Progress Report on

Scoping Study for a PRA Method for Seismically Induced Fires and Floods

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Abstract

Seismic events at a nuclear power plant (NPP) have the potential to induce additional undesirable events, such as separate fires or floods, possibly even in multiple locations at the site, while also degrading the capability of the NPP's systems and operators that are intended to mitigate the effects of fires and floods. Currently, there is no endorsed method for modeling and quantitatively evaluating seismically-induced fires and floods in a Probabilistic Risk Assessment (PRA) of a NPP. Hence, the potential contribution of these scenarios to the risk of an NPP is uncertain. Brookhaven National Laboratory (BNL) was tasked by the Nuclear Regulatory Commission's Office of Research (NRC/RES) to carry out first steps in investigating the feasibility of developing such a PRA method.

The goal of this report is to document the initial steps that BNL has carried out for this project. In particular, in coordination with the NRC's Technical Monitor, BNL's staff completed the following three initial activities:

1. Organized a workshop on seismic-induced fires and floods that identified issues related to modeling the risk from these hazards.

2. Prepared three questionnaires mainly addressing the qualitative screening of these hazards.

3. Conducted a survey of the literature on seismic-induced fires and floods.

Accordingly, this report documents the insights gained and the issues identified while conducting these activities.

List of Acronyms

ANS	American Nuclear Society
ASME	American Society of Mechanical Engineers
BNL	Brookhaven National Laboratory
CNSC	Canadian Nuclear Safety Commission
EPRI	Electric Power Research Institute
GSI	Generic Safety Issue
IAEA	International Atomic Energy Agency
IPE	Individual Plant Examination
IPEEE	Individual Plant Examination of External Events
ISA	Integrated Safety Analysis
LOCA	Loss of Coolant Accident
NEA	Nuclear Energy Agency
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission
NTTF	Near-Term Task Force
PFDHA	Probabilistic Fault Displacement Hazard Analysis
PFHA	Probabilistic Flood Hazard Assessment
PIRT	Phenomena Identification and Ranking Table
PRA	Probabilistic Risk Assessment
PTHA	Probabilistic Tsunami Hazard Assessment
RCS	Reactor Coolant System
RES	NRC's Office of Nuclear Regulatory Research
SEL	Seismic Equipment List
SI	Seismic-induced
SI-F&IEF	Seismic-induced Internal Fire, and Internal and External Flooding
SMA	Seismic Margin Analysis
SPRA	Seismic Probabilistic Risk Assessment
SSC	Structure, System, or Component
SSHAC	Senior Seismic Hazard Analysis Committee
USACE	US Army Corps of Engineers
USBR	US Department of Interior's Bureau of Reclamation
USGS	US Geological Survey

Contents

1. Introduction

1.1 Background

Seismic events near a nuclear power plant (NPP) have the potential to lead to the following events:

- Cause multiple failures of safety- and non-safety-related structures, systems, and components (SSCs),
- Induce separate fires or floods in multiple locations at the site, and,
- Degrade the capability of the plant's SSCs that are intended to mitigate the effects of fires and floods.

Seismically induced fires and floods, and the threat they may present to nuclear power plants, were addressed previously by the U.S. Nuclear Regulatory Commission (NRC) via several programs. Among the safety issues raised in Generic Safety Issue 172 (GSI-172), the Multiple System Response Program, were seismically induced fires and floods. NUREG-1407, "Procedural and Submittal Guidance for the Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities," [5] also stated that seismically induced fires and floods were to be considered as part of the IPEEE, and licensees did provide such information in their IPEEE submittals. However, mostly it was qualitative information and the level of detail varied greatly from plant to plant. Based on this information, the NRC's Near-Term Task Force (NTTF) that was convened after the Fukushima Dai-ichi accident, concluded that a re-evaluation of the closure of GSI-172 was warranted.

As noted in Enclosure 3, "Program Plan for Tier 3 Recommendations," to SECY-12-0095 [24], the NTTF recommended "…as part of the longer term review, that the U.S. Nuclear Regulatory Commission (NRC) evaluate potential enhancements to the capability to prevent or mitigate seismically induced fires and floods." The scope includes seismic-induced internal fires (e.g., breakers, transformers), internal floods (e.g., tanks, piping systems), and external fires and floods.

In SECY-11-0137 [21], this NTTF recommendation was formalized as Recommendation 3, "Potential Enhancements to the Capability to Prevent or Mitigate Seismically Induced Fires and Floods (long-term evaluation)." In the same document, the NRC's staff prioritized this recommendation as Tier 3 because longer-term staff evaluation was required to support a decision on the need for regulatory action. In the SRM to SECY-11-0137 [22], the Commission agreed with the Tier 3 prioritization of Recommendation 3, but directed the staff to initiate a methodology of probabilistic risk assessment (PRA) to evaluate potential enhancements to the

capability to prevent or mitigate seismically induced fires and floods as part of their Tier 1 activities. The Commission indicated that the prerequisite activity to begin developing an appropriate PRA methodology to support this issue should be started without unnecessary delay, while other Recommendation 3 activities remained prioritized as Tier 3.

In SECY-12-0025 [23], the NRC's staff summarized the pre-planning activities needed for devising a detailed project plan for formulating a PRA method for seismically induced fires and floods. Along with the proposed schedule, these pre-planning activities addressed several key aspects of this work, including the objectives of the methodology, stakeholders' involvement, information gathering, and coordination with other initiatives, resource needs.

On June 7, 2012, the NRC's Office of Nuclear Regulatory Research (RES) issued the "Plan for the Development of a PRA Methodology for Seismically Induced Fires and Floods" [6]. That document contained a detailed plan for starting the work needed to develop a PRA methodology for assessing these hazards.

Subsequently, the PRA branch of the RES and staff at Brookhaven National Laboratory (BNL) began preparing a scoping study on the technical feasibility of having a method (or a graded approach) for the PRA of Seismically Induced Internal Fire, and Internal and External Flooding (SI-F&IEF). A report documenting this feasibility will be one of the inputs for generating a staff recommendation to the NRC's Commissioners.

1.2 Objective

The overall objective of the feasibility study is to generate sufficient information about the feasibility of a PRA approach to assess risk from seismically induced fires and floods in domestic NPPs, such that the NRC can make informed decisions about the appropriate next steps to take. The conclusions of this study will be used as one of the inputs to reevaluate the NTTF's Tier 3 Recommendation 3, along with information obtained from Tier 1 activities, and PRA method development, and to recommend further research in this area.

The intent of the feasibility scoping study is to identify issues associated with the risk assessment of multiple concurrent hazards, and to evaluate the available PRA methods to carry out such an assessment. The idea is to evaluate the feasibility of improving on previous estimates of risk due to seismically induced fire and floods. The feasibility encompassed technical- and methodological-issues, such as the scarcity of applicable data, and the variety, or lack of, seismic- and fire-PRA models for all US plants. The study also will take into account whether a better ability to characterize and manage plant risk from seismically induced fire and flood has sufficient value relative to the investment of resources required by both the NRC and industry to better address this issue.

The goal of this report is to document the initial steps that BNL has carried out for this project. In particular, in coordination with the NRC's Technical Monitor, BNL completed the following three initial activities:

1. Organized a workshop on seismic-induced fires and floods that identified the problems related to modeling the risk from these hazards,

2. Prepared three questionnaires mainly concerning the qualitative screening of these hazards, and,

3. Conducted a survey of the literature on seismic-induced fires and floods.

This report documents the insights and issues identified while conducting these activities.

1.3 Scope

The scope of the project encompasses seismic-induced fires, and seismic-induced internal and external floods. The focus of the initial activities is on at-power level-1 PRA models, that is, the on the hazard posed to cooling the fuel in the reactor core at the time of the seismic event.

Other levels (levels 2 and/or 3) of PRA, other modes of operating a NPP (such as shutdown operation), and other impacts (e.g., the effects on the cooling of the spent-fuel pool) may be included later, but are not considered within the current scope. As discussed in this report, modeling or estimating the risk from seismic-induced fires and internal and external floods poses numerous difficult technical challenges, even for the most widely used PRA models, i.e., at-power level-1 PRA.

1.4 Organization of the Report

This report is organized as follows. Section 2 describes the approach to assessing the feasibility of estimating the risk posed by seismic-induced fires and internal and external floods. Section 3 summarizes the NRC workshop on such events held in December 2013. Section 4 discusses the result of the questionnaires soliciting comments on qualitatively assessing and screening each of the three types of seismic-induced hazards: fires, internal floods, and external floods. Section 5 gives an overview of the issues identified for consideration in modeling the risk from these hazards. Section 6 presents the conclusions drawn so far and the recommendations for proceeding with the next phase in this project. Section 7 lists the references cited in the report.

Finally, the report contains four appendices. Appendices A, B, and C respectively present the questionnaire and the consolidated responses on seismic-induced fire, internal floods, and external floods. Appendix D summarizes a literature survey on seismic-induced fires and floods.

2.0 Approach Used to Assess Feasibility

As noted in the Introduction, the intent of the feasibility scoping study was to identify issues associated with the risk assessment of multiple concurrent hazards of seismically induced fire and floods, and to evaluate current methods to improve on previous estimates of risk caused by such events. The feasibility examined herein involves not only the technical- and methodological- issues, but also takes into account whether the improved ability to characterize and manage plant risk from such fires and floods has sufficient value relative to the resource investment needed from both the NRC and industry to better assess this issue.

While a quantitative approach for assessing combined hazards may be desirable, it is recognized that valuable insights might be obtained from qualitative approaches. For the purposes of the following descriptions, “PRA methods” includes other methods of risk assessment, both quantitative and qualitative.

As mentioned in the Introduction, BNL carried out three initial steps regarding the feasibility scoping study for a PRA method for seismically-induced fires and floods. These three steps are briefly introduced in Subsection 2.1, 2.2, and 2.3 below, and are elaborated on in Sections 3, 4, and 5 and the appendices of this report.

2.1 Workshop on the Feasibility of Developing a PRA Method

BNL and NRC organized a public meeting/workshop to identify issues that need to be addressed successfully to develop a feasible PRA method(s) for seismically induced fires and floods. Due to the complexity of the issues , the involvement of recognized experts, preferably representing the various stakeholders and future intended users of any consensus method developed (including regulators, industry organizations, National Laboratories, consultants, Standards development organizations) interested in the results of a feasibility study on this topic, was felt to be essential. Their inclusion would provide confidence that important aspects or concerns that could affect the future direction in this area would not be missed. Knowledgeable practitioners in PRA, seismic margin assessment (SMA), seismic risk, flooding risk, and internal fire risk were selected in consultation with the NRC.

The workshop participants identified key issues that needed to be considered for developing a PRA method for seismically induced fires and floods, and proposed some initial approaches to deal with some of the issues. A description of the Workshop is given in Section 3 of this report, and the issues identified are discussed in Section 5.

2.2 Questionnaires on seismically-induced fires, internal floods, and external floods

An outcome of the workshop was several ideas on ways to better understand, and thus, better model and quantify seismically induced fire and internal and external flood scenarios. At least three of those ideas involved the future participation of experienced practitioners, either individually or in group panels, to simplify or expedite the approach to modeling and quantifying these scenarios:

On the basis of the workshop, BNL and NRC identified several practitioners experienced in the area of seismic- and/or internal or external flood-hazards. Some were attendees at the workshop, others were not, but were identified as a result of the workshop, as having extensive

experience in these areas. BNL and NRC asked these individuals if they would be willing to participate individually, or on a panel, to address topics associated with the hazards from seismic-induced fire and flooding.

Due to the larger than expected response to the requests for participation, and the tight schedules of some interested participants, as well as funding limitations, BNL and NRC felt that it would be more efficient first to get some individual inputs from the interested parties before holding a meeting with them. With the infusion of new funds, a subsequent meeting (or meetings) then could be used to discuss variances among contributors, as well as to clarify (and possibly resolve) differences on the inputs received.

Therefore, BNL prepared questionnaires for each of the three hazards, (i.e., seismic-induced fires, internal floods, and external floods), and asked interested participants to respond. The focus of the questionnaires varied for the different hazards. For seismically-induced fires, the focus of the questionnaire was on screening certain plant systems, structures, and components (SSCs) from consideration as ignition sources. For seismically induced internal floods, the focus was on what kind of screening of these sources might be possible. Since there is very limited availability of any external-flood PRAs or probabilistic studies of the impact of this kind of flood on a NPP, for seismically induced external floods the focus was on techniques for estimating the frequency of a flood of this type, and estimating the correlation and dependency between the flood-source site and the plant site, given an earthquake.

A description of the questionnaires and the insights gained from the responses received is given in Section 4 of this report. Appendices A, B, and C respectively present the questionnaire and consolidated responses on seismic-induced fire, internal floods, and external floods.

2.3 Survey of literature related to seismic-induced fires and floods.

A survey was conducted of the literature related to seismic-induced fires and floods. It included searching the operational experience of nuclear power plants worldwide that have experienced such fires and floods, and looking for published reports and papers that address these hazards.

Regarding operational experience, the survey found four seismic-induced fires that had occurred since 2007, and the seismic-induced external flood (i.e., flooding due to a tsunami) at Fukushima Daiichi in 2011. These events confirm that this type of event has happened at NPPs.

For the survey of literature related to seismic-induced fires and floods, the following sources of reports or papers were searched:

- Nuclear Regulatory Commission (NRC)
- Electric Power Research Institute (EPRI)
- International Atomic Energy Agency (IAEA)
- Canadian Nuclear Safety Commission (CNSC)
- Los Alamos National Laboratory
- Papers in conferences or journals

The survey indicates that the potential for seismic-induced fires and floods has been recognized by the NRC and industry for several decades. However, the Individual Plant Examination of External Events (IPEEE) carried out for the domestic NPPs typically was a qualitative exercise. Apparently, it was only after the Fukushima Daiichi accident in 2011, and specifically during the last few years, that methods for modeling these fires and floods in PRA began to be discussed in the literature. Appendix D presents the literature survey.

3. Workshop

3.1. Introduction

This public meeting, held in the form of a workshop, was part of a lessons-learned activity that originated from NTTF Recommendation 3, which recommended "…as part of the longer term review, that the U.S. Nuclear Regulatory Commission (NRC) evaluate potential enhancements to the capability to prevent or mitigate seismically induced fires and floods."

The public workshop was part of an effort of the PRA Branch of the Office of Nuclear Regulatory Research (RES) of the NRC and its contractor, Brookhaven National Laboratory (BNL), to carry out a scoping study on the technical feasibility of having a method (or a graded approach) for the risk analysis of Seismically-Induced Internal Fire, and Internal and External Flooding (SI-F&IEF).

BNL organized the public workshop to derive a perspective on Seismically-Induced Fires and Floods. Several people knowledgeable on related topics from the U.S- and Canadian-regulatory bodies (namely, the NRC and the Canadian Nuclear Safety Commission (CNSC)) and the nuclear industries in both countries specifically were invited to participate in the meeting. To maximize the usefulness of the workshop, an introductory list of topics for discussion was sent to the invitees in the form of 15 questions that BNL and NRC prepared. To enhance the effectiveness of the workshop, the invitees' feedback was requested in the form of comments or preliminary responses to the questions. Participants also were encouraged to raise any additional issues that they felt were relevant, but that were not covered in the questions.

This Section presents a summary of the workshop and the main insights obtained. An overview of the workshop and seven appendices giving details about the workshop are published in the NRC's ADAMS Public Document Library, as shown in the following table.

Contents	ADAMS Accession Number
Summary	ML14022A252
Appendix A - Questions Sent to the Invitees	
Appendix B - Kevin Coyne's Presentation	ML14022A270
Appendix C - Bob Budnitz' Presentation	
Appendix D - Barry Sloane's Presentation	
Appendix E - BNL Slides Summarizing the Preliminary Responses to the 15 Questions	
Appendix F - List Of Participants	ML14022A252

3.2. Workshop Presentations

The public workshop took place on Wednesday, December 11, and the morning of Thursday 12, 2013, at the RES office in Rockville, MD. It had been announced publicly, and a telephone line was available for any participants not able to attend in person. There were twenty-nine participants in the workshop, 28 attended in person, and one communicated via phone. Participants were from the NRC, the CNSC, and the U.S- and Canadian-nuclear industries; the person connected via telephone was from a U.S. nuclear utility.

The workshop format consisted of three short presentations, followed by interactive discussion among the participants. The discussion was broadly organized according to the preliminary questions (and the responses received prior to the workshop).

On the morning of Wednesday 11, Kevin Coyne (NRC) made the first presentation, "NTTF Recommendation 3: Seismically Induced Fires and Floods." He pointed to the following challenges for a PRA method that attempts to assess SI-F&IEF scenarios:

- Hazard definition & characterization,
- Seismic fragilities for systems, structures and components (SSCs), including fire-protection components,
- Modeling concurrent- and subsequent-initiating events,
- Treatment of systems' interactions,
- Methods of human-reliability analyses suitable for seismically induced hazards, and,
- Multiunit risk considerations.

He noted that there are no current consensus state-of-practice methods for seismically induced fires and floods for nuclear power plants (NPPs). He also felt that the findings from several Tier 1 recommendations might better inform the SI-F&IEF issue, i.e., those from recommendations:

- 2.1 Seismic- and flooding-hazard evaluations
- 2.3 Seismic- and flooding-vulnerability walkdowns
- 4.2 Mitigation strategies
- 5.1 Containment venting
- 7.1 Spent fuel pool

Finally, he highlighted the following ongoing near-term activities:

- Engaging in organizing standards development (for example, the American Society of Mechanical Engineers (ASME)/American Nuclear Society (ANS) Joint Committee on Nuclear Risk Management has an ongoing initiative on multiple concurrent events).
- Assessing interim results from the NTTF's recommendations and other activities
- Continuing the development of PRA methods, including considering quantitative- and qualitative-approaches.

Next, Bob Budnitz from Lawrence Berkeley National Laboratory (LBNL)) presented "Comments on Developing a Proper "Fragility Curve" for Seismic-Induced Fire Analysis (or Seismic-Induced Flooding Analysis)." He pointed out that at the time of the individual plant examination for external events (IPEEE), there was no consideration of PRA quantification of the risk from SI-F&IEF. Accordingly, while plants carried out some type of SI-F&IEF appraisal, they did not

quantify the risk. The IPEEE was a vulnerability assessment, and the guidance for IPEEEs for both seismic-induced fires and internal floods consisted of the following steps:

- Undertake walkdowns with these issues in mind
- Find any issues
- Fix these issues

He noted that for a seismic-PRA, the "failure" of an SSC, meaning the "…failure to perform its desired safety function," is expressed in terms of a "fragility curve" with "the probability of failure to perform the desired function" on the ordinate, and with the "size of the load," that is, the peak ground acceleration (PGA) of the earthquake on the abscissa. In his opinion, the single major problem that stands in the way of quantifying a seismic-induced (SI) fire PRA is that, for an SSC of interest in such a PRA, he knows of no evidence showing with what probability the SSC might produce a fire as a function of the "earthquake size." In other words, given a specific earthquake PGA load, and a specific SSC in the plant, he knows of no evidence that would allow developing such a "fragility curve" linking the PGA with the probability of causing a fire.

He also observed that a major concern in fire PRAs is fires in cables. He noted that cable fires are of three general types: (i) Those arising because an external fuel catches on fire and then ignites the nearby cable; (ii) fires arising from within the cable because electrical energy "misbehaves", such as from a short-circuit type of phenomenon in the cable; and, (iii) fires arising when a surge of electricity occurs in some component to which the cable is attached, and this surge then overheats and ignites the cable due to the additional current or voltage. He raised the question of what is known, if anything, about how seismic excitation could cause any of these three phenomena to occur in a cable, for example, as a function of the type of cable.

He also stated his belief that for seismically induced internal flooding there is a parallel to the problem noted for fire, although it may not be that difficult to develop fragility curves for SSCs that can be potential flooding sources, such as a water tank, a heat exchanger, or some piping.

For seismically induced external flooding, he felt that the problem was different. Here, one must deal with dams, dikes, rivers, levees, or other external flooding sources, and with phenomena such as tsunamis and seiches. At least in principle, the threat to a nuclear power plant, when these hazards are caused by an earthquake, is amenable to analysis, although such an analysis may be quite difficult in specific cases.

Barry Sloane (ERIN Engineering and Research) made the third presentation, "Perspectives on Identifying and Addressing Seismically-Induced Internal Fires and Internal Floods in a Seismic PRA or PRA-Based SMA." He detailed a process to identify potential vulnerabilities in the plant after a seismic event and the consequential internal fires or internal floods, focusing on seismically induced internal fires and internal floods that might significantly affect the plant's seismic risk. He pointed out that although various guidance documents note the importance of undertaking such an assessment, little guidance is available. He felt a phased approach is appropriate, where the focus initially is on potentially large-source impacts and walkdown observations, and refinement is added based on initial insights and qualitative risk impacts, to the degree supported by available knowledge, and wherein those insights can drive the development of additional research and development to address issues of quantification.

He stated that attempting to quantify all seismically induced internal fire- and internal flood-scenarios is impractical currently, due to lack of fragilities for seismically-induced fires and floods, and the large uncertainties associated with their impacts. Instead, he advocated a

graded approach that allows for a level of analysis detail appropriate to the plant-specific features, and that can provide qualitative insights, and also lead to quantitative assessment if warranted. In such an approach, insights from plant earthquake experience and reviews of available internal flooding and fire PRAs are used to look for significant sources of fire or flooding and assess their potential impact on existing seismic PRA sequences. A list of significant SSCs is developed for examination in additional walkdowns focused on gaining insights into potential seismic-induced fire/flood scenarios. He stated that the results of this process offer insights that may be used to determine if enhancements to the plant's seismic probabilistic risk assessment or PRA-based seismic margins assessment are appropriate to explicitly address individual consequential hazards.

He presented insights from applying this process to a CANDU plant's seismic PRA. The approach consisted of a separate process for the seismic event and the consequential internal fire, and for the seismic event and the consequential internal flood. A next step would be to combine into a single PRA the consequential internal fire and flood.

3.3. Workshop Discussion

With the presentations concluded, workshop participants turned their attention to discussing the issues raised in the presentations and in the questions that had been sent to invited participants before the meeting. Several participants responded to these questions before the workshop. BNL's staff consolidated and summarized these responses into several main points for each question, and both the questions and the preliminary responses were used as an outline to guide the workshop discussion.

The participants also discussed some possible ways to initiate the research in this challenging field. Several ideas were posited for approaches to better understand SI-F&IEF scenarios, thus helping to model and quantify the risk from them.

1. Instead of focusing on a "PRA method" for analyzing SI-F&IEF risk, it may be more useful in the immediate future to focus on graded risk methods, along the lines of the example in the presentations. In keeping with this approach, it would be useful to develop a robust method that efficiently screens out the SSCs that are not expected to contribute, or that are negligible contributors, to the NPP's risk due to SI-F&IF scenarios. It may be possible to develop, using the experience of seasoned practitioners, generic lists of fire SSCs and flood SSCs that can be screened from SIF&IEF risk analysis.

2. A pilot study that begins in 18 to 24 months may be useful to develop such a screening method, as well as a method for dealing with those SSCs that are not screened out. That is, an approach would have to be formulated to estimate the SI-F&IEF risk that cannot be screened. A pilot study may be the most efficient way in terms of time and resources, and may also give insights into assessing the value gained as a function of the resources invested.

3. The establishment of small groups of expert panels also was suggested. Meetings of a small number of experts (between five and ten) were recommended to address specific areas identified as important for estimating SI-F&IEF risk. For example, a group could discuss approaches for developing seismic-induced fire fragilities, and another could address methods for assessing seismic-induced flood fragilities, while yet another could deliberate, for example, on the "joint hazard curve" between a dam (or other source of

external flooding, such as a tsunami) and a NPP. The screening of fire-ignition source bins by an expert panel is another example, as is the expected response from the plants' operators to fires/floods when the crew has to deal with many issues, including assuring the functionality of the safe-shutdown equipment after an earthquake. The possibility was discussed of using an appropriate level of the Senior Seismic Hazard Analysis Committee (SSHAC) process, or some other kind of expert elicitation process.

4. Several participants stressed that the focus should be on significant earthquakes that can impact the safe-shutdown equipment, since analyses of SI-F&IEF scenarios that do not impact this equipment are not very useful (an exception may be multiple fire scenarios).

5. Current efforts should focus on full power scenarios, which can already be quite complex, leaving possible consideration of the implications of SI-F&IEF for low-power and shutdown states for the future.

It was noted that many of the activities detailed above may be carried out in parallel, and some order for them would have to be established. If the NRC and industry undertake these activities jointly, the regulatory process likely would be faster, more robust, and more understandable to both parties.

The research for supporting the pilot(s) (e.g., developing the screening methods) would be accomplished within about two years, and the pilot(s) themselves would start sometime within this time.

The insights and issues identified during the workshop are discussed further in Section 5 of this report.

4. Qualitative Assessment and Screening

4.1 Screening of Seismic-induced Internal Fires

As mentioned in Section 1, an earthquake of sufficient magnitude potentially could cause seismic-induced fires, external floods, and internal floods. This section of the report discusses the possibility of screening some ignition sources involving the first type of hazard, namely, seismic-induced fires, from further consideration. Specifically, a questionnaire was sent to persons who from their experience with seismic- and/or fire risk-analysis, were anticipated to be knowledgeable on this subject. The questionnaire's main objective was to assess whether some potential sources of this kind of fire can be screened generically. Within the context of this questionnaire, a source was considered any structure, system, or component (SSC) that could ignite as a result of an earthquake. For the purpose of this report, "generic screening" of a potential source means that this source does not have to be considered as a source of seismic-induced internal fire for nuclear power plants (NPPs) in the United States unless plant-specific conditions warrant otherwise.

Six contributors responded to the questionnaire (listed in alphabetical order by last name):

- R. D. Campbell (EQE International)
- ERIN Engineering and Research, Inc. (mentioned in this report as ERIN)
- James Lin (ABSG Consulting Inc.)
- Andrea Maioli (Westinghouse)
- M. K. Ravindra (MKRavindra Consulting)
- Marty Stutzke (Office of Research, NRC)

The questionnaire presented a table listing ignition sources that may cause a fire after an earthquake. The 38 potential ignition sources in an NPP in this table were reproduced from Table 6-1 of NUREG/CR-6850 (EPRI 1011989), "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities" (2005) [9]. Each contributor was asked to use this list as a starting point, and to remove and/or add sources from this table, as deemed appropriate.

In addition, each contributor was requested to analyze each ignition source in the table for its potential to cause a fire given an earthquake. Specifically, he was expected to classify each SSC into one of the following three categories: I) Not a seismic-induced fire ignition source: Can be screened out, II) May be a potential seismic-induced fire ignition source, and, III) Must be evaluated as a seismic-induced fire ignition source. Participants were asked to explain their responses, and in this regard the replies were mixed: Three responders provided informative explanations, and three only indicated which category the source should be placed in without their reasoning for the choice. Appendix A presents the questionnaire and the complete responses of the contributors.

Table 4.1 lists the ignition sources (and their locations), with their NUREG/CR-6850 ID (or bin) numbers, that the six participants were asked to evaluate.[1] More detailed descriptions of the equipment in each bin are given in Section 6.5.6 of NUREG/CR-6850.

[1] Although the ID numbers only go to 37, there are 38 bins in the table since there is a 23a and a 23b ID.

Table 4.1 List of Fire Ignition Sources for Initial Screening

ID	Ignition Source	Location	ID	Ignition Source	Location
1	Batteries	Battery Room	20	Off-gas/H_2 Recombiner (BWR)	Plant-Wide Components
2	Reactor Coolant Pump	Containment (PWR)	21	Pumps	Plant-Wide Components
3	Transients and Hotwork	Containment (PWR)	22	RPS MG Sets	Plant-Wide Components
4	Main Control Board	Control Room	23a	Transformers (Oil filled)	Plant-Wide Components
5	Cable fires caused by welding and cutting	Control/Aux/Reactor Building	23b	Transformers (Dry)	Plant-Wide Components
6	Transient fires caused by welding and cutting	Control/Aux/Reactor Building	24	Transient fires caused by welding and cutting	Plant-Wide Components
7	Transients	Control/Aux/Reactor Building	25	Transients	Plant-Wide Components
8	Diesel Generators	Diesel Generator Room	26	Ventilation Subsystems	Plant-Wide Components
9	Air Compressors	Plant-Wide Components	27	Transformer – Catastrophic	Transformer Yard
10	Battery Chargers	Plant-Wide Components	28	Transformer - Non Catastrophic	Transformer Yard
11	Cable fires caused by welding and cutting	Plant-Wide Components	29	Yard transformers (Others)	Transformer Yard
12	Cable Run (Self-ignited cable fires)	Plant-Wide Components	30	Boiler	Turbine Building
13	Dryers	Plant-Wide Components	31	Cable fires caused by welding and cutting	Turbine Building
14	Electric Motors	Plant-Wide Components	32	Main Feedwater Pumps	Turbine Building
15	Electrical Cabinets	Plant-Wide Components	33	Turbine Generator Excitor	Turbine Building
16	High Energy Arcing Faults	Plant-Wide Components	34	Turbine Generator Hydrogen	Turbine Building
17	Hydrogen Tanks	Plant-Wide Components	35	Turbine Generator Oil	Turbine Building
18	Junction Boxes	Plant-Wide Components	36	Transient fires caused by welding and cutting	Turbine Building
19	Misc. Hydrogen Fires	Plant-Wide Components	37	Transients	Turbine Building

There were eleven ignition sources that all but one participant agreed could be screened from consideration. These sources are listed in Table 4.2.

Table 4.2 Candidate ignition bins that may be screened out

ID	Ignition Source	Location
3	Transients and Hotwork	Containment (PWR)
4	Main Control Board	Control Room
5	Cable fires caused by welding and cutting	Control/Aux/Reactor Building
6	Transient fires caused by welding and cutting	Control/Aux/Reactor Building
11	Cable fires caused by welding and cutting	Plant-Wide Components
18	Junction Boxes	Plant-Wide Components
24	Transient fires caused by welding and cutting	Plant-Wide Components
25	Transients	Plant-Wide Components
31	Cable fires caused by welding and cutting	Turbine Building
36	Transient fires caused by welding and cutting	Turbine Building
37	Transients	Turbine Building

The principal reasons given by some contributors for screening these SSCs out are the following:

1. For ignition sources associated with transients, hot work, and welding and cutting (Bins 3, 5, 6, 11, 24, 31 and 36), the reasoning was similar for the seven bins:

   “For hot work, personnel would be present and could respond even given a seismic event; fraction of time during the year when hot work occurs is small”

   “The joint likelihood of performing hot work during an earthquake causing ignition of nearby cables is too low to be considered.”

   “Not related to seismic event.”

2. For the Main Control Board, Bin 4, the reasoning is as follows:

   “MCB damage would most likely result in sufficient seismic plant response impact that [conditional core damage probability] CCDP would be ~ 1.0 regardless of consequential fire.”

   “The likelihood of fire caused by an arc flash resulting from the low voltage electrical cabinets induced by the earthquake motion is too low to be considered.”

3. For the Junction Boxes of Bin 18, the following were the reasons stated:

   “The energy generated from an arc flash associated with low voltage junction boxes should be insufficient to cause ignition of such nearby solid combustible materials as cable insulation/jacket and other plastic materials.”

   “Generally have high seismic ruggedness unless seismic weaknesses are found in walkdown.”

4. For the Transients in Bins 25 and 37, the following are the reasons for screening:

   "Sources that might lead to fire would be things like portable space heaters, exposure time would be limited."

   "Not related to seismic event."

