire PRAs. What is clear today is that the basic rule was often misunderstood resulting in significant false starts and rework by utilities. This paper will attempt to highlight some of the more important lessons learned from the many years of compliance and inspection of U.S. Nuclear plants against the requirements of "Appendix R."

Keywords: Fire Protection Program, Reactor Oversight Process (ROP), Fire, Post Fire Safe Shutdown Analysis

1. PAPER OVERVIEW

- Introduction
- Key US Regulatory Milestones
- Common Examples of Lessons Learned in Post-Fire Safe Shutdown Analyses
- Conclusions

2. INTRODUCTION

Appendix R to 10CFR 50 was a significant step forward in improving safety because it established specific criteria for protection of systems and components required for safe shutdown from the effects of fire. Following the issuance of Appendix R, significant progress was made to improve safety, but the lack of consensus standards and detailed NRC guidance made progress difficult and expensive Many utilities experienced significant re-work on their path to implement the NRC requirements.

The original Appendix R consisted of 9 pages of text. It is interesting to note that to date, more than 19,000 pages of additional regulatory requirements and industry guidance has been written on the implementation of the requirements of Appendix R. In the year 2000, the NRC implemented the Reactor Oversight Process which included systematic inspections of licensees' safe shutdown capability. This organized NRC inspection initiative brought fresh NRC and industry scrutiny to the implementation of safe shutdown analyses for US nuclear power plants.

3. Key Regulatory Milestones

As stated in the Introduction, the ARS library contains more than 19,000 pages of regulations, guidance documents, and inspection reports related to 10 CFR 50, Appendix R (post-fire safe shutdown) implementation. Most of the significant insights from these documents are contained in the following 12 regulatory and guidance documents. These documents continue to have a significant and lasting impact on the implementation of US post-fire safe shutdown analyses.

- 10 CFR 50 and Appendix R - Nov. 1980 [4]
- NRC, GL 81-12, "Fire Protection Rule (45 FR 76602, November 19, 1980)," Washington, DC, February 20, 1981, and Clarification Letter, March 1982. [5]
- NRC, Information Notice (IN) 84-09, "Lessons Learned from NRC Inspections of Fire Protection Safe Shutdown Systems (10 CFR 50, Appendix R), February 13, 1984. [7]
- NRC, GL 86-10, "Implementation of Fire Protection Requirements," April 24, 1986, and Supplement 1, "Fire Endurance Test Acceptance Criteria for Fire Barrier Systems Used to Separate

Redundant Safe-Shutdown Trains Within the Same Fire Area," Washington, DC, March 25, 1994. [10]
- NRC, GL 88-12, "Removal of Fire Protection Requirements from Technical Specifications," Washington, DC, August 2, 1988. [11]
- Nuclear Energy Institute (NEI), NEI 00-01, "Guidance for Post-Fire Safe-Shutdown Circuit Analysis," Revision 4, Washington, DC, September 2016. IP71111.05 - March 2003 [24]
- NRC, NUREG-1852, "Demonstrating the Feasibility and Reliability of Operator Manual Actions in Response to Fire," Washington, DC, October 2007. (ADAMS Accession No. ML073020676) [19]
- NRC, Inspection Procedure (IP) 71111.05, Fire Protection (Annual) – March 2003 [8]
- NRC, Inspection Procedure (IP) 71111.05T, Fire Protection (Triennial) - March 2003 [9]
- NUREG 1805 – December 2004 [1]
- RG 1.189 –Nuclear Regulatory Commission, Regulatory Guide 1.189, Fire Protection For Nuclear Power Plants, April 2001

4. Common Examples of Lessons Learned in Post-Fire Safe Shutdown Analyses

The following are a few examples of common errors in post-fire safe shutdown analyses that have been identified in audits and inspections of post-fire safe shutdown analyses.

4.1 Identifying too many components (SSEL)

As part of the safe shutdown equipment selection the systems and paths necessary to achieve and maintain safe shutdown for an exposure fire event are identified. While it is important to identify the SSD Functions, Systems & Paths, identifying additional components that are <u>not</u> needed for compliance significantly complicates the analysis and could result in unnecessary plant modifications.

<u>Example: Auxiliary Feedwater Pump flow indication</u>
Appendix R, Section III.G.2 [4] does not specify what instrumentation needs to be protected for post-fire safe shutdown. If all "Train A" safety related instrumentation were selected as required for safe shutdown, all AFW instrumentation could be identified as required. This would likely include, but not be limited to valve position indication, pump flow indication, etc. Subsequent NRC guidance in IN 84-09 [7] established that Steam Generator level indication would provide adequate instrumentation to confirm AFW flow. If the additional components such as flow indication, valve position indication, pump amperage, etc. were selected as SSD components, then cable selection and cable routing for these components would likely identify separation issues and mitigating strategies could include re-routing cables, installation of expensive fire wrap, construction of new fire barriers, or even installation of dedicated shutdown equipment or systems. Identifying too many components often results in spending resources on mitigating strategies that are not necessary for compliance and often do not improve safety.

From NRC Information Notice IN 84-09 [7]:

"The following lists provide the minimum monitoring capability the NRC staff considers necessary to achieve safe shutdown:

Instrumentation Needed for PWRs
a. Pressurizer pressure and level.
b. Reactor coolant hot leg temperature or exit core thermocouples, and
cold leg temperature.
c. Steam generator pressure and level (wide range).
d. Source range flux monitor.
e. Diagnostic instrumentation for shutdown systems.
f. Level indication for all tanks used (e.g., CST)

Information Needed for BWRs
a. Reactor water level and pressure.
b. Suppression pool level and temperature.

c. Emergency or isolation condenser level.
d. Diagnostic instrumentation for shutdown systems.
e. Level indication for all tanks used"

4.2 Failure to identify components that could adversely affect safe shutdown (SSEL)
As part of the safe shutdown equipment selection the systems and paths necessary to achieve and maintain safe shutdown for an exposure fire event are identified. Failure to identify all the components that could adversely affect safe shutdown (SSEL) can mask vulnerabilities and increase fire risk.

<u>Example: VCT Isolation Valves</u>
Most PWRs identify the RWST flowpath to the charging or safety injection pumps as the post-fire safe shutdown path that needs to be protected for Appendix R safe shutdown. Because the charging pumps are normally supplied by the VCT, spurious closure of the VCT isolation valves before the RWST valves are opened could result in loss of NPSH and damage to the charging pumps – which could result in failure of the safe shutdown path. Failure to identify components that could result in failure of safe shutdown paths can result in a non-compliance with Appendix R, III.G.2 separation and could contribute to increased risk.

4.3 Inadequate methodology for Cable Selection

Once safe shutdown methodologies are established and the Safe Shutdown Equipment List is developed, the post fire safe shutdown analysis relies heavily on the identification of cables that could adversely affect safe shutdown. Identification of the cables that affect safe shutdown is a key element in developing the safe shutdown analysis and determining the effects of fire on the ability to safely shutdown for each fire area or zone.

Once the cables are identified and the routing is determined, the analyst can determine the fire effects on post-fire safe shutdown for each fire area.

Although the importance of not missing required cables seems obvious, selecting too many cables can also have a significant negative impact on safe shutdown by expending project resources to identify routing of cables that do not adversely affect safe shutdown, and identifying and implementing mitigating strategies for these cables.

Because there were no consensus standards for cable selection in the early years after Appendix R to 10 CFR 50 was issued, this has been perhaps the biggest area of re-work for US utilities.

This issue even continues today as many plants implementing Fire PRA discover that the original Safe Shutdown Cable Selection methodology missed cables that are important to safety.

4.4 Qualification of Fire Barrier Materials
Once the safe shutdown analysis identifies separation issues (against the requirements of 10 CFR 50, Appendix R), mitigating strategies are identified to resolve the separation issues. One common mitigating strategy is the use of fire wrap to achieve a 1 hour or two hour fire barrier. The example below illustrates the importance of thorough review of the qualification documentation for the fire barrier material.

<u>Example: Fire Barrier Qualification - Salem</u>
Over the years between the issuance of 10 CFR 50, Appendix R [4], and approximately 1997 - Salem Nuclear Generating Station, Unit Nos. 1 and 2 installed an extensive amount of 1 hour fire wrap to meet the requirements of Appendix R, Section III.G.2. Some estimates indicated that Salem Nuclear Generating Station had installed in excess of 5 linear miles of fire wrap material.

Between April 14 and 18, 1997 [56], the NRC performed a Fire Protection Follow-up Inspection at

Salem that determined that qualifications associated with the three fire barrier systems could not be determined. As documented in NRC letter to PSEG Nuclear in June 2001 [57] the PSEG response to these findings committed to resolving the issues by the following three options:

1. Upgrade the fire wrap material per the revised safe shutdown analysis;

2. Evaluate the current configuration using risk-informed and performance-based methods in order to minimize the amount of fire wrap material that needed replacement; and

3. Study the feasibility of installing a cross-tie (piping) system between each units charging system boric acid storage tanks (BATs), and cross-ties between the volume control tanks (VCTs) and refueling water storage tanks (RWSTs). The purpose of the cross-ties would be to minimize Salem's reliance on fire wrap material necessary to provide a 1-hour barrier to allow for safe shutdown in the event of a fire at one of the plants.

Salem ultimately implemented an extensive safe shutdown re-analysis and implementation of an "alternative or dedicated shutdown" strategy using cross-ties from the opposite unit. This approach meant that much (if not most) of the extensive fire wrap originally installed was a wasted effort that did not achieve compliance or improve safety.

The USNRC has issued many regulatory guidance documents related to fire barrier material integrity and documentation including but not limited to:

NRC, IN 91-47 "Failure of Thermo-Lag Fire Barrier Material to Pass Fire Endurance Test", dated August 6, 1991

NRC, IN 91-79 "Deficiencies Found in Thermo-Lag Fire barrier Installation", dated December 6, 1991

NRC, IN 91-79, Supplement 1, "Deficiencies Found in Thermo-Lag Fire barrier Installation", dated August 4, 1994

NRC, IN 92-46 "Thermo-Lag Fire Barrier Review Team Findings, Current Fire Endurance Tests, and Ampacity Calculation Errors", dated June 23, 1992

NRC, IN 92-55 "Current Fire Endurance Test Results for Thermo-Lag Fire Barrier Material", dated July 27, 1992

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NRC, IN 94-86 "Legal Actions Against Thermal Science, Inc., Manufacturer of Thermo-Lag", dated December 22, 1994

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NRC, IN 95-27, "NRC Review of Nuclear Energy Institute, Thermo-Lag 330-1 Combustibility Evaluation Methodology Plant Screening Guide", dated May 31, 1995

NRC, IN 95-32 "Thermo-Lag 330-1 Flame Spread Test Results", dated August 10, 1995

NRC, IN 95-49, "Seismic Adequacy of Thermo-Lag Panels", dated October 27, 1995

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NRC, GL 06-03, "Potentially Nonconforming Hemyc and MT Fire Barrier Configurations", April 10, 2006.

NRC, IN 05-07, "Results of HEMYC Electrical Raceway Fire Barrier System Full Scale Fire Testing", April 1, 2005

The lesson learned from this example is the importance of verifying that fire wrap or fire barrier materials are well qualified and documented before selection for the safe shutdown mitigation strategy.

4. CONCLUSION

At the time that 10 CFR 50, Appendix R was issued, consensus standards and guidance documents for implementation of the Appendix R requirements largely did not exist for US Nuclear Utilities. The result was that achieving compliance was slow, and in some cases took nearly two decades to achieve - at a cost of significantly more than was necessary due to confusion and re-work.

The US nuclear industry has seen a significant improvement in fire safety – as indicated both in the decline in NRC inspection findings related to fire protection in triennial fire protection inspections and in improvement in US Plant Fire PRA results. This significant reduction in inspection findings and improvement in safety can be attributed to continued NRC focus as part of the Regulatory Oversight Process, stability of NRC compliance expectations, and implementation of industry consensus standards in key areas.

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