FIRE RISK MANAGEMENT, INC.
Fire Protection Engineers & Code Consultants

Flood Penetration Seal Performance
at
Nuclear Power Plants

Flood Penetration Seal Assemblies at Operating Nuclear Power Plants

Task 1.1
of
Contract No.: NRC-HQ-60-15-C-0010

Provided To:

U.S. Nuclear Regulatory Commission
One White Flint North
11555 Rockville Pike
Mailstop 03-E17A
Rockville, MD 20852-2738

Provided By:

Fire Risk Management, Inc.
1 Front Street
Bath, ME 04530
207/442-7200

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Table of Contents

INTRODUCTION

The March 2011 disaster that occurred at the Fukushima Daiichi nuclear plant in Japan highlighted the potential damage that can be caused as the result of a significant flooding event. Many of the commercial nuclear power plants (NPPs) in the U.S. are known to be located in areas that are subject to potential flooding events of varying degrees of severity. Equally, flooding damage is not restricted to an external event. Due to the high volume of water that is used inside NPPs for cooling, fire suppression and other auxiliary systems, the potential exists for flooding to also occur within a plant as a result of damage to internal piping. Areas within NPPs that may contain equipment/systems that are important to safety and that have been identified as being susceptible to flooding damage must be properly protected, which may include the need for the walls and/or floor/ceiling assemblies that bound these areas to be designated as "flood barriers." As such, any penetrations through a barrier that is designated to be flood-resistance must also be designed and installed to mitigate the potential for water intrusion through the penetration opening.

Subsequent to the Fukushima nuclear incident, the Nuclear Regulatory Commission (NRC) issued a request for information pursuant to Title 10 of the Code of Federal Regulations (CFR), Section 50.54(f), regarding the design-basis flood estimates used at NPPs and requesting that each site perform a walkdown, using the Nuclear Energy Institute (NEI) Walkdown Guidance 12-07, to verify compliance with their current licensing basis (CLB) for protection and mitigation from external flood events. This included an evaluation of flood seal assemblies installed in any penetrations that existed in barriers that were designated to be flood-resistant; albeit the NEI guidance focuses primarily on "visual" reviews of the various flood-credited penetration seal assemblies. Additionally, NRC staff performed a number of site surveys at NPPs. As outlined in a number of the NRC's Audit Reports and Information Notices (INs) that were reviewed[1], numerous penetration seal assemblies installed in barriers designed to be flood-resistant were in a degraded condition or could not be verified as being appropriate for use in supporting flood mitigation. The NRC also issued an additional request for information (RAI) on December 23, 2013; *Request for Additional Information Associated with Near-Term Task Force Recommendation 2.3 Flooding Walkdowns Available Physical Margin (APM)*.

Associated with its audit of Licensee flood protection walk-downs and a review of the Licensee walkdown reports, the NRC Staff also noted that there did not appear to be any form of regimented test methodologies being used by the Licensees to verify or quantify the level of performance associated with specific flood seal assemblies. Without a set of methodologies that can be used to test and evaluate the performance of specific flood seal configurations, it is not possible to verify whether or not a specific penetration seal assembly can adequately support the flood mitigation requirements for the various NPPs.

As part of an overall effort to evaluate and quantify the expected performance of flood penetration seal assemblies, including types/configurations that are currently being credited by NPPs as part of their flood mitigation strategies, the NRC began a research task to develop a flood penetration seal testing methodology that could be used to assess the performance and reliability of those

[1] Data regarding Information Notices reviewed that contained data pertinent to this research effort are included in Appendix A.

seals that are used (credited) at NPPs. The initial phase of this research effort (Task 1.1) was to conduct a review of the types of flood penetration seals that are currently being credited by NPPs in the U.S. to support their flood mitigation strategies. The primary objective for this initial review is to develop a series of candidate flood penetration seal assemblies that will then be included as representative example seal configurations in the subsequent testing phase (Task 2) of this research effort. This report summarizes the results of this initial research and provides recommendations for some of the candidate seal assembly configurations that are to be subjected to the proposed test methodology(s) that are to be developed for evaluating the performance of flood penetration seals.

DISCUSSION

The overall objective for this research project is to develop a test methodology that could be used to evaluate the effectiveness and performance of the various types of seal assemblies that are installed in barriers designed to prevent the intrusion of water. This test methodology is not intended to be an NRC approved standard/guidance, but rather a starting point or framework for any additional testing work that could be developed into an industry consensus standard. To better understand the metrics that will be needed to support performance-based evaluations of penetration seal assemblies designed to prevent or mitigate the passage of water, it was considered prudent to develop an understanding of the types of flood seals, both materials used and prospective configurations for the installed penetrants that are currently being used within NPPs. To accomplish this, a detailed literature search was performed to obtain as much information as possible regarding the types, configurations, and numbers of penetration seal assemblies that are currently installed in NPPs throughout the U.S. and being credited as supporting flood mitigation. It is planned that the penetration seal assembly data that result from this initial review of the seal assemblies in the existing NPPs will form the basis for determining some of the candidate seal assemblies used in the second phase of this research effort (Task 2).

Review of Existing Flood-Credited Penetration Seal Assemblies

The primary source for much of the documentation that was reviewed in connection with this literature research was that which is publically available through the NRC's web-based Agency-wide Documents Access and Management System (ADAMS). Given that the NRC had previously submitted requests to all operating NPPs to provide input with regards to evaluations of their flooding risks subsequent to the Fukushima incident[2], those responses that were available on the ADAMS site were reviewed and represented a primary source of specific details regarding the individual penetration seal assemblies being used to support flood mitigation. Additionally, other documents available through ADAMS, along with other commercially-available sources were reviewed to identify potential seal configuration and performance data; including plant engineering documents provided to the NRC, Licensee Event Reports (LERs), fire tests, information available from vendors, and other NRC generated documents such as NUREGS, Information Notices (INs), and Inspection Reports.

[2] 180-day Response to NRC Request for Information Pursuant to 10 CFR 50.454 (f) Regarding the Flooding Aspect of Recommendation 2.3 of the Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident.

A review of approximately 54 Plants responses to the 10 CFR 50.54(f) Request for Information, Recommendation 2.3, Flooding, that were available through ADAMS resulted in the development of a database (MS Excel spreadsheet) with a population of approximately 1880 specific penetration seal assemblies that are flood-credited. The majority of the assemblies contained in this database were provided by a sampling of four (4) of the responding NPPs that provided significant installation details and are expected to be representative of typical plants.

The NRC Licensee Event Report (LER) database was also queried for flooding information. Using a general key word search for flooding 172 LERS were identified and reviewed; with twenty-eight providing some relevant information. Similar search processes identified 15 Information Notices (INs) and 13 Inspection Reports (IRs) that also provided some pertinent information on flooding issues at NPPs. Summaries (tables) of the penetration seal assembly data obtained from these various documents are contained in Appendix B.

The quality of the data that was included in the various plant responses to the NRC's requests for flooding evaluation information varied significantly. The number of described penetrations with flood-credited seals within the individual plant responses to the NRC ranged from 1330 to none. However, the vast majority of the responses included only the number of the flood penetration seals installed at their plant(s), but provided no other details regarding their type, size, or configuration. In some instances, the barriers themselves and not the individual penetrations were referenced in the reports. Other responses listed many penetrations as being "Not Immediately Judged as Acceptable" or as having "Restricted Access" or being "Inaccessible." Some responses only identified cases where some corrective action was taken for a specific seal assembly(ies).

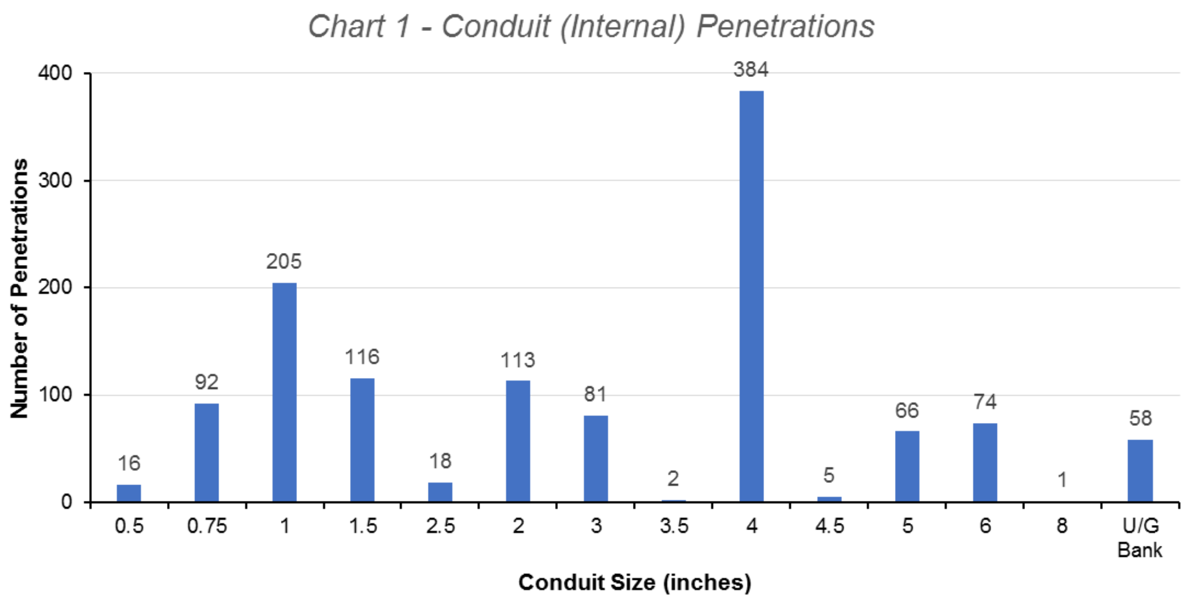
The specific penetration seal data that was available from the plant responses was collated based on the sizes and configurations of the various penetrations and penetrants. The types of seal assemblies/materials used to protect the penetrations also varied over a range of assemblies and materials; which are also listed below. The information contained in the following charts will be used to assist in the future decision-making process as to the configurations and types of seal assemblies that will be used as potential candidate penetration seal assemblies to be included in Task 2 (testing) of the overall research effort. Charts 1 through 4 below represent a general breakdown of these data; indicating the sizes of the penetrations, the types of penetrating items, and the numbers of flood-credited penetrations that were reported by the NPPs. Although only about 10% of the responses by the various NPPs included detailed information regarding the sizes and types of individual penetrations that were credited for flood mitigation, it is likely that these data are generally representative of penetrations that exist at other NPPs.

Although not all responses from the individual NPPs provided details on the seal assemblies, the data indicate that a wide range of seal materials and configurations exist within flood-credited barriers throughout the NPPs. In addition to the use of grout or mortar, the reported installed flood seal assemblies in NPPs include;

- Mechanical seals, such as "boot", "link" or compression seals,
- Grout, mortar, and concrete,
- Silicone foams; both high and low density,

- Epoxies and elastomers,
- Urethane,
- Caulking, and
- Combinations of various "fill" materials with the addition of an exterior "damming" material(s).

Depending on the specific manufacturer of the different types of materials being used, their individual formulations, which can affect how each will perform in supporting flood mitigation, can vary significantly. A review of the information provided by the NPPs did not include any specific basis on which to justify or qualify why specific seal assemblies were chosen or if the specific seal had been verified as being capable of supporting the specific flood mitigation requirements of the barriers in which they were installed.



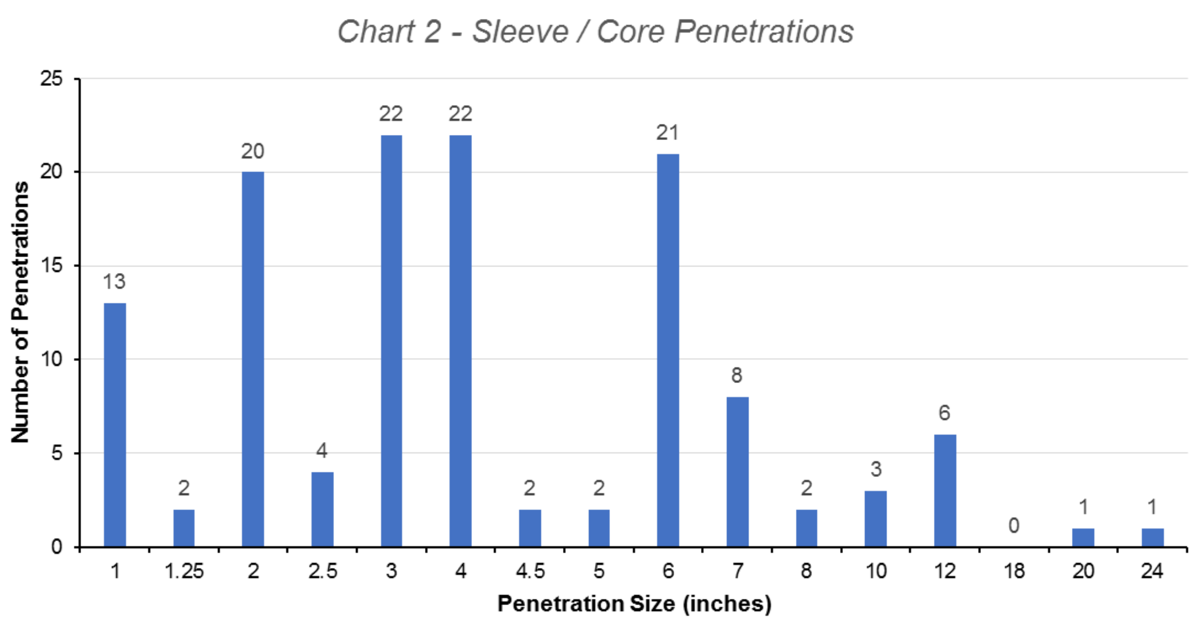


Chart 3 - Pipe Penetrations

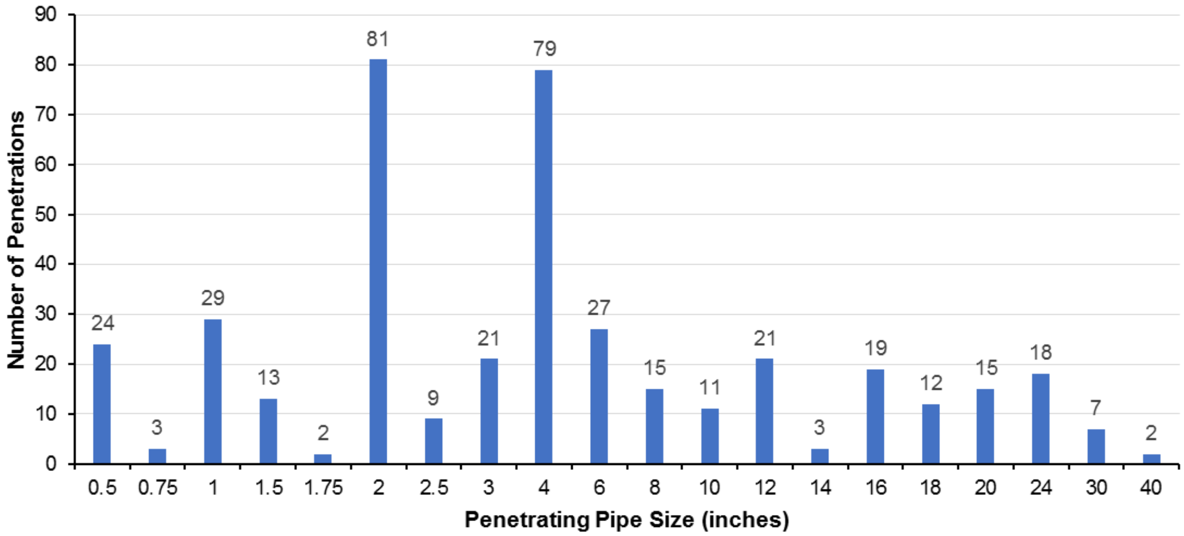
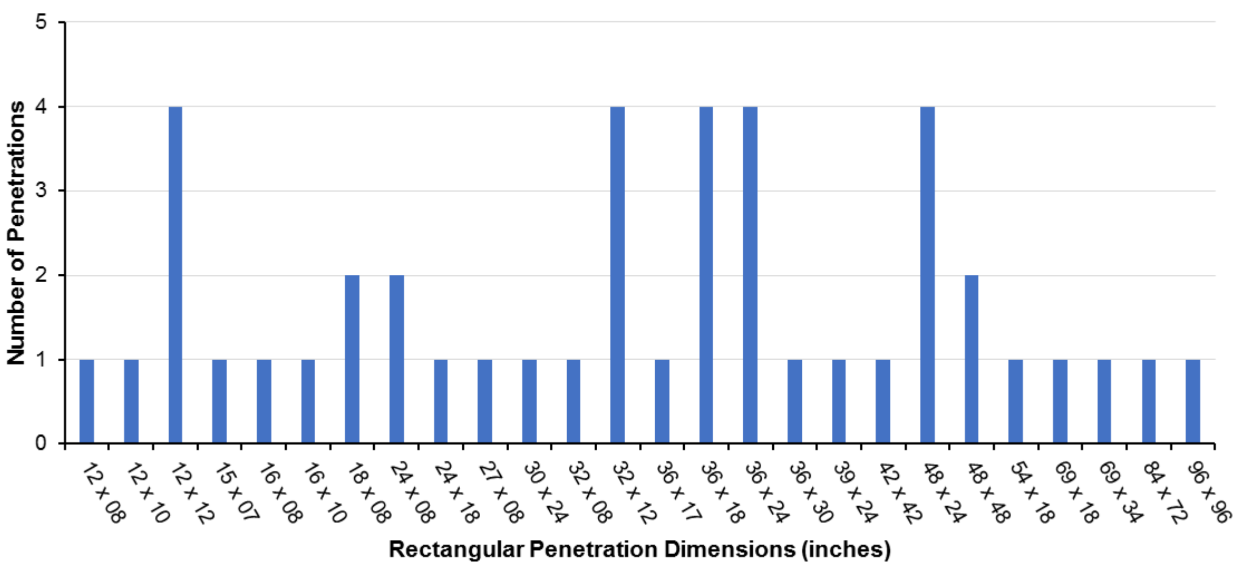


Chart 4 - Rectangular Penetrations



As noted in the charts above, the majority of the reported penetrations in credited flood barriers were either conduit, which are provided with internal seals, or pipe penetrations. Sleeved or core bored penetrations, which are often used to run multiple penetrants such as cabling or small pipes, were noted in numbers that were approximately half of those observed for single pipe penetrations. The larger rectangular openings that are often used to support large numbers of penetrants in a single penetration, such as those associated with multiple cable trays, represented the smaller subset of the data reviewed.

Also included in the data from the individual plants' responses to the NRC's query were examples of where flood seals were discovered as being deficient. Primarily, the deficiencies consisted of either no flood seal being installed in the penetration, such as inside conduits, or the seal assembly was not properly installed or was damaged and would not have been expected to prevent water intrusion. In several instances, the responses included identifying penetrations that exhibited evidence of prior water intrusion, but did not necessarily elaborate on a specific cause or failure mechanism; other than to state that some "leakage" was present. The plant responses also provided input with regards to the number of penetrations that were permanently sealed, such as through the use of a grout or where the penetrant had been cast in place when the barrier was originally constructed. These data also provided input on numerous flood seals that could not be inspected due to their inaccessibility; often the result of "congestion", whereby numerous penetrations exist within a single location/barrier.

In addition to the NPP responses to the NRC's request for information, the search of the ADAMS database for flooding-related data identified numerous LERs, INs, and IRs that contained information that provided additional insight into problems noted with regards to the installation of flood penetration seals, along with some examples regarding how these seals have performed. The following represents a brief listing of the most common issues and lessons-learned that were noted within the various documents reviewed, whereby problems pertaining to the performance of seal assemblies used in flood-credited barriers were identified either by the NRC during inspections or by the Licensee's themselves[3]:

- Flooding can occur as a result of either in internal or external damage event.
- Water intrusion into the plants resulting from missing seal assemblies, including unsealed conduit installed below grade; often leading from underground cable tunnels that had flooded.
- Broken, degraded due to corrosion, or improperly installed mechanical seals; including boot seals that were installed on the "dry" side of the penetration.
- Large rectangular penetration assembly was dislodged from the barrier during a flooding event due to the pressure (force) exerted on the overall penetration area.
- Degraded silicone foam seals, including one instance where seal was "pushed" out of the conduit penetration due to water pressure.
- Improperly sealed cable penetrations using foam materials, resulting from the "congested" configuration of cable bundles passing through the penetration such that foam could not completely surround all cables.
- Lack of proper documentation to qualify penetration seal assemblies (materials) for use in specific flood barrier applications.
- Inspection results regarding assemblies involving silicone seals indicate that special attention to the design of any assembly using this material may be warranted during testing (Task 2). This includes investigating issues involving voids, cracks, and gaps resulting from "shrinkage", along with its ability to properly adhere to many materials; including penetrating items and the barrier interfaces.
- Lack of documentation to demonstrate that seismic requirements, where applicable, had been considered as part of penetration seal assembly selection.

[3] Tables outlining flood penetration seal assembly information obtained from LERs and IRs are contained in Appendix B.

Prospective Candidate Seal Assemblies for Inclusion in Task 2

The licensee response typically identified the penetration by dimensions of the barrier opening or a description of the penetrating item. In some cases both the size of the barrier opening and the description of the penetrating item(s) were given. This information was entered into a spreadsheet, which includes approximately 270 unique assembly descriptions; with each containing as few as one item and as many as 384 (4” conduit). Each of the penetrations’ description was grouped into one of four categories; conduits (1231), sleeve or core bore openings (129), pipes (411), and rectangular openings (44). The graphs (Charts 1 through 4 above) that were generated for each of the four groups allow for a quick review of the range of penetration configurations and the numbers reported within each. Those configurations that appear to be most prevalent within the NPPs are considered to be likely candidates for inclusion in the testing program that will be performed as part of Task 2 of this research effort. It is not the intent of Task 2 to actually “qualify” any specific penetration seal assembly, but to perform the proposed test methodology and ensure that its procedures, definitions, and metrics used are appropriate to support the evaluation of all types of flood penetration seal assemblies. However, through the inclusion of seal assembly configurations that have been reported as being installed in existing plants, along with application of some of the lessons-learned by industry regarding those installed seal configurations, additional knowledge can be gained that will benefit the NRC in their ongoing evaluation of the flood risks that may exist at NPPs throughout the U.S.

There are two separate sets of parameters that must be considered for each candidate penetration seal assembly; the size and configuration of the penetration and the material selection for the seal assembly. Included within the size and configuration of the penetration are;

- Circular or rectangular opening,
- Sleeves or other coatings to be applied to the opening (wall) surfaces,
- Depth of (wall) penetration, and
- Barrier construction materials.

Additionally, the testing will need to address other variables that effect the performance of the individual penetration seal assemblies, such as “soak times” and the maximum water (head) pressure to which the assembly will be exposed.

The planned test program should also address the variability associated with different types of penetration assemblies. For example, the following is a list of various sizes and shapes of potential barrier opening and their associated penetrating items that may be included in the research testing program;

- Conduits (internal seals) at 2”,4”, and 6” diameters,
- Sleeved and Core Bore openings at 4”, 12”, and 20” diameters, with various penetrants,
    - Single or multiple pipes,
    - Cable bundle(s),
    - Blank (no penetrating items), and
- Rectangular openings at 8”x16”, 12”x32”, and 24”x36”, with various penetrants.

In addition to varying the sizes and configurations of the various penetrations, the types and materials used for the individual seal assemblies should also be varied during the testing. Silicone foam is recommended for inclusion as a candidate material in seal assemblies during the testing phase of this research project due to its extensive use and operating history within the NPP industry. This inclusion may provide background information as to its actual flood performance and act as a starting point for possible further development by the NRC in assessing potential flood risks that may be associated with their continued use in NPPs. Equally, testing of some of the "repaired" configurations that have been applied to silicone foam seals may also be considered for inclusion in the research test plan to assess any potential improvements in the seal's ability to support specific flood mitigation requirements.

In addition to the above, inclusion of seal assemblies that have been specifically (commercially) marketed for flood mitigation will also be included in the testing program, regardless of whether or not they have been previously identified as being installed at existing NPPs. The proposed test procedures must be demonstrated as being appropriated to support the testing of all types of flood penetration seal assemblies. It is anticipated that the research program will include testing of the above listed penetration / seal configurations using a wide range of materials, including elastomers and epoxies, caulking materials, along with mechanical type seals (boot, link, etc.).

Applicable Lessons-Learned From Fire Testing of Penetration Seal Assemblies

In addition to the tasking to review existing flood penetration seal configurations at NPPs, the NRC included a request to review any historical "lessons learned" that may have resulted from performing fire testing of penetration seal assemblies, which may then have some applicability to potential test methodologies for flood mitigation. In addition to a search of the NRC (ADAMS) database, other publically available, web-based sites were reviewed to assess if any specific fire testing lessons-learned could be identified that may also have applicability to the testing of penetration seal assemblies for preventing water intrusion.

The search of the NRC's database resulted in the identification of a number of technical reports (NUREGs) that provided some historical fire testing experience that could be applicable to flood mitigation testing. The NRC's NUREG library was queried for "fire protection" that resulted in 123 NUREGs being identified. Of those identified, twenty four (24) contained information relevant to the project; of which 5 were selected as containing some applicable lessons learned[4]. For example, both NUREG 1552 - *Development and Verification of Fire Tests for Cable Systems and Components* and NUREG 4112 – *Investigation of Cable and Cable System Fire Test Parameters* highlighted a need to ensure that testing be "repeatable" and "reproducible." Effectively, this highlights the fact that any test methodology(s), inclusive of the test apparatus, used must be sufficiently well-defined such that no matter what entity is performing the test, if the seal assembly is the same, the test results should be the same; albeit within the limitations of any variables that may exist regarding the installation of the particular assembly/material. Similar issues (lessons learned) were also noted in a review of a report issued by Sandia National Laboratory, Sand-94-0146 – *An Evaluation of the Fire Barrier System Thermo-Lag 330-1*. NUREG 0152 – *Development and Verification of Fire Tests for Cable Systems and System Components* also highlights the impact on "repeatability" if there is the potential for movement of the penetrants (in this instance cabling) during the test. As such, if for a specific application it is

[4] A table of the NUREGs selected as having some applicable lessons-learned is provided in Appendix A.

anticipated that movement of the penetrating items could occur, this is a variable that will need to be considered by the test; either by ensuring the penetration seal assembly could allow for movement or ensuring the penetrating items are properly secured to the barrier to prevent movement within the penetration. NUREG 2321 – *Investigation of Fire Stop Test Parameters* highlights the fact that when performing tests of this nature, it is imperative that the penetration seal assembly must be installed in the test apparatus in configuration that "matches" the manufacturer's requirements to obtain the optimal performance by the assembly.

An important international standard to consider in the development of the draft flood test methodology is ASTM E814 – *Standard Test Method for Fire Tests of Penetration Firestop Systems*. This standard is used to determine the performance of through-penetration firestops with respect to exposure to a standard time-temperature fire test curve and a hose stream test. Particular insight can be gained by the rating criteria section of ASTM E814. Although the establishment of rating criteria is beyond the scope of this research effort, the design of the flood test methodology should be thorough and flexible enough to support future testing work undertaken to develop such criteria. For example, as outlined by ASTM E814, for a firestop system to acquire a "T" rating, "the transmission of heat through the firestop system during the rating period shall not have been such as to raise the temperature of any thermocouple on the unexposed surface of any penetrating item or on the materials or devices, or both, that seal the opening, more than 325°F above the initial temperature." Similarly for water leakage, it may not be a specific requirement that flood penetration seals be fully watertight; some leakage may be considered acceptable, depending on specific applications and installation locations. Further, the test methodology may develop and quantify a "leakage rate" that would be assigned to penetration seals for performance-based applications. As such, the draft test methodology should be developed to incorporate this performance-based approach rather than a "pass/fail" rating method.

SUMMARY AND RECOMMENDATIONS

As the initial phase of a research effort to evaluate the performance of penetration seal assemblies used to support flood mitigation in nuclear power plants (NPPs), a detailed literature search was performed to identify the types of seal assemblies that are currently being used in the industry to support this requirement. Additionally, the literature search included a review of available operational experience for the installed flood penetration seal assemblies; as noted by either the Staff of the Nuclear Regulatory Commission (NRC) during inspections or as reported by individual plants. The majority of the data evaluated was located on the NRC's publically-accessible web-based Agency-wide Documents Access and Management System (ADAMS); albeit other web-based document searches were also performed.

The overall purpose for this research is to explore the development of a test methodology that could be used to quantify the capabilities of specific penetration seal assemblies typically found in flood barriers at NPPs. Currently, no standardized method for verifying the flood-resistance capabilities of penetration seal assemblies exists. As such, the bases for the use of many of the penetration seal assemblies in flood barriers at NPPs are the result of subjective evaluations.

Operational and historical experience, as reported by NRC Inspectors and individual Licensees have indicated that some of the materials being used in the flood penetration seal assemblies may not be appropriate for this application; such as the use of silicone foam, which has demonstrated a propensity to degrade over time and does not possess good resistance to water intrusion. In general, the data provided in the various documents reviewed indicate that the majority of reported "failures" in flood barriers were the result of either unsealed penetrations or where a penetration seal assembly was either broken, degraded, or not properly installed. Several of the flood events reported by individual NPPs indicated that flooding occurred via sources (damage events) and "pathways" that had not been previously analyzed and therefore, the barriers through which the water passed were not designated to be flood resistant.

Other general assumptions and observations resulting from the review of the various documents listed in Appendices A and B regarding the performance of flood penetration seal assemblies, both pertaining to historical operational experience and associated issues to be considered during future testing efforts include:

- Flooding can occur as a result of either external or internal damage events. Determination of the maximum flood resistance (head pressure) needed for specific barriers must consider all potential flood damage events to which a barrier may be exposed.
- Groundwater leakage through penetrations that are located below grade does not appear to represent a significant contributor to flooding events although this has resulted in the ejection of a foam seal, corrosion, and cable immersion.
- Formed in place seals (silicone foams and elastomers) depend on adhesion to keep them in place and for sealing. There are known adhesion issues with different materials that must be considered in seal material selection.
- Silicone foam is currently widely used in flood penetration seal assemblies and proper installation is critical to acceptable seal performance. Tightly spaced penetrants may result in voids as the liquid material may not flow into all areas and the bonding interface must be clean. Silicone foam is known to be compressible, which may result in seal failure as internal (hydrostatic) pressures within the penetration increase. Foam density, which determines performance characteristics, can vary significantly.
- Penetrating items may affect the seal performance. If the item is compressible or deforms under pressure such as duct work or to a lesser extent electrical cabling, leakage paths can form at the penetrating item/seal interface.
- The penetrating item(s) may create additional forces on the seal, or in other instances may actually provide support for keeping a seal in place when exposed to hydrostatic pressure. Such dynamics must be considered during testing, including when "bounding" tests of specific seal assembly configurations.

Based on the data resulting from this initial research, it is recommended that the candidate penetration seal assemblies used to support the testing phase of this research effort (Task 2) consist of a combination of seal assemblies and penetration configurations that are known to exist in the various NPPs, along with a sampling of other seal assemblies that may are commercially available and are marketed as providing a specific flood resistance.

"Formed in place" seals, such as silicone foam, silicone elastomers, caulk, and to a lesser extent epoxies, are likely to exhibit the greatest variability in performance; based on the manner and configurations in which they are installed, along with their specific material properties; which may vary greatly between manufacturers. These appear to be used heavily in the commercial nuclear industry, with a number of performance problems being documented over the years. The data obtained from both the assessments of previously reported flooding events, regarding specific failure mechanisms, have highlighted several specific seal assemblies that are considered worthwhile for inclusion in the subsequent testing program associated with this research effort. These include both silicone foams and elastomers. Additionally, a number of the mechanical type seals will also need to be included. Each type of seal assembly will also be varied in its application to a range of penetration sizes and types of penetrants installed; with the information contained within Charts 1 through 4 above being used as a guide to determine the specific configurations for candidate test assemblies. Using these data, a listing of candidate flood penetration seal assemblies, types, sizes, and configurations, will be included as part of the draft Test Plan that is being developed in connection with Task 2 of this NRC research project.

APPENDIX A

Reference Data Summary Pages

Information Notice Data

Information Notice	Relevant Information
IN 88-04, Inadequate Qualifications and Documentation of Fire Barrier Penetration Seals	Experience with silicone foam indicates that any one of many factors could affect the adequacy of the final seal installation. These factors include the method of installation (e.g., damming technique), technical and quality control of material, material mixing process, pouring and curing process, method of final inspection, training and experience of installing personnel, and environmental factors, such as temperature and humidity.
IN 88-56, Potential Problems With Silicone Foam Fire Barrier Penetration Seals	Documents leakage within a bundle of cables noting the cables were so tightly massed that foam did not completely surround the individual cables.
IN 88-60, Inadequate Design and Installation of Watertight Penetration Seals.	Documents two events in which water leaked into manholes and then into the plants through unsealed or inadequately sealed conduits.
IN 92-69, Water Leakage from Yard Area through Conduits Into Buildings	Despite the intensity of the hurricane and the age of the plant, onsite damage was limited to fire protection, security, and several non-safety related systems and structures. There was no damage to the safety-related systems except for minor water intrusion and some damage to insulation and paint, and there was no radioactive release to the environment. The units remained in a stable condition and functioned as designed.
IN 93-53, Supplement 1, Effect of Hurricane Andrew on Turkey Point Nuclear Generating Station and Lessons Learned	Documents an event at Cooper 1994, in which an Unusual Event was declared. Plant grade level is stated at 903 feet MSL. The Missouri River peaked at 900.8 feet MSL. Licensee noted that water was leaking in around safety related cable trays. The turbine building in-leakage was eventually stopped when the licensee pumped out the underground cables that encircled the plant. The heavy rains had flooded the cable tunnels and water was covering the manways and storm drains at grade level. In the area of the Reactor Core Isolation Cooling (RCSI) room in leakage did not stop until the river level dropped. The report also noted that flood drains had backed up.
IN 94-27, Facility Operating Concerns Resulting From Local Area Flooding	This Information notice is included on this list as sealing a lower elevation in conduit can result in submergence of the cables in the conduit.
IN 94-28, Potential Problems with Fire-Barrier Penetration Seals	Noted degraded silicone foam seals also some seals were made of combustible urethane foam
IN 2007-01, Recent Operating Experience Concerning Hydrostatic Barriers	Documents several events: 1) Water had entered the essential switchgear room from the cable spreading room (CSR) through degraded foam penetration seals in the CSR floor. 2) Water entered the emergency diesel generator room through unsealed, underground, four-inch conduits. 3) Water from a heavy rainfall entered through a manhole. An inadequately installed silicone foam seal was pushed out of a conduit penetration due to water pressure. A corrective action as a result of the failure is to seal the conduit at the highest elevation. ML14141A460 also documents conduit seals modified to have weep holes in the sealant to prevent cables from being submerged.
IN 2002-12, Submerged Safety-Related Electrical Cables	Documents several events: 1) Water had entered the essential switchgear room from the cable spreading room (CSR) through degraded foam penetration seals in the CSR floor. 2) Water entered the emergency diesel generator room through unsealed, underground, four-inch conduits. 3) Water from a heavy rainfall entered through a manhole. An inadequately installed silicone foam seal was pushed out of a conduit penetration due to water pressure. A corrective action as a result of the failure is to seal the conduit at the highest elevation. ML14141A460 also documents conduit seals modified to have weep holes in the sealant to prevent cables from being submerged.

IN 2015-01, Degraded Ability to Mitigate Flooding Events	Documents several events: 1) Water entered the reactor auxiliary building (RAB) through two degraded conduits that lacked internal flood barriers. 2) Licensee identified degraded or nonconforming flood protection features the majority of which were penetration seals. 3) Inadequate conduit penetration seals provided an in-leakage path into the essential raw cooling water (ERCW) room. 4) NRC Inspectors noted degraded conduit couplings later identified to be missing sealant.

The following Information Notices were also reviewed and contained information concerning configuration control, quality assurance, installation issues such as lack of damming and inadequate thickness, and inspection issues.

IN 89-63, Possible Submergence of Electrical Circuits Located Above Flood Level Because of Water Intrusion and Lack of Drainage.

IN 97-70, Potential Problems with Fire Barrier Penetration Seals

In 2003-08, Potential Flooding Through Unsealed Concrete Floor Cracks

IN 2005-11, Internal Flooding/Spray-Down of Safety Related Equipment Due To Unsealed equipment Floor Plugs and/or Blocked Floor Drains

IN 2005-30 Safe Shutdown Potentially Challenged By Unanalyzed Internal Flooding Events and Inadequate Design

NUREG (Fire Testing Lessons-Learned) Data

<table>
<tr><th>NUREG</th><th>Relevant Information</th></tr>
<tr><td>NUREG 1552, Development and Verification of Fire tests for Cable Systems and System Components</td><td>This test was to study the effects of forced ventilation on flame tests for cable trays. Three types of cable were used. It demonstrated the level of detail necessary to document test configurations. The importance of selecting test components (3 types of cables). Recommended standardization of testing. Recommended that ”round-robin testing be undertaken to determine the repeatability and reproducibility of the test results”</td></tr>
<tr><td>NUREG 0152, Development and Verification of Fire Tests for Cable Systems and System Components</td><td>Experiments were performed to define the effects of a number of test parameters. The testing was not continued as planned “since reproducibility of the test method was not established”. Random and unexpected cable movement occurred during the test. Also noted that securing the cable could result in reproducible results but that would “not be at all indicative of behavior in actual fire conditions”.</td></tr>
<tr><td>NUREG 2321, Investigation of Fire Stop Test Parameters Final Report</td><td>Testing was performed to determine the effects of pressure differential, fire exposure conditions and sample construction on seal performance. Test found that defects or damage to the seal affects performance, different configurations - larger size conductors and pipes produced higher temperatures, increasing the number of cables increased temperature and aluminum and steel performed differently. It also noted that “the size of the opening appeared to affect the structural integrity of the material”.</td></tr>
<tr><td>NUREG 2377, Tests and Criteria for Fire Protection of Cable Penetrations</td><td>Testing was performed to investigate the effects of furnace pressure and excess pyrolyzates to seal performance. The test noted “The performance of the urethane foam during this experiment serves to illustrate the inadvisability of evaluating the fire resistance capabilities of proposed penetration seal designs using a test furnace that is operated at negative internal pressure differentials” (it passed).</td></tr>
<tr><td>NUREG 4112 Vol.1, Investigation of Cable and Cable System Fire Test Parameters</td><td rowspan="2">These tests were to develop modifications in test equipment and test procedures that would increase the repeatability of results and be useful on accessing cable system performance in response to a real fire. Good example of evaluating the variables in construction and testing, measurement of data and attempt at standardizing assembly/testing. Evaluated changes in sample construction such as wire size, different metals, cable jacketing, pipe size, opening size and differential pressure. Useful information when bounding configurations.</td></tr>
<tr><td>NUREG 4112 Vol.2, Investigation of Cable and Cable System Fire Test Parameters</td></tr>
</table>

APPENDIX B

Flood Penetration Seal Assembly Research Summary Data

Seal Configuration Data from 50.54(f) Response

Component	Sample Plant 1	Sample Plant 2	Sample Plant 3	Sample Plant 4	Total
0.5" Conduit	7	0	0	9	16
0.75 Conduit	1	0	0	91	92
1"Conduit	4	0	0	20	205
1.5" Conduit	2	1	0	11	116
2" Conduit	8	24	0	81	113
2 1/2" Conduit	0	0	0	18	18
3" Conduit	4	3	0	74	81
3 1/2" Conduit	0	0	0	2	2
4" Conduit	9	25	0	36	384
4 1/2" Conduit	0	0	0	5	5
5" Conduit	1	0	0	65	66
6" Conduit	0	0	0	74	74
8" Conduit	0	0	0	1	1
Underground Con. Bank	5	0	0	0	58
0.375" BO	0	0	0	1	1
01" BO	8	0	0	5	13
01.25" BO	0	0	0	2	2
02" BO	0	0	0	20	20
02.5" BO	0	0	0	4	4
03" BO	0	0	0	22	22
04" BO	3	0	0	19	22
04.5" BO	0	0	0	2	2
05" BO	0	0	0	2	2
06" BO	4	0	0	17	21
07" BO	0	0	0	8	8
08" BO	0	0	0	2	2
10" BO	0	0	0	3	3
12" BO	3	0	1	2	6
18" BO	0	0	0	0	0
20" BO	0	0	1	0	1
24" BO	0	0	1	0	1
0.5" Pipe	1	0	0	5	24
0.75" Pipe	0	0	0	3	3
01" Pipe	8	0	0	21	29
01.5 Pipe	2	0	0	11	13
01.75 Pipe	0	0	0	2	2
02" Pipe	1	0	0	63	81
02.5" Pipe	7	0	0	2	9
03" Pipe	5	2	0	14	21
04" Pipe	5	0	0	29	79
06" Pipe	1	7	1	18	27
08" Pipe	1	3	2	0	15
10" Pipe	4	3	0	4	11

12" Pipe	8	3	1	9	21
14" Pipe	0	0	0	3	3
16" Pipe	8	6	0	5	19
18" Pipe	0	1	0	11	12
20" Pipe	3	3	0	9	15
24" Pipe	7	4	0	7	18
30" Pipe	7	0	0	0	7
40" Pipe	0	2	0	0	2
08"x 08" BO	1	0	0	0	1
12"x 08" BO	1	0	0	0	1
12"x 10" BO	1	0	0	0	1
12"x 12" BO	2	0	0	2	4
15"x 07" BO	1	0	0	0	1
16"x 08" BO	0	0	0	1	1
16"x 10" BO	1	0	0	0	1
18"x 08" BO	2	0	0	0	2
24"x 08" BO	0	0	0	2	2
24"x18" BO	0	0	0	1	1
27"x 08" BO	1	0	0	0	1
30"x 24" BO	1	0	0	0	1
32"x 08" BO	1	0	0	0	1
32"x 12" BO	1	0	0	3	4
36"x 17" BO	0	0	0	1	1
36"x 18" BO	0	4	0	0	4
36"x 24" BO	0	4	0	0	4
36"x 30"B0	0	0	0	1	1
39"x 24" BO	0	1	0	0	1
42"x 42" BO	0	1	0	0	1
48"x 24" BO	0	4	0	0	4
48"x 48" BO	0	0	0	2	2
54"x 18" BO	0	1	0	0	1
69"x 18" BO	0	1	0	0	1
69"x 34" BO	0	0	0	1	1
84"x 72" BO	0	0	0	1	1
96"x 96" BO	0	1	0	0	1
Ducts for station exhaust	1	0	0	0	1
Vent Openings #225	2	0	0	0	2
Seismic Gap seal	8	0	0	0	8
12" Ventilation Duct	1	0	0	0	1
Construction Gap #351	2	0	0	0	2
Sum	**383**	**332**	**7**	**1110**	**1832**

Seal Issues Identified in the 50.54(f) Response

Plant 50.54 (f) 2.3 Flooding	Missing Conduit Internal Seals	Deficient or Missing Conduit Seals	Silicone Foam Internal Conduit	Deficient Penetration Seal	Missing Penetration Seal	Note
50-528						1,2
50-529						1,2
50-530						1,2
50-317						3
50-318						3
50-220						3
50-410						3
50-325		x		x	x	4
50-324				x	x	4
50-413						1
50-414						1
50-369						5
50-370						5
50-400	x					6
50-313						1,7
50-368						1,7
50-456						1,8
50-457						1,8
50-458						1
50-247						1
50-255	x				x	1
50-271		x		x		9
50-277						10
50-278	x	x				10
50-334						11
50-412						11
50-346						11
50-440						11
50-315						12
50-316						12
50-331						1
50-266						13
50-301						13
50-282						1
50-306						1
50-285						14
50-275						1
50-323						1
50-272						15
50-311						15
50-498						16
50-499						16
50-259						1
50-260						1
50-296						1
50-327						1
50-238						1
50-390						1
50-445						1
50-446						1
50-482						1

50-483						17
50-373	x	x		x	x	18
50-374	x	x		x	x	18

(1) No specific seal information.
(2) Reported as dry Site.
(3) Report notes that a 8 inch hollow block wall can support a 3 foot water depth and a 4 inch thick hollow block wall with a 4 inch thick brick exterior can support a 2.8 foot water depth
(4) Report(s) identifies 32 deficient and 13 inaccessible link type seals. The report also notes that silicone and resin had been injected to repair seals. Also, in other cases "link seal extrusion" was noted.
(5) Below grade piping is encased in the structural foundation slabs or structural walls – these low level pipes do not require penetration seals. The exception is a fire protection pipe which has a flexible water seal on the inside of the Auxiliary building between the pipe and sleeve.
(6) Electrical and pipe penetrations are noted as having some degree of leakage. The report also notes the use of Type B2 boot seals.
(7) Ground water present to within 9.5 feet of ground surface
(8) Identified ground water intrusion without specific details
(9) CST-4, a 12" pipe had a ½" gap in the grout along the bottom of the pipe
(10) Data in database
(11) Leakage less than 0.04 gpm per the equivalent 5-inch penetration(based on 31 pounds per square inch (gage) pressure or about 30 feet of water head behind the seal. A PMF event would only create about 5 feet of head on the lowest seals. Typically electrical penetrations consist of cable inside conduits filled with an elastomer sealant material. The grouted duct banks appeared to be in acceptable condition. In some cases, where gaps were noted between the cork material and concrete, a dark material, appearing to be a sealant could be observed further inside the penetration. Implicit to the protection features is that below grade on exterior walls are generally sealed by incorporation of a "Link-seal at the external face of the building. Other penetrations ate sealed by either grout or elastomer between the pipe and the building. Two penetrations which originally had link seals were replaced with silicone foam SF-60 "Based on a review of manufacture's test report contained in Reference IV, this material for a similar application has a pressure capacity of 30 psi which is in excess of 69 feet of static head. Penetrations leading to manhole 1 through 4 were modified to have weep holes in the sealant to prevent cables from being submerged.
(12) All piping penetrating the Screenhouse -Turbine Building interface below the elevation of 594-6' is imbedded in concrete, those seals being incorporated Passive components.
(13) Duct banks penetrating the walls have partially of fully degraded seals by design with open drain pans to prevent cable submersion. Evidence of groundwater intrusion.
(14) Flood level is reported at the 1014 ft level with the lowest penetration at the 974.8 ft level; resulting in 39.2 ft of head pressure (Pen #252). Report includes a discussion of a "test" that qualifies Dow corning 3-6548 as a flood barrier.
(15) There are several penetration seals throughout the plant which do not have a hydrostatic rating that is sufficient for the licensing basis flood level – notification # 20585542. Response also notes "possible separation of the seal from the conduit."
(16) Flood seals were found to be degraded due to chronic exposure to water on some electrical manholes and below grade building penetrations were replaced and others were scheduled for replacement.
(17) Two torn boot seals and groundwater leakage.
(18) Cast Iron pipe which transports water for an eye wash station was not sealed. Pipe with sleeve noted the rubber penetration seal must be repaired or replaced. Ground water leakage an issue.

Seal Issues Identified in NRC Inspection Reports

Plant	Inspection	Missing Conduit Internal Seals	Deficient or Missing Conduit Seals	Silicone Foam Internal Conduit	Deficient Penetration Seal	Missing Penetration Seal	Note
05000302	2007003				x		1
05000483	2009004						2
05000528	2008005				x		3
05000413	2006010	x	x				4
05000289	2012005	x					5
05000325	2014011		x		x		6
05000336	2013004	x					7
50-269	00-07				x		8
05000313	2008003						9
05000277	2008007						10
05000335	2014011	x					11
05000348	2009005		x				12
05000390	2013008						13

1) Degraded silicon boots on several auxiliary building pipe penetrations.
2) The cable were not visible to the inspector as the cable trays were mostly sealed with an epoxy. The report also identified "kerite" insulated cables
3) The licensee inspected more than 1500 seals. Over 100 were degraded and needed repair. The worst case was a Low Density Foam 1 penetration seal with a through hole of about one inch in diameter. The seal was reworked to its original design condition; "detail Low Density Foam -1, which requires a minimum of nine inches over the entire seal area".
4) Event covered in LER data. Work orders note use of Duxseal and RTV732.
5) Exelon used a friction coefficient derived from test results for a similar material i.e. BISCO SF-20 foam. NPB-92, "BISCO Seal Test Equivalency for Use in Conduit Sealing," documented the test results for BISCO SF-20 foam (i.e., a low density fire resistant penetration seal), which had been performed to determine seal blowout resistance, not to verify or test the seal's hydrostatic properties. The inspectors identified that the NPB-92 test results also documented seal water leakage, but the leakage rates were not qualified or evaluated. Thirteen (13) missing seals. The inspectors identified numerous Crouse-Hines couplings with visible external degradation due to being exposed to a wet environment. In addition the inspectors identified that the couplings were missing plugs in the bottom drain ports and visually observed cables from the open port.
6) None
7) Covered in LER's
8) Preliminary White Finding – "a temporary aluminum cover was installed on the reactor building (RB) emergency hatch. The aluminum cover contained two four-inch diameter penetrations filled with temporary services (e.g., cables, etc.) and Dow Corning silicone RTV foam (Firestop 3-6548). Since the penetrations were not coated with Dow Corning 1200 primer coat, the RTV foam did not adhere to the metal surface of the penetration."
9) Licensee staged a "Hawke seal" for containment closure however closure could not be accomplished in 30 minutes.
10) Under documents – External Pipe or Conduit Seal (SF-60), Bisco Seal, Internal Conduit Seal (Ceramic Fiber), Link Seals, Internal Conduit Seals (SF-20).
11) Example of plant documents: EC 2811564, Flood Seal Installation on Conduit, EC 277219, Alternate Flood Seal Details for Electrical Conduits at ST Lucie Units 1 and 2.
12) The licensee stated exposure to external elements over time caused foam cells to loose gas, causing the foam to relax inside the frame of the penetration. The type of foam "installed since plant startup in 1981" was not

identified. Approximately 240 seals were affected. FNP-0-EMP-1370.02, Installation and Repair of Penetration Conduit Seals, Version 15.0 was referenced.

13) To determine the resistance of the foam-to-pipe movement, TVA performed a series of tests to evaluate the spring constraints of various pipe/sleeve configurations and used this data to compare the stiffness of the foam seals to that of the pipe supports; which is documented in civil engineering branch (CEB) reports 82-2 and 82-9. The data indicated that the foam seal stiffness was insignificant except for pipe movement exceeding one inch. To correct this deficiency, boot seals were installed that allowed for greater pipe movement with no detrimental impact of seal integrity. An attached letter dated April 14, 1982 noted that "during the second test program the silicone foam on some of the samples separated from some of the sleeve piping."

Flooding and Other Seal Issues Identified in Licensee Event Reports (LERs)

LER Number	Missing Conduit Internal Seals	Deficient or Missing Conduit Seals	Silicone Foam Internal Conduit	Deficient Penetration Seal	Missing Penetration Seal	Note
50-313/2014-001-00	X	X	X	X	X	1
50-259/1988-023-00					X	1
50-346/1989-004-01					X	2
50-237/1995-017-00				X		3
50-249/1992-008-00						4
50-413/2006-002		X				5
50-348/2009-002-00						6
50-285/2011-003		X			X	none
50-244/2013-003		X			X	7
50-213/1988-006-00	X		X			8
50-336/2012-003-01	X	X				9
50-410/1986-026-01		X				10
50-410/1989-002-01	X	X	X	X	X	11
50-410/1987-075-00				X		12
50-338/2010-001-00			X			13
50-277/1988-009-01	X	X			X	14
50-440/1993-010-00		X				15
50-266/2015-001-00				X		16
50-361/1984-033					X	17
50-443/2006-003-00				X	X	18
50-335/2014-001	X					19
50-280/2010-002-00			X			20
50-271/1997-002-01		X				21
50-271/2012-001-01		X				22
50-271/2013-001-00	X	X				23
50-271/2013-002-00	X	X				24
50-397/1992-034-02		X	X	X		25
50-410/1987-016-01				X	X	26

1) Ground water intrusion through underground pipe penetration. A watertight seal was not part of the original design.
2) Unsealed construction block-out between condenser pit and service water tunnel.
3) Link Seal failed 15 psi air test (acceptance criteria was no leakage).
4) Leaking door seal failed at 3 gallons per hour; Technical Specification limit was one gallon per minute at 13-17 psig.
5) Cooling tower experienced excessive overflow causing flooding of Diesel Generator room through unsealed conduit penetration.
6) Missing self-expanding cork seal in gap between main steam valve room and the containment building.
7) Unqualified wall penetration material – two smaller (4") conduits not sealed. No information on original or repair material.
8) Unsealed underground electrical duct banks Corrective action – sealed low end duct bank conduit with silicone foam to withstand 30' MSL flood.
9) Found 20 four (4) inch and 2 two (2) inch unsealed conduits – no information on repair seal material.
10) Manhole #5 conduit seals in noncompliance with FSAR 3.4.1.1.3 – repair was to seal manhole cover.
11) Missing electrical blockout seal in pressure boundary wall – leakage could cause failure of non-pressure walls. Eight (8) duct lines were sealed with a silicone foam seal that was not capable of maintaining leak tightness at flood pressures. Three (3) core bores did not have caulk installed over the silicone seal on the water (flood) side of the penetration. Piping penetrations (thimbles) were found to be improperly sealed (caulking on the wrong

side of the penetration or missing). One (1) piping thimble had movement exceeding those acceptable for a foam seal.

12) Leakage from cracked tank caused failure of boot seal (secondary containment penetration seal). The penetration is a 24” wall sleeve containing a 20” pipe - root cause the seal was likely damaged prior to the event by workers in the area.
13) Three (3) of the seven (7) types of aluminum conduit using silicone foam seals failed IEEE 634-1978 test. Dow Corning Q3-6548 Silicone RTV Sealing Foam was specifically identified.
14) Unsealed items include: electrical penetrations, conduits, internal conduit, mechanical penetrations, and a ventilation duct. Non-fire barrier walls serving as flood barriers were not inspected
15) Underground service water pipe catastrophic failure. A majority of the water inside the plant entered through spare conduits previously containing plugs that were expelled by the incoming water. Electrical penetrations and doors were the primary source of water in buildings (estimated at 1 to 8 inches). An Alert was declared due to the event.
16) Inadequately Sealed Pipe Penetration. The sealant around four (4) three quarter (3/4) inch penetrations was inadequate. The seismic qualification of the penetration seal material was called into question. No information on corrective action.
17) Water flowed through newly installed telecommunications ducts into the Unit 1 4KV Switchgear Room. No information on seals or corrective action.
18) Inadvertent actuation of deluge system discharged approximately 1000 gallons of water into the cable spreading room. A large electrical block-out containing multiple cable trays was sealed with BOSCO SF-60 elastomeric material, five small penetrations were filled with a foam material not meeting hydrostatic design requirements and two holes were unsealed. In the case of the sealed penetrations there were through holes in the material.
19) Water entered the reactor auxiliary building through two degraded conduits that lacked internal flood barriers. The extent of condition identified four additional conduits also lacking internal seals. No information of seal material.
20) Aluminum conduit originally internally foamed to a depth of 10 inches with at least part of the foam contained within the wall or floor do not meet fire barrier requirements. The corrective action was to install smoke or silicone foam seals on both sides of the penetration.
21) Potential for water intrusion via underground conduit into manholes located in switchgear room floors. Corrective action was to install high density silicone seals in conduits.
22) Missing flood seal in spare conduit. Screw type seal did not provide an adequate seal to prevent the seal from becoming dislodged (seal expanded to 4.25” in a 4.125” ID conduit when compression screw was tightened). Corrective action was to replace the mechanical flood seal with SYLGARD 170 silicone elastomer in spare conduits communicating with the switchgear rooms.
23) Missing conduit flood seal and flow path through abandoned sump pump discharge line. Screw type seal did not provide an adequate seal to prevent the seal from becoming dislodged after compression screw was tightened and capped abandoned pump discharge line. Corrective action was to replace the mechanical flood seal with SYLGARD 170 silicone elastomer.
24) Loose screw type conduit flood seal and missing conduit seal. Screw type seal did not provide an adequate seal to prevent loosening after compression screw was tightened. Corrective action was to replace the mechanical flood seal with SYLGARD 170 silicone elastomer.
25) Penetrations were sealed with BISCO silicone foam SF-20. “The silicone foam is not qualified or rated by the vendor for pressures greater than 0.25 inches of water”. The area in question per the FSAR requires protection to 44 feet head. The majority of the penetrations of concern is less than four inches and is internal conduit seals that contain cable.
26) Abandoned penetration not properly sealed. The seal consisted of some undetermined foam and a half inch of concrete. Seven other deficient penetration seals were identified and resealed. Abandoned penetrations are to be sealed by installing (welding) a quarter inch metal plate and grouting inside the penetration”.