For bins that cover transient materials, such as 3, 25 and 37, one responder cautioned that for transient materials to be ignited, they must be located nearby energized cables or equipment that can potentially be snapped by the earthquake's motion and produce an arc flash. Therefore, there is a need to examine, compartment- by-compartment, the possibility of potential transient materials located nearby potential sources of arc flash (e.g., cables or electrical or electro-mechanical equipment with a voltage of 480V or higher).

A majority of responders, that is, four out of six, felt that the following four additional potential ignition sources could be screened:

- Bin 1, Batteries in the Battery Room
- Bin 7, Transients in Control/Aux/Reactor Building
- Bin 12, Self-ignited cable fires in cable runs plant wide
- Bin 13, Dryers plant wide

Therefore, the total number of bins considered by at least 4 of the 6 contributors to have a potential for screening was 15 (11 bins in Table 4.2, and the 4 bins above).

On the other hand, there were 11 bins where all, or all but one responder, felt some further examination always was warranted. These ignition sources and their locations are listed in Table 4.3.

Table 4.3 Candidate ignition bins that always need to be examined as a potential source of ignition

ID	Ignition Source	Location
8	Diesel Generators	Diesel Generator Room
15	Electrical Cabinets	Plant-Wide Components
17	Hydrogen Tanks	Plant-Wide Components
19	Misc. Hydrogen Fires	Plant-Wide Components
20	Off-gas/H_2 Recombiner (BWR)	Plant-Wide Components
23a	Transformers (Oil filled)	Plant-Wide Components
27	Transformer - Catastrophic	Transformer Yard
28	Transformer - Non Catastrophic	Transformer Yard
32	Main Feedwater Pumps	Turbine Building
34	Turbine Generator Hydrogen	Turbine Building
35	Turbine Generator Oil	Turbine Building

There were six additional sources where four responders felt further examination always was warranted. These ignition sources and their locations are the following:

- Bin 9, Air Compressors plant-wide
- Bin 10, Battery Chargers plant-wide
- Bin 16, High Energy Arcing Faults plant-wide
- Bin 29 Others equipment (non-transformer) in the transformer yard
- Bin 30, Boiler in the Turbine Building
- Bin 33, Turbine Generator Excitor in the Turbine Building.

Therefore, the majority of responders felt that some examination always is warranted for 17 bins (11 bins in Table 4.3, and the 6 bins above).

Based on these tallies, there are 15 bins with ignition sources that the majority of responders felt could be screened, 17 bins with sources that the majority felt need always be examined, and 6 bins where responders were split between screening and always needing some evaluation.

The major sources of the diversity of responses obtained for particular ignition sources lie in the assumptions made by various contributors to clarify the conditions under which screening could occur. This included suggested additional refinement to some bins, and the screening out of sub-categories of sources but not the full bin.

The following are some of the relevant comments from the contributors on these issues:

> "The distinction between the criteria listed for Category II vs. Category III is not completely clear, and it seems that for most SSCs the outcome is the same. That is, some level of assessment "must" be performed (i.e., Category III) for any SSC that "may be a potential" source (i.e., Category II)."

"…Depending on the potential source SSC and location relative to seismic equipment list (SEL) SSCs, the assessment needed might involve various combinations of walkdown observation, mapping of potential source SSC proximity to SEL SSCs, and so forth to allow screening of some potential sources, followed by more detailed screening options yet to be determined (e.g., screening based on ignition point temperatures for lube oil sources)."

"Any potential sources located in an area for which the fire PRA has determined that the fire risk is very low should be able to be screened regardless of the SEL SSCs in those areas if there is reasonable confidence that a fire resulting from a seismic event could only occur at relatively high g-levels, i.e., levels at which the seismic PRA conditional core damage probability approaches 1.0."

"…It would seem possible to use an existing fire PRA done for [National Fire Protection Association] NFPA 805 implementation as a starting point for identifying seismically induced fire ignition sources. Rather than using random ignition frequencies, we need an approach to estimating the likelihood that the source causes a fire given that an earthquake occurs (that is, development of a seismic ignition fragility curves as a function of ground motion)."

Clearly, while the results of this survey are promising, they should be followed by discussions among the responders, preferably in person, to achieve greater clarity on ignition sources that are candidates for screening. Hopefully, this can lead to a consensus on which sources can generally be ruled out, and which sources always must be examined.

4.2 Screening of Seismic-induced Internal Floods

As mentioned in Section 1, an earthquake of sufficient magnitude potentially could cause seismic-induced fires, external floods, and internal floods. This section of the report discusses the possibility of generically screening the latter type from further consideration. Specifically, a questionnaire was sent to persons who, as a result of their experience with seismic and/or internal flood risk analysis, were anticipated to be knowledgeable on this subject. The questionnaire's main objective was to assess whether some potential sources of internal flooding can be screened generically. Within the context of this questionnaire, a source was considered any structure, system, or component (SSC) within a nuclear power plant (NPP) that contains a liquid and whose physical boundary's integrity may be lost as a result of an earthquake, thus releasing its contents to its surroundings. For this report, "generic screening" of a potential source means that this source does not have to be considered as a source of seismic-induced internal flood for NPPs in the United States, unless plant-specific conditions warrant otherwise. The questionnaire also asked about the possibility of carrying out other types of generic screening that would reduce the scope of the required analysis, for example, screening on the basis of the flood area/zone location.

Seismic-induced internal plant flooding results from breaches of plant water systems located inside buildings. In other words, an earthquake-induced break or breech of any internal water

source could result in an internal flood if the plant's physical layout is such that the water could accumulate to the extent that plant's equipment may fail. Hence, for this type of flood to lead to core damage, the following conditions must apply:

1. Earthquake-induced uncontrolled release(s) of water or other liquid in the plant.

2. Accumulation of the released liquid in one or more locations within the plant.

3. A failure of the plant's equipment in those locations, due to flooding, that reduces the plant's capability to reach a safe shutdown condition following the seismic- and flooding- (and possibly fire) events.

Three contributors responded to the questionnaire (in alphabetical order by last name):

- ERIN Engineering and Research, Inc. (mentioned in this report as ERIN)
- M. K. Ravindra (MKRavindra Consulting)
- Marty Stutzke (Office of Research, NRC)

Participants were asked to explain the reasoning for their answers. The following paragraphs summarize their views. Appendix B presents the questionnaire and the complete contributors' responses.

Overall, the three contributors agreed that it is not very practical to screen out potential sources of seismic-induced floods according to the type of SSC involved. For example, ERIN noted that it "…is not meaningful to consider components such as pumps, valves, and heat exchangers as potential sources. The source would be the fluid system that such components are a part of. For seismically-qualified systems, the likelihood of pressure boundary failure due to failure of such components will be relatively low unless the normal seismic walkdowns have identified specific issues (e.g., proximity of valve operators to other equipment, inadequate heat exchanger anchorage, etc.). A better approach is to use insights from the internal flooding PRA to identify systems whose failure may lead to flooding of seismic equipment list (SEL) SSCs, and ensure that there are no such specific seismic issues in those systems' components."

The conclusion that it is not practical to screen out potential sources of seismic-induced floods according to the type of SSC involved is consistent with other previous assessments related to this subject. For example, the Callaway Individual Plant Examination (IPE) stated, "Internal floods … analysis is plant specific since the likelihood of occurrence, progression, and subsequent impact on plant systems is highly dependent upon factors such as plant layout, piping arrangements, drainage as well as prevailing flood protection features and programs."

ERIN's contribution was the most thorough in providing useful observations, so a large excerpt is reproduced next. The points made in other contributors' responses are largely consistent with the similar ERIN points.

> It should be possible to identify certain sources of potential seismically-induced internal flooding on a "category" basis such that they would not need to be considered in any assessment. However, the attributes that define such sources are not related to type of systems, structures, and components – SSCs (e.g., tanks, heat exchangers) as suggested by this question. Instead, the attributes that would allow screening are more related to the quantity of source fluid and the availability of a motive driver (e.g., electric

power or gravity) following a seismic event of sufficient magnitude to cause rupture of the source boundary.

If individual components are to be considered …, these should be viewed from the perspective of representing additional fragility failure modes of the piping system itself. However, in this response, the recommendation is to consider a list of screening bases such as the following, and not pursue a component-based screening list ...

Possible bases for complete screening of particular categories of SSCs would include:

- location (i.e., sufficient distance away from SEL SSCs and anticipated operator routes taken in response to a seismic event such that the contained source would not affect these)

- seismic qualification or other demonstration of ruggedness (e.g., inherently rugged piping or pressure boundary features of SSCs). There may be several considerations, e.g., Class I piping systems are likely to have high ruggedness even under above-design basis seismic demands; whereas fluid-filled tanks are likely to have lower ruggedness under the same conditions. (Note that tanks are also addressed below).

- quantity of contained fluid (e.g., closed system or small tank, in either case with volume insufficient to affect SEL SSCs or operator routes)

- large / unlimited source but with lack of motive driver following a significant seismic event (e.g., circulating water system tied to a lake or river but very high probability that pumps would lose (non-emergency) power at a seismic magnitude sufficient to have a high probability of failing the piping, and gravity feed cannot affect SEL SSCs credited for safe shutdown)

- flood area/zone does not contain SEL SSCs and does not contain less-robust structures (e.g., masonry walls), whose failure could result in structural failures that could create propagation pathways to adjacent areas containing SEL SSCs.

For the most part, such bases cannot be applied “generically”, and will require evaluation of each such source.

However, it is likely that certain potential sources can normally be screened, or at least identified as sources that are “unlikely” to need to be dealt with. Examples are:

- Seismically qualified piping – failure probability is low, normally below g levels at which other failures dominate (i.e., where seismic PRA conditional core damage probability, CCDP, approaches 1.0); this includes qualified piping of systems connected to the [reactor coolant system] RCS (see RCS primary and secondary system piping bullets below); so screening out this category is appropriate within the limits of refinement of current [seismic PRA] SPRA models.

- Buried tanks – postulated leakage from such tanks would tend to disperse outside of plant areas needed for seismic event mitigation, and impact of the mechanism that caused the tank failure (e.g., seismic displacement, soil liquefaction) would already

result in the need for re-routing of any required operator actions requiring nearby access; so screening out this category is appropriate.

- Tanks in vaults – tanks in vaulted rooms or compartments such that postulated flooding would only impact the tank source itself should be screened from further consideration. Even if the tank is an SEL SSC, there is no seismic PRA impact beyond the direct component failure, which is already accounted for.

- Buried piping – the same rationale as listed for buried tanks would generally apply; the primary difference would be the potentially larger volume of the source; such sources can be screened unless the internal flood analysis has identified particular issues.

- RCS primary system piping – typically the SPRA will already address seismic induced [loss of coolant accident] LOCA, and the RCS should be designed to accommodate primary system high energy break considerations; so screening out this category is appropriate.

- BWR secondary loop piping or PWR secondary side high energy line piping – For these potential sources, consideration needs to be given to environmental impacts due to high energy effects, and flooding impacts. The SPRA typically would already address the potential for [high energy line break] HELB impacts on SEL SSCs; if so, screening of these sources from additional consideration for seismically-induced flooding is appropriate.

There are some sources that probably should never be generically screened out, i.e., should always be evaluated. Examples include:

- Nonseismically-qualified Fire Protection system piping – such piping may be pervasive throughout the plant, and may include threaded connections such that adequacy of piping supports and location of piping relative to SEL SSCs should be assessed.

- Gravity drain sources with high consequences – examples would include situations where the ultimate heat sink could drain into areas of the plant containing SEL SSCs if the normal isolation capability should fail (or where the postulated break occurs in a location that cannot be isolated); a detailed assessment of the potential impact on SEL SSCs, considering the seismic impacts of the normally-credited isolation mechanisms and operator’s actions would be warranted.

Note that the need to “evaluate” does not necessarily equate to the need to “model” in the seismic PRA. An evaluation may lead to the conclusion that the scenario(s) with potential impact are sufficiently unlikely that no insight is gained by adding detail and uncertainty to the seismic PRA model.

ERIN also noted that “Tanks internal to the plant, whether vertical, horizontal, or suspended, would always require some consideration for flooding impacts to SEL SSCs unless they can be screened on the basis of location (i.e., in an area that cannot impact SEL SSCs). This comment applies to chillers. However, the focus of any future guidance in this area should be on assessment of sources with significant potential impact.”

Another contributor pointed out the importance of taking into account flood sources that were screened out as part of the (non-seismic-induced) internal flood analysis and of plant walkdowns as follows: "…Even those flood sources (SSCs) that have been screened out for random failures may need to be included in the seismic induced flooding analysis. Plant walkdown looking for flood sources and assessing their vulnerability to seismic loading is an important task in the seismic induced flooding PRA. The plant walkdown could be coordinated between the seismic and internal flood PRA teams to identify the seismically induced flood sources in an efficient and complete way…"

In summary, the contributors agreed that screening flood sources by the type of SSC involved was not practical, but that it should be possible to eliminate groupings of potential seismically-induced internal flooding sources from consideration based on certain attributes. Such attributes include the quantity of source fluid, the proximity of source to SEL SSCs, available barriers, and seismic ruggedness.

4.3 Seismically-Induced External Flood Assessment

Estimating the seismically-induced external flood risk to a nuclear plant differs in several ways from the other two other topics discussed above, i.e., seismically-induced fires and seismically-induced internal floods. Two fundamental differences are the following. First, unlike the estimates of the risks of seismically-induced fire and seismically-induced internal flood, which can, if necessary, build on the seismic PRA as well as the fire- and internal flood-PRAs, the availability of external flood PRAs is very limited. Some of the issues and difficulties related to creating external flood PRAs are discussed in NUREG/CR-7046 [19], NUREG/CR-6966 [20], and ASME- ANS RA Sb-2013 PART 8 [2]. Second, the fact that the flood source and the plant are not likely to be co-located adds another difficulty to the analysis: correctly estimating the correlation and dependency between the site of the flood source and the plant site.

Contributors to the topic "Seismic-Induced External Flooding Questions" were presented with the following introductory material, and the listed five questions:

Seismic-induced external plant flooding occurs from sources of water located outside buildings. In other words, an earthquake-induced flow of any external water source could result in an external flood if the physical layout of the plant is such that the water could accumulate to the extent that plant equipment may fail. Hence, for this type of flood to lead to core damage, the following conditions must happen:

1. *Earthquake-induced flow of water from locations outside the plant.*
2. *Accumulation of the water in one or more locations within the plant. The kinetic energy of the flow may be a factor in breaching some flooding barriers and the water reaching some locations.*
3. *A failure of plant equipment due to the flooded location(s) that reduces the plant's capability to reach a safe shutdown condition following the seismic and flooding (and possibly fire) events.*

The following description has been adapted mainly from Chapter IV of "An Evaluation of the Reliability and Usefulness of External-Initiator PRA Methodologies" (NUREG/CR-5477 by Budnitz and Lambert, 1990) [4].

Depending on the site, the generic sources of this type of flooding include the following:

1. *Tsunamis.*
2. *Upstream dam failure.*
3. *Failure of dikes and levees.*
4. *Seiches.*
5. *Landslides*

The flood hazard methodology determines the frequency per year of a seismic-induced flood large enough to cause damage to equipment at the nuclear power plant. This frequency [$F_F(f)$] is a function of the "size" (usually the high-water level) of the flood, f. At any given site, the values of F_F will depend on which phenomenon (or combinations of phenomena) are considered. Also, for a given elevation of extreme flood water, the analyst's ·knowledge of F_F is never exact, so the analysis of F_F should provide a distribution rather than a point value to capture the uncertainty in the state of knowledge.

Flooding analysis typically deals with a single parameter (floodwater height) as its figure-of-merit. This height is then compared to the site features (river bank, dike height, ocean or lake shoreline, etc.). Once flooding reaches a certain undesired height, it is assumed that the waters will flow to all elevations at that height. It is then considered a trivial matter to determine which structures and equipment are flooded. The important observation worth noting here is that sometimes floodwater height alone may not be a sufficient endpoint for the hazard analysis. Sometimes, the duration of the event can be important, such as for wave effects, landslide-induced flooding, and so on. Also, sometimes the total water volume may be limited, such as for an upstream dam failure or a single-strike tsunami.

In principle, an earthquake may trigger several sources of external flooding, such as failure of upstream dam and of dikes and levees, so due consideration must be taken of this issue where appropriate.

Since there are significant uncertainties in the flood hazard analysis, it is important that the methodology capture these. The flood hazard is generally expressed in terms of values of F_F as a function of flood height. The uncertainty is expressed as a distribution of F_F values at each given flood height, to capture the analyst's state of knowledge. Families of curves are often used to show the functional relationships, with different curves showing the 50th-percentile or median value of F_F, the 5th, 25th, 75th and 95th percentile values, the mean value, and so on.

In light of these considerations, please respond the following questions providing the rationale for your answers, and if possible include published references supporting them:

1. *Do you consider the above list of sources of external flooding, resulting from a seismic event, complete? Are there additional generic sources that you could add?*

2. *May a single flood hazard methodology be applied for assessing the frequency per year of a seismic-induced flood [$F_F(f)$] for all types of sources? Or is it necessary to apply a*

different type of method for different sources? Please enumerate the methodology(ies) that you propose for estimating $F_F(f)$.

3. *Are the methodology(ies) that you proposed in the previous question capable of expressing the uncertainties, that is, the analyst's state of knowledge? If not, how would you propose to express them?*

4. *There may be a correlation between the impact of an earthquake on a flooding source (e.g., an upstream dam) and on the plant itself. How could this correlation be accounted for? Are you aware of methods for this purpose?*

5. *An earthquake may trigger several sources of external flooding, such as failure of upstream dam and of dikes and levees. How could this dependency be accounted for? Are you aware of methods for this purpose?*

Six contributors responded to the questionnaire (in alphabetical order by last name):

- ERIN Engineering and Research, Inc. (mentioned in this report as ERIN)
- Fernando J. Ferrante (Office of Nuclear Reactor Regulation, NRC)
- Joseph F. Kanney (Office of Research, NRC)
- Martin W. McCann, Jr. (Jack R. Benjamin & Associates, Inc.)
- M. K. Ravindra (MKRavindra Consulting)
- Marty Stutzke (Office of Research, NRC)

4.3.1 Comments on introductory material

Some of the responding contributors commented on the introductory material before responding to the questions. The following were the salient comments on the introductory material:

- Regarding the three listed conditions for external flood to lead to core damage: Instead of citing "kinetic energy of flow" as a factor in breaching flood barriers, it would be better to refer to hydrostatic and hydrodynamic forces. Additional factors for breaching flood barriers and water reaching some locations are impact forces due to flood born debris, and intake clogging due to sediment and debris.

- The reference for description of flooding analysis and flooding sources, Chapter IV of NUREG/CR-5477, 1990, should be updated with Chapter 3 of "Design-Basis Flood Estimation for Site Characterization at Nuclear Power Plants in the United States of America," NUREG/CR-7046, PNNL-20091, 2011. The updated generic sources of flooding include the following:

    1. Flooding in Rivers and Streams
    2. Dam Breaches and Failures
    3. Storm Surge
    4. Seiche

5. Ice-Induced Flooding
6. Tsunami
7. Combined-Effects Flood

- The paragraph starting with “Flooding analysis typically deals with a single parameter (flood water height)…” elicited a number of comments:
-
  1. Other factors besides flood water height, such as flow velocity and erosion, may be considered implicitly or explicitly;
  2. The statement “Once flooding reaches a certain undesired height, it is assumed that the waters will flow to all elevations at that height” ignores the importance of site-scale topography;
  3. The statement “It is then considered a trivial matter to determine which structures and equipment are flooded” is contraindicated by operating experience such as NTTF Recommendation 2.3 Flood Protection Walkdowns and numerous inspection findings, and the apparent insufficient understanding of pathways by which water may enter buildings at many sites;
  4. The duration of a flooding event needs to be defined carefully and used consistently. What constitutes the start of the flooding event (first warning? arrival of flood waters on site?). What constitutes the end of the flooding event (water recedes from SSCs? water recedes from site?);
  5. It is also important to note that flooding may have impact on the ability to perform certain manual actions or even impede site access before flood waters reach levels that threaten SSCs.

4.3.2 Responses to Question 1

Do you consider the above list of sources of external flooding, resulting from a seismic event, complete? Are there additional generic sources that you could add?

There was general agreement among the contributors that the list was reasonably inclusive, and that all the listed sources can be potentially important depending on the site and the plant’s design. However, it was pointed out that each site is somewhat unique in terms of the associated potential sources of external flooding. There may be combined events that are very site-specific (e.g., landslide-induced flooding due to seismic events). In addition, there are ‘likely’ combinations of events that can impact the flooding that occurs. For instance, the time of year that an earthquake occurs can have important implications as to the extent of flooding (‘dry’ season versus ‘wet’ season). NUREG/CR-7046 (PNNL-20091A) was cited as a reference that provides a list of flooding mechanisms considered by the NRC and other Federal Agencies. While a full set of the flood sources identified in references should be considered for a specific-site, the consideration of additional site-specific hazards may be even more relevant than the others explicitly identified in reference documents.

In evaluating the list of flood sources in the introductory material, one contributor provided additional details for consideration in the following table:

No.	Flooding Type / Source
1	Tsunamis
2	Releases from Upstream Dams: a. Dam Breach (uncontrolled) b. Releases associated with failure of spillway structures (non-dam breach related) (Uncontrolled) c. Controlled releases that are made to reduce the load on the dam in order to prevent its failure as a result of seismically initiated damage.
3	Releases from Downstream Dams A seismic event could breach a downstream dam or require significant lowering of the reservoir in order to prevent a failure. These events could lead to a loss of the reservoir (heat sink).
4	Failure of Dikes and Levees This could be particularly problematic for a couple of reasons: • The potential seismic damage that could lead to failure may be subtle (limited transverse cracking) that could contribute to seepage and piping in the event of an upstream dam failure. • The time available to make repairs to the levee may be limited. • If the seismic event causes a levee failure and it occurs during high spring flows, the plant may be dealing with a certain amount of flooding or fighting a flood (sandbagging, etc.). A coincident dam failure or large release from an upstream dam would compound the flood threat at the plant.
5	Seiche
6	Landslides Upstream – Reservoirs For a plant located on a reservoir, a landslide could induce waves that result in plant flooding. Landslides in an upstream reservoir (upstream of the dam) could contribute to a breach of the dam or a flood wave that goes over the dam and downstream.
7	Landslides - Rivers Landslides can create upstream dams that could potentially pose a threat to downstream facilities. Landslides could also produce a downstream dam that leads to flooding upstream.

This contributor also noted that there may different metrics that can be important when characterizing a flood hazard. In addition there also may be accompanying issues, such as the potential for debris, sediment, and erosion that may need to be considered.

Other potential flood sources suggested by contributors were:

1. “River diversion” resulting from seismic failures that might divert the flow of a river or large stream that would not normally be a source of flood at a site, such that it becomes one. While likely difficult to analyze, such a source could be included for completeness, and addressed as part of the broader process of selecting significant sources for a particular site.

2. “Lateral spreading” resulting from a seismic-induced soil liquefaction event. The NRC’s Regulatory Guide 1.198, “Procedures and Criteria for Assessing Seismic Soil Liquefaction at Nuclear Power Plant Sites”, was cited as a reference that addresses this phenomenon for design purposes, but may also provide insights relative to beyond-design-basis seismic events.

An important set of possible flood sources, noted by several contributors, are large onsite sources that have not been considered as sources of internal floods. Water-holding structures, such as large tanks, cooling water reservoirs, or ponds (e.g., large service-water ponds), and failures of dams that are located on the site property could be external sources of flooding.

4.3.3 Responses to Question 2 and Question 3

Question 2: May a single flood hazard methodology be applied for assessing the frequency per year of a seismic-induced flood [FF(f)] for all types of sources? Or is it necessary to apply a different type of method for different sources? Please enumerate the methodology(ies) that you propose for estimating FF(f).

Question 3: Are the methodology(ies) that you proposed in the previous question capable of expressing the uncertainties, that is, the analyst’s state of knowledge? If not, how would you propose to express them?

Since Question 2 is on the choice of a methodology and this choice will govern the modeling of the aleatory uncertainty, and Question 3 is on the treatment of epistemic uncertainties, some contributors felt that the responses to these two modeling questions should be linked. The rationale is that since both types of uncertainty must be addressed, and since their characterization and evaluation are inter-related, the uncertainties, and therefore the questions, should be considered together. Indeed, the responses to the two questions had considerable overlap, and so the responses to both questions therefore are combined and summarized in this subsection.

The contributors all agreed that a single methodology for assessing the frequency per year of a seismic-induced flood for all types of sources was not appropriate. There were several reasons given. The mechanisms leading to flooding differ for each of the various generic sources, and therefore, the mechanistic models that are used are different. The probabilistic models also will be different. Different models and data are required to develop the probabilistic-hazard curves.

As outlined by one contributor, the different methodologies that generally will be required are the following: (1) A method to estimate the frequency of the seismic hazard of interest (e.g. ground shaking, surface faulting, landsliding, liquefaction); (2) a fragility or failure model for the entity impacted by the seismic hazard (e.g. a dam, levee, dike, hill slope, water tank, fault displacement); (3) a model to estimate the initial hydrograph (e.g., initial water-surface displacement, dam or level breach hydrograph or peak flow, discharge hydrograph or peak discharge from tank); (4) a model for the propagation and attenuation of a flood wave as it moves towards a site (e.g., propagation of a tsunami wave or of a riverine flood wave); and finally, (5) a model for site-scale interactions of the flood wave with local bathymetry, topography, buildings, etc. Some more specific examples of different source hazard assessment methodologies offered by contributors include the following:

1. Upstream dam failure – The assessment of source impact on the site requires determining the probability of dam failure resulting in a given site flood impact (e.g., flow rate and duration) for a seismic event of a given magnitude. The flooding from failure of an upstream dam should take into account the characteristics of that dam and the failure modes. Such an assessment would need to address the dam's structural response as described in the US Army Corps of Engineers' (USACE) guidance, and then determine the probability of propagation to the site, e.g., using a river model.

2. Tsunami – The assessment of source impact on the site needs to deal with the development of the seismic-event-induced wave and would need to address parameters such as wave height, wave speed/timing of coastal impact, and coastal parameters.

3. Seiche – The assessment of source impact on the site might include similar considerations as those for the tsunami, but also would need to address issues such as lake-embankment properties, and the lake's depth.

For specific flood mechanisms, one can consider whether a single flood hazard curve is possible, e.g., dam failures and river flooding - these types of analyses have been performed. For other flood mechanisms, it may be necessary to consider a separate hazard curve as a contributor for specific scenarios, e.g., local intense precipitation. For seismically-induced floods due to dam failures, it may be necessary to consider individual dams that may contribute to flooding at the site, and to screen out dams (or assume they failed) that, by themselves, or in combination, would not produce significant flooding.

It was suggested that, in general, it may be better to treat each flooding source separately, and add the frequencies at the end if appropriate. One contributor provided the following list of references that could be helpful in developing an appropriate flood methodology that could be used for seismically-induced flooding from different sources:

- A general discussion of risk assessment for dams is given in Hartford and Baecher (2004) [10]. The most likely seismic failure modes for dams include (1) sliding failure through a weak lift line; (2) horizontal cracking; (3) liquefaction of dam or foundation;

(4) cracking from severe shaking; (5) displacement of a surface fault through the foundation; and, (6) Overtopping from a landslide failure into reservoir.

- While probabilistic assessment of seismic hazards due to ground shaking is a mature discipline that has approaches for considering both aleatory and epistemic uncertainties (e.g., McGuire, 2004 [15]), probabilistic fault-displacement hazard analyses (PFDHAs) have been done in only a few cases. The basic methodology was developed for the proposed Yucca Mountain, Nevada Nuclear Waste Repository (Stepp et al. 2001 [25]). An example of PFDHA applied to a dam is an analysis conducted for Lauro Dam, near Santa Barbara, California (Anderson and Ake, 2003).

- Probabilistic liquefaction analysis is discussed in NUREG/CR-6622 (NRC, 1999) [26] and by Holzer (2008) [11].

- Regression models for peak discharge due to dam failures are discussed by USBR (1982 [27], 1983 [28]). Regression models for the parameters of dam breach are discussed by Wahl (2004 [29], 2010 [30]). Wahl (2010) discusses uncertainty in regression models for breach parameters.

- Probabilistic tsunami hazard assessment (PTHA) is less mature than PSHA, but there are approaches and models that have gained a certain degree of acceptance. The maturity of PTHA for tsunamis caused by subaerial- or submarine landslides is considerably less mature than PTHA for tsunamis caused by fault rupture.

- Regarding the seismic failure of dikes, levees which are usually not seismically qualified, it may be appropriate to simply assume failure at some modest level of ground shaking.

Contributors pointed out that the difficulties of performing a credible hazard analysis are discussed in NUREG/CR-7046, NUREG/CR-6966, and the ongoing work at the IAEA. Part 8 of ASME/ANS RA-Sb-2013 [2], the ASME/ANS PRA Standard, also discusses these difficulties. Probabilistic hazard models are needed, for example, for tsunamis, seismic dam failures, and seiches. Each of these has unique phenomenological aspects and likely will require different expertise. Site-specific details also are important. Comprehensive probabilistic assessments of flooding hazards have not been carried out traditionally by the nuclear industry, but efforts are under way to provide guidance in this area.

It was pointed out that NRC/RES has a research effort underway on probabilistic assessment of flood hazards that potentially could be leveraged for the treatment of seismically induced external floods. Several methods were discussed at the NRC-hosted Workshop on Probabilistic Flood Hazard Assessment ("Proceedings of the Workshop on Probabilistic Flood Hazard Assessment (PFHA): U.S. Nuclear Regulatory Commission Headquarters, Rockville, MD, January 29–31, 2013, NUREG/CP-0302" [17]). In that workshop, multiple extrapolation methods were discussed, including [U.S. Geological Survey] USGS Bulletin 17b, Regionalization methods (i.e., L-moments), inclusion of paleoflood information, and physics-

based stochastic modeling for extreme floods. Depending on the method used, different levels of credibility may be assessed depending on the return period ranges considered.

One contributor noted that an over-arching probabilistic framework for conducting a PFHA is planned for inclusion in the new version of ANS 2.8, "Determining Design Basis Flooding at Power Reactor Sites[2]." This framework will provide guidance on how a PFHA should be carried out. Elements of this framework are borrowed from the Senior Seismic Hazard Analysis Committee (SSHAC) process (NUREG-2117, "Practical Implementation Guidelines for SSHAC Level 3 and 4 Hazard Studies," April, 2012) [12], developed for performing a probabilistic seismic hazard analysis (PSHA). The ANS 2.8 probabilistic framework that provides guidance on how a PFHA project is carried out, and includes the evaluation of aleatory and epistemic uncertainties, is applicable to all sources and types of flooding, but the details of its implementation and the actual probabilistic modeling that is done would differ for different cases.

It was also observed that a probabilistic analysis of flood hazards needs to be scalable so to meet the range of problems that exists for a fleet of plants. In other words, a graded approach is needed that requires the expenditure of resources commensurate with the size and complexity of the potential risk posed. For instance, at a plant one might be able to do a limited analysis that shows the frequency of flooding is low enough that it does not have to be considered in the design basis, or in a PRA. Such an analysis should address the aleatory and epistemic uncertainties in a systematic rigorous manner to make the case that the frequency of exceeding plant grade (for example) is sufficiently low, less than 10^{-7} per year. This analysis does not necessarily require an extensive study (such as use of experts, or a lot of hydrologic or other modeling). For another plant that clearly has a flood problem, a more comprehensive analysis (more depth, more detail) potentially including the use of experts and therefore the need for structured expert elicitation, could be required. In the SSHAC[3] process and in the new ANS standard on flooding, the concept of levels of analysis (scalability) is used. The analyses have the same goal and same probabilistic framework, but the level (depth of analysis; cost) of evaluation may be different.

Aleatory and epistemic uncertainties must be accounted for, irrespective of which methodology is chosen for the seismic-induced analysis. For different flood types, the sources of aleatory uncertainty differ, and the way these uncertainties are modeled will vary accordingly. The choice of mechanistic- and probabilistic models for a given type of flooding will impact what aleatory uncertainties are considered, and how they are modeled.

[2] The scope of the proposed new version of ANS 2.8 is stated on the ANS website as "This document presents criteria to establish design basis flooding for nuclear safety-related features at power reactor sites. Methodology is described to evaluate the flood having virtually no risk of exceedance that can be caused by precipitation and snowmelt and any resulting dam failures; seismically induced dam failures; surge or seiche and attendant wind-generated wave activity; or a reasonable combination of these events."

[3] The original SSHAC guidelines defined four levels at which a PSHA can be conducted, with the number of participants, resources, and time required increasing as one progresses from Level 1 to Level 4.

While most methodologies are expected to be capable of expressing uncertainties, it is likely that different methodologies deal with uncertainties in different, and possibly inconsistent, manners. For example, available references for soil liquefaction may not provide probabilities with uncertainties. In some cases, the failure is assumed to occur at a given g-level.

Some methodologies simply do not capture modeling uncertainty because they rely on extrapolating limited available historical data to ranges well beyond the observed record. Other methodologies based on physics-based stochastic modeling are more promising in capturing modeling uncertainty more explicitly. However, even this latter approach may not necessarily capture all the uncertainty because it is limited by the available historical records, and/or the assumptions of expert judgment about the uncertainty in the inputs to the analyses. Such an approach may capture modeling uncertainty to a certain degree depending on the specific application and the return period of the floods considered.

Several contributors suggested that some sort of SSHAC exercise could be used to identify and quantify the uncertainties. The development of a probabilistic hazard assessment involves two basic steps: First, selecting or developing a probabilistic model for the flood frequency, and second, estimating the parameters in that model. It was suggested that the first step would seem to warrant a PIRT process to address modeling uncertainty, while the second step needs a SSHAC process to address parametric uncertainty.

It also was noted that uncertainties in the impact of the seismic hazard on each flood source complicate the consideration of uncertainty in the consequential event. The case where there may be multiple flooding sources initiated by the same seismic event is significantly more complex. Further, the uncertainties in the seismic hazard frequency and the probability of the consequential event need to be addressed and integrated to obtain the frequency of the combined event and its integrated uncertainty. One contributor noted that it seems likely that the uncertainty in the flood hazard for some sites could be substantially greater than that of the seismic hazard, such that it may be challenging to derive meaningful insights from a quantitative assessment.

4.3.4 Responses to Question 4 and Question 5

> *There may be a correlation between the impact of an earthquake on a flooding source (e.g., an upstream dam) and on the plant itself. How could this correlation be accounted for? Are you aware of methods for this purpose?*
>
> *An earthquake may trigger several sources of external flooding, such as failure of upstream dam and of dikes and levees. How could this dependency be accounted for? Are you aware of methods for this purpose?*

Since Question 4 deals with the correlation of the impact of an earthquake on the plant and the impact on a relevant flooding source, and Question 5 deals with the correlation of the impact on

several flooding sources, some contributors felt the questions should be considered together. The responses to the two questions did show some overlap and the responses to both questions therefore are combined and summarized in this subsection.

In reference to the issue that an earthquake may cause ground motions at a plant and an upstream flood source like a dam, one contributor noted that the ground motions at both sites depend on several factors and there are a number of sources of correlation (Park, et al., (2007) [18]; McCann (2012) [13]; McCann, et al. (2015) [14]). The sources of dependence and correlation are the following:

- Earthquake magnitude,
- Distance of each site to the earthquake,
- Inter-event variability of earthquakes of the same magnitude,
- Intra-event variability of earthquake ground motions, and,
- Separation distance between the plant and the upstream dam(s).

Modeling all of the factors listed above requires specialized seismic hazard/risk quantification software. In addition to information in the referenced papers, firms in the insurance industry and possibly some firms that do earthquake risk analysis for lifeline systems (spatially distributed systems) may be sources for software that model this problem. The importance of modeling each of these sources of correlation/dependence to plant risk is problem-/circumstance-specific.

Another contributor outlined the more basic considerations for correlation/dependence:

- It would seem important to focus on flood events that are caused by the same seismic event that is being evaluated for its seismic impact on the plant, i.e., focus on correlated-response events. Since seismic events tend to affect large geographic areas (e.g., the recent Mineral, Va. Earthquake), a seismic event sufficiently remote that it would not affect the plant can be assumed also to be sufficiently remote to not be considered as a seismically-induced flood source. While there may be far away flood sources that could result from a seismic event near the source, any subsequent cascading effects that might ultimately affect a far away (from the flood source) plant should be considered as part of the external flood-risk assessment, not as part of the seismic-induced flood risk assessment for the plant.

- For close-in sources (where close-in needs to be defined based on considerations of seismological impact), and where the source (e.g., dam) and plant are founded on very similar foundation media (e.g., same soil/rock material properties and layer thicknesses), complete correlation between plant and dam foundation input response impacts might be

appropriate. However, this does not mean that structure of the flood source and the responses of the site structure would necessarily be highly correlated.

- For "farther away" sources that may be subject to the same seismic event (where again, the distance to be considered would be based on considerations of seismological impact), specific determination of the seismic input response for the flood source, separate from the seismic input response to the plant for the same event, likely would be required. In addition, the correlation impact in this case also must address the timing of the accident sequence, i.e., impact on the plant of the seismic event followed, at different times, with different accident sequence impacts due to different flood sources.

- Other scenarios might involve a seismic event weakening a nearby dam but also failing a far-away dam, whose failure subsequently results in failure of the nearby dam, with subsequent impact on the plant. Clearly, some boundary conditions need to be placed on the scope of the analysis.

- Where multiple simultaneous flooding sources are taken into account, the hazard should be considered from the perspective of the plant site. The impact of that hazard then should be considered as it affects potential flood sources, accounting for their distance from the site, with some seismologically based regional impact boundary established to determine which sources should be considered. The impacts of multiple sources then could be accounted for probabilistically. Issues of timing would need to be considered for the impacts of each source. At some point, the analysis needs to be subject to some boundary conditions (i.e., limit on number of cascading impacts considered), and the uncertainties may be such that only a parametric analysis can be performed, and then only to provide insights, but no real meaningful quantitative results on risk.

One contributor outlined the challenges in analyzing the significant correlation between a seismic event challenging a facility and a loss of impounding reservoir at the facility, such as a dam or levee. The initial challenge is where to locate the seismic sources, such that significant ground motion would be experienced at either one or more dams (i.e., the location may have to be optimized such that the most critical dam is failed, or a combination of dam failures producing the highest water level at the site is the dominant contributor). Establishing failure metrics for the dam itself due to seismic events will be the next challenge, as the "weakest link" in the dam system will need to be determined according to intensity and failure mode. For example, for a concrete dam, the failure modes related to a specific reinforced concrete section for a buttress dam would differ for specific designs or for an embankment dam. In addition, the failure of appurtenant structures, such as spillways, may need to be considered as additional scenarios. The combination of specific levels at the dam when the seismic event occurs also can be treated probabilistically (e.g., if flow level records are available, it may be postulated that the reservoir's elevation has a specific likelihood of exceeding a certain level when a postulated seismic event impacts the dam). Alternatively, a specific assumption about level may need to be assumed, with above-normal pond elevation for conservatism. Guidance such as ANSI/ANS-2.8-1992 [1] provides combinations of seismic events with hydrological events, but

these are deterministically-derived scenarios (e.g., a specific percentage of the safe shutdown earthquake in combination with a percentage of the probable maximum flood), and therefore would not easily translate into frequencies, although specific generic numbers are presumed (e.g., 10^{-6}/year) for such combinations[4]. Finally, the breach mechanism for a dam failure may be different from a hydrologic-induced event and would have to be assessed by physical modeling. The relevance of this item is that timing of the unintended release of the reservoir may be different, with a different warning time and probability of success for implementing flood protection mitigation at downstream facilities, such as nuclear sites. The contributor recommended looking into the US Department of Interior's Bureau of Reclamation (USBR) approach to risk assessment of dams, since this includes a discussion of how to assess the dam's risk via some of the above concepts explicitly considered.

The contributor further noted that if concurrent cascading dam failures are being considered, the complexity of the analysis will depend on the complexity of the watershed in several aspects. Large watersheds with significant regulated structures may require an optimization of the impact of the local seismology and the optimal location of a seismic event that would induce the scenarios of relevance to flooding at a specific site, such as a nuclear site downstream. Several scenarios may be screened or combined so that those critical for flooding aspects are included. Then, a realistic combination of scenarios would have to be identified and an approach established to determine the likelihood with respect to the likelihood of the ground motion that produces multiple failures, along with any conditional probabilities associated with these scenarios (e.g., a set of dams fails seismically, causing downstream dams to fail in a cascading fashion if reservoir impounding capability is insufficient to contain the releases).

It also was noted that NRC's Interim Staff Guidance for Evaluation of Flood Hazards due to Dam Failure (JLD-ISG-13-01 [16]) outlined an approach (but not a detailed method) for considering the seismic failure of multiple dams. It also could be applied to investigating the correlation between dam failure and seismic impacts at the site.

Other observations from contributors included the need to account for the time lag in impact on the plant from the earthquake and from the flood, as well as the need to consider aftershocks. The possibility that flooding may impact the ability to perform certain manual actions, or even impede site access before the plant site's flood level threatens plant SSCs also was pointed out.

One contributor noted that failure of multiple water-retaining structures could be beneficial. An example is the propagation of a flood wave from a dam break. If a dike or levee between the dam and the plant fails, it will result in a lower discharge and water level at the plant compared to the case where the levee or dike does not fail.

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[4] Note that, as discussed in Section 4.3.3, ANS 2.8 is being updated and probabilistic framework for conducting a probabilistic flood hazard analysis (PFHA), using some elements from the SSHAC process for PSHA is planned to be included in the new version of ANS 2.8. So, the revised version of ANS 2.8 should address the problems mentioned above that are in the 1992 version.

Another contributor noted that a successful approach to treating multiple external-flood sources also could potentially address the damage to other nearby civil structures (e.g., roadways, bridges) that could have an impact on evacuation and, hence, consequences.

Also, one contributor pointed out that, beyond the seismic hazard correlation issues, there are several factors/sources of dependence that need to be considered:

In the event of an earthquake, there are sequences that may occur that could lead to core damage as a result of the seismic event, flooding, or the combined effect of both hazards. A plant may survive the seismic event, but at the same time experience damage to structures and selected equipment items that compromise the response to onsite flooding. For example, damage to structures may deform doorway frames complicating installation of flood barriers and creating leak paths, and cracked exterior walls creating a leak path into the building, and potentially expanding small cracks that may exist in the foundations of structures containing flood-mitigation equipment. Furthermore, following a seismic event there is a likelihood that flood preparatory actions would need to occur without the benefit of off-site power.

Successful flood mitigation at a plant requires considering seismic damage to flood-mitigation structures and components that may not be considered in the seismic PRA, such as the following:

- Damage that allows in-leakage into structures. This leak could occur above and/or below grade
- Damage to flood mitigation systems, such as levees, floodwalls
- Impact of the seismic event on operators and the systems required to mitigate flood events
- Assessment of flood fragility for structures and components

5. Issues Identified

The participants in the workshop that took place in December 2013 in Rockville, MD, on seismic-induced fires and internal and external floods, expressed various opinions on numerous issues relevant to estimating the risk to nuclear power plants (NPPs) from these hazards. These issues may be grouped into the following categories:

- The availability of probabilistic data,
- The PRA modeling of concurrent events,
- Human-reliability analysis (HRA),
- An understanding of mechanisms of failure,
- Screening of SI-F&IEF scenarios,
- Other PRA-related issues for modeling seismic-induced scenarios, and
- Current PRA standard activities and actions associated with Recommendations 2.1, 2.3, and 4.2 of the NRC's Near Term Task Force (NTTF), which was convened as a result of the Fukushima Dai-ichi accident.

The questionnaires and associated responses, discussed in Section 4, partially address some of these categories:

1. The lack of availability of probabilistic data, as related to correlating seismic impact on the plant and the external flood source, is discussed in Subsection 4.3, as is (briefly) the difficulty of modeling the combined effect of the seismic and flood and/or fire hazard.
2. Screening of SI-F&IF scenarios is discussed, respectively, in Subsections 4.1 and 4.2, and
3. Some future PRA standard activities related to probabilistic assessment of flooding hazards was mentioned by a contributor whose comments are included in Subsection 4.3.

The following subsections highlight the main points discussed for each category of issues, principally as they were identified in the workshop.

5.1 Probabilistic Data

1. Possibly, the most difficult technical challenge is developing fragility information (i.e., typically fragility curves) for seismic-induced internal fires, and internal floods.
2. For external flooding, the problem of assessing the frequency of the initiating event of correlated seismic-induced failure of external structures (e.g., a dam) probably is the most demanding. Even for determining the effects of a tsunami, it is a non-trivial task to

relate the occurrence of the tsunami-inducing seismic event and the flooding impact at a specific site. This problem is expected to extend into seismically induced dam failures, and possibly to other sources of external flooding. Specifically, the NPP site's ground motion is not necessarily the same as that experienced at an upstream dam. Since the sources of the effect of earthquakes on a dam (or another source of external flooding) and a NPP may be correlated, a "joint hazard curve" might be developed. Another requirement would be an analysis of the dam's seismic fragility (or that of another external structure, such as a dike or a water reservoir).

3. Fragility curves for seismic-induced fire or flood would be needed for the SSCs typically included in a fire- or flood-PRA. Of particular interest are the fragilities of SSCs that are non-seismically-qualified because their failure potentially could cause the failure of safety-related seismically qualified SSCs; for example, flooding due to failure of a non-seismically-qualified tank may cause a safety-related seismically qualified SSC to fail (for instance, a pump). Hence, walkdowns may have to include the potential of non-seismically-qualified SSCs to initiate a fire or flood after an earthquake.

4. A survey of earthquake-induced fires in electric power and industrial facilities by the Electric Power Research Institute (EPRI) states "…Review of the data identified only a small number of minor earthquake-induced fire events. Of the 108 sites studied, incidents of earthquake-induced fire were encountered at four sites…" Seemingly, the probability of seismic-induced fires in industrial facilities is low. However, this survey was published in 1990, so updating this survey is advisable to include more recent operational experience, preferably including nuclear- and international-experience. Similar summaries related to seismic-induced flooding would be useful.

5. The Seismic Qualification Utility Group (SQUG), an industry organization established in 1982, may be a source of earthquake data for different types of equipment. However, it was pointed out that their database focuses on functional failure, not on the failure modes of equipment that cause fire or flood.

6. It was mentioned that data may be generated or collected by a joint effort between NRC and EPRI. The latter organization seems to have produced significant studies on the events in Japan, and has also been involved in developing a seismic database. International organizations, such as the International Atomic Energy Agency (IAEA), and the Nuclear Energy Agency (NEA), also may be sources of this type of data, but no specifics were discussed.

7. It was suggested that some important data on induced fire/flood fragility could be generated using shake tables, used now to generate information on seismic functional fragility. Care should be taken that electrical equipment is energized fully and under its normal load when tested, as its electrical state would affect the physical processes leading to arcing and fire.[5]

5.2 PRA Modeling of Concurrent Events

1. A seismic event potentially can cause fires and/or floods in multiple locations inside an NPP. Modeling their concurrent occurrence in a PRA would enhance its realism.

[5] Currently, electrical equipment is tested energized, but not under load.

2. Understanding the full impact of concurrent events is difficult. Each of them (internal fire or internal flood) may impact the other events. For example, an induced fire can entail an internal flood, while an induced internal flood may impact the mitigation of a fire source. Accounting for external floods would add other complexities.

3. Correlating multiple concurrent events also presents complexities. Since several correlated events may be happening due to a seismic event, there is the potential for defeating train redundancy. For example, if two redundant trains have the same component that is susceptible to seismic-induced fire, then both trains may fail due to the seismic-induced event. Accordingly, we may need to develop a method to define the level of correlation between failures of equipment due to seismic-induced fire or flood. One participant mentioned that he is leading a project whose objective is to better correlate seismic-induced failures for selected equipment, not just fully correlated or uncorrelated. The method presumably could be used for seismic-induced fire.

4. Considering additional dependencies for multi-unit stations may be required in the following cases:
   A) There is a correlation between two or more units with identical- or similar-components that are subjected to the same earthquake.
   B) For sites where the units share some equipment or systems, if one or more shared SSCs fail, some or all the units at a site will be affected.
   C) Typically, it is assumed in a PRA that an earthquake at a nuclear site causes loss of offsite power (LOOP). For analyzing seismic-induced fires/floods, applying this assumption may eliminate some accident scenarios, such as flooding due to loss of power to a pump. Hence, it seems more realistic to model probabilistically the availability of offsite power.

5.3 Human Reliability Analysis (HRA)

1. There is a need to extend HRA research to cover earthquakes, consequential fires/floods, and post-core-damage actions. In particular, the operator's actions need re-assessing taking into account the possibility of concurrent fires and floods resulting from the seismic event. If there are multiple consequential fires/floods, the operating crew probably will assign a different priority for coping with each event; this practice may, at least partly, help explain why a fire caused by an earthquake burned unextinguished for several hours at the Onagawa plant.

2. The quantification of the operators' actions should be revised because performance-shaping factors are not the same given a seismic event with induced fires/floods in multiple locations (such as increased stress level, lack of, or false indication).

3. The issues of the operators' access also should be reassessed. Some issues are blockage of access (e.g., due to flooding or toxic environments), and the possibility of finding alternate paths.

4. NPPs typically have their own fire brigades on site, but some also rely on their local fire-departments to help put out some fires. However, after an earthquake, the local fire department may be busy taking care of other local issues, and may not be able to fully support an NPP.

5.4 An Understanding of Mechanisms of Failure

1. Failure mechanisms for some SSCs are well understood and can be modeled, provided that all the physical interactions are identified clearly. One issue lies in assessing the severity of the seismic-induced fire or flood of an SSC. For example, if the SSC is a tank, and its failure causes a flood, estimating the flow rate from the tank may prove challenging.

2. There are some mechanisms of failure that are not fully understood:
   a) Seismically induced failure mechanisms of a component may cause the component to catch fire.
   b) Some problems should be studied in detail to gain insights; for example, the seismic-induced arcing fire in a metal-clad medium-voltage switchgear cabinet at Onagawa after the March 2011 tsunami. Apparently, the equipment inside the cabinet was not anchored properly. Also, this induced fire lasted for several hours. Further, there is the possibility of other seismic-induced shorts causing a fire.
   c) The fire experiences during the March 2011 tsunami, and the Kashiwazaki-Kariwa 2007 seismic event should be examined closely for failure mechanisms.
   d) Seismic-induced spurious actuations of the Halon- or Foam-system or others that could cause key equipment to fail (e.g., EDGs) should be considered as a failure mode for that equipment.

3. For seismic-induced internal flood or fire scenarios, there may be potential differences in their propagation path. In other words, the issue is whether the fire- and flood-areas defined in the individual fire- and flood-PRAs remain the same. For example, two flood areas or rooms may be separated by a wall, but if the wall collapses due to an earthquake, a consequential flood in one of the rooms may propagate into the other one.

4. The NRC prepared Interim Staff Guidance (ISG) JLD-ISG-2013-01 establishing that if the seismic failure of an upstream dam poses a potential challenge to an NPP, the NRC would like to have an analysis of such failure, and also one of a “sunny day” dam failure. These analyses may be factored into the PRA supporting the quantification of the initiating event’s magnitude and frequency.

5.5 Screening SI-F&IEF Scenarios

1. A “low-intensity” earthquake is unlikely to cause a consequential fire or flood. On the other hand, a “high-intensity” earthquake may be severe enough to directly damage the core, regardless of any consequential fires or floods. Hence, the “medium-intensity” earthquakes are the most relevant for evaluating SI-F&IEF scenarios. However, seemingly there are difficulties in identifying these earthquakes:
   a) It is difficult to know a priori what the boundaries of the “medium-intensity” earthquake are, that is, a lower boundary below which an earthquake is considered “low-intensity,” and an upper boundary above which it is deemed “high-intensity.”
   b) “Medium-intensity” earthquakes are site-specific, since the geological conditions in one site may differ from those at another site.

c) The impact of "medium-intensity" earthquakes is NPP-specific; viz., the SSCs that are susceptible to damage from a "medium-intensity" earthquake in one NPP may differ from those SSCs in another plant. The SSCs that are susceptible to damage from a "medium-intensity" earthquake at a particular NPP may be identified by an approach similar to that presented by one meeting participant, which involves walk-downs specifically intended to identifying those SSCs that may be vulnerable to fire or flood caused by an earthquake. In addition, some SSCs may be identified as vulnerable, but they may be screened out given their location. For example, a non-seismically qualified fire-water tank is likely to cause a flood in a "medium-intensity" earthquake, but it may drain outside the plant, so its impact on the plant's risk is very minor. This process may identify a few generic items that may apply to many or to all NPPs, such as tanks with a gravity drain that potentially can cause a flood, even if offsite power is lost. Identifying those SSCs that are susceptible to damage from a "medium-intensity" earthquake was considered important for screening SSCs when analyzing SI-F&IEF scenarios.

2. Most of the discussion focused on a Level-1 PRA. If a Level 2 or 3 PRA is contemplated, additional considerations may apply. In particular, the screening mentioned in the previous point may differ, depending on the PRA level that is the study's objective. In addition, different walkdowns and fragility curves may have to be developed for a Level-2 PRA. For a Level-3 PRA, the impact of earthquakes and possible external floods on evacuation must be considered.

3. Another type of screening discussed was screening out an SCC from an SI-F&IEF PRA when the impact of the seismic-induced fire or flood is expected to be less than the impact of the failure of the SSC itself, as caused by the earthquake.

4. Screening out seismic initiating events and SI-F&IEF scenarios based only on low frequency was discussed. While this practice is common in PRAs, some participants warned that this should be done very carefully for these events and scenarios because there appears to be substantial epistemic uncertainty about them (i.e., parameter, model, and completeness).

5. If the seismic fragility of an SSC is weaker than the building it is in, the SSC should be considered in the PRA. If the SSC's seismic fragility is stronger, the building will fail first, and hence, the SSC may be screened out if all the components in the building are considered failed due to the building's collapse.

6. It was suggested that a process similar to the Multiple Spurious Operations (MSO) process, which lists items that "screen in" for PWRs and BWRs, may serve in screening SSCs in SI-F&IEF scenarios. An expert panel then searches for plant-specific items to be added to the list. Apparently, this process would have to be examined in practice for its applicability to screening SSCs that potentially are related to seismic-induced fires and floods.

5.6 Other PRA-related Issues for Modeling Seismic-induced Scenarios

1. Most workshop attendees concurred that the basic approach for developing a PRA for SI-F&IEF scenarios consisted of using an existing seismic PRA (or one under development), and then augmenting it to include seismically induced fires (and floods)

("setting a seismic PRA on fire (and flooding it)"). Although the participants generally agreed that the progression of the initial accident would follow the seismic PRA, the later phases of the accident could be affected significantly by the seismic-induced fires/floods. This will require modifying the seismic PRA models (such as event trees, fault trees, and rules). Although there are options for the technical resolution of this issue, it would greatly benefit from a pilot application.

2. Some seismic-induced fires/floods may be caused only by a seismic event, and hence, were not considered in the individual fire- and flood-PRAs. Also, mitigating equipment, such as fire-suppression equipment (most of which is not seismically qualified), though credited in an individual fire PRA, may be degraded or failed due to the seismic event. Furthermore, if a NPP has a seismic PRA, and a fire PRA and/or an internal (and/or external) flood PRA, a SI-F&IEF PRA cannot be constructed simply by bringing together the seismic PRA and the other individual PRA(s).

3. Accordingly, though theoretically feasible, using a fire- or flood-PRA and quantifying each scenario in the presence of the seismic event ("shaking a fire or flood PRA"), seemingly involves additional complexities.

4. Existing individual fire and/or flood PRAs may serve to obtain insights about a particular NPP's vulnerabilities to these hazards. These insights, in turn, may inform the work on "setting a seismic PRA on fire (and flooding it)."

5. For seismic-induced internal fires, the following issues must be addressed fully:

   a) Problems already identified in "The Fire Risk Scoping Study."[6]
   b) Credit for firefighting-support equipment, and access routes for the fire brigade.
   c) The analysis should cover and incorporate into the existing PSA the failure probability of active- and passive-fire-protection systems caused by an earthquake.
   d) The large flammable sources inside the plant with relatively low estimated fragilities should be identified (e.g., elevated turbine lube-oil tank in the Turbine Building) since they can cause a significant fire.

6. For seismic-induced internal floods, the following points were made:

   a) Identify the systems that can pump during LOOP/station blackout (SBO) scenarios (or gravity drain) from the ultimate heat sink, and so cause significant flooding in the plant.
   b) Consider that a heat exchanger could fail during an earthquake, and that not only could its contents be released, but since it is connected to other piping and possibly some pumps, additional flow could be released.
   c) If the fire-suppression system conservatively is not credited in the plant's Fire PRA, this should be revisited, since this system may fail after a seismic event, causing an internal flood.

7. Since an SI-F&IEF PRA encompasses several distinct technological fields, such as seismic expertise, and expertise in fires, and in floods, the ownership of the method(s) to be developed to address the gaps identified needs to be defined. Ownership means establishing the type of experts who will be the "owners" of the method. For example, it was suggested that PRA experts are the owners, and would coordinate the work with experts from the other disciplines. However, other possibilities could be explored.

8. There may be some NPPs that implement the "self-induced SBO (SISBO)" as a strategy to cope with a fire. Accordingly, the analysis of the impact of a seismic-induced fire in this type of plant may be plant-specific, and so involve additional complexities.

5.7 Current PRA Standard Activities and Actions Associated with NTTF Recommendations 2.1, 2.3, and 4.2

1. The current Part 5 of the ASME/ANS PRA Standard does not include concurrent events. However, it was pointed out that guidance was drafted on how to implement concurrent hazards for the standard, and that it will be included, with other items, in the standard's next edition. It also was mentioned that Part 6 of the standard is being modified, and will offer guidance on how to screen concurrent hazards. As is true for the current guidance, all the added guidance will present "what to address" in a PRA, but not "how to do it."

2. However, it was stated that such guidance may not be meaningful unless the "how to" has been developed (i.e., shown that it can be done in at least one way). It was noted that it may take 3 to 4 years before the next edition of the standard is released.

3. The specific walk-downs already completed for NTTF 2.3, and being undertaken for NTTF 2.1, likely would not capture the insights needed for seismic-induced fire/flood scenarios, unless such issues specifically were included in planning the walk-down. Some insights may be learned from these walkdowns, but they are not specific to seismically-induced fire and flood scenarios. In addition, the assessment required by NTTF 2.1 is not a probabilistic one, so that its findings may not be fully useful for probabilistic considerations. Hence, more walk-downs seemingly are needed to conduct a PRA of these scenarios.

4. In considering NTTF 4.2, "Mitigation Strategies for Beyond-Design-Basis External Events," the discussions centered on the concept, developed by the US nuclear industry after the Fukushima event , of a diverse, flexible mitigation capability called "FLEX" that includes several principles, such as multiple supplies of power and cooling water, and portable equipment that is reasonably protected. Accordingly, once a PRA of seismic-induced fire/flood scenarios is developed, these mitigation capabilities may be credited in the PRA, provided that they meet the typical guidelines for including them in a PRA, for example, being part of the written procedures.

6. Conclusions and Recommendations

The understanding of the risk from seismic-induced fires and floods based on (1) a survey of the literature, (2) the 2013 workshop, and (3) interactions with knowledgeable PRA practitioners, indicates that the current “state-of-the-art” is incomplete in many areas related to modeling the risk to NPPs from these hazards. As delineated in this report, many different types of complex issues should be addressed. The challenge is to continue to address these issues in the most efficient and productive way. This includes proceeding in a manner that is mindful of expending resources commensurate with the risk that is being guarded against.

Most of the PRA community seems to support a phased- or graded-approach for estimating the risk from these induced hazards. Using screening methods based on familiarity with plant equipment and operation, combined with observations from walk-downs, the initial focus is on reducing the scenarios that need detailed analyses to those that potentially could significantly impact the plant. The initial insights and impact identifications thus obtained can be used to guide the development of additional research that may be needed to address problems in modeling and quantifying the risk from possibly important scenarios.

While the potential hazards to an NPP arising from seismically induced (SI) internal fire, SI internal flood, and SI external flood, are distinct, there are similarities in approaches for SI fire and SI internal flood that do not carry over to SI external flood. Moreover, an SI external flood analysis must consider some fundamental issues that do not arise in analyzing the other two hazards.

Most plants that have a seismic PRA also are likely to have PRAs for internal fire and internal flood. Consequently, approaches for estimating SI internal fire or flood risk can typically build on the existing seismic PRAs and internal fire and flood PRAs. This usually is not the case for estimating SI external flood hazards, since external flood hazards have almost always been dealt with deterministically in the past, so very few probabilistic analyses of external floods have been performed to date.[6] In addition, the sources of internal fires and internal floods are on the plant site, and hence experience the same seismic motion as do the other plant SSCs. On the other hand, the site of the external flood source may be sufficiently far away from the plant site that the seismic motion at the site of the flood source may differ substantially from that at the plant site, and their correlation must be estimated. The distance between the flood source site and the plant site also carries other implications, such as the timing between seismic damage at the plant and damage from external flooding at the plant.

[6] This situation may change as methods for carrying out probabilistic flood hazard analysis (PFHA) are standardized and adopted.

The discussions at the workshop and the replies to the questionnaires also highlighted differences between the approaches for dealing with SI internal fire and SI internal flood. In any approach, and even more so in a graded approach, screening is an important step to focus the effort. As the responses to the questionnaires showed, for internal-fires the screening of some generic SSCs that could be ignition sources is a feasible approach, but this does not appear to be the case for internal flood, where the consensus is that screening has to be done mainly using other criteria than type of SSC.

6.1 Seismically-induced Internal Fire

Attempting to quantify all potential scenarios in a combined seismic-fire PRA currently is impractical, partly due to a dearth of fragility data about potential sources of ignition. While fragilities about the functional failure of the SSCs identified as such sources may be known, or estimated with reasonable effort, their propensity for igniting a fire as a function of earthquake intensity is not known, and would be much more difficult to estimate.

The qualitative screening of such potential sources in terms of the generic equipment in nuclear plants, and previously identified as ignition sources for an internal fire PRA, is discussed in Subsection 4.1 of this report. The survey responses from six knowledgeable PRA practitioners showed trends in agreement about which ignition sources are good candidates for initial qualitative screening, and which always should be examined in greater detail. But no universal consensus was reached, often apparently due to different assumptions and considerations.

An immediate recommendation is to get the responders, and perhaps a few others, together to resolve these differences, and to arrive at an agreed-upon list of fire sources that firstly can be screened from further consideration in the SI fire analysis, and possibly another list of fire sources that always should be considered in this type of analysis.

A further recommendation is to use the same panel or another to discuss and reach some consensus on additional qualitative screening criteria, as well as quantitative criteria, such as seismic ruggedness, ignition likelihood, and the impact of fire considered together.

Subsequently, another panel could be formed to agree upon a methodology on dealing with unscreened SI fire scenarios where a risk estimate, and its uncertainty, is needed. This panel also could make recommendations on estimating ignition fragilities for identified critical items through shake tests or other means, such as obtaining a better understanding of the mechanisms of starting SI fires.

These recommendations could be implemented individually to prepare for a pilot study, or as part of a pilot study involving a complete analysis of an actual plant or plants that goes through the various screening steps, as well as the quantification of critical unscreened scenarios. To

maximize the panels' effectiveness, they should be made up of specialists from industry, regulatory bodies, and PRA standard organizations. Any pilot studies also would benefit from involving all the interested stakeholders to get the most out of such an effort, and smooth the way for future acceptance of any methods developed during the studies.

6.2 Seismically-induced Internal Flood

As discussed in Subsection 4.2, the survey responses from three knowledgeable PRA practitioners that responded to the SI internal flood questions showed a consensus that screening of SI flood scenarios was certainly possible, but not based simply on identifying certain generic SSCs that could be screened as potential flood sources. Instead other attributes for screening should be looked at.

Therefore, the first recommendation here is to gather the responders, and probably a few other experts, to identify screening criteria, first qualitative, and possibly then quantitative that can be used to screen out some SI flood scenarios from further consideration in the SI flood analysis.

Subsequently, another panel could be formed to agree upon a methodology on dealing with unscreened SI flood scenarios where a risk estimate, and its uncertainty, is needed. This panel also can make recommendations on estimating fragilities for identified potentially important items through calculations, shake tests, or other means.

These recommendations again might be implemented individually to prepare for a pilot study, or as part of a pilot study involving a complete analysis for an actual plant or plants that goes through the various screening steps, as well as the quantification of critical unscreened scenarios. The same remarks that were made for the SI fire approach regarding the selection of specialists and the participation of all interested stakeholders in panels and pilot studies, also apply to the approach to SI floods.

6.3 Seismically-induced External Flood

As discussed at the beginning of this section, additional considerations must be taken with any approach for estimating risks associated with SI external floods. Most notably these involve the lack of existing Probabilistic Flood Hazard Assessments (PFHAs) to build on, and the need to deal with the possible significant distances between the plant and the external source of the flood. The latter involves correlation and the dependence of the seismic hazard at the plant site and the site of the source of the flood, as well as the potentially large difference in the timing of seismic hazard and the induced flood hazard.

With respect to PFHA approaches, as mentioned in Subsection 4.3 above, there appear to be some efforts underway by interested parties, including a PRA standard organization, to offer

guidance on an endorsed probabilistic approach to estimating the risk from external floods. It would be practical and beneficial to await the results of these efforts and then convene a panel to build on them to investigate further the specific needs for estimating the risk from SI external floods.

Regarding the correlation and dependence issue, a panel could be formed to discuss and hopefully achieve some consensus about under which circumstances which of the various correlation/dependence factors must be accounted for (such as quake magnitude, distance of each site to the earthquake, distance between the plant and the flood source). A process to prioritize the issues to be addressed, like a Phenomena Identification and Ranking Table (PIRT) process, might be usefully employed. The panel also would explore what simplifying assumptions could be adopted, and if or when specialized seismic hazard/risk quantification software may be required, and where it could be obtained.

6.4 Other Recommendations

Some of the recommendations in the sections above include activities that likely will involve expert elicitation. In some cases, it may be productive to carry out a PIRT process to prioritize the issues to be addressed. The actual elicitation could be conducted with a Senior Seismic Hazard Analysis Committee (SSHAC) process at a level deemed appropriate for each individual activity or combination of activities.[7]

The following are a few other issues, that cut across all three SI hazards, that are likely to need addressing so to advance the analysis of risk from SI hazards (that also likely benefit from application of a PIRT and/or a SSHAC type process):

- Addressing the possibility of multiple fires and floods due to a single earthquake. This would include deciding on an appropriate treatment of accounting for correlations of multiple concurrent seismic-induced failures at a plant.

- Addressing appropriate treatment of human-reliability analysis for scenarios involving combined seismic failures and SI fire or flood failures, including those from multiple SI fires and floods.

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[7] The SSHAC guidelines defined four levels at which a Probabilistic Seismic Hazard Analysis (PSHA) can be conducted, with the number of participants, resources, and time required increasing in progressing from Level 1 to Level 4.

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Appendix A Questionnaire and Consolidated Responses on Seismic-Induced Fire

Please prepare a list of plant components that you believe may be generically screened out from consideration in a PRA of seismically induced fires.

Table 1, "Generic List of Fire Ignition Sources for Initial Screening," lists SSCs that may cause a fire given an earthquake. The SSCs in this table are from Table 6-1 of NUREG/CR-6850 (Reference 1), and are the potential ignition sources in an NPP.[8] This list may be used as a starting point. Please remove and/or add sources from this table, as you deem appropriate.

1) Please analyze each SSC in Table 1 for its potential to cause a fire given an earthquake. Specifically, classify each SSC into one of the three categories on the right side of this table: I) Not a seismic-induced fire ignition source: can be screened out, II) May be a potential seismic-induced fire ignition source, and III) Must be evaluated as a seismic-induced fire ignition source. These three categories may be revised as part of the overall process of screening SSCs.

Please provide the rationale for your answers, and if possible include published references supporting them.

Campbell: [He only provided checkmarks in Table 1 without supporting rationale.]

ERIN: A markup of Table 1 follows. Please note the following assumptions and other considerations that are relevant to this response and the information in the table:

1) **The distinction between the criteria listed for Category II vs. Category III is not completely clear, and it seems that for most SSCs the outcome is the same. That is, some level of assessment "must" be performed (i.e., Category III) for any SSC that "may be a potential" source (i.e., Category II).**

2) **The focus of this response is on providing input to the set of SSCs that can be considered to be Category I (can be screened out generically). In some cases, certain qualifiers have been noted, either in the table cells or as notes following the table.**

3) **Where there is no entry ("X") in the Category I cell, this should be interpreted as "some level of assessment must be performed" (i.e., a check in the other columns).[9] Depending on the potential source SSC and location relative to seismic**

[8] More specifically, NUREG/CR-6850 mentions "…The combination of locations and equipment types (ignition source) are referred to here as ignition frequency bins…" To simplify the discussion, these bins are simply referred to here as SSCs.

[9] For brevity in this report, ERIN's "X" in Category I cell was removed from the consolidated table, and ERIN's text in this cell was entered in the appropriate cell (usually Category I). When ERIN gave an "X", but no explanatory text, the "X" was kept in the table. Where there was no entry ("X") in ERIN's Category I cell, this report added "Some level of assessment must be performed" in Category III. This assignment

equipment list (SEL) SSCs, the assessment needed might involve various combinations of walkdown observation, mapping of potential source SSC proximity to SEL SSCs, and so forth to allow screening of some potential sources, followed by more detailed screening options yet to be determined (e.g., screening based on ignition point temperatures for lube oil sources).

4) **For some of the SSCs / NUREG-CR/6850 bins, additional refinement is suggested, to allow screening out of sub-categories of SSCs but not the full category. The bases for the sub-categorization is indicated in the new entries.[10]**

5) **There is an implicit assumption that the equipment in the screened bins has been appropriately maintained, including equipment anchorage or mounting, such that it would not be expected to malfunction in response to the seismic event.**

6) **It is assumed that SSCs for which a consequential fire would only fail the source (and not other SEL SSCs) can be screened from detailed assessment in the seismically-induced fire evaluation. However, if there is a structural weakness related to release of combustible material from the source SSC, and that source SSC is on the SEL, this might result in a need to reassess the high confidence of low probability of failure (HCLPF) for that component with regard to its impact on the SPRA model and results.**

ERIN also includes Note "H" to Table 1: "Any potential sources located in an area for which the fire PRA has determined that the fire risk is very low should be able to be screened regardless of the SEL SSCs in those areas if there is reasonable confidence that a fire resulting from a seismic event could only occur at relatively high g-levels, i.e., levels at which the seismic PRA conditional core damage probability approaches 1.0."

Lin: Based on the SSCs listed in Table 1, the plant components that we believe may be generically screened out from consideration in a PRA of seismically induced fires include the following:

Bin 1: Batteries – Battery Room
Bin 4: Main Control Board – Control Room
Bin 5: Cable fires caused by welding and cutting – Control/Aux/Reactor Building
Bin 6: Transient fires caused by welding and cutting – Control/Aux/Reactor Building
Bin 10: Battery Chargers – Plant-Wide Components
Bin 11: Cables fires caused by welding and cutting – Plant-Wide Components
Bin 12: Cable Run (Self-ignited cable fires) – Plant-Wide Components
Bin 13: Dryers – Plant-Wide Components
Bin 18: Junction Boxes – Plant-Wide Components
Bin 24: Transient fires caused by welding and cutting – Plant-Wide Components
Bin 31: Cables fires caused by welding and cutting – Turbine Building
Bin 36: Transient fires caused by welding and cutting – Turbine Building

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to the Category III cell must be understood under ERIN's consideration that "some level of assessment "must" be performed (i.e., Category III) for any SSC that "may be a potential" source (i.e., Category II)."

[10] To simplify the consolidated table, ERIN's sub-categories of SSCs were integrated into the full category. All information about these sub-categories was included in the row of the full category.

In addition, portion of the following fire ignition bins can also be screened out from consideration in a PRA of seismically induced fires (see Table 1 for explanation):

Bin 3 (partial): Hotwork – Containment (PWR)
Bin 14 (partial): Electric Motors (below 480V) – Plant-Wide Components
Bin 15 (partial): Electrical Cabinets (below 480V) – Plant-Wide Components
Bin 21 (partial): Pumps (below 480V) – Plant-Wide Components
Bin 23b (partial): Transformers (Dry, below 480V) – Plant-Wide Components
Bin 26 (partial): Ventilation Subsystems (below 480V) – Plant-Wide Components

Also, the possibility of transient materials located nearby potential sources of arc flash (e.g., energized cables or electrical or electro-mechanical equipment with a voltage of 480V or higher) need to be examined compartment by compartment. For seismic induced transformer fires, the likelihood of the transformers overturning and the cables snapping also needs to be examined by walkdown. Similarly, walkdown examination of selected electrical equipment and electro-mechanical equipment (e.g., electrical cabinets, etc.) should also be performed to identify the possibility of equipment overturning, seismic-induced arc flash, location and ignition of nearby combustibles, etc.

Furthermore, each SSC in Table 1 (below) was analyzed for its potential to cause a fire in the event of an earthquake. Each SSC was classified into one of the following three categories on the right side of Table 1: I) Not a seismic-induced fire ignition source; can be screened out, II) May be a potential seismic-induced fire ignition source, and III) Must be evaluated as a seismic-induced fire ignition source. Also, the rationale for this categorization is provided in the cell associated with the category selected.

Maioli: [He only provided information in Table 1.]

Ravindra: [He only provided information in Table 1.]

Stutzke: I filled in the table based mainly on what I've seen done in older fire PRAs, and applying my "expert" opinion (which isn't too informed and admittedly dated). It would seem possible to use an existing fire PRA done for NFPA 805 implementation as a starting point for identifying seismically induced fire ignition sources. Rather than using random ignition frequencies, we need an approach to estimating the likelihood that the source causes a fire given that an earthquake occurs (that is, development of a seismic ignition fragility curves as a function of ground motion).

Table 1 Generic List of Fire Ignition Sources for Initial Screening

ID	SSC (Equipment Type)	Location	Not a seismic-induced fire ignition source; can be screened out I	May be a potential seismic-induced fire ignition source II	Must be evaluated as a seismic-induced fire ignition source III
1	Batteries	Battery Room	**ERIN**: Assuming normal battery maintenance, likelihood of fire due to incipient failure due to shaking is low for batteries not requiring ventilation **Lin**: I. In principle, arc flash from cables pulled loose or snapped by the seismic motion could cause ignition of the hydrogen gas and cable insulation/jacket material. However, the likelihood of snapping the energized cables in the battery room by the earthquake motion should be extremely low due to the lower-profile configuration of the battery racks. Due to the design of battery room ventilation fans, hydrogen concentration inside the battery room is typically below the ignition concentration. Also, the energy generated from the brief arc flash of low voltage cables may not be sufficient to ignite the cable insulation/jacket material. **Maioli**: X **Ravindra**: Batteries would fail in earthquakes resulting in fire only if they are not properly supported and the frame not anchored to the floor. Walkdown should focus on this. Item screened out if walkdown does not discover any weaknesses.	**Campbell**: x	**ERIN**: Some level of assessment must be performed for batteries requiring active ventilation to address H_2 purging **Stutzke**: Yes

ID	SSC (Equipment Type)	Location	Not a seismic-induced fire ignition source; can be screened out I	May be a potential seismic-induced fire ignition source II	Must be evaluated as a seismic-induced fire ignition source III
2	Reactor Coolant Pump	Containment (PWR)	**Campbell**: x **ERIN**: PWR: Reactor coolant pumps would already have an oil collection system that is required to be designed for seismic conditions BWR: Reactor recirculation pumps for BWRs with Mark I or Mark II Containment BWRs Only, given containment inerting **Ravindra**: Seismic failure of reactor coolant pump is not credible.	**ERIN**: Reactor recirculation pumps for Mark III containment BWRs cannot be generically screened on the basis of inerting, although it seems likely that other bases could be developed. **Lin**: II. Arc flash resulting from snapping of energized cables due to overturning of the RCP by the seismic motion could ignite any lube oil that leaks out or nearby combustibles such as cable insulation/jacket materials. **Stutzke**: Yes – do we normally consider fires that are initiated within containment in a fire PRA?	**Maioli**: X (large oil source)
3	Transients and Hotwork	Containment (PWR)	**ERIN**: For hot work (other than BWR MK I and II), personnel would be present and could respond even given a seismic event; the time during which this can occur is very small; for BWR MK I and II, containment inerted almost all the time at power. **Lin**: I. The joint likelihood of performing hot work inside the containment during an earthquake is extremely. Can be screened. **Maioli**: X **Ravindra**: Not related to seismic event **Stutzke**: Yes	**Campbell**: x **Lin**: II. For transient materials to be ignited, they must be located nearby energized cables or equipment that can potentially be snapped by the earthquake motion and produce an arc flash. Need to examine compartment by compartment the possibility of potential transient materials located nearby potential sources of arc flash (e.g., energized cables or electrical or electro-mechanical equipment with a voltage of 480V or higher).	

ID	SSC (Equipment Type)	Location	Not a seismic-induced fire ignition source; can be screened out I	May be a potential seismic-induced fire ignition source II	Must be evaluated as a seismic-induced fire ignition source III
4	Main Control Board	Control Room	**ERIN**: MCB damage would most likely result in sufficient seismic plant response impact that CCDP would be ~ 1.0 regardless of consequential fire. **Lin**: I. The likelihood of fire caused by an arc flash resulting from the low voltage electrical cabinets induced by the earthquake motion is too low to be considered. **Maioli**: X	**Campbell**: x	
5	Cable fires caused by welding and cutting	Control/Aux/ Reactor Building	**ERIN**: For hot work, personnel would be present and could respond even given seismic event; fraction of time during the year when hot work occurs is small **Lin**: I. The joint likelihood of performing hot work during an earthquake causing ignition of nearby cables is too low to be considered. **Maioli**: X **Ravindra**: Not related to seismic event **Stutzke**: Yes	**Campbell**: x	
6	Transient fires caused by welding and cutting	Control/Aux/ Reactor Building	**ERIN**: For hot work, personnel would be present and could respond even given seismic event; fraction of time during the year when hot work occurs is small **Lin**: I. The joint likelihood of performing hot work during an earthquake causing ignition of nearby transient materials is too low to be considered. **Maioli**: X **Ravindra**: Not related to seismic event **Stutzke**: Yes	**Campbell**: x	

ID	SSC (Equipment Type)	Location	Not a seismic-induced fire ignition source; can be screened out I	May be a potential seismic-induced fire ignition source II	Must be evaluated as a seismic-induced fire ignition source III
7	Transients	Control/Aux/ Reactor Building	**ERIN**: Sources that might lead to fire would be things like portable space heaters, exposure time would be limited **Maioli**: X **Ravindra**: Not related to seismic event **Stutzke**:???	**Campbell**: x **Lin**: II. For transient materials to be ignited, they must be located nearby energized cables or equipment that can potentially be snapped by the earthquake motion and produce an arc flash. Need to examine compartment by compartment the possibility of potential transient materials located nearby potential sources of arc flash (e.g., cables or electrical or electro-mechanical equipment with a voltage of 480V or higher).	
8	Diesel Generators	Diesel Generator Room	**ERIN**: Assumes no structural weaknesses in lube / fuel oil supplies, and that if spilled, oil would not result in fire that could affect other SEL SSCs; also possible that EDG hot exhaust leakage due to seismic event could cause local combustibles to catch fire, but such a fire not likely to affect lube/fuel oil supplies.	**Campbell**: x **Lin**: Arc flash resulting from snapping of energized cables/equipment with voltage 480V or higher could ignite any diesel fuel oil or lube oil that leak out or other combustible materials such as cable insulation/jacket. **Ravindra**: Although diesel generators have high seismic capacity, failure of auxiliary components such as diesel day tank, lube oil cooler etc. may lead to ignition. Their seismic vulnerabilities are typically discovered in a walkdown.	**Maioli**: X (large fuel oil source) **Stutzke**: Yes

ID	SSC (Equipment Type)	Location	Not a seismic-induced fire ignition source; can be screened out I	May be a potential seismic-induced fire ignition source II	Must be evaluated as a seismic-induced fire ignition source III
9	Air Compressors	Plant-Wide Components	**ERIN**: Lube oil completely within compressor casing (rupture of casing unlikely at seismic levels below which seismic CCDP < 1.0.) **Campbell**: x	**Lin**: An arc flash resulting from snapping of energized cables with voltage 480V or higher could ignite any lube oil that leak out or other combustible materials such as cable insulation/jacket. **Maioli**: X (potential large oil source) **Ravindra**: Only if the anchorage fails in an earthquake and the component topples over	**ERIN**: Some level of assessment must be performed for pressurized lube oil supply with external components **Stutzke**: Yes
10	Battery Chargers	Plant-Wide Components	**Lin**: The energy generated from an arc flash associated with battery chargers should be insufficient to cause ignition of such nearby solid combustible materials as cable insulation/jacket and other plastic materials. **Maioli**: X	**Campbell**: x **Ravindra**: Only if the anchorage fails in an earthquake and the component topples over	**ERIN**: Some level of assessment must be performed **Stutzke**: Yes
11	Cable fires caused by welding and cutting	Plant-Wide Components	**ERIN**: For hot work, personnel would be present and could respond even given seismic event; fraction of time during the year when hot work occurs is small. **Lin**: I. The joint likelihood of performing hot work during an earthquake causing ignition of nearby cables is too low to be considered. **Maioli**: X **Ravindra**: Not related to seismic event **Stutzke**: Yes	**Campbell**: x	

ID	SSC (Equipment Type)	Location	Not a seismic-induced fire ignition source; can be screened out I	May be a potential seismic-induced fire ignition source II	Must be evaluated as a seismic-induced fire ignition source III
12	Cable Run (Self-ignited cable fires)	Plant-Wide Components	**ERIN**: Unless walkdown identifies specific cabling issues **Lin**: I. The likelihood of an earthquake induced electrical malfunction causing a cable fires is too low to be considered. **Maioli**: X **Ravindra**: Not credible failure; can be screened out.	**Campbell**: x	**Stutzke**: Yes
13	Dryers	Plant-Wide Components	**Campbell**: x **ERIN**: No seismic-fire impact likely. (Clothes dryers per NUREG/CR-6850) **Lin**: The energy generated from an arc flash associated with dryers of both the re-generation and desiccant types should be insufficient to cause ignition of such nearby solid combustible materials as cable insulation/jacket and other plastic materials, although it may possibly ignite the desiccant. **Maioli**: X	**Ravindra**: Only if the anchorage fails in an earthquake and the component topples over **Stutzke**: Yes	
14	Electric Motors	Plant-Wide Components	**ERIN**: Not a significant seismic-fire source. **Lin**: The energy generated from an arc flash associated with electric motors below 480V is typically insufficient to cause ignition of such nearby solid combustible materials as cable insulation/jacket and other plastic materials. **Maioli**: X	**Campbell**: x **Ravindra**: Only if the anchorage fails in an earthquake and the component topples over **Lin**: An arc flash generated by electric motors at 480V and above during an earthquake can potentially ignite such nearby solid combustible materials as cable insulation/jacket and other plastic materials.	**Stutzke**: Yes

ID	SSC (Equipment Type)	Location	Not a seismic-induced fire ignition source; can be screened out I	May be a potential seismic-induced fire ignition source II	Must be evaluated as a seismic-induced fire ignition source III
15	Electrical Cabinets	Plant-Wide Components	**Lin**: I. The energy generated from an arc flash associated with electric cabinets below 480V is typically insufficient to cause ignition of such nearby solid combustible materials as cable insulation/jacket and other plastic materials.	**Campbell**: x **Lin**: II. An arc flash generated by electric cabinets at 480V and above during an earthquake can potentially ignite such nearby solid combustible materials as cable insulation/jacket and other plastic materials. **Ravindra**: Only if the anchorage fails in an earthquake and the component topples over	**ERIN**: Some level of assessment must be performed **Maioli**: X (focus on >4kV) **Stutzke**: Yes
16	High Energy Arcing Faults[1]	Plant-Wide Components	**ERIN**: If turbine building fire does not affect seismic response, then can screen certain components in TB, e.g., HEAF-susceptible equipment, MFW pumps, Turbine-Generator sources. **Ravindra**: Not related to seismic event	**Campbell**: x **Maioli**: X	**Lin**: III. HEAF resulting from earthquake induced loose connection of equipment with voltage in excess of 480V can potentially ignite such solid combustibles as cable insulation/jacket. **Stutzke**: Yes
17	Hydrogen Tanks	Plant-Wide Components	**ERIN**: It may be possible to develop criteria for screening source based on location sufficiently far from structures with SEL components.	**Campbell**: x **Ravindra**: Only if the anchorage fails in an earthquake and the component topples over	**Lin**: III. Any sparks generated by the seismic motion can ignite hydrogen that leaks out of the hydrogen tanks, which may be caused by seismic-induced overturning of the tanks. **Maioli**: X **Stutzke**: Yes

ID	SSC (Equipment Type)	Location	Not a seismic-induced fire ignition source; can be screened out I	May be a potential seismic-induced fire ignition source II	Must be evaluated as a seismic-induced fire ignition source III
18	Junction Boxes	Plant-Wide Components	**Campbell**: x **ERIN**: X **Lin**: I. The energy generated from an arc flash associated with low voltage junction boxes should be insufficient to cause ignition of such nearby solid combustible materials as cable insulation/jacket and other plastic materials. **Maioli**: X **Ravindra**: Generally have high seismic ruggedness unless seismic weaknesses are found in walkdown		**Stutzke**: Yes
19	Misc. Hydrogen Fires	Plant-Wide Components		**Campbell**: x **Ravindra**: Only if the anchorage fails in an earthquake and the component moves or topples over. **Stutzke**: Yes – may be plant-specific	**ERIN**: Some level of assessment must be performed **Lin**: III. Any sparks generated by the seismic motion can ignite hydrogen that may leak out, which may be caused by seismic-induced failures or overturning of the hydrogen containing equipment. **Maioli**: X

ID	SSC (Equipment Type)	Location	Not a seismic-induced fire ignition source; can be screened out I	May be a potential seismic-induced fire ignition source II	Must be evaluated as a seismic-induced fire ignition source III
20	Off-gas/H2 Recombiner (BWR)	Plant-Wide Components	**ERIN**: H2 recombiner only needed post-accident; Off-gas system generally located remotely from SEL SSCs, FPRAs do not show risk significant scenarios.	**Campbell**: x **Lin**: III. Sparks generated by the seismic motion can possibly ignite hydrogen that may leak out, which may be caused by seismic-induced failures or overturning of the hydrogen containing equipment. **Maioli**: ? **Ravindra**: Only if the anchorage fails in an earthquake and the component moves or topples over.	**Stutzke**: Yes
21	Pumps	Plant-Wide Components	**ERIN**: lube oil completely within pump casing, or < = 5HP **Lin**: I. The energy generated from an arc flash associated with pumps below 480V is typically insufficient to cause ignition of such nearby solid combustible materials as cable insulation/jacket and other plastic materials. **Ravindra**: Generally have high seismic ruggedness unless seismic weaknesses are found in walkdown	**Campbell: x** **Lin**: II. Arc flash resulting from snapping of energized cables with voltage 480V or higher could ignite any lube oil that leak out or other combustible materials such as cable insulation/jacket. **Maioli**: X (only large oil pumps, such as MFW)	**ERIN**: Some level of assessment must be performed for pressurized lube oil supply with external components **Stutzke**: Yes
22	RPS MG Sets	Plant-Wide Components	**ERIN**: lube oil completely within pump casing **Maioli**: X **Ravindra**: Generally have high seismic ruggedness unless seismic weaknesses are found in walkdown	**Campbell**: x **Lin**: II. Arc flash resulting from snapping of energized cables with voltage 480V or higher could ignite such nearby combustible materials such as cable insulation/jacket.	**ERIN**: Some level of assessment must be performed for pressurized lube oil supply with external components **Stutzke**: Yes

ID	SSC (Equipment Type)	Location	Not a seismic-induced fire ignition source; can be screened out I	May be a potential seismic-induced fire ignition source II	Must be evaluated as a seismic-induced fire ignition source III
23a	Transformers (Oil filled)	Plant-Wide Components		**Lin**: II. Arc flash resulting from snapping of energized cables with voltage 480V or higher could ignite any transformer oil that leak out (possibly due to seismic induced overturning of the transformer and the associated impact stress) or other combustible materials such as cable insulation/jacket. **Ravindra**: Only if the anchorage fails in an earthquake and the component moves or topples over.	**Campbell**: x **ERIN**: Some level of assessment must be performed **Maioli**: X **Stutzke**: Yes
23b	Transformers (Dry)	Plant-Wide Components	**ERIN**: Transformers 45k VA or smaller (basis is NUREG/CR-6850 size cutoff.) **Lin**: I. The energy generated from an arc flash associated with dry transformers below 480V is typically insufficient to cause ignition of such nearby solid combustible materials as cable insulation/jacket and other plastic materials. **Maioli**: X	**Campbell**: x **ERIN**: Transformers ~900 kVA or smaller (Proposed. No current basis for this cutoff size, but suggest this as an area for future research, since the size that can reasonably be screened is likely to be >> 45 kVA.) **Lin**: II. An arc flash resulting from snapping of energized cables with voltage 480V or higher could possibly ignite such nearby combustible materials such as cable insulation/jacket. **Ravindra**: Only if the anchorage fails in an earthquake and the component moves or topples over.	**ERIN**: Some level of assessment must be performed for transformers > 900 kVA **Stutzke**: Yes

ID	SSC (Equipment Type)	Location	Not a seismic-induced fire ignition source; can be screened out I	May be a potential seismic-induced fire ignition source II	Must be evaluated as a seismic-induced fire ignition source III
24	Transient fires caused by welding and cutting	Plant-Wide Components	**ERIN**: For hot work personnel would be present and could respond even given seismic event; fraction of time during the year when hot work occurs is small. **Lin**: I. The joint likelihood of performing hot work during an earthquake causing ignition of nearby transient materials is too low to be considered. **Maioli**: X **Ravindra**: Not related to seismic event **Stutzke**: Yes	**Campbell**: x	
25	Transients	Plant-Wide Components	**Campbell**: x **ERIN**: Sources that might lead to fire would be things like portable space heaters, exposure time would be limited. **Maioli**: X **Ravindra**: Not related to seismic event **Stutzke**:???	**Lin**: II. For transient materials to be ignited, they must be located nearby energized cables or equipment that can potentially be snapped by the earthquake motion and produce an arc flash. Need to examine compartment by compartment the possibility of potential transient materials located nearby potential sources of arc flash (e.g., cables or electrical or electro-mechanical equipment with a voltage of 480V or higher).	

ID	SSC (Equipment Type)	Location	Not a seismic-induced fire ignition source; can be screened out I	May be a potential seismic-induced fire ignition source II	Must be evaluated as a seismic-induced fire ignition source III
26	Ventilation Subsystems	Plant-Wide Components	**Campbell**: x **ERIN**: Fan motors would already be screened out per the Motors assessment. **Lin**: I. The energy generated from an arc flash associated with ventilation equipment below 480V is typically insufficient to cause ignition of such nearby solid combustible materials as cable insulation/jacket and other plastic materials. **Maioli**: X	**Lin**: II. An arc flash generated by ventilation equipment at 480V and above during an earthquake can potentially ignite such nearby solid combustible materials as cable insulation/jacket and other plastic materials as well as oil. **Ravindra**: Only if the anchorage fails in an earthquake and the component moves or topples over	**ERIN**: Some level of assessment must be performed **Stutzke**: Yes
27	Transformer – Catastrophic[2]	Transformer Yard		**Campbell**: x **Lin**: II. An arc flash resulting from snapping of energized cables with voltage 480V or higher could ignite any transformer oil that leak out (e.g., due to seismic induced overturning of the transformer and the associated impact stress) or other combustible materials such as cable insulation/jacket. Need to examine by walkdown the likelihood of overturning and snapping of the cables. **Ravindra**: Typically, yard transformers are not properly anchored and could move resulting in spillage of coolant fluid. A transformer caught fire in the Niigataken Cheutsu-Oki Earthquake in 2007	**ERIN**: Some level of assessment must be performed **Maioli**: X **Stutzke**: Yes, if considered in fire PRA

ID	SSC (Equipment Type)	Location	Not a seismic-induced fire ignition source; can be screened out I	May be a potential seismic-induced fire ignition source II	Must be evaluated as a seismic-induced fire ignition source III
28	Transformer - Non Catastrophic[2]	Transformer Yard	**Maioli**: X	**Campbell**: x **ERIN**: Bin 28 involves same components as Bin 27. The failure mode associated with Bin 28 can be screened to the extent that the impact is only to availability of offsite power following the seismic event. However, if the possibility for catastrophic failure exists, the component is not generically screened. **Lin**: II. An arc flash resulting from snapping of energized cables with voltage 480V or higher could ignite any transformer oil that leak out (e.g., due to seismic induced overturning of the transformer and the associated impact stress) or other combustible materials such as cable insulation/jacket. Need to examine by walkdown the likelihood of overturning and snapping of the cables. **Ravindra**: Typically, yard transformers are not properly anchored and could move resulting in spillage of coolant fluid. A transformer caught fire in the Niigataken Cheutsu-Oki Earthquake in 2007	**Stutzke**: Yes, if considered in fire PRA

ID	SSC (Equipment Type)	Location	Not a seismic-induced fire ignition source; can be screened out I	May be a potential seismic-induced fire ignition source II	Must be evaluated as a seismic-induced fire ignition source III
29	Yard transformers (Others)	Transformer Yard	**ERIN**: Impact is loss of offsite power, and location is typically unlikely to affect SEL SSCs. **Maioli**: X	**Campbell**: x **Lin**: II. Arc flash resulting from snapping of energized cables/equipment with voltage 480V or higher could ignite any transformer oil that leak out (e.g., due to seismic induced overturning of the transformer and the associated impact stress) or other combustible materials such as cable insulation/jacket. Need to examine by walkdown the likelihood of overturning and snapping of the cables. **Ravindra**: Typically, yard transformers are not properly anchored and could move resulting in spillage of coolant fluid. A transformer caught fire in the Niigataken Cheutsu-Oki Earthquake in 2007	**Stutzke**: Yes, if considered in fire PRA
30	Boiler	Turbine Building	**Campbell**: x **Ravindra**: Seismic failure is not credible.	**ERIN**: It may be possible to develop criteria for screening source based on location sufficiently far from structures with SEL components.	**Lin**: III. Sparks generated by the seismic motion can potentially ignite propane or other hydrocarbon fuel that leaks out of the boiler, which may be caused by seismic-induced overturning of the containing equipment. **Maioli**: X (fuel oil) **Stutzke**: Yes

ID	SSC (Equipment Type)	Location	Not a seismic-induced fire ignition source; can be screened out I	May be a potential seismic-induced fire ignition source II	Must be evaluated as a seismic-induced fire ignition source III
31	Cable fires caused by welding and cutting	Turbine Building	**ERIN**: For hot work personnel would be present and could respond even given seismic event; fraction of time during the year when hot work occurs is small. **Lin**: **I**. The joint likelihood of performing hot work during an earthquake causing ignition of nearby cables is too low to be considered. **Maioli**: X **Ravindra**: Not related to seismic event **Stutzke**: Yes	**Campbell**: x	
32	Main Feedwater Pumps	Turbine Building	**Ravindra**: Generally have high seismic ruggedness unless seismic weaknesses are found in walkdown	**Campbell**: x **ERIN**: If turbine building fire does not affect seismic response, then can screen certain components in TB, e.g., HEAF-susceptible equipment, MFW pumps, Turbine-Generator sources. **Lin**: **II**. An arc flash resulting from snapping of energized cables with voltage 480V or higher could ignite any lube oil that leak out or other nearby combustible materials such as cable insulation/jacket.	**Maioli**: X (large oil source) **Stutzke**: Yes

ID	SSC (Equipment Type)	Location	Not a seismic-induced fire ignition source; can be screened out I	May be a potential seismic-induced fire ignition source II	Must be evaluated as a seismic-induced fire ignition source III
33	Turbine Generator Excitor	Turbine Building	**Maioli**: X **Ravindra**: Turbine generators experience more severe vibrations during the startup and shutdown compared to the seismic induced vibrations. As such seismic failure leading to an ignition source is not credible.	**Campbell**: x **ERIN**: Generator-shaft-mounted components can be screened based on location remote from SEL SSCs. If exciter located remotely then should be assessed. **Lin**: II. An arc flash generated by TG excitor during an earthquake can potentially ignite such nearby solid combustible materials as cable insulation/jacket and other plastic materials.	**Stutzke**: Yes
34	Turbine Generator Hydrogen	Turbine Building	**Ravindra**: As such seismic failure leading to an ignition source is not credible	**Campbell**: x **ERIN**: If turbine building fire does not affect seismic response, then can screen certain components in TB, e.g., HEAF-susceptible equipment, MFW pumps, Turbine-Generator sources.	**Lin**: III. Any sparks generated by the seismic motion can ignite hydrogen that may leak out, which may be caused by seismic-induced failures of the hydrogen containing equipment. **Maioli**: X **Stutzke**: Yes

ID	SSC (Equipment Type)	Location	Not a seismic-induced fire ignition source; can be screened out I	May be a potential seismic-induced fire ignition source II	Must be evaluated as a seismic-induced fire ignition source III
35	Turbine Generator Oil	Turbine Building	**Ravindra**: As such seismic failure leading to an ignition source is not credible	**Campbell**: x **ERIN**: If turbine building fire does not affect seismic response, then can screen certain components in TB, e.g., HEAF-susceptible equipment, MFW pumps, Turbine-Generator sources.	**Lin**: II. An arc flash resulting from snapping of energized cables or equipment with voltage 480V or higher could ignite the TG oil that leak out due to seismic induced equipment failures. The source of arc flash must be located close to the path of turbine oil leakage. **Maioli**: X **Stutzke**: Yes
36	Transient fires caused by welding and cutting	Turbine Building	**ERIN**: For hot work personnel would be present and could respond even given seismic event; fraction of time during the year when hot work occurs is small. **Lin**: I. The joint likelihood of performing hot work during an earthquake causing ignition of nearby transient materials is too low to be considered. **Maioli**: X **Ravindra**: Not related to seismic event **Stutzke**: Yes	**Campbell**: x	

ID	SSC (Equipment Type)	Location	Not a seismic-induced fire ignition source; can be screened out I	May be a potential seismic-induced fire ignition source II	Must be evaluated as a seismic-induced fire ignition source III
37	Transients	Turbine Building	**Campbell**: x **ERIN**: Sources that might lead to fire would be things like portable space heaters, exposure time would be limited. **Maioli**: X **Ravindra**: Not related to seismic event **Stutzke**:???	**Lin**: II. For transient materials to be ignited, they must be located nearby energized cables or equipment that can potentially be snapped by the earthquake motion and produce an arc flash. Need to examine compartment by compartment the possibility of potential transient materials located nearby potential sources of arc flash (e.g., cables or electrical or electro-mechanical equipment with a voltage of 480V or higher).	
38	Fuel Tanks[3] (including associated fuel piping)	Yard (except for vaulted tanks: various locations inside or outside below grade)	**ERIN**: Vaulted Fuel Tanks: X Buried Fuel Tanks: X	**ERIN**: For above ground fuel tanks, it may be possible to develop criteria for screening source based on location sufficiently far from structures with SEL components	

Notes of Table 1:

1. See Appendix M of NUREG/CR-6850 for a description of high-energy arcing fault (HEAF) fires.
2. See Section 6.5.6 of NUREG/CR-6850 for a definition.
3. SSC with ID 38, “Fuel Tanks (including associated fuel piping),” was added by ERIN.

Appendix B Questionnaire and Consolidated Responses on Seismic-Induced Internal Flood

Seismic-induced internal plant flooding occurs from breaches of the plant's water systems located inside buildings. In other words, an earthquake-induced break or breech of any internal water source could result in an internal flood if the physical layout of the plant is such that the water could accumulate to the extent that plant equipment may fail. Hence, for this type of flood to lead to core damage, the following conditions must occur:

1. Earthquake-induced uncontrolled release(s) of water or other liquid in the plant.
2. Accumulation of the released liquid in one or more locations within the plant.
3. A failure of plant equipment in those locations, due to flooding, that reduces the plant's capability to reach a safe shutdown condition following the seismic- and flooding- (and possibly fire) events.

Mainly due to conditions 1 and 2, the vulnerability of a plant to this kind of flooding appears to be plant-specific. As the Callaway IPE stated, "Internal floods … analysis is plant specific since the likelihood of occurrence, progression, and subsequent impact on plant systems is highly dependent upon factors such as plant layout, piping arrangements, drainage as well as prevailing flood protection features and programs."

In light of these considerations, please respond to the following questions:

1. Is it possible to screen out some potential sources of seismic-induced flooding (e.g., tanks, heat exchangers) on a generic basis (i.e., these sources could be removed from consideration for all light-water plants)? Or is it possible to carry out any other type of screening that would reduce the scope of the effort required? For example, are there some flood areas/zones that can be screened out on a generic basis? Please explain the reasoning for your answers.

ERIN: It should be possible to identify certain sources of potential seismically-induced internal flooding on a "category" basis such that they would not need to be considered in any assessment. However, the attributes that define such sources are not related to type of systems, structures, and components – SSCs (e.g., tanks, heat exchangers) as suggested by this question. Instead, the attributes that would allow screening are more related to the quantity of source fluid and the availability of a motive driver (e.g., electric power or gravity) following a seismic event of sufficient magnitude to cause rupture of the source boundary.

If individual components are to be considered (e.g., in the provided table of sources), these should be viewed from the perspective of representing additional fragility failure modes of the piping system itself. However, in this response, the recommendation is to consider a list of screening bases such as the following, and not pursue a component-based screening list such as that provided in the table.

Possible bases for complete screening of particular categories of SSCs would include:

- **location (i.e., sufficient distance away from seismic equipment list (SEL) SSCs and anticipated operator routes taken in response to a seismic event such that the contained source would not affect these)**
- **seismic qualification or other demonstration of ruggedness (e.g., inherently rugged piping or pressure boundary features of SSCs). There may be several considerations, e.g., Class I piping systems are likely to have high ruggedness even under above-design basis seismic demands; whereas fluid-filled tanks are likely to have lower ruggedness under the same conditions. (Note that tanks are also addressed below).**
- **quantity of contained fluid (e.g., closed system or small tank, in either case with volume insufficient to affect SEL SSCs or operator routes)**
- **large / unlimited source but with lack of motive driver following a significant seismic event (e.g., circulating water system tied to a lake or river but very high probability that pumps would lose (non-emergency) power at a seismic magnitude sufficient to have a high probability of failing the piping, and gravity feed cannot affect SEL SSCs credited for safe shutdown)**
- **flood area/zone does not contain SEL SSCs and does not contain less-robust structures (e.g., masonry walls), whose failure could result in structural failures that could create propagation pathways to adjacent areas containing SEL SSCs.**

For the most part, such bases cannot be applied "generically", and will require evaluation of each such source.

However, it is likely that certain potential sources can normally be screened, or at least identified as sources that are "unlikely" to need to be dealt with. Examples are:

- **Seismically qualified piping – failure probability is low, normally below g levels at which other failures dominate (i.e., where seismic PRA conditional core damage probability, CCDP, approaches 1.0); this includes qualified piping of systems connected to the RCS (see RCS primary and secondary system piping bullets below); so screening out this category is appropriate within the limits of refinement of current SPRA models.**
- **Buried tanks – postulated leakage from such tanks would tend to disperse outside of plant areas needed for seismic event mitigation, and impact of the mechanism that caused the tank failure (e.g., seismic displacement, soil liquefaction) would already result in the need for re-routing of any required operator actions requiring nearby access; so screening out this category is appropriate.**
- **Tanks in vaults – tanks in vaulted rooms or compartments such that postulated flooding would only impact the tank source itself should be screened from further consideration. Even if the tank is an SEL SSC, there is no seismic PRA impact beyond the direct component failure, which is already accounted for.**
- **Buried piping – the same rationale as listed for buried tanks would generally apply; the primary difference would be the potentially larger volume of the source; such sources can be screened unless the internal flood analysis has identified particular issues.**
- **RCS primary system piping – typically the SPRA will already address seismic induced LOCA, and the RCS should be designed to accommodate primary system high energy break considerations; so screening out this category is appropriate.**

- **BWR secondary loop piping or PWR secondary side high energy line piping – For these potential sources, consideration needs to be given to environmental impacts due to high energy effects, and flooding impacts. The SPRA would typically already address the potential for HELB impacts on SEL SSCs; if so, screening of these sources from additional consideration for seismically-induced flooding is appropriate.**

There are some sources that probably should never be generically screened out, i.e., should always be evaluated. Examples include:

- **Nonseismically-qualified Fire Protection system piping – such piping may be pervasive throughout the plant, and may include threaded connections such that adequacy of piping supports and location of piping relative to SEL SSCs should be assessed.**
- **Gravity drain sources with high consequences – examples would include situations where the ultimate heat sink could drain into areas of the plant containing SEL SSCs if the normal isolation capability fails (or where the postulated break occurs in a location that cannot be isolated); a detailed assessment of potential impact on SEL SSCs, considering seismic impacts of the normally-credited isolation mechanisms and operator actions would be warranted.**

Note that the need to "evaluate" does not necessarily equate to the need to "model" in the seismic PRA. An evaluation may lead to the conclusion that the scenario(s) with potential impact are sufficiently unlikely that no insight is gained by adding detail and uncertainty to the seismic PRA model.

Ravindra: Internal flooding risk is extremely plant specific. It depends on the inventory of flood source, drainage systems in the zone and the exposed SSCs in the zone. In a study of seismically induced flooding, the additional consideration is whether the flood source (tank or piping) could be damaged by the earthquake. Even those flood sources (SSCs) that have been screened out for random failures may need to be included in the seismic induced flooding analysis. Plant walkdown looking for flood sources and assessing their vulnerability to seismic loading is an important task in the seismic induced flooding PRA. The plant walkdown could be coordinated between the seismic and internal flood PRA teams to identify the seismically induced flood sources in an efficient and complete way. I do not think that certain flood areas/zones can be screened out a priori on a generic basis.

Stutzke: The biggest bang-for-the-buck is screening on the volume of water contained within an internal flood source. Screening on flood areas/zones may also be viable, depending on the number and type of barriers that each area/zone has between it and vital plant equipment. I'm not optimistic that we can screen on equipment type (tanks, piping, etc.) since the seismic fragility will depend on anchorage. Of course, the elephant in the room are plant-specific design variations – it may be possible to develop a screening approach that works well for some plants but not for others.

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2. If you believe that some screening can be done on a generic basis, please describe it.

Then address the following points:

a. Table 1, "Generic List of Sources of Internal Floods for Initial Screening," lists systems, structures and components (SSCs) that may cause an internal flood given an earthquake. This table already contains a preliminary list of generic types of potential sources of seismic-induced flooding (e.g., tanks, heat exchangers). Please remove and/or add sources from this table, as you deem appropriate. The table is expected to include SSCs with the potential for seismically-induced:

   - Internal flooding
   - Failure of tanks/buried large pipes otherwise deemed as low random failure probability
   - Actuation of fire suppression systems.

   Please analyze each SSC in Table 1 for its potential to cause an internal flood given an earthquake. Specifically, classify each SSC into one of the three categories on the right side of this table: I) Not a seismic-induced internal flood source (it can be screened out), II) May be a potential seismic-induced internal flood source, and III) Must be evaluated as a seismic-induced internal flood source. Feel free to revise these three categories as part of the overall process of generically screening SSCs, that is, modify, add, or delete categories.

b. If you consider that other type(s) of generic screening, such as screening of flood areas/zones, could be carried out in addition to, or instead of screening of sources of seismic-induced internal flooding, describe these other type(s).

Please provide the rationale for your answers, and if possible include published references supporting them.

ERIN: Please see response to Q1 regarding bases for generic screening, and alternate considerations for screening.

With regard to Table 1:

- **The distinction between the criteria listed for Category II vs. Category III is not completely clear, and it seems that for most SSCs the outcome is the same. That is, some level of assessment "must" be performed (i.e., Category III) for any SSC that "may be a potential" source (i.e., Category II).**
- **It is not meaningful to consider components such as pumps, valves, and heat exchangers as potential sources. The source would be the fluid system that such components are a part of. For seismically-qualified systems, the likelihood of pressure boundary failure due to failure of such components will be relatively low unless the normal seismic walkdowns have identified specific issues (e.g., proximity of valve operators to other equipment, inadequate heat exchanger anchorage, etc.). A better approach is to use insights from the internal flooding PRA to identify systems whose failure may lead to flooding of SEL SSCs, and ensure that there are no such specific seismic issues in those systems' components.**

- **Note that lines 12, 13, 14 in the table (pumps, valves, chillers) duplicate lines 7, 8, and 9. (But, per the observation above, it does not seem that any of these should be included in the table.)**
- **Tanks internal to the plant, whether vertical, horizontal, or suspended, would always require some consideration for flooding impacts to SEL SSCs unless they can be screened on the basis of location (i.e., in an area that cannot impact SEL SSCs). This comment applies to chillers. However, the focus of any future guidance in this area should be on assessment of sources with significant potential impact.**
- **Please refer to responses to Q1 for other Table 1 entries, including items that should be added for Category I. A markup of Table 1 is not provided with this response.**

Ravindra: Screening could only be done on a plant-specific basis via review and walkdown of potential flood sources and their impact on SSCs of interest to PRA.

Stutzke: I point out some internal flood sources were screened out during development of the internal flooding PRA. It seems reasonable to take advantage of this effort, but we need to bear in mind that the screening may need to be revisited in the context of seismically induced internal flooding.

Table 1 Generic List of Internal Flood Sources for Initial Screening

ID	SSC (Equipment Type)	Location	Not a seismic-induced internal flood source: can be screened out I	May be a potential seismic-induced internal flood source II	Must be evaluated as a seismic-induced internal flood source III
1	Vertical Tank or Heat Exchanger			**Ravindra**: To be confirmed in the walkdown and depends on volume of liquid, drainage system, presence of SSCs needed in the PRA and their location	**Stutzke**: Yes
2	Horizontal Tank or Heat Exchanger			**Ravindra**: To be confirmed in the walkdown and depends on volume of liquid, drainage system, presence of SSCs needed in the PRA and their location	**Stutzke**: Yes
3	Suspended Tank			**Ravindra**: To be confirmed in the walkdown and depends on volume of liquid, drainage system, presence of SSCs needed in the PRA and their location	**Stutzke**: Yes
4	Buried Tanks			**Ravindra**: To be confirmed in the walkdown and depends on volume of liquid, drainage system, presence of SSCs needed in the PRA and their location **Stutzke**: Yes – will be site specific, so can't generically dismiss	
5	Above Ground Piping			**Ravindra**: Generally not a source since the nuclear plant piping, even if not seismically designed, should have a high seismic resistance as borne out in real earthquakes. However, there are some unique features that may make piping seismically vulnerable; the walkdown should focus on them (see EPRI NP - 6041 for details)	**Stutzke**: Yes; need to include connection points with other equipment

ID	SSC (Equipment Type)	Location	Not a seismic-induced internal flood source: can be screened out I	May be a potential seismic-induced internal flood source II	Must be evaluated as a seismic-induced internal flood source III
6	Buried Piping			**Ravindra**: Foundation failure modes come into play **Stutzke**: Yes – will be site specific, so can't generically dismiss	
7	Pumps		**Ravindra**: x **Stutzke**: Yes – small volume		
8	Valves		**Stutzke**: Yes – small volume	**Ravindra**: Seismically very rugged unless some weak configurations and spatial interactions are found in the walkdown (EPRI NP 6041)	
9	Chillers		**Stutzke**: Yes – small volume	**Ravindra**: To be confirmed in the walkdown and depends on volume of liquid, drainage system, presence of SSCs needed in the PRA and their location	
10	RCS Primary Loop		**Ravindra**: These are seismically robust and should not fail	**Stutzke**: Yes, but only the potential for ISLOCAs	
11	RCS Secondary Loop (BWRs)		**Ravindra**: These are seismically robust and should not fail	**Stutzke**: Yes; also need to consider the potential for steam floods that cause high humidity or dynamic effects such as pipe whip	
12	~~Pumps~~ Fire protection piping with threaded joints[11]				**Ravindra**: If these piping systems exist as "wet systems" may fail in earthquakes creating flooding/spray hazard to electrical components.
13	~~Valves~~				
14	~~Chillers~~				

[11] Ravindra: added "fire protection piping with threaded joints," and removed pumps, valves and chillers from table.

Appendix C Questionnaire and Consolidated Responses on Seismic-Induced External Flood

Seismic-induced external plant flooding occurs from sources of water located outside buildings. In other words, an earthquake-induced flow of any external water source could result in an external flood if the plant's physical layout is such that the water could accumulate to the extent that plant equipment may fail. Hence, for this type of flood to lead to core damage, the following conditions must happen:

1. Earthquake-induced flow of water from locations outside the plant.

2. Accumulation of the water in one or more locations within the plant. The kinetic energy of the flow may be a factor in breaching some flood barriers and the water reaching some locations.

Regarding the "kinetic energy of the flow," Kanney pointed out that he "…would use hydrostatic and hydrodynamic forces here instead of "kinetic energy". Also impact forces due to flood-borne debris. Potentially intake clogging due to sediment and/or debris."

3. A failure of plant equipment due to the flooded location(s) that reduces the plant's capability to reach a safe shutdown condition following the seismic and flooding (and possibly fire) events.

The following description was adapted mainly from Chapter IV of "An Evaluation of the Reliability and Usefulness of External-Initiator PRA Methodologies" (NUREG/CR-5477 by Budnitz and Lambert, 1990).

Depending on the site, the generic sources of this type of flooding include the following:

1. Tsunamis.

2. Upstream dam failure.

3. Failure of dikes and levees.

4. Seiches.

5. Landslides

Ferrante modified the last paragraphs above as follows: [12]

"The following description has been adapted ~~mainly~~ from Chapter ~~IV~~ 3 of "Design-Basis Flood Estimation for Site Characterization at Nuclear Power Plants in the United States of America~~An Evaluation of the Reliability and Usefulness of External-Initiator PRA Methodologies~~" (NUREG/CR-7046, PNNL-20091, 2011~~NUREG/CR-5477 by Budnitz and Lambert, 1990~~).

[12] In this document, modifications by contributors are marked as follows: Additions in blue font, and deletions in red and strikeout font.

Depending on the site, the generic sources of this type of flooding include the following:

1. **Flooding in Rivers and Streams**
2. **Dam Breaches and Failures**
3. **Storm Surge**
4. **Seiche**
5. **Ice-Induced Flooding**
6. **Tsunami**
7. **Combined-Effects Flood"**

The flood hazard methodology determines the frequency per year of a seismic-induced flood large enough to cause damage to equipment at the nuclear power plant. This frequency [$F_F(f)$] is a function of the "size" (usually the high-water level) of the flood, f. At any given site, the values of F_F will depend on which phenomenon (or combinations of phenomena) are considered. Also, for a given elevation of extreme flood water, the analyst's ·knowledge of F_F is never exact, so the analysis of F_F should provide a distribution rather than a point value to capture the uncertainty in the state of knowledge.

Flooding analysis typically deals with a single parameter (floodwater height) as its figure-of-merit. This height is then compared to the site features (river bank, dike height, ocean or lake shoreline, etc.). Once flooding reaches a certain undesired height, it is assumed that the waters will flow to all elevations at that height. It is then considered a trivial matter to determine which structures and equipment are flooded. The important observation worth noting here is that sometimes floodwater height alone may not be a sufficient endpoint for the hazard analysis. Sometimes, the duration of the event can be important, such as for wave effects, landslide-induced flooding, and so on. Also, sometimes the total water volume may be limited, such as for an upstream dam failure or a single-strike tsunami.

Ferrante suggested modifying the paragraph above as follows:

"Flooding analysis typically deals with a single parameter (floodwater height) as its figure-of- merit (although other factors such as flow velocity and erosion may be considered implicitly or explicitly). This height is then compared to the site features (river bank, dike height, ocean or lake shoreline, etc.). Once flooding reaches a certain undesired height, it is assumed that the waters will flow to all elevations at that height. It is then considered ~~a trivial matter~~more straightforward to determine which structures and equipment are flooded. The important observation worth noting here is that sometimes floodwater height alone may not be a sufficient endpoint for the hazard analysis. Sometimes, the duration of the event can be important, such as for wave effects, landslide-induced flooding, and so on. Also, sometimes the total water volume may be limited, such as for an upstream dam failure or a single-strike tsunami."

Kanney offered some comments and modifications to the same paragraph, as follows:

Flooding analysis typically deals with a single parameter (floodwater height) as its figure-of- merit. This height is then compared to the site features (river bank, dike height, ocean or lake shoreline, etc.). Once flooding reaches a certain undesired height, it is assumed that the waters will flow to all elevations at that height. It is then considered a trivial matter to determine which structures and equipment are flooded. The important observation worth noting here is that sometimes floodwater height alone ~~may~~ is often

not be a sufficient endpoint for the hazard analysis. Sometimes, the duration of the event can be important, such as for wave effects, landslide-induced flooding, and so on. Also, sometimes the total water volume may be limited, such as for an upstream dam failure or a single-strike tsunami. It is also important to note that flooding may have impact the ability to perform certain manual actions or even impede site access before flood waters reach levels that threaten SSCs.

Kanney also commented on specific sentences of the paragraph above:

- **Regarding the sentence "Once flooding reaches a certain undesired height, it is assumed that the waters will flow to all elevations at that height," Kanney commented "This statement ignores the importance of site-scale topography."**

- **Referring to the statement "It is then considered a trivial matter to determine which structures and equipment are flooded," Kanney remarked "Operating experience (e.g. NTTF R2.3 Flood Protection Walkdowns, numerous inspection findings) indicates otherwise. There appears to be insufficient understanding of pathways by which water may enter buildings at many sites."**

- **Pointing to "Sometimes, the duration of the event can be important…," he stated "Duration needs to be defined carefully and used consistently. What constitutes the start of the flooding event (first warning? arrival of flood waters on site?). What constitutes the end of the flooding event (water recedes from SSCs? water recedes from site?)"**

Kanney further offered the following general observation "Warning time, which will be function of distance to upstream dam and notification procedures, may be very important because with sufficient warning time, measures may be taken that will reduce potential impact of flood (shut down reactor, install temporary flood protection, etc.)"

In principle, an earthquake may trigger several sources of external flooding, such as failure of upstream dam and of dikes and levees, so due consideration must be taken of this issue where appropriate.

Since there are significant uncertainties in the flood hazard analysis, it is important that the methodology capture these. The flood hazard is generally expressed in terms of values of F_F as a function of flood height. The uncertainty is expressed as a distribution of F_F values at each given flood height, to capture the analyst's state of knowledge. Families of curves are often used to show the functional relationships, with different curves showing the 50th-percentile or median value of F_F, the 5th, 25th, 75th and 95th percentile values, the mean value, and so on.

In light of these considerations, please respond the following questions providing the rationale for your answers, and if possible include published references supporting them:

1. Do you consider the above list of sources of external flooding, resulting from a seismic event, complete? Are there additional generic sources that you could add?

ERIN: The listed sources, i.e., tsunamis, upstream dam failure, failure of dikes and levees, seiches, and landslides are all potentially important, depending on the site and plant design. Note that use of the term "generic" may be problematic, since each site, and the associated potential external flooding sources, is somewhat unique.

The following additional possible sources should be considered:

a. **Consider adding "river diversion" resulting from the seismic event, unless this is assumed to be addressed by "failure of dikes and levees". Although it is not clear how such a source (e.g., seismic failures that might divert the flow of a river/large stream that would not normally be a site flood source such that it becomes one) would be analyzed, perhaps it should be included for completeness and dispositioned as part of the broader process.**

b. **Consider adding "lateral spreading" resulting from a seismic induced liquefaction event. NRC Regulatory Guide 1.198, "Procedures and Criteria for Assessing Seismic Soil Liquefaction at Nuclear Power Plant Sites", addresses this phenomenon for design purposes and may provide insights relative to beyond-design basis seismic events.**

c. **In considering sources, we have assumed that large onsite sources (e.g., cooling tower basins) are intended to be considered as internal flood sources. If not, these should also be added to the list.**

Ferrante: There may be combined events that are very site-specific (e.g., landslide-induced flooding due to seismic events). Hence it is not possible to obtain a complete list. A discussion of the list of flooding mechanisms considered by the NRC and other Federal Agencies is contained in NUREG/CR-7046, PNNL-20091. A full set should be considered for a specific-site with consideration of which additional hazards may be relevant (even more so than others explicitly identified in documents).

Kanney: No. Water holding structures such as large tanks, cooling tower basins, etc. could be external flooding sources. Onsite cooling water reservoirs or ponds could also be external flooding sources.

McCann: The list that is given is reasonably complete is generally completed and consistent with lists that are typically used. In the following table I have added some additional details.

No.	Flooding Type / Source
1	**Tsunamis**
2	**Releases from Upstream Dams:** d. Dam Breach (uncontrolled) e. Releases associated with failure of spillway structures (non-dam breach related) (Uncontrolled) f. Controlled releases that are made to reduce the load on the dam in order to prevent its failure as a result of seismically initiated damage.
3	**Releases from Downstream Dams** A seismic event could breach a downstream dam or require significant lowering of the reservoir in order to prevent a failure. These events could lead to a loss of the reservoir (heatsink).
4	**Failure of Dikes and Levees** This could be particularly problematic for a couple of reasons: • The potential seismic damage that could lead to failure may be subtle (limited transverse cracking) that could contribute to seepage and piping in the event of an upstream dam failure. • The time available to make repairs to the levee may be limited. • If the seismic event causes a levee failure and it occurs during high spring flows, the plant may be dealing with a certain amount of flooding or fighting a flood (sandbagging, etc.). A coincident dam failure or large release from an upstream dam would compound the flood threat at the plant.
5	**Seiche**
6	**Landslides Upstream – Reservoirs** For a plant located on a reservoir, a landslide could induced waves that result in plant flooding. Landslides in an upstream reservoir (upstream of the dam) could contribute to a breach of the dam or a floodwave that goes over the dam and downstream.
7	**Landslides - Rivers** Landslides can create upstream dams that could potentially pose a threat to downstream facilities. Landslides could also produce a downstream dam that leads to flooding upstream.

In addition to these events, there are 'likely' combinations of events that can impact the flooding that occurs. For instance, the time of year that an earthquake occurs can have important implications as to the extent of flooding ('dry' season versus 'wet' season).

As noted in the discussion above, there may different metrics that can be important when characterizing a flood hazard. In addition there also may be accompanying issues such as the potential for debris, sediment, erosion, etc. that may need to be considered.

Ravindra:

- **The sources are site and region specific**
- **The list of sources of external flooding resulting from a seismic event is generally complete; cannot think of any additions**

Stutzke: There seems to be a boundary definition issue here – would seismically induced external floods include failures of tanks and dams/levees that are located outside of the plant structures, but on the site? For example, some sites have large service water ponds. Suggest that you review information on the proposed generic issue concerning upstream dam failures, which also includes failures of dams that are located on the site property.

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2. May a single flood hazard methodology be applied for assessing the frequency per year of a seismic-induced flood [$F_F(f)$] for all types of sources? Or is it necessary to apply a different type of method for different sources? Please enumerate the methodology(ies) that you propose for estimating $F_F(f)$.

ERIN: No, frequencies (and associated uncertainties) are source-specific and likely also site-specific. Further, the methods by which these are assessed are also unique to many types of sources. So a single methodology could not be used for all. Examples of different source hazard assessment methodologies would include the following:

a. **Upstream dam failure – assessment of source impact on the site needs to determine the probability of dam failure resulting in a given site flood impact (e.g., flowrate and duration) for a given magnitude seismic event. Such an assessment would need to address dam structural response as described in US Army Corps of Engineers (USACE) guidance, and then determine the probability of propagation to the site, e.g., using a river model.**

b. **Tsunami – assessment of source impact on the site needs to deal with seismic eventinduced wave development, and would need to address parameters such as wave height, wave speed/timing of coastal impact, coastal parameters, etc.**

c. **Seiche – assessment of source impact on the site might include similar considerations as tsunami, but would also need to address issues such as lake embankment properties, lake depth, etc.**

Ferrante:

1) **Assess which flooding mechanisms are relevant to the site**
2) **For specific flood mechanisms, consider whether a single flood hazard curve is possible, e.g., dam failures and river flooding (this type of analyses have been performed.**

3) **For other flood mechanisms, it may be necessary to consider a separate hazard curve as a contributor for specific scenarios, e.g., local intense precipitation.**
4) **For seismically-induced floods, it may be necessary to consider individual dams that may contribute to flooding at the site and to screen out dams (or assume failed) that, by itself or in combination, would not produce significant flooding.**

There are a number of methods that have been discussed at the NRC-hosted Workshop on Probabilistic Flood Hazard Assessment (see "Proceedings of the Workshop on Probabilistic Flood Hazard Assessment (PFHA): Held at the U.S. Nuclear Regulatory Commission Headquarters, Rockville, MD, January 29–31, 2013 (NUREG/CP-0302)". Multiple extrapolation methods exist, including USGS Bulletin 17b, Regionalization methods (i.e., L-moments), inclusion of paleoflood information, and physics-based stochastic modeling for extreme floods. Depending on the method used, different levels of credibility may be assessed depending on the return period ranges considered.

Kanney: Different methodologies will generally be required: (1) a method to estimate the frequency of the seismic hazard of interest (e.g. ground shaking, surface faulting, landsliding, liquefaction); (2) a fragility or failure model for the entity impacted by the seismic hazard (e.g. a dam, levee, dike, hill slope, water tank, fault displacement); (3) a model to estimate the initial hydrograph (e.g. initial water surface displacement, dam or level breach hydrograph or peak flow, discharge hydrograph or peak discharge from tank); (4) a model for flood wave propagation and attenuation as it moves toward site (e.g. tsunami wave propagation, riverine flood wave propagation); and finally (5) a model for site-scale interactions of the flood wave with local bathymetry, topography, buildings, etc.

McCann: [See his response to Question 3.]

Ravindra:

- **The mechanisms leading to flooding are different for each of these generic sources (tsunami could be locally generated –ocean floor subsidence or could arrive from a distant earthquake) and requires different models and data to develop the probabilistic hazard curves. Similarly, the flooding from upstream dam failure should take into account the characteristics of the dam in question and the failure modes. The probabilistic models are different and the impacts on the site in terms of flood height, volume and debris are also different. It is better to treat each source separately and add the frequencies at the end if appropriate.**
- **Probabilistic flooding hazard assessment has not been attempted in the industry for various reasons. It requires concerted efforts by the hydrologists and structural engineers to name a few. The difficulties of performing a credible hazard analysis are discussed in NUREG/CR-7046, NUREG/CR-6966 and the ongoing work at IAEA. ASME/ANS PRA Standards Methodology Part 8 also discusses these difficulties**
- **Just because it has not been done in the past, does not mean it cannot be done or should not be done. There is always a first time. Otherwise, we will have to wait**

for real events (e.g, Fort Calhoun flooding, Blayais flooding and Fukushima accident) to goad us into action.

Stutzke: I think that different methods are needed to treat the various external flooding sources. We need probabilistic hazard models for tsunamis, seismic dam failures, seiches, etc. Each of these has unique phenomenological aspects and, to my knowledge, will require different expertise. Also, site-specific details will be important. Note that NRC/RES has a research effort underway on probabilistic flood hazard assessment (Tom Nicholson is a good source of information), which could potentially be leveraged for the treatment of seismically induced external floods.

3. Are the methodology(ies) that you proposed in the previous question capable of expressing the uncertainties, that is, the analyst's state of knowledge? If not, how would you propose to express them?

ERIN: It is expected that most methodologies are capable of expressing uncertainties, although it is likely that different methodologies deal with uncertainties in different, and possibly inconsistent, manners. For example, available references for soil liquefaction may not provide probabilities with uncertainties. In some cases, the failure is assumed to occur at a given g-level.

Uncertainties in the impact of the seismic hazard on each flood source complicate the consideration of uncertainty in the consequential event. The case where there may be multiple flooding sources initiated by the same seismic event is significantly more complex. Further, the uncertainties in both the seismic hazard frequency and consequential event probability need to be addressed in both steps to obtain the frequency with integrated uncertainty of the combined event. It seems likely that the uncertainty in the flood hazard for some sites could be substantially greater than that of the seismic hazard, such that it may be challenging to derive meaningful insights from a quantitative assessment.

Ferrante: To varying degrees. Some methodologies simply do not capture modeling uncertainty as they rely on extrapolating limited available historical data to ranges well beyond the observed record. Other methodologies based on physics-based stochastic modeling are more promising in allowing modeling uncertainty to be capture more explicitly. However, even this latter approach may not necessarily capture all the aleatory and modeling uncertainty as it is bound by the historical records and/or expert judgment for the uncertainty in the inputs to the analyses and may capture modeling uncertainty to a certain degree depending on the specific application and the return period of the floods considered.

Kanney: A general discussion of risk assessment for dams is given in Hartford and Baecher (2004).[13]

The most likely seismic failure modes for dams include: (1)sliding failure through weak lift line; (2) horizontal cracking; (3) Liquefaction of dam or foundation; (4) Cracking from severe shaking; (5) Surface fault displacement through the foundation (6) Overtopping from landslide failure into reservoir.

Probabilistic assessment of seismic hazards due to ground shaking is a mature discipline that has approaches for considering both aleatory and epistemic uncertainties. An extensive literature is available (e.g., McGuire, 2004).

Probabilistic fault displacement hazard analyses (PFDHA) have been done in only a limited number of cases. The basic methodology was developed for the proposed Yucca Mountain, Nevada nuclear waste repository (Stepp et al. 2001). An example of PFDHA applied to a dam is an analysis conducted for Lauro Dam near Santa Barbara, California (Anderson and Ake, 2003).

Probabilistic liquefaction analysis is discussed in NUREG/CR-6622 (NRC, 1999) and Holzer (2008)

Regression models for peak discharge due to dam failures are discussed by USBR (1982,1983). Regression models for dam breach parameters are discussed by Wahl(2004,2010). Wahl (2010) discusses uncertainty in regression models for breach parameters.

Probabilistic tsunami hazard assessment (PTHA) is less mature than PSHA, but there are approaches and models that have gained a certain degree of acceptance. The maturity of PTHA for tsunamis caused by subaerial or submarine landslides is conserably less mature than PTHA for tsunamis caused by fault rupture.

I'm not aware of probabilistic models for seimic failure of dikes, levees or on-site cooling reservoirs, But it should be noted that very few dikes and levees are seismically qualified. So it may be appropriate to simply assume failure at some modest level of grounshaking.

I'm not aware of analysis methods for seismic failure of tanks and cooling tower basins, but in principle they should be similar to other seismic analysis of other structures

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McCann: In my view these modeling questions are intrinsically related. In simple terms, Question 2 is referring to a methodology for modeling the aleatory uncertainties in the flood hazard analysis (the aleatory flood model). Question 3 deals with the evaluation of the epistemic uncertainties (knowledge uncertainties). In my view an analysis must address both sources of uncertainty; their characterization and evaluation are inter-related and as such they should be considered together.

The simple answer to Question 2 is no. There are a number of reasons for this. For instance, the mechanisms for each source/type of flooding is different, therefore the

[13] Kanney's references are presented at the end of this section.

mechanistic models that are used are different, the sources of aleatory uncertainty are different, and the way these uncertainties are modeled will vary. In addition, for a given type of flooding there may be different mechanistic and probabilistic models the analyst could use. The choice of models will impact what the aleatory uncertainties are and how they are modeled.

In the flood area, I think an over-arching probabilistic framework can be established (it will appear in the new version of ANS 2.8) that guides how probabilistic flood hazard analysis (PFHA) should be carried out. Elements of this framework are borrowed from the seismic SSHAC process (see NUREG-2117). The probabilistic framework (evaluation of aleatory and epistemic uncertainties) and how a PFHA project is carried out is applicable to all sources/types of flooding, but the details of the implementation and the actual probabilistic modeling is done would be different.

There is another aspect to flood hazard analysis that is different than other natural hazards such as seismic ground motion. A probabilistic analysis of flood hazards must be scalable in order to meet the range of problems that exists for a fleet of plants. In the seismic area, all plants may be exposed to the effects of earthquake ground motions; there is no avoiding the hazard. In the flooding area, this is not the case. For instance, at a plant one might be able to do a limited analysis that shows the frequency of flooding is low enough that it does not have to be considered in the design basis or in a PRA. In my view, this analysis must address aleatory and epistemic uncertainties in a systematic and rigorous manner in order to make the case that the frequency of exceeding plant grade (for example) is less than 10^{-7} per year. This analysis does not necessarily require an extensive study (use of experts, lots of hydrologic or other modeling, etc.). For another plant that clearly has a flood problem, a more comprehensive analysis (more depth, more detail) potentially the use of experts and therefore the need for structured expert elicitation, etc. could be required. In the SSHAC process and in the new ANS standard on flooding, the concept of levels of analysis (scalability) is used. The analysis has the same goal and same probabilistic framework, but the level (depth of analysis; cost, etc.) of evaluation may be different (thus different levels of analysis; 1 – 4).

Ravindra: Current methodologies do not fully account for uncertainties in the models and data. Some sort of SSHAC exercise is needed to identify the uncertainties and to quantify them. It took over 30 years for the profession to accept probabilistic seismic hazard analysis techniques. The external flooding hazard analysis has not even seriously begun.

Stutzke: There's basically a two-step process in developing a probabilistic hazard assessment. First, one needs to develop some sort of model for $F_F(f)$. Second, one needs to estimate the parameters of that model. In addition to a literature review, the first step would seem to warrant a PERT process to address modeling uncertainty. The second step needs a SSHAC process to address parametric uncertainty.

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4. There may be a correlation between the impact of an earthquake on a flooding source (e.g., an upstream dam) and on the plant itself. How could this correlation be accounted for? Are you aware of methods for this purpose?

ERIN: In the following, it is assumed that the question is focused on correlation of input ground motion at different locations resulting from a given hazard event, and not correlation of capacity of different sources relative to a given event.

a. **It would seem important to focus on flood events that are caused by the same seismic event that is being evaluated for seismic impact on the plant, i.e., focus on correlated-response events. Since seismic events tend to affect large geographic areas (e.g., the recent Mineral, Va. Earthquake), a seismic event sufficiently remote that it would not affect the plant can be assumed to also be sufficiently remote to not need to be considered as a seismically-induced flood source. While there may be far away flood sources that could result from a local (to the flood source) failure, any subsequent cascading effects that might ultimately affect a far away (from the flood source) plant should be considered as part of the external flood risk assessment (not the seismic risk assessment) for the plant.**

b. **For close-in sources (where close-in needs to be defined based on seismological impact considerations), and where the source (e.g., dam) and plant are founded on very similar foundation media (e.g., same soil/rock material properties and layer thicknesses), complete correlation between plant and dam foundation input response impacts might be appropriate. However, this does not mean that flood source structure and site structure responses would necessarily be highly correlated.**

c. **For "farther away" sources that may be subject to the same seismic event (where again, the distance to be considered would be based on seismological impact considerations), specific determination of the seismic input response for the flood source, separate from the seismic input response to the plant for the same event, would likely be required. In addition, the correlation impact in this case must also address accident sequence timing, i.e., plant impact of the seismic event followed, at different times, with different accident sequence impacts due to different flood sources.**

d. **Other scenarios might involve a seismic event weakening a nearby dam but also failing a far away dam, whose failure subsequently results in failure of the nearby dam, with subsequent impact on the plant. Clearly, some boundary conditions need to be placed on the scope of the analysis.**

Ferrante: There is significant correlation between a seismic-failure and a loss of impounding reservoir at a facility such as a dam or levee. The initial challenge is where to locate the seismic sources such that significant ground motion would be experienced at either one or more dams (i.e., the location may have to be optimized such the most critical dam is failed or a combination of dam failures producing the highest water level at the site is the dominant contributor). Establishing failure metrics for the dam itself due to seismic will be the next challenge, as the "weakest link" in the dam system will need to be determined according to intensity and failure mode. For example, for a concrete

dam, the failure modes related to a specific reinforced concrete section for a buttress dam would be different for specific designs or for an embankment dam. In addition, the failure of appurtnent structures such as spillways may need to be considered as additional scenarios. The combination of specific levels at the dam when the seismic event occurs can also be treated probabilistically (e.g., if flow level records are available, it may be postulated that the reservoir elevation has a specific likelihood of exceeding a certain level when a postulated seismic event impacts the dam). Alternatively, a specific assumption regarding level may need to be assumed, above normal pond elevation for conservatism. Guidance such as ANSI/ANS-2.8-1992 provides combinations of seismic events with hydrological events, but these are deterministically-derived scenarios (e.g., a specific percentage of the safe shutdown earthquake in combination with a percentage of the probable maximum flood) and therefore would not easily translate into frequencies; although specific generic numbers are presumed (e.g., 1E-6/year) for such combinations. Finally, the breach mechanism for a dam failure may be different from a hydrologic-induced event and would have to be assessed by physical modeling. The relevance of this item is that timing of the unintended release of the reservoir may be different, with different warning time and probability of success for implementation of flood protection mitigation at downstream facilities such as nuclear sites. Recommend looking into the US Department of Interior's Bureau of Reclamation approach to risk assessment of dams, since this includes a discussion of how to perform dam risk assessment with some of the above concepts explicitly considered.

Kanney: Interim Staff Guidance for Evaluation of Flood Hazards due to Dam Failure (JLD-ISG-13-01) outlined an approach (but not detailed method) for considering the seismic failure of multiple dams. This approach could also be applied to investigate the correlation between dam failure and seismic impacts at the site.

McCann: I believe this question is referring to the issue that an earthquake may cause ground motions at a plant and an upstream dam. The ground motions at both sites depend on a number of factors and there are sources of correlation (Park, et al., (2007); McCann (2012); McCann, et al. (2015)). Sources of dependence and correlation are:

- **Earthquake magnitude,**
- **Distance of each site to the earthquake,**
- **Inter-event variability of earthquakes of the same magnitude,**
- **Intra-event variability of earthquake ground motions, and the**
- **Separation distance between the plant and the upstream dam(s).**

Other factors that contribute to the assessment of this risk is the uncertainty in the elements of the seismic hazard analysis; seismic source characterization, ground motion prediction models, and the site conditions at each facility.

The importance of modeling these sources of correlation/dependence to plant risk is problem/circumstance specific.

Specialized seismic hazard/risk quantification software is required to model all of the factors listed above. In addition to the referenced papers, firms in the insurance industry

and possibly some firms that do earthquake risk analysis for lifeline systems (spatially distributed systems) may have software that model this problem.

References

McCann, Jr., M.W. (2011). Seismic Risk of a Co-Located Portfolio of Dams – Effects of Correlation and Uncertainty, 3rd International Week on Risk Analysis, Dam Safety, Dam Security and Critical Infrastructure Management, Valencia, Spain.

McCann, Jr., M.W. (2015). Dam Failure-Nuclear Plant Seismic PRA Model – Modeling Correlations and Uncertainty, Proceedings of the U.S. Society on Dams annual conference, Louisville, Ky.

Park, J., Bazzurro, P., Baker, J.W., "Modeling Spatial Correlation of Ground Motion Intensity Measures for Regional Seismic Hazard and Portfolio Loss Estimation," Applications of Statistics and Probability in Civil Engineering. Edited by Kanda, Takada, and Furuta. London: Taylor & Francis Group, 2007.

Ravindra: True, this is an important issue. However, the correlation studies should take into account the time lag between the seismic event affecting the plant and the flood hitting the plant due to upstream dam failure (caused by the earthquake). In the Fukushima accident, the tsunami arrived at the plant a long time after the earthquake. Of course, in a large earthquake occurrence, the potential for aftershocks combining with the flooding should also be considered.

Stutzke: I'm not aware of any specific methods here, but it would seem to require an evolution of existing methods. Basically, we're after the correlation between a site seismic hazard curve and the hazard curve for an external flooding source (e.g., a dam). There are agreed-upon seismic source models for the US and also ground motion prediction models. So, the probabilistic/statistical challenge is to somehow link these models across different geographical regions. This could prove challenging since we want a complete response spectrum (as opposed to only the peak ground acceleration hazard curve).

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5. An earthquake may trigger several sources of external flooding, such as failure of upstream dam and of dikes and levees. How could this dependency be accounted for? Are you aware of methods for this purpose?

ERIN: The hazard should be considered from the perspective of the plant site. The impact of that hazard should then be considered as it affects potential flood sources accounting for their distance from the site, with some seismologically-based regional impact boundary established to determine which sources should be considered. The impacts of multiple sources could then be accounted for probabilistically. Issues of timing would need to be considered for impacts of each source. At some point the analysis needs to be subject to some boundary conditions (i.e., limit on number of cascading impacts considered), and the uncertainties may be such that only a parametric analysis can be

performed, and then only to provide insights but no real meaningful quantitative risk results.

Ferrante: I perceived this question to be similar than above, unless concurrent cascading dam failures are being considered. If that's the case, the complexity of the analysis will depend on the complexity of the watershed in several aspects. Large watersheds with significant regulated structures may require an optimization of the impact of the local seismology and the optimal location of a seismic event that would induce the scenarios of relevance to flooding at a specific site such as a nuclear site downstream. Several scenarios may be screened or combined so that those critical for flooding aspects are included. Then a realistic combination of scenarios would have to be identified and an approach to establish the likelihood would have to be established with respect to the likelihood of the ground motion that produces multiple failures along with any conditional probabilities associated with these scenarios (e.g., a set of dams fails seismically causing downstream dams to fail in a cascading fashion if reservoir impounding capability is not sufficient to contain the releases).

Kanney modified question 5 as follows: "An earthquake may trigger several sources of external flooding, such as failure of multiple upstream dams and of dikes and levees…", and pointed out that "Should keep in mind that unless the dike or levee provides protection of the NPP site, failure of such structures would generally be beneficial. Consider, for example, dam break flood wave propagation. If a dike or levee between the dam and the plant fails, it will result in lower discharge and water level at the plant compared to the case where the levee or dike does not fail."

In answering question 5, Kanney stated "Interim Staff Guidance for Evaluation of Flood Hazards due to Dam Failure (JLD-ISG-13-01) outlined an approach (but not detailed method) for considering the seismic failure of multiple dams."

McCann: Assuming this question is referring to other sources of dependence (beyond the seismic hazard issues discussed in response to Question 4), there are a number of factors/sources of dependence that need to be considered in evaluating this type of an event.

In the event of an earthquake, there are sequences that may occur that could lead to core damage as a result of the seismic event, flooding, or the combined effect of both hazards. A plant may survive the seismic event, but at the same time experience damage to structures and selected equipment items that compromise the response to onsite flooding. For example, damage to structures may deform doorway frames complicating installation of flood barriers and create leak paths, crack exterior walls creating a leak path into the building, and potentially expanding small cracks that may exist in the foundations of structures containing flood mitigation equipment. Furthermore, following a seismic event there is a likelihood that flood preparatory actions would need to take place without the benefit of off-site power.

Successful flood mitigation at a plant requires consideration:

- **Seismic damage to flood mitigation structures and components that may not be considered in the seismic PRA**
- **Seismic damage to structures that may not be considered in the seismic PRA such as:**
  - **Damage that allows in-leakage into structures. This leak could occur above and/or below grade**
  - **Damage to flood mitigation systems such as levees, floodwalls**
  - **Impact of the seismic event on operators and systems required to mitigate flood event**
  - **Flood fragility assessment for structures and components**

The quantification of this risk can be done in a couple of different ways. In the references cited above the hazard and risk quantification is carried out simultaneous. Alternatively, the seismic hazard and dam-plant risk quantification can be carried out in two steps. Both approaches require special software tools to carry out the quantification.

Ravindra: Such scenarios are very region and site-specific. The analyst should construct these scenarios (event trees would help) and assign probabilities based on data and expert judgment.

Stutzke: I'm not aware of any specific methods for considering multiple, simultaneous seismically induced external flood sources. As I mentioned in Item 4, there should be a way to adapt/extend existing seismic source models and ground motion models. However, there's the curse of dimensionality to be considered, depending on the number of credible external floods that are nearby a plant site. By the way, if we could somehow treat multiple external flood sources, we could also potentially address the damage to other nearby civil structures (roadways, bridges, etc.) which could have an impact on evacuation and, hence, consequences.

Kanney's references:

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Wahl, T.L. (2004), Uncertainty of Predictions of Embankment Dam Breach Parameters, Journal of Hydraulic Engineering, 130(5): p. 389-397.

Wahl, T.L. (2010), Dam Breach Modeling – An Overview of Analysis Methods, Parameters, Joint Federal Interagency Conference on Sedimentation and Hydrologic Modeling, June 27 - July 1, Las Vegas, NV.

Appendix D Literature Survey

A survey of the literature related to seismic-induced fires and floods was conducted. It included searching the operational experience of nuclear power plants worldwide that have experienced such fires and floods, and looking for reports and papers in the literature that address these hazards.

D.1 Seismic-induced fires and floods

The following seismic-induced fires and floods were found:[14]

1. Kashiwazaki-Kariwa (2007)
2. Fukushima Daiichi (2011)

Some fires occur because an earthquake induces a mechanism called high energy arcing fault (HEAF). A Nuclear Energy Agency (NEA) report discusses HEAF events in general (i.e., due to any cause, seismic related or not), and two seismic-induced HEAF fires were identified. These two events happened in Japan, and they are:

1. BWR[15] (2009)
2. Onagawa (2011)

These four events are summarized in the following subsections.

D.1.1 Kashiwazaki-Kariwa (2007)

The IAEA published two reports on this event: "Preliminary Findings and Lessons Learned from the 16 July 2007 Earthquake at Kashiwazaki-Kariwa NPP" and "Follow-Up IAEA Mission In Relation To the Findings and Lessons Learned From the 16 July 2007 Earthquake at Kashiwazaki-Kariwa NPP." This summary presents relevant excerpts from these two reports.

On 16 July 2007, a strong earthquake, the Niigataken Chuetsu-oki earthquake, with a moment magnitude of 6.6, occurred at 10:13 h local time with its hypocentre below the seabed of the Jo-chuetsu area in Niigata prefecture in Japan, affecting the Kashiwazaki-Kariwa Nuclear Power Plant (NPP) located approximately 16 km south of its epicentre.

[14] On December 26, 2006, a series of earthquakes occurred near Hengchun, Taiwan, where the Maanshan Nuclear Power Station is located. Two large earthquakes occurred within 8 minutes of each other and were both of magnitude 7.0. One unit was manually tripped; the other remained operating. There was an accumulation of dust inside the ventilation pipe in the ceiling of the main control room. During and following the earthquake, this dust floated down from the top of the ceiling into the main control room. The operators misinterpreted the dust to be smoke from a fire and decided to trip one of the reactors as a safety precaution. Since apparently no fire happened, this event was not discussed further.

[15] The name of the NPP was not found in the NEA report.

Kashiwazaki-Kariwa NPP is the biggest nuclear power plant site in the world. It is located in the Niigata prefecture, in the northwest coast of Japan, and it is operated by Tokyo Electric Power Company (TEPCO). The site has seven units with a total of 7965 MW net installed capacity. Five reactors are of BWR type and two reactors are of ABWR type.

At the time of the earthquake, four reactors were in operation: Units 2, 3 and 4 (BWRs) and Unit 7 (ABWR). Unit 2 was in start-up condition but was not connected to the grid. The other three reactors were in shutdown conditions for planned outages: Units 1 and 5 (BWRs) and Unit 6 (ABWR).

Although the Niigataken Chuetsu-Oki earthquake on 16 July 2007 significantly exceeded the level of the seismic input taken into account in the design of the plant, the installation behaved in a safe manner, during and after the earthquake.

The earthquake caused automatic shutdown of the operating reactors, a fire in the in-house electrical transformer of Unit 3…

Seismically induced fires are frequent events after an earthquake in urbanized areas but are relatively rare at a nuclear power plant. Although not directly related to nuclear safety, the Unit 3 in-house electrical transformer fire… demonstrated problems in the fire fighting capability of the plant…Common cause failure should be avoided in any case. Failure of the fire fighting system (tanks, pumps, piping, distribution system) and its consequences can be minimized by providing adequate seismic capacity, redundancy and diversity of the system.

The fire was initiated by sparks from a short circuit caused by large ground displacements (settlements) of the transformer foundation (see Appendix V of Volume II of this mission report). The spark caused the ignition of oil leaked from the transformer. The fire was extinguished by the local municipality fire brigade approximately 2 hours after it began.

Although the transformer was separated by a firewall, active actions for extinguishing the fire were not possible because the outdoor fire protection system of Units 1-4 was damaged.

The IAEA report points out that the safety significance of this fire is as follows:

- The particular fact of the fire in the in-house transformer has no safety significance for the plant. The in-house transformer is not an item of safety related equipment and does not affect the nuclear safety of the unit. Nevertheless, the fact is significant from the broad point of view of safety due to seismically induced events.

- Frequently fire protection systems are not seismically qualified and may suffer seismic damage. However, the IAEA Safety Guide NS-G-1.6 recommends that seismically induced events, such as fires, be carefully considered in the plant safety analyses and adequate counter measures be taken.

- The damage of the outside water fire protection system of Units 1 to 4 is a cause of serious concern.

- The multiple failure of the fire protection system was caused mainly due to large ground deformations produced by the earthquake. The fire protection piping was not seismically

qualified because this is not required by current codes. It was indicated by TEPCO that the code requires only the installation of fire protection walls and that has been provided.

An upgrade of the fire extinguishing system is planned with increased capacity. The source of water is the filtrated water tank that is shared by Units 1 to 4. The indoor and outdoor fire systems have a total capacity of 350m3/h and they are driven by motor and diesel pumps, respectively. Although the present capacity might be sufficient, the effects of the earthquake showed that the outdoor system has been affected by a common cause failure.

- The underground piping is very vulnerable to large soil deformations such as those that occurred at the Kashiwazaki-Kariwa nuclear power plant and this should have been considered as a weak link in the analyses of the fire extinguishing system. Associated counter measures should have been properly taken.

Further, the IAEA report includes the following finding s about this fire:

- Multiple failures of the fire fighting water system in Units 1 to 4;
- Failure of one of the fire fighting water storage tank;
- Failure of other fire suppression systems;
- Communications problems to call in the fire brigade.

The post earthquake analysis identified some weak points in the fire protection programme such as:

- Insufficiency of in-house fire fighting capability
- Insufficiency of training in the fire protection area
- Areas for improvement in regulatory guidelines

The IAEA report also points out the following examples of flooding hazards during the 16 July earthquake:

- Sloshing of the spent fuel pool water onto the reactor building operating floor of Unit 6 and leakage through cable penetrations in the floor leaking water to lower elevations.
- Failure of the rubber flexible connection of the condenser B seawater box and connecting valve in Unit 4 leaking sea water onto the turbine building floor at lower elevations. The flexible connection that failed had originally been installed 13 years ago –plant personnel stated that the normal replacement schedule was 10 to 15 years – and so ageing of the flexible connection was a factor in its failure.
- Localized soil failure caused failure of fire suppression piping at a cable penetration to the Unit 1 reactor building. Water (about 2000 m3) and soil entered the reactor building at grade elevation and flowed through floor penetrations and stairwells to lower levels, finally reaching the B5 level at about 38 m below the plant grade level. A 40 cm deep puddle of

water formed at the B5 level. It seems that this water and soil did not produce adverse consequences to SSCs. The total evaluation by TEPCO is not completed yet.

D.1.2 Fukushima Daiichi, 2011

The following summary is based on a report by the Institute of Nuclear Power Operations (INPO) published in November 2011.

On March 11, 2011 at 1446, a severe earthquake measuring 9.0 on the Richter scale occurred off the eastern coast of Japan. The epicenter of the earthquake was 112 miles (180 km) from the Fukushima Daiichi site and the hypocenter was 15 miles (24 km) under the Pacific Ocean. The earthquake lasted approximately three minutes, and it was the largest Japan has ever experienced.

The earthquake caused all of the operating units (units 1, 2, and 3) to automatically scram on seismic reactor protection system trips. The power lines connecting the site to the transmission grid were damaged during the earthquake, resulting in a loss of all off-site power. The emergency diesel generators started and loaded as expected in response to the loss of off-site power to supply electrical power, with the exception of one emergency diesel generator on Unit 4, which was out of service for planned maintenance. Feedwater and condensate pumps, which are powered by non-vital AC sources, were not available because of the loss of AC power.

Three minutes after the earthquake, the Japan Meteorological Association issued a major tsunami warning, indicating the potential for a tsunami at least 3 meters high. Station workers were notified of the warning and evacuated to higher ground.

Forty-one minutes after the earthquake, at 1527, the first of a series of seven tsunamis arrived at the site. The maximum tsunami height impacting the site was estimated to be 46 to 49 feet (14 to 15 meters). This exceeded the design basis tsunami height of 18.7 feet (5.7 meters) and was above the site grade levels of 32.8 feet (10 meters) at units 1-4. All AC power was lost to units 1-4 by 1541 when a tsunami overwhelmed the site and flooded some of the emergency diesel generators and switchgear rooms. The seawater intake structure was severely damaged and was rendered nonfunctional. All DC power was lost on units 1 and 2, while some DC power from batteries remained available on Unit 3. Four of the five emergency diesel generators on units 5 and 6 were inoperable after the tsunami. One air-cooled emergency diesel generator on Unit 6 continued to function and supplied electrical power to Unit 6, and later to Unit 5, to maintain cooling to the reactor and spent fuel pool.

With no core cooling to remove decay heat, core damage may have begun on Unit 1 on the day of the event. Steam-driven injection pumps were used to provide cooling water to the reactors on units 2 and 3, but these pumps eventually stopped working; and all cooling water to the reactors was lost until fire engines were used to restore water injection. As a result of inadequate core cooling, fuel damage also occurred in units 2 and 3. Challenges in venting containments contributed to containment pressures exceeding design pressure, which may have caused containment damage and leakage.

Hydrogen generated from the damaged fuel in the reactors accumulated in the reactor buildings -either during venting operations or from other leaks- and ignited, producing explosions in the Unit 1 and Unit 3 reactor buildings and significantly complicating the response. The hydrogen generated in Unit 3 may have migrated into the Unit 4 reactor building, resulting in a subsequent

explosion and damage. The loss of primary and secondary containment integrity resulted in ground-level releases of radioactive material. Following the explosion in Unit 4 and the abnormal indications on Unit 2 on the fourth day of the event, the site superintendent directed that all nonessential personnel temporarily evacuate, leaving approximately 70 people on site to manage the event.

D.1.3 High Energy Arcing Faults (HEAF) Events

Operating experience from nuclear installations has shown a non-negligible number of reportable events with non-chemical explosions and rapid fires resulting from high energy arcing faults (HEAF) in high voltage equipment such as circuit breakers and switchgears. Such electric arcs have led in some events to partly significant consequences to the environment of these components exceeding typical fire effects. Investigations of this type of events have indicated failures of fire barriers and their elements as well as of fire protection features due to pressure build-up in electric cabinets, transformers and/or compartments.

Due to the high safety significance and importance to nuclear regulators, the Organisation for Economic Co-operation and Development / Nuclear Energy Agency / Committee on the Safety of Nuclear Installations (OECD/NEA/CSNI) initiated in 2009 an international activity on 'High Energy Arcing Faults (HEAF)' to investigate these phenomena in nuclear power plants in more detail as to better understand fire risk at a nuclear power plants. It is believed that this is better accomplished by an international group that can pool international knowledge and research means.

The main objective of the NEA analysis was to examine if HEAF is a common phenomenon and how HEAF develops, in order to extend the existing knowledge of this particular fire phenomenon, and to improve electrical safety standards and to design proper preventive measures.

A 2013 report by the OECD/NEA/CSNI documents this activity, and presents the results of the analyses of the HEAF events in the OECD FIRE Database.

The examination of the OECD FIRE Database indicated a contribution of 48 HEAF-induced fire events out of the total 415 fire events collected in the Database up to mid-2012. Two out of these 48 HEAF events were induced by an earthquake, and happened in Japan in 2009 (event JPN047) and 2011 (event JPN022).

<u>Event 28 – JPN047</u>

On July 26, 2009, the Niigata-Chuetsu-Oki earthquake occurred. The house transformer fire due to arcing fault at a boiling water reactor (BWR) plant followed the earthquake.

Operational mode prior to the fire was 100 % of full power, reactor coolant pressure and temperature were nominal values. The reactor was automatically tripped by high seismic acceleration signal prior to the fire, and was cooled down to the cold-shutdown mode without suffering any effects from the fire.

The fire started at the house transformer that was installed outside and adjacent to the turbine building, and was isolated from the other components by the fire wall.

The ignition mechanism was that the electrical arcing between the bushing and the bus duct had ignited the insulation oil leaked from the transformer to the bus duct. The analysis of the current and voltage records of the generator circuit revealed that the arc discharge was caused by the three-phase short circuit due to the contact of the bushing terminal contactor with the secondary side of the bus duct, which failed due to the large scale seismic motion. The arcing induced the melting of the upper part of the bushing. The residual magnetic field and the generator rotating due to inertia still generated electric power to the transformer. The generator voltage changed from 17.2 kV to 13.2 kV during the arc discharge as recorded. The circuit current induced by the arcing might have been 50 kA approximately, based on the records, and the insulation oil fire was induced by more than 1000 °C arc-discharge.

The fuel involved was insulation oil leaked from the transformer; flash ignition temperature of the insulation oil is higher than 130 °C according to the Japanese Industrial Standard Code. The transformer contained about 17 m^3 of insulation oil during normal operation.

The fire was detected by post-earthquake patrol of plant personnel. The fire was extinguished by chemical hydrate from the regional fire engine.

<u>Event 25 – JPN022</u>

The "Tohoku District – Off the Pacific Ocean Earthquake" occurring on March 11, 2011 at 14:46 h (the same earthquake that affected the Fukushima Daiichi site) caused an arcing fault in two (No. 7 and No. 8) of ten sectors of the non-emergency M/C 6-1A switchgear cabinet at the Onagawa nuclear power plant (a BWR). The arcing fault resulted in a fire affecting all ten sectors within the cabinet. The cabinet was installed in the underground floor of the turbine building.

Prior to the earthquake, the plant was at full power operation, and it was automatically shut down due to the signal of high seismic acceleration at 14:46 h.

This event can be identified as HEAF for the following reasons:

- Arcing started at the high voltage electric component (6.9 kV M/C).
- The energy was released in the form of light and high energy gas.
- Arcing was caused by short circuit and short to ground.
- This arcing fault resulted in a fire but not in missiles.
- Control cables for non-emergency components, such as feedwater pumps, condenser pumps, etc., directly above the cabinet were affected by the heat generated by the fire.
- No emergency components and cables in the room were affected.

The causes of arcing in the non-emergency M/C 6-1A may be the following:

1. The earthquake shook Magne-Blast Breakers (MBBs), which were hung up by buses in the cabinet since MBBs were not fixed to the floor.
2. The shaking of MBBs resulted in damages of insulators and connectors. It resulted in short circuit and short to ground.
3. The short circuit and the short to ground of connectors resulted in arcing. The heat due to the arcing resulted in the fire inside the cabinet.

The fire in M/C 6-1A due to arcing caused a trip of the over-current relay at the upper stream of the startup transformer at 14:55 h. The trip of the over-current relay caused a loss of offsite power in combination with switching over of power supply system and loss of auxiliary transformer due to the earthquake. The emergency buses were supplied by DG-A. After the loss of offsite power, decay heat was removed by SRV and RHR-A/C (suppression chamber cooling mode) being supplied by DG-A.

RHR-A/C were automatically isolated at 15:55 h due to instantaneous under-voltage of emergency bus C supplying to RHR-A/C. The instantaneous under-voltage of emergency bus C was caused by rush current from the emergency bus to auxiliary transformer damaged by the earthquake. The rush current was caused by a short circuit of synchronous detector in the non-emergency M/C 6-1A due to the fire. The short circuit caused spurious current from the non-emergency M/C 6-1A to emergency M/C 6-1C, inadvertently energizing the coil for the breaker from the emergency bus to the auxiliary transformer.

With respect to the fire sequence, the following details are important to be mentioned:

The fire was detected by an optical detector, although the on-site fire brigade could not identify the fire location due to heavy smoke at first. At 15:41 h, the public fire brigade was called. Because of damage of the access ways to the site due to the earthquake and tsunami, the off-site fire brigade was however not able to come.

At 17:15 h, portable CO_2 fire extinguishers were manually used for fire extinguishing efforts in the turbine main oil tank room, the EHC room, etc. after evacuation of people from the turbine building without identification of the fire location. At 18:03 h, the on-site fire brigade started to access the turbine building BF1 with an on-spot smoke remover. The fire location and fire source could be identified at that time. Fire fighting started at 22:56 h with seven cylinders of dry chemical extinguishers.

At 22:55 h the fire was declared to be successfully extinguished. The fire duration was approx. seven hours.

The consequences of the seismically induced HEAF with consequential fire were the following:

- In the cabinet M/C 6-1A, the sector where the fire started and its adjacent one were completely damaged by arcing and fire.
- The further eight of ten sectors in M/C 6-1A were only partially damaged (upper portions of the sectors).
- High energy gas was released in the sector where the fire started, which could have been generated by the electric arc and fire and propagated to other sectors through the penetration of the control cable bundle (control duct) located in the upper area of the cabinet.
- Jackets and insulators of the cables above M/C 6-1A seem to be affected by the fire.
- Other components and/or cables except those just above M/C 6-1A were not affected by the fire.
- There were no missiles.
- The door of the cabinet sector, where the fire started, opened when the on-site fire brigade accessed the room. It is unknown whether the door opening is due to the earthquake or the pressurization of the cabinet.

D.2 Reports and papers related to seismic-induced fires and floods

A survey of the literature related to seismic-induced fires and floods was conducted. The following sources of reports or papers were searched:

- Nuclear Regulatory Commission (NRC)
- Electric Power Research Institute (EPRI)
- International Atomic Energy Agency (IAEA)
- Canadian Nuclear Safety Commission's (CNSC)
- Los Alamos National Laboratory
- Papers in conferences or journals

D.2.1 Nuclear Regulatory Commission (NRC)

The NRC has published many NUREG reports, Commission Papers (SECYs), and other documents related to seismic-induced fires and floods. The publications that seem most relevant to these hazards are summarized below.

D.2.1.1 NUREG Reports

NUREG-1407

NUREG-1407, "Procedural and Submittal Guidance for the Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities", addresses seismically-induced fires and floods in the following subsections:

6.3.2 Coordination Among External Events Programs

C.2.1 Seismic PRA Methodology

D.2 Detailed Response to Public Comments and Questions

Text from these subsections is reproduced next.

6.3.2 Coordination Among External Events Programs (page 21)

The issue of integration between external events primarily involves interactions between seismic events and fires and seismic events and floods. Seismically induced fires and floods are to be addressed as part of the IPEEE. The effects of seismically induced fires and the impact of inadvertent actuation of fire protection systems on safety systems should be addressed. The effects of seismically induced external flooding and internal flooding on plant safety should be included. The scope of the evaluation of seismically induced floods, in addition to that of the external sources of water (e.g., tanks, upstream dams), should include the evaluation of some internal flooding consistent with the discussion in Appendix I of EPRI NP-6041. The coordination between the seismic and the fire or flood analysts should be based on the following:

1. The seismic analysts should generally search for and identify the initiating events (certain specific seismically initiated failures of equipment or structures) that can cause fires or floods, and

2. The seismic and fire or flood analysts should also discuss other concurrent seismically induced failures or possible effects on human actions and then, proceed to complete the rest of the IPEEE analysis.

The coordination should include a meeting, prior to seismic walkdown, in which the fire and flood analysts discuss the key issues, how the analysis will be done, and what to look for. The fire or flood analyst may need to participate in parts of the seismic walkdown or revisit the areas identified during the seismic walkdown to grasp the issues from the seismic-capacity point of view.

C.2.1 Seismic PRA Methodology (page C-2)

The following information on the seismic IPEEE should be documented and submitted to the NRC:

1. A description of the methodology and key assumptions used in performing the seismic IPEEE.

2. The hazard curve(s) (or table of hazard values) used and the associated spectral shape used in the analysis. Also, if an upper bound cutoff to ground motion of less than 1.5g peak ground acceleration is assumed, the results of sensitivity studies to determine whether the cutoff affected the overall results and the delineation and ranking of seismic sequences.

3. A summary of the walkdown findings and a concise description of the walkdown team and the procedures used.

4. All functional/systemic seismic event trees as well as data (including origin and method of analysis). Address to what extent the recommended enhancements have been incorporated in the IPEEE. A description of how nonseismic failures, human actions, dependencies, relay chatter, soil liquefaction, and seismically induced floods/fires are accounted for. Also, a list of important nonseismic failures with a rationale for the assumed failure rate given a seismic event…

D.2 Detailed Response to Public Comments and Questions

6. Internal Fires (page D-9)

6.2 What are the procedurally directed walk-downs in terms of addressing seismic-fire interaction. Do they pertain to walk-downs for the fire or walkdowns for the seismic IPEEE. (Ref. D.16, p. 130)

SR:[16] The procedurally directed walk-downs associated with internal fires vulnerability evaluation can be planned as part of the seismic walk-downs that would specifically look for the seismic-induced fire vulnerability issues. The idea is to first identify those areas that could be vulnerable so that they can be brought into focus during the walkdown.

[16] SR means NRC staff responses.

For example, if a plant didn't have its diesel fuel tank strapped down properly one could postulate a large fuel source for fire as a result of a seismic event. Other similar seismic/fire interactions were summarized in Section 7 of NUREG/CR-5088.

7. Seismic Events (page D-10)

Page D-11:

7.6 Seismically induced floods are mentioned for the first time in draft NUREG-1407, Section 6.3.2 and not in Generic Letter 88-20 Supplement 4. We understand that the scope of review for seismically induced external flooding is limited to a review of external sources of water (e.g., tanks, upstream dams, or other significant structures) and not internal water sources such as piping. This should be clearly stated in Generic Letter 88-20, Supplement 4, in order to avoid possible confusion in future interpretations. (Ref. D.1)

SR: The scope of the seismically induced floods, in addition to the external sources, includes the evaluation of some internal flooding consistent with the discussion in Appendix I, Check Lists and Walkdown Data Sheets, of EPRI NP-6041. Section 6.3.2 will be modified to include reference to EPRI NP-6041. In addition, the generic letter has been modified.

Page D-17:

7.28 Does Section 6.3.2 imply that seismic event success paths must also be simultaneously protected from postulated fire/floods? The sentence "The effects of seismically induced external flooding and internal flooding on plant safety should be included" is not clear. (Ref. D.5)

SR: With regard to floods, see the comment and the staff response to item 7.6 of this section.

With regard to fire, see the staff response to item 6.2 of this section.

NUREG-1742

NUREG-1742, "Perspectives Gained from the IPEEE Program", addresses seismically-induced fires and floods mainly in the following subsections of Volume 1:

2.3.1.7 Seismic-Fire and Seismic-Flood Evaluations

5.4.8.2.3 Seismically Induced Fires

5.4.8.2.8 Seismically Induced Flooding

Volume 2 of NUREG-1742 also contains Table 2.12, "Seismic-fire interaction and seismic-flood interaction" in the following chapter:

2. SEISMIC TABLES

Text from these parts of NUREG-1742 is reproduced next.

<u>2.3.1.7 Seismic-Fire and Seismic-Flood Evaluations</u> (Vol. 1, page 2-25)

All licensees qualitatively examined seismic-fire interaction issues as part of their assessment of fire risk. To varying degrees, such examinations have included the potential for, and effects of, seismically initiated fires, seismic actuation of fire suppression systems, and degradation of fire suppression systems from seismic events. Some licensees undertook quantitative assessments of component capacities related to seismic-fire and seismic-flood interactions. A few licensees performed some form of SPRA study for seismic-fire and/or seismic-flood initiating events and documented it in their submittal.

In most of the submittals, licensees included seismic-fire and seismic-flood considerations within the scope of their overall seismic walkdown effort. The seismically induced fire interactions were generally addressed by first identifying combustion sources (e.g., hydrogen lines, oil tanks) and then performing walkdowns to evaluate whether these sources are both significant hazards and seismically vulnerable. Some of the seismic-fire interaction evaluations have led to a number of fixes, such as restraining gas cylinders, strengthening anchorages for fuel oil tanks, and, where feasible, relocating combustion sources away from safety equipment. The most consistent strong points of these evaluations appear to be the treatment of inadvertent actuation of fire suppression systems and the identification of potential interaction concerns involving safety equipment. However, the scope, and detail of efforts to address seismic-fire and seismic-flood issues have varied significantly among the IPEEE submittals. Some licensees did not include any seismic-fire or seismic-flood evaluation in their submittal, but provided some information on these topics in RAI responses. In most cases, licensees have limited their seismic-fire and seismic-flood evaluations exclusively to assessing direct impacts on safe shutdown equipment, and some submittals did not consider the potential for seismically induced loss of fire suppression systems.

Some licensees have sought to include all relevant plant areas and equipment in their evaluations of the potential and effects of seismic-fire and seismic-flood events. Such relevant items include, for instance, fire suppression system components and non-safety piping and tanks, which may not be part of the seismic plant model or safe shutdown equipment list, but are nonetheless important and/or may have indirect effects on safety equipment.

In many of the IPEEE submittals, the seismic-fire and/or seismic-flood interaction evaluations revealed concerns and, in a number of instances, resulted in significant plant improvements. Some of the relevant improvements include strengthening component anchorages, replacing vulnerable (e.g., mercury) relays and switches, restraining gas cylinders, waterproofing, replacing sight glass tubes, and implementing procedures to properly secure transient fire-protection equipment.

In one instance, the licensee evaluated the potential for seismically induced toxic chemical release, as part of its seismic-interactions walkdown. As a result, the licensee identified a plant-specific improvement related to strengthening the anchorage of an ammonia storage tank.

Information on this issue for individual plants can be found in Table 2.12 of Volume 2 of this report.

<u>2. SEISMIC TABLES</u> (Vol. 2, page 2-1)

…Other potential effects of earthquakes include seismically induced fires or floods. The results of the licensees' assessments of these two possibilities are shown in Table 2.12…

5.4.8.2.3 Seismically Induced Fires (Vol. 1, pages 5-26 and 5-27)

All of the IPEEE submittals reported that the licensees qualitatively examined seismically induced fire interaction issues as part of the treatment of Sandia fire risk scoping study issues. A few licensees performed a PRA study for seismically induced fire-initiating events; albeit the level of detail varied from a simplistic probabilistic analysis to inclusion in their plant's seismic or fire PRA.

In most of the submittals, licensees included seismically induced fire considerations within the scope of their overall seismic walkdown. The level of effort, scope, and detail directed toward addressing seismically induced fire issues varied significantly among the IPEEE submittals. One licensee (LaSalle) did not discuss seismically induced fire evaluations in their IPEEE submittal. In most other cases, licensees limited their seismically induced fire evaluations exclusively to assessing direct impacts on safe shutdown equipment.

Some licensees sought to include all relevant plant areas and equipment in their evaluations of the potential and effects of seismically induced fire events. Such relevant items include, for example, non-safety-related piping and tanks containing flammable materials, which may not be part of the seismic plant model or safe shutdown equipment list, but may have indirect effects on safety-related equipment.

In some of the IPEEE submittals, the evaluations of the seismically induced fire interaction resulted in plant improvements. An example of the relevant improvements is the installation of restraints for gas cylinders.

Table 2.12: Seismic-fire interaction and seismic-flood interaction

Plant	Evaluation approach	Seismic-fire observations/outliers	Seismic-flood observations/outliers	Related plant improvements
Arkansas Nuclear One 1	Walkdown for seismic- fire and seismic-flood concerns.	Potential safety concerns with hydrogen pipe rupture (in the turbine generator and the makeup tank) and flammable liquids identified and dismissed.	Potential failure of dams evaluated and found adequately considered in the development of the Probable Maximum Flood, per the Standard Review Plan (SRP).	None.
Arkansas Nuclear One 2	Walkdown for seismic-fire and seismic-flood concerns.	Potential safety concerns with hydrogen pipe rupture (in turbine generator and volume control tank) and flammable liquids identified and dismissed.	Potential failure of dams evaluated and found adequately considered in the development of the Probable Maximum Flood, per the SRP.	None.
Beaver Valley 1	Seismic walkdown and frequency consideration.	Seismically induced fires screened out based on comparison with the frequency of initiation of internal fires. Fire suppression equipment not found to be a seismic concern by walkdown.	The failure of the Conemaugh Dam, considered the worst case scenario was evaluated and found not to be a problem for the site.	None.
Beaver Valley 2	Seismic walkdown and frequency consideration.	Seismically induced fires screened out based on comparison of equipment HCLPF with the frequency of initiation of internal fires. Fire suppression equipment not found to be a seismic concern by walkdown.	The failure of the Conemaugh Dam, considered the worst case scenario was evaluated and found not to be a problem for the site.	None.

Table 2.12: Seismic-fire interaction and seismic-flood interaction				
Plant	Evaluation approach	Seismic-fire observations/outliers	Seismic-flood observations/outliers	Related plant improvements
Braidwood 1&2	Walkdown for seismic-fire and seismic-flood concerns.	Potential issues with respect to seismic-induced fire hazards, such as gas bottles with insufficient constraints and locations of flammable storage cabinets, were identified and resolved except for the issue related to "unanchored hydrogen local control panel."	No concerns identified.	None.
Browns Ferry 2&3	Walkdowns to identify sources of combustion and possible interactions	No concerns identified.	Potential outliers for seismic-induced spray and flooding hazards from non-Class I systems and components were identified and resolved (which principally included maintenance of deficient hardware and support modifications or new installations).	None for IPEEE.
Brunswick 1&2	Walkdown for seismic-fire and seismic-flood concerns.	Potential interactions involving water piping for the fire protection system, as well as mobile/cart	Potential concerns with overhead water lines and CST were ultimately screened out.	Procedure to secure CO_2 cylinders when not in use; the submittal also cites mounted CO2 cylinders, several past improvements made to enhance fire protection system seismic capability.

Table 2.12: Seismic-fire interaction and seismic-flood interaction

Plant	Evaluation approach	Seismic-fire observations/outliers	Seismic-flood observations/outliers	Related plant improvements
Byron 1&2	Walkdown for seismic-fire and seismic-flood concerns.	No significant concerns. Potential issues were identified and resolved except for the following issues: overturning of storage cabinets for oil, grease, and lubricants; interaction between hydrogen piping and a clothing bin on wheels; and poorly restrained gas bottles (resolution not discussed).	No concerns identified.	None.
Callaway	Walkdown for seismic-fire and seismic-flood concerns.	No concerns identified.	Relay chatter effects on fire pumps, and sprinkler head breakage, could lead to localized flooding; but they were determined not to affect SSEL equipment.	None.
Calvert Cliffs 1&2	Walkdown for seismic-flood concerns. Both fire and flood initiators are screened at 0.3g, with some fire-inducing components also screened at 0.5g.	No concerns identified.	No concerns identified.	None.
Catawba 1&2	Walkdown for seismic-fire and seismic-flood concerns.	None.	None.	None.

Table 2.12: Seismic-fire interaction and seismic-flood interaction				
Plant	Evaluation approach	Seismic-fire observations/outliers	Seismic-flood observations/outliers	Related plant improvements
Clinton	Walkdown for seismic-fire and seismic-flood concerns.	No risks were found.	No risks were found.	None.
Columbia Generating[17]	Walkdown for seismic-fire concerns.	No unusual or unique vulnerabilities. However, some problems were identified and addressed (e.g., inadequate support for the batteries of the diesel driven fire pumps and the possibility of inadvertent Halon actuation).	Seismic-induced floods are screened out in the submittal. The external floods are screened out based on the worst case Grand Coulee Dam failure. The internal floods are screened out based on comparison of the effects and frequencies of the loss of offsite power scenarios, or based upon the ruggedness of the piping.	Actions were taken to address the support problem for the batteries of the diesel driven fire pumps.
Comanche Peak 1&2	Walkdown for seismic-fire and seismic-flood concerns.	None.	None.	None.
Cooper	Walkdown for seismic-fire and seismic-flood concerns.	Four "seismic vulnerabilities" were identified in the fire suppression systems (two electric driven pumps, the diesel driven pump, and the water storage tanks) and included in the IPEEE Issue Resolution Plan; however, no specific corrective action was identified.	Seismic-induced failures of upstream dams were addressed. No unacceptable conditions concerning seismically-induced flooding were noted.	None.

[17] Formerly known as Washington Nuclear Project Number 2.

Table 2.12: Seismic-fire interaction and seismic-flood interaction

Plant	Evaluation approach	Seismic-fire observations/outliers	Seismic-flood observations/outliers	Related plant improvements
Crystal River 3	Not addressed. The licensee states that the GL 88-20, Supplement 4, does not require that a seismic/fire interaction review be performed for a "reduced-scope" plant like CR-3.	Not addressed in IPEEE.	Not addressed in IPEEE.	None.
D.C. Cook 1&2	Walkdown for seismic-fire and seismic-flood concerns.	Potential breakage of glass fuses in pilot lines; subsequently screened out because no potential was identified for sprinkler head breaks.	Same as for seismic-fire.	None.
Davis-Besse	Walkdown for seismic-fire and seismic-flood concerns.	Two small flammable compressed gas bottles in the auxiliary building were found to have inadequate anchorage.	No concerns identified.	The anchorage problem of two small flammable compressed gas bottles in the auxiliary building was being resolved.
Diablo Canyon 1&2	Walkdown for seismic-fire and seismic-flood concerns.	None.	None.	Addressed earlier in LTSP and Seismically Induced Systems Interaction Program (SISIP).
Dresden 2&3	Walkdown for seismic-fire and seismic-flood concerns.	Potential issues with respect to seismic-induced fire hazards identified and resolved (e.g., the effect of the failure of the hydrogen seal oil panel and hydrogen monitors on the integrity of the hydrogen lines).	Some concerns were identified and resolved (e.g., tanks behind switchgear).	Resolutions to the potential problems identified in the evaluation are presented in Tables3.3 and 3.4 of the submittal.

Table 2.12: Seismic-fire interaction and seismic-flood interaction

Plant	Evaluation approach	Seismic-fire observations/outliers	Seismic-flood observations/outliers	Related plant improvements
Duane Arnold	Walkdown screening evaluations performed in conjunction with the IPEEE SSEL equipment walkdown.	Three additional outliers were identified for equipment having nearby gas storage bottles that were not adequately restrained for seismic loadings.	Two air handlers in the HPCI room were identified as flood/spray outliers because nearby piping could potentially impact fire protection sprinkler piping and break off the sprinkler heads, whose spray could damage the air handler motors.	The air handler concern was resolved by analysis which showed adequate clearance between sprinkler heads and other piping, and the bottle concern was resolved by providing adequate restraint or removing the bottles.
Farley 1&2	As part of the seismic capacity walkdown, all potential internal flooding sources, mainly piping and tanks, were evaluated by the SRT in areas containing SSEL equipment.	No seismic-fire interaction issues exist at a seismic capacity of at least SSE level.	No flooding concerns were identified because piping has a high seismic capacity, and all tanks were well anchored.	None.
Fermi 2	Walkdown for seismic-fire and seismic-flood concerns.	No concerns identified.	No concerns identified.	None.

Table 2.12: Seismic-fire interaction and seismic-flood interaction

Plant	Evaluation approach	Seismic-fire observations/outliers	Seismic-flood observations/outliers	Related plant improvements
FitzPatrick	Walkdown for seismic-fire and seismic-flood concerns.	A vulnerability to fire or explosion as a result of the seismic-induced failure of the hydrogen line in the turbine building was identified.	No concerns identified.	Procedure AOP-14, "Earthquake," was modified. A note was added to AOP-14 stating that the hydrogen supply piping in the turbine building is susceptible to failure during seismic events and that the piping can be isolated by closing 89A-H2HAS-1, the hydrogen supply isolation valve.
Fort Calhoun	Walkdown for seismic-fire and seismic-flood concerns.	Various concerns identified in turbine building; in the intake building, a fuel oil tank supplying fire water pumps has low capacity (HCLPF of about 0.05g).	Low seismic capacity of shutdown heat exchangers; flooding of junction boxes in Room 23; external flooding due to seismic dam break.	Fuel oil tank to be adequately anchored; a sight glass tube is to be replaced; anchorage of storage cabinet; additional anchor bolts on shutdown heat exchangers; waterproofing of junction boxes; external flooding addressed by severe accident management guidance.

Table 2.12: Seismic-fire interaction and seismic-flood interaction

Plant	Evaluation approach	Seismic-fire observations/outliers	Seismic-flood observations/outliers	Related plant improvements
Ginna	Issues examined by the SRT during the seismic capability walkdown.	Several issues were identified. They are related to the lack of anchorage for the house heating boiler (which could shift and damage the attached natural gas line) and the failure of block walls (which are used as fire barriers throughout the plant). The two reactor coolant pump oil collecting tanks in the containment basement were not reviewed during the seismic walkdown because the containment was inaccessible.	A concern was system failure due to seismically induced flooding from failure of the Reactor Makeup Water tank and the Monitor tank. These tanks will be considered outliers and will be examined to determine the correct course of action.	The seismic-fire issues were resolved as a part of Ginna's IPEEE fire analysis by either design evaluations or design changes.
Grand Gulf 1	Included in the SSEL for the IPEEE.	No concerns identified.	No concerns identified.	None.
H.B. Robinson 2	Walkdown for seismic-fire and seismic-flood concerns.	Some issues pertaining to panel interactions and poorly anchored electrical cabinets were identified.	None reported.	None reported.
Haddam Neck	Walkdown for seismic-fire and seismic-flood concerns; SPRA modeling of flooding due to dam failure.	Eight vulnerabilities or risk outliers were identified.	None reported.	Issues have been resolved or proposed for resolution (See Table 7.1-1 of IPEEE submittal).
Hatch 1&2	Issues reviewed as a part of the seismic walkdown.	No concerns identified.	No concerns identified.	None.

Table 2.12: Seismic-fire interaction and seismic-flood interaction

Plant	Evaluation approach	Seismic-fire observations/outliers	Seismic-flood observations/outliers	Related plant improvements
Hope Creek	Walkdown for seismic-fire concerns and analysis.	The only seismic capacity concerns are: (1) FPS water pump house - assumed to fail, and (2) FPS water tanks - no credit taken after a seismic event (median acceleration capacity of 0.73g, HCLPF of 0.26g).	There is no discussion of seismic-induced flooding concerns.	None.
Indian Point 2	Walkdown for seismic-fire and seismic-flood concerns; no modeling of seismically induced fire or flood sequences in seismic PRA.	Questionable anchorage of the reactor coolant pump lube oil collection tank; subsequently determined to be adequate. Concern with hydrogen bottles stored near alternate shutdown panel; no action taken because alternate shutdown panel is not credited in the seismic PRA.	None reported.	None.
Indian Point 3	Walkdown for seismic-fire and seismic-flood concerns.	The seismic "vulnerabilities" identified are: (1) the CO_2 system whose rupture poses little risk; (2) the low seismic fragility level of the two 350,000-gallon fire water tanks; (3) the availability of the FPS pumps which are housed in the FPS pump house with masonry block walls; and (4) the marginal lateral support capacity of the fuel tank for the diesel pump.	No concerns identified.	No discussion is provided in the submittal on improvements for the identified seismic-fire "vulnerabilities."

Table 2.12: Seismic-fire interaction and seismic-flood interaction				
Plant	Evaluation approach	Seismic-fire observations/outliers	Seismic-flood observations/outliers	Related plant improvements
Kewaunee	Walkdown for seismic-fire and seismic-flood concerns.	Potential damage to fire water capability and sprinklers/lines; mercoid fire pump jockey switches and Cardox pressure switches.	Same as for seismic- fire.	None.
La Salle 1&2	None documented.	None.	None.	None.
Limerick 1&2	Walkdown for seismic-fire and seismic-flood concerns.	Sight glass tubes on lube oil make-up tanks do not have isolation valves; mercoid switches in two fire protection systems. These concerns were determined not to be significant.	No additional.	None.
McGuire 1&2	Walkdown for seismic-fire and seismic-flood concerns.	None.	None.	None.
Millstone 2	Walkdown for seismic-fire and seismic-flood concerns.	Identified three issues: adequacy of the seismic capacity of the Unit 1 diesel fire pump fuel tank, seismic capacity of a long run of the fire header system piping, and the block wall construction of the fire pump house.	No concerns identified.	Resolutions of seismic-fire outliers include additional evaluation to ensure seismic adequacy or hardware modification.
Millstone 3	None documented.	None.	None.	None.

Table 2.12: Seismic-fire interaction and seismic-flood interaction

Plant	Evaluation approach	Seismic-fire observations/outliers	Seismic-flood observations/outliers	Related plant improvements
Monticello	Walkdown for seismic-fire and seismic-flood concerns.	Sliding of turbine lube oil tank located in MCC-133/feedwater pump area, was identified as a potential concern; but based on a qualitative assessment, the licensee judged that additional analysis was unwarranted.	Several non-safety tanks were found to have low seismic resistance, but these were determined to be isolated, or far from, success path equipment.	None.
Nine Mile Point 1	Walkdown for seismic-fire and seismic-flood concerns.	No concerns identified.	No concerns identified.	None.
Nine Mile Point 2	Walkdown for seismic-fire and seismic-flood concerns.	None.	None.	None.
North Anna 1&2	Walkdown for seismic-fire and seismic-flood concerns.	A potential issue is seismic-induced fires from the lube oil heat exchanger, hydrogen piping, and hydrogen bottles.	Two issues identified: (1) inadequate support for feedwater heaters in turbine building, and (2) the flooding potential for the casing cooling tanks, located next to the auxiliary feedwater pump house.	Issues to be resolved by the end of the NAPS Unit 1 refueling outage currently scheduled to commence in April 2000.
Oconee 1,2,&3	Walkdown for seismic-fire and seismic-flood concerns. More detailed analysis for items not screened by walkdown.	Issues identified in seismic-fire review resulted in procedural and physical improvements.	The fault tree models used in the seismic analysis include the effect of both internal and external flooding sources.	Possible improvements, such as replacement of sprinkler heads, are discussed in Section 4.9.

Table 2.12: Seismic-fire interaction and seismic-flood interaction

Plant	Evaluation approach	Seismic-fire observations/outliers	Seismic-flood observations/outliers	Related plant improvements
Oyster Creek	The seismic-fire-flood interactions were not directly considered in the seismic PRA, but were qualitatively screened in the fire analysis section, with some ambiguity as to which earthquake levels were included in the walkdown and the evaluation.	The conclusion is that no sources of seismic induced fire initiation at "reasonable levels of earthquake beyond the design basis" were identified. Words such as "nominal" earthquake appear elsewhere in this section. It is not clear whether the licensee considered the same ground acceleration levels as in the seismic study for this evaluation. It appears that this was mostly a qualitative evaluation. In the area of inadvertent fire suppression actuation, it is noted that electrical equipment is usually well protected by shields or is sealed.	No discussion in the submittal is provided regarding any seismic-flood interactions, whether internal or external.	None.
Palisades	Walkdown and SPRA modeling of seismic-fire and seismic-flood concerns.	Hydrogen piping through turbine building is not seismically designed and passes through block walls and cable trays which pose a rupture hazard; there exist a number of unanchored flammable liquid storage cabinets throughout the turbine building.	Seismic-induced flooding in the turbine building and screenhouse were identified for SPRA modeling; circulating water pipe failures in screenhouses were later screened out.	None.

Table 2.12: Seismic-fire interaction and seismic-flood interaction

Plant	Evaluation approach	Seismic-fire observations/outliers	Seismic-flood observations/outliers	Related plant improvements
Palo Verde 1,2,&3	Seismically-induced fires/floods addressed in the plant walkdown	No concerns identified.	One flooding concern was found and this was judged not to be a problem by the seismic review team.	None.
Peach Bottom 2&3	Walkdown for seismic-fire and seismic-flood concerns.	Mercoid switches encountered in fire protection systems. Unanchored CO_2 tanks in Cardox room of the DG building. No spacers between batteries, and lack of end rails, on CO_2 battery racks.	No problems encountered other than potential inadvertent actuation of fire protection systems due to spurious behavior of mercoid switches.	- Replace four mercoid switches in fire water manual pull stations with non-mercoid switches. - Establish procedures to mitigate spurious relay operation in Cardox panels. - Add restraints to Cardox tank protecting diesel generator areas. - Evaluate the potential and effects of CO2 release in the turbine building, due to failure of Cardox tanks.
Perry 1	Walkdown for seismic-flooding, seismic-fire concerns.	The one concern is the seismic capacity of the FPS diesel driven pump's fuel oil tank located in the ESW pumphouse was identified and dismissed by HCLPF evaluation.	No concerns identified.	None.

Table 2.12: Seismic-fire interaction and seismic-flood interaction

Plant	Evaluation approach	Seismic-fire observations/outliers	Seismic-flood observations/outliers	Related plant improvements
Pilgrim 1	Walkdown for seismic-fire and seismic-flood concerns.	Truck lock in turbine building contains hydrogen and lube oil piping runs, and a hydrogen control station; switchgear room "B" also contains lengths of piping which contain lube oil.	Interaction potential between CST 105B and cryogenic nitrogen storage tank, modeled as leading to loss of CST as water source for HPCI and RCIC.	None, but the licensee stated that consideration should be given to isolation of combustible sources following an earthquake.
Point Beach 1&2	Walkdown for seismic-fire and seismic-flood concerns.	None.	RWST could fail and disable RHR pumps.	None.
Prairie Island	Seismic walkdown.	No concerns identified.	No concerns identified.	None.
Quad Cities 1&2	Walkdown for seismic-fire and seismic-flood concerns.	Several concerns pertaining to seismically-induced fires, inadvertent seismic actuation of fire suppression systems, and seismically induced failure of fire protection capability were noted.	Fire piping risers in the cable spreading room may break via interaction with adjacent multi-tier cable trays. Piping attached to cubicle coolers (located in corners of the reactor building) was observed to have inadequate flexibility to accommodate movement of the rod-hung units.	Six mercoid relays were replaced in the Cardox system protecting the emergency diesel generators; oxygen cylinders in the common turbine building mezzanine floor are now chained top and bottom to a newly installed cylinder rack. Cubicle coolers are being addressed under USI A-46, and HCLPF capacities for these components have been determined.

Table 2.12: Seismic-fire interaction and seismic-flood interaction

Plant	Evaluation approach	Seismic-fire observations/outliers	Seismic-flood observations/outliers	Related plant improvements
River Bend	Walkdown for seismic-fire and seismic-flood concerns.	No vulnerabilities were reported.	No vulnerabilities were identified.	None.
Salem 1&2	Walkdown for seismic-fire and seismic-flood concerns.	Several concerns were identified and dismissed after additional mitigating considerations.	No concerns identified. However, there was no discussion of any external flooding by river water, etc., caused by seismic events.	None.
San Onofre 2&3	Walkdown for seismic-fire and seismic-flood concerns; detailed qualitative evaluation	No concerns identified.	As a potential flooding source, CCW seals were not screened out, and were included in the core damage model. The licensee concluded that there is no significant risk of core damage due to seismically induced flooding.	The licensee's evaluation also examined the potential for seismically induced toxic material releases, and identified a plant improvement to the anchorage of an ammonia storage tank.
Seabrook	Walkdown for seismic-fire and seismic-flood concerns. A seismic-induced flooding analysis was conducted in 1991 as part of the update of the seismic PRA.	No concerns identified.	No seismically-induced flooding scenarios were identified that would have the potential to fail other risk-important equipment or systems.	None.

Table 2.12: Seismic-fire interaction and seismic-flood interaction

Plant	Evaluation approach	Seismic-fire observations/outliers	Seismic-flood observations/outliers	Related plant improvements
Sequoyah 1&2	Walkdown for seismic-fire and seismic-flood concerns.	Potential of four light transformers in the auxiliary building to impact SSEL-related cables. (Transformers were subsequently assessed as having an HCLPF capacity of 0.37g.)	Potential for sprinkler head breakage, but not in the vicinity of SSEL equipment.	None.
Shearon Harris 1	Walkdown for seismic-fire and seismic-flood concerns.	No risks were found.	No issues were identified.	None.
South Texas Project 1&2	None documented.	None.	None.	None.
St. Lucie 1&2	Documentation review; no discussion of a seismic-fire walkdown.	None.	None.	None.
Summer	Walkdown for seismic-fire and seismic-flood concerns.	Identified some minor concerns, which were either resolved by evaluation (e.g., no impact on SSEL equipment) or by simple corrective actions (e.g., better housekeeping with regard to unsecured flammable gas bottles). Seismic actuation of fire suppression systems and seismic degradation of fire suppression systems were not evaluated in IPEEE.	No concerns were identified for seismically-induced external flooding. Although internal seismic-induced flooding hazard was not specifically discussed, it was considered adequately addressed by the original design basis of the plant and the individual plant examination program.	None.

Table 2.12: Seismic-fire interaction and seismic-flood interaction

Plant	Evaluation approach	Seismic-fire observations/outliers	Seismic-flood observations/outliers	Related plant improvements
Surry 1&2	Walkdown for seismic-fire and seismic-flood concerns and PRA modeling of seismic-induced fire concerns.	Some concerns identified and dismissed after further evaluation. The potential fire arising from a concern of anchorage of lube oil tanks in the turbine building, which may lead to the loss of plant service water, was modeled in the seismic event tree.	Some concerns were identified and dismissed after further evaluation. Some tanks in the turbine building were identified which could slide causing a severance of connections. The concern was dismissed because the resulting flooding scenario would be enveloped by the internal flooding analysis. The question of whether such scenarios which could lead to a large conditional core damage probability should be modeled above the RLE is not addressed.	None.
Susquehanna 1&2	Walkdown for seismic-fire and seismic-flood concerns.	Fire pumps in non-seismically-designed structure; CO2 supply tank is not seismically anchored; batteries for fire pumps do not have spacers; unanchored small electrical cabinets.	Non-seismically-designed fire water system. The submittal notes that the potential for inadvertent actuation of fire water system is low.	None.
TMI 1	Walkdown for seismic-fire and seismic-flood concerns.	No significant concerns identified. Some concerns regarding the availability of the fire protection system following a seismic event were identified.	Potential failure of the piping and heat exchangers in the heat exchanger vault area was identified and was dismissed because the walkdown team determined that the area annunciation was adequate to allow the plant operators to respond long before flooding became a concern.	None.

Table 2.12: Seismic-fire interaction and seismic-flood interaction

Plant	Evaluation approach	Seismic-fire observations/outliers	Seismic-flood observations/outliers	Related plant improvements
Turkey Point 3&4	Documentation review; no discussion of a seismic-fire walkdown.	None.	None.	None.
Vermont Yankee	Walkdown for seismic-fire and seismic-flood concerns.	Identified a few "improvement opportunities" related to seismic resistance of the H_2 piping in the turbine building, the lack of positive attachment between the diesel-driven fire pump fuel tank and its supports, the lack of anchorage of Buses 1 and 2 to the structure, and the support of the fire system northwest standpipe in the reactor building.	No concerns identified.	Modification to locally reroute the fuel line tubing for the diesel fire pump fuel tank; Improvement to enhance the support of the fire system standpipe.
Vogtle 1&2	Walkdown for seismic-fire and seismic-flood concerns.	No concerns identified.	No concerns identified.	None.

Table 2.12: Seismic-fire interaction and seismic-flood interaction

Plant	Evaluation approach	Seismic-fire observations/outliers	Seismic-flood observations/outliers	Related plant improvements
Waterford 3	Walkdown screening evaluations were performed in conjunction with the IPEEE SSEL walkdown. Potential seismic induced fire/flood sources were identified. Verification walkdowns were performed by the SRT.	As a result of the seismic-induced fire walkdown, no vulnerabilities were identified.	As a result of the seismic-induced flood walkdown, no vulnerabilities were identified.	None.
Watts Bar 1	Walkdown for seismic-induced flooding and seismic-induced fire issues.	No safety issues were identified.	The submittal did not contain much discussion on the seismically induced flooding issues, except the mention that the potential for seismic-induced floods was evaluated by the SRT as a part of walkdown procedures.	None.
Wolf Creek	Addressed as part of the SSEL walkdown; no walkdown was performed to evaluate seismic-fire or seismic-flooding effects outside the direct influence on SSEL equipment.	None identified.	None identified.	None.

5.4.8.2.8 Seismically Induced Flooding (Vol. 1, page 5-28)

Some licensees undertook quantitative assessments of components' seismic capacities related to seismically induced flooding interactions. A few licensees performed a PRA study for seismically induced flooding events, albeit the level of detail varied from simplistic probabilistic analysis to inclusion in their plant's seismic PRA.

In most of the submittals, licensees included seismically induced flooding considerations within the scope of their overall seismic walkdown. However, the level of effort, scope, and detail directed toward addressing seismically induced flooding issues varied significantly among the IPEEE submittals. All but six of the licensees provided adequate information to verify this issue. Of the remaining six submittals, five did not provide any discussion of evaluations related to seismically induced flooding in their IPEEE submittal, and one licensee did not provide adequate information to completely verify this issue. In most other cases, licensees limited their seismically induced flooding evaluations exclusively to assessing direct impacts on safe shutdown equipment.

Some licensees sought to include all relevant plant areas and equipment in their evaluations of the potential for and effects of seismically induced flooding events. Such relevant items include, for example, non-safety-related piping and tanks that may not be part of the seismic plant model or safe-shutdown equipment list, but may nonetheless be important or may have indirect effects on safety equipment.

In some of the IPEEE submittals, the evaluations of seismically induced flood interaction resulted in plant improvements. Some of the relevant improvements include adding seals to waterproof electrical cabinets and implementing enhanced drain inspection procedures. Evaluations of external flooding (see Chapter 4) also addressed this sub-issue.

NUREG/CR-5042

NUREG/CR-5042 [1987], “Evaluation of External Hazards to Nuclear Power Plants in the United States,” documents a study of the risk of core damage to nuclear power plants in the United States caused by external floods, high winds/tornadoes, internal fires, and transportation accidents. A first supplement [1988] to this report examined the seismic hazard. A second supplement [1989] considered other externally initiated hazards not covered by the previous two reports. “Other external events” were divided into two categories of events; the first one is human-related events (e.g., accidents from nearby industrial/military facilities), and the second one is natural events (e.g., severe temperature transients). For these studies, the broad objective was to gain an understanding, for existing U.S. light water reactor (LWR) power plants, of whether or not these external initiators are major potential accident initiators that may pose a threat of severe reactor core damage or of a large radioactive release to the environment from the reactor core.

The first supplement [1988] briefly discusses seismically induced fires and floods in Section 3.5, “Insight from Seismic Probabilistic Analyses,” as follows:

> Seismically induced fires have not been systematically considered in the seismic PRA literature for nuclear power plants. A review of recent earthquakes throughout the world indicates that fires have been caused by earthquakes at industrial facilities particularly where there is a significant amount of flammable material like refineries and chemical facilities. A majority of the damage during the 1906

San Francisco earthquake was caused by fire. There where as many as 86 fires caused by the Whittier 1987 earthquake.

Seismically induced floods were analyzed in the Oconee PRA ... No other analysis of seismically induced floods is given in the seismic PRA literature. The Oconee analysis considered late failure of long-term cooling due to the seismic failure of the Jocassee Dam. Short term cooling is initially successful, but fails when the site is flooded due to the dam failure. The mean probability of core damage as a result of the Jocassee Dam failure was given as 2.6 E-6 per reactor year.

Comparison of the core damage frequency for the seismic failure of the Jocassee Dam indicated that it does not meet the core damage figure-of-merit. However, a judgment as to the inclusion of this type of failure in the severe accident policy implementation cannot be made on the virtue of only one analysis. This seismic failure of an upstream dam is a unique feature of the Oconee site because the Jocassee Dam was not built to nuclear safety grade standards as was the nearby Keowee Dam. Upstream dam failures at other plant sites may pose a potential for severe accidents. Other seismic induced flooding issues involve the seismic failure of threaded fire water piping, other liquid carrying piping and liquid storage tanks that result in local flooding of electrical equipment, distribution and control panels and rooms without drains that house these type of components.

Common-cause failures are characteristic of external initiators, in particular, seismic events. Several plant components and systems can fail simultaneously because they are subjected to the same initiating event or caused as a result of the same external initiator. The plants ability to respond to the external event is then reduced because of multiple failures. Earthquake motion is felt by all plant components and systems simultaneously. The resulting seismic responses of the components are correlated based on their location in the plant and their elevation above ground level.

NUREG/CR-5088

NUREG/CR-5088, "Fire Risk Scoping Study: Investigation of Nuclear Power Plant Fire Risk, Including Previously Unaddressed Issues," identified six fire risk issues which had not previously been addressed in a fire risk context. One of the issues is seismic/fire interactions, and Chapter 7 of this NUREG discusses it. The following text is a reproduction verbatim of this chapter.

7.0 RISK SIGNIFICANCE OF SEISMIC/FIRE INTERACTIONS

7.1 Background Discussions

In contrast to conventional applications where one tends to associate earthquakes with the occurrence of fires, in nuclear power plant risk analyses the issue of seismic/fire interactions has been largely dismissed. While it is true that nuclear power plants do not contain large unsupported gas pipelines, electrical distribution networks, and open flames often associated with earthquake induced urban fires, and that Category I safety systems are qualified to seismic events, the possibility of seismically-induced fires still exist. One must also consider the possibility of seismically induced spurious suppression system actuation, and the potential degradation of suppression capability.

There are a number of potential interactions that one can envision that could cause an interaction between earthquakes and fire. For example, earthquakes could cause fire initiators by pulling cables loose due to vibration or shifting of cabinets. Flammable liquids could be spilled. Oil spilling from a day tank is another potential fuel source.

Gases can be released from the hydrogen system, and there is always no shortage of sparks that could ignite flammable gases. If nothing else, there will always be broken light bulbs that will provide whatever sparks needed. Given that gas has been released, there are sources of sparks.

In addition, consider, for example, that most areas of a power plant will house both Category I and non-safety systems. While Category I equipment is protected from non-safety equipment which may fall during a seismic event, the non-safety systems generally have not been designed to withstand seismic events. As a result it is possible that a seismic event will initiate a fire in a non-safety system. This fire may then involve the safety systems in the area through suppression activity, smoke generation, physical spread of flames, and high temperatures.

A second aspect closely related to that just described is the potential unavailability of suppression systems following a seismic event. Under current regulation only fire water standpipes are required to be qualified to seismic events. This leaves the internal distribution system as a whole and the external water supply system potentially vulnerable. Also, no requirements exist for the seismic qualification of gaseous suppression systems. These gaseous systems will be particularly vulnerable to the failure of the associated control systems which may not be adequately secured.

One must also recognize the potential for spurious operation of suppression and detection systems to occur during a seismic event. In addition to the potential problems associated with induced damage due to such spurious operations, these operations could in some cases result in the unavailability of suppression to other plant areas. An example of this type of failure, though not as a result of a seismic event, occurred recently at Surry. As a result of a feedwater line break, in addition to other spurious operations, a carbon dioxide fire suppression system control panel component failure resulted in dumping the plant's total carbon dioxide inventory into a single enclosure. Thus, carbon dioxide suppression capability throughout the plant was unavailable. As fire suppression system control circuits are not generally qualified to seismic events it is not difficult to postulate similar failures during a seismic event.

Finally, the post-earthquake environment can hamper fire recognition and fire fighting effectiveness. In general, we expect many spurious fire alarms which would require operator attention in the control room. Aftershocks, loss of off-site power and using only emergency lighting will hamper any manual fire fighting. So in the environment after an earthquake it will be difficult to trace down the numerous fire alarms and manually suppress fires.

7.2 Evaluation of Risk of Seismic/Fire Interactions

We did not attempt to quantify this issue because we could not quantify the frequency of fires given an earthquake. There is no data that exist on fires at nuclear power plants following an earthquake because only three power plants have experienced earthquakes. These quakes were all small, and no fires resulted. The plants were the Fukushima plant, the Humbolt Bay plant and the Perry plant. Humbolt Bay was permanently shut down at the time. Perry was temporarily down at the time. The Fukushima plant in Japan was operating, but did not even trip. So there are no data on seismically induced fires in nuclear power plants, and hence there is no way to assess the seismically-induced fire initiating frequency.

There are, however, limited data on how fire suppression systems perform. This primarily came out of a study by Brookhaven National Laboratories (BNL) which reviewed four major earthquakes and the fire suppression systems' performance following and during those earthquakes at non-nuclear facilities (Reference 14). The four earthquakes that they studied, were the San Francisco, Alaska, San Fernando and the Point Mugu earthquakes. In Alaska and San Fernando in particular, because of the building damage associated with them, there was quite a bit of observed damage to fire suppression systems. However, the only systems that they have any fire damage information on were water sprinkler systems.

In general, for automatic water sprinkler systems, it was concluded that if installed in accordance with nationally recognized standards, such systems did not suffer significant impairment unless there was major structural collapse. However, instances were found where the waterlines were inadequately laterally supported so that sprinkler heads could easily be damaged by impact with adjacent pipes. The inertial loads themselves did not cause failure, but rather the impact.

In general, fire mains withstood earthquake forces reasonably well. Several cases in which breakage of cast iron fire mains and pulling apart of slip joints or fiberglass joints were identified. Thus it was concluded, and we would concur, that cast iron fire mains have a high probability of failure following a major earthquake.

Lastly, the BNL study found temporary impairments to fire alarm service due to the actuation of many transmitters simultaneously. This tended to show up in all the earthquakes studied. If extrapolated to a nuclear power plant, it would be expected that many inadvertent detection, and possibly suppression, system actuations would occur following a large earthquake. Indications of such spurious actuations in the control room would complicate operator response.

7.3 Recommendations for Seismic/Fire Interactions

Realistic assessments of the possibility of electrical cabinets shaking, vibrating, and causing shorts and fires cannot be made. The types of interactions that would be expected were identified. It is concluded that these interactions would be easier to identify and fix than to quantify. To eliminate such interactions, it is recommended that each plant perform a walkdown looking for a number of different mechanisms that have been observed or which would be expected to be important. A preliminary but reasonably complete list is as follows.

1. One should look for CO_2 or Halon tanks that were unanchored. The concern is that they could slide and the pipes that lead to the distribution systems would break and dump the whole CO_2 or Halon inventory in that room, and all the problems that have been identified with that situation would occur for that room.

2. One should look at the actuation systems, that is, for the CO_2, Halon or water systems, and try to identify whether or not there was any possible problem with vibration and relay chatter and locking circuits. Some of the fire system manufacturers now are starting to seismically qualify their equipment. But, in the past, this has not been required. It would be fairly simple to review these actuation circuits to identify locking circuits, because you will get relay chatter during an earthquake.

3. In general, if there is an area that has only a smoke alarm, (that is, an ionization *or photoelectric type alarm) one would want to identify those areas and might perhaps want to add either a heat or flame detector back-up system to prevent getting spurious alarms. This would minimize the number of spurious alarms caused by dust actuating smoke detectors.

   This is done now for certain plant areas, for example, in diesel generator rooms or other rooms with rotating motors. The problem there is that oil falls down on hot cooling fins, and generates smoke which sometimes trips the fire alarm. In those areas, there will often be one of these other types of back-up detectors. A plant could review their various areas and decide where they wanted to have some back-ups so they would not get spurious alarms in the control room.

4. A plant ought to look at its fire pumps to see whether or not they have either weak mounts or vibration mounts. Vibration mounts are notoriously weak during seismic events. The fix is very easy. One weld stops on each end to limit the amount of motion so they do not vibrate out of their mounts. Many of these vibration mounts essentially allow the motor pump to just walk right off to the side and leave the mounting.

5. Cast iron fire mains should be identified or other seismically weak water sources that the fire system depends on such as sprinkler heads through drop ceilings. Due to the motion of the ceilings, sprinkler heads are often damaged by seismic events. So one would want to identify that situation and make sure that the suspended ceiling itself could not damage the sprinkler heads. That happened frequently in the four earthquakes that were reviewed.

6. A plant should review all electrical cabinets to make sure that, (a) they had proper anchorage (but presumably that is being taken care of as part of Generic Issue A-46) and (b) to verify that there is enough slack in the cables entering the cabinets so that the cabinet could vibrate and not pull wires loose and hence generate sources of sparks or fires.

7. A plant should search for any unanchored oxygen bottles or hydrogen bottles to make sure that those could not fall over. If a typical high pressure tank falls and breaks its neck, one has a missile problem, and also a very flammable gas mixture available. A similar potential exists when local storage of Halon or CO_2 is utilized.

8. Lastly, a plant should review all sprinkler systems to make sure there is no interaction possible between the sprinkler heads and adjacent pipes.

9. All plant fire suppression and detection control circuits should be reviewed for the existence of mercury switches. All such switches should be removed from these systems and replaced with alternate, seismically insensitive switches.

This is a preliminary list of interactions that have been identified based on a review of past experience. It is expected that others have yet to be identified. Further review would provide a more complete list of potential interactions. Such a listing could be used by plants in the performance of a walkdown to identify these interactions. In this manner, it is concluded most of the risk associated with seismic/fire interactions could be eliminated by performing such a review and implementing the review recommendations on a plant by plant basis.

Subsection 11.2.5, “Seismic/Fire Interactions,” gives a summary of the findings on this subject, and is reproduced below.

In reviewing the knowledge base regarding the potential for seismic/fire interactions one study, performed by Brookhaven National Laboratories (BNL), was identified in which non-nuclear experience in this regard has been reviewed. This study identified certain potential vulnerabilities relevant to the nuclear industry. These vulnerabilities included the potential loss of fire suppression capability, and the potential actuation of multiple spurious alarms which would complicate operator responses. No attempt was made to specifically quantify the impact of such vulnerabilities on core damage frequency estimates.

It would appear that this is an issue which is more easily corrected than quantified. A series of simple steps was outlined which if implemented on a plant specific basis would significantly reduce the potential impact of such considerations. These steps would provide for the identification and rectifying of vulnerabilities. Thus, the issue of seismic/fire interactions is considered an issue best addressed on a plant specific basis, rather than as an issue of significant generic concern.

NUREG/CR-5477

NUREG/CR-5477, “An Evaluation of the Reliability and Usefulness of External-Initiator PRA Methodologies,” “…prepared to assist policy-level decision-makers, evaluates the extent to·which each category of external-initiators PRA methodology produces reliable and useful results and insights, at its current state-of-the-art level…”

Chapters III, “Earthquakes,” and IV, “External Flooding,” contain information related to seismic-induced fires and floods (SIF&F). The following text presents information from each one.

III. Earthquakes

Sections III.A, "Summary Evaluation," and III.D.5, "Evaluation of the seismic-PRA systems analysis methodology," discuss issues associated with the plant's response within the context of the earthquake itself, and not within the framework of SIF&Fs, but the insights are also applicable to the later. These issues are the following:

1. Correlations among earthquake-induced failures. Though these sections refer to these failures as loss of function due to the earthquake, their discussion about these correlations appears also applicable to SIF&Fs. For example, an earthquake may cause several fires in a plant, and perhaps several within a single area of within the same system, possibly reducing or even eliminating redundancies of SSCs.

2. Relay chatter. This issue does not appear to be directly related to SIF&Fs, but relay chatter is a potential additional complication to SIF&Fs scenarios.

3. Design and construction errors. These errors also may exacerbate an SIF&F scenario, but they are difficult to include in a PRA.

4. Operator response. Again, this response is complicated given the occurrence of SIF&Fs.

The following are excerpts from these sections.

<u>III.A, "Summary Evaluation</u>

<u>5) How reliable and useful is the systems-analysis methodology?</u>

The objective of the systems-analysis methodology, given which equipment is damaged by the earthquake (typically with a probability distribution), is to determine which core-damage accident sequences may result, and the core-damage frequencies for each.

The systems-analysis work is broadly similar to traditional PRA systems analysis for internal initiators, and is within the technical capability of any competent PRA systems analyst, with no special training. It uses the same tools and types of data, and the same way of setting up the analysis and solving it numerically. There are only a few special issues: correlations among failures, relay chatter, design and construction errors, and operator response.

The problem of analyzing <u>correlations</u> among earthquake-induced failures can sometimes be difficult, especially for co-located equipment. Typically, the assumption is made of complete correlation in the response for nearby and similar equipment subject to the same floor motion. However, different equipment types, even if located in close proximity, are usually assigned only minor if any response correlation.

The problem for the analyst is that there is only very limited experimental information, from either testing or actual earthquakes, upon which to rely. Therefore, while the <u>methodology</u> for coping with correlations is well-developed, the underlying <u>knowledge</u> is typically inadequate. The usual fallback approach is to perform a sensitivity analysis, to obtain a measure of the uncertainty in the final results.

Whenever the accident sequences of concern involve components for which correlation might or might not be large, this issue is one of the important sources of uncertainty in the overall analysis.

The seismic-PRA methodology does not systematically take into account possible design and construction errors. The only consolation for the analyst (and the decision-maker) is that these omissions are directly parallel to possible similar omissions in the rest of PRA.

Recently, the relay-chatter issue has received significant attention. While the earliest seismic PRAs did not examine this issue, today an acceptable methodology does exist for treating it properly. Furthermore, the issue should not be ignored, because it certainly has a potential for contributing significantly to the overall seismic risk.

It seems likely that,·during and after a strong-motion earthquake, operator response without error should be substantially degraded. However, this issue does not have as much effect on the results of PRAs as might be thought at first, principally because in PRAs no credit is usually allowed for operator control actions during the early minutes after a large earthquake. Based on this, the general consensus is that the operator-response aspect of the methodology, while not as strong as ultimately desired, is as robust (more-or-less) as the approach for operator error analysis used in internal-initiators PRA studies.

III.D.5, "Evaluation of the seismic-PRA systems analysis methodology

The objective of the systems-analysis methodology is as follows:

Given which equipment is damaged by the earthquake (typically with a probability distribution), the analyst must determine which core-damage accident sequences may result, and the core damage frequencies for each.

Discussion of the Methodology: The systems-analysis work is broadly similar to traditional PRA systems analysis for internal initiators. It uses the same tools and types of data, and the same way of setting up the analysis and solving it numerically. The following paragraphs will point out a few special considerations.

Logically,… the analyst should begin with the results of the seismic fragility analysis, which will have determined which structures and equipment have been damaged by the postulated earthquake (as a function of earthquake "size" in terms of, say, peak ground acceleration, frequency, etc.). The systems analyst must then take into account issues such as the random (non-earthquake-caused) likelihood that other vital equipment might be out-of-service due to testing, maintenance, operator error, or failure; possible correlations among failures; and the procedures used by the operators, including their ability to recover certain earthquake-damaged or failed equipment, or to substitute other equipment, or to perform the needed function another way.

The systems analysis requires developing one or more accident sequence event trees, that include the various functions or systems needed for safe shutdown, possible operator prevention and recovery actions, and the like. The success-or-failure numerical values on the event-tree branch points are then worked out using either data or fault trees. If we assume that the analyst has access to a completed internal-initiators PRA, then direct use can be made of such vital information as the emergency procedures and the support-system matrix. (Support systems such as AC power, instrument air, service water, and so on support the vital front-line equipment.) Otherwise, the analyst must develop this information anew. If fault trees from an internal-initiator analysis are used, they must be modified somewhat to account for location correlations and to introduce different failure modes.

The outcome of the systems analysis is the numerical value of core-damage frequency (actually, a density function that captures uncertainties) for each of several (usually discrete) earthquake sizes.

There are four special issues to discuss here: correlations among failures, relay chatter, design and construction errors, and operator response.

Correlations among failures: The problem of analyzing correlations among earthquake-induced failures can sometimes be hard.

The usual assumption, which seems obviously appropriate, is that the earthquake motion coming into the site will affect all buildings in a fully correlated way. However, at different locations in a building, and certainly in different buildings, this correlation is diluted by intervening factors. Typically, the assumption is made of complete correlation in the response for nearby and similar equipment subject to the same floor motion. However, different equipment types, even if located in close proximity, are usually assigned only minor if any response correlation. Furthermore, even high response correlation doesn't imply high capacity correlation, which would arise when, for example, two valves come from the same manufacturer and the same assembly line.

The problem for the analyst is that there is only-very limited experimental information, from either testing or actual earthquakes, upon which to rely. Therefore, while the methodology for coping with correlations is well-developed …, the underlying knowledge needed to perform the calculations is typically inadequate. The usual fallback approach is to perform a sensitivity analysis, for example assuming complete correlation and then complete independence and ascertaining what difference these two assumptions make. The difference is then taken as representing a measure of the uncertainty in the final results.

Care must be taken about correlations not only in the central values but in the uncertainties. If neither of two parameters is known well, but what little is known comes from the same data set, the correlation in the uncertainty can be high.

Whenever the accident sequences of concern involve components for which correlation might or might not be large, this issue is one of the important sources of uncertainty in the overall analysis. (Conversely, if a key sequence is dominated by a single failure, or by two failures of very different kinds --- a large yard tank together with a battery rack would be examples --- both response and capacity correlations should be minor and the sensitivity of the results also minor.)

To summarize, while the methodology for this aspect of the analysis certainly exists in an adequate form, the underlying data are often inadequate, so that uncertainties in the final PRA results can sometimes be important from the issue of correlation.

Relay chatter: The issue of relay chatter was not analyzed at all in the first several seismic PRAs (early 1980s). Instead, the assumption was made that all relay chatter was recoverable by the operating crew, which assumption is tantamount to assuming no chatter. Recently, however, this issue has received significant attention. An NRC-sponsored study of chatter at two power plants … demonstrated that if there is no operator recovery the chattering of relays could lead to core-damage accident sequences with high annual frequencies. This study also developed and used a methodology for examining relay-chatter issues in the context of a full-scope PRA. The recent Diablo Canyon PRA … included a thorough examination of relay chatter, which was found to be a significant issue in the study. Also, the currently ongoing seismic margin review at Plant Hatch, jointly undertaken by EPRI, NRC, and the utility has examined this issue thoroughly ... Furthermore, the test data base on seismic capacities for relay chatter has become more and more extensive.

A summary of the relay-chatter issue as of today is that (1) an acceptable methodology does exist for treating it properly; and that (2) the issue should not be ignored,·because it certainly has a potential for contributing significantly to the overall seismic risk.

Design and construction errors: The seismic-PRA methodology does not systematically take into account possible design and construction errors, except in the rare case that such an error may be identified during the walkdowns or the study of design drawings. This may seem like a serious flaw in the methodology. In actual fact, there is no way to know whether or not it is! The only consolation for the analyst (and the decision-maker) is that these omissions are directly parallel to possible omissions in the rest of PRA, such as in the analysis of internally-initiated accidents, where possible

design errors affecting the configuration of systems are also not accounted for properly either. This is not an excuse, but rather a generic weakness of all PRAs. Of course, a rigorous pre-operational testing program should identify most of these errors.

Operator response: It seems likely that, during and after a strong-motion earthquake, the ability of control-room operators to perform their assigned tasks without error should be substantially degraded, due to high levels of stress and confusion. This issue has been examined recently …, and a model has been proposed to account more effectively for possible high operator stress. However, this issue does not have as much effect on the results of PRAs as might be thought at first, principally because in PRAs the assumption is commonly made that no credit is allowed for operator control actions during the early minutes --- often for as long as a half-hour --- after a large earthquake. By that time, things should have settled down (literally and figuratively), so that the normal PRA methodology for analyzing operator errors should apply. Based on this, the general consensus is that the operator-response aspect of the methodology, while of not as strong as ultimately desired, is as robust (more-or-less) as the approach for operator error analysis used in internal-initiators PRA studies.

Evaluation of the Systems-Analysis Methodology: As mentioned briefly above, the seismic systems sub-methodology is, in its basic outline, a variant of the type of systems analysis that is now a well-developed, mature PRA discipline. While certain issues must be specially treated, every aspect of the methodology, including correlations, relay chatter, and operator response, is fully within the routine capability of PRA analysts. Therefore, we conclude that any competent PRA systems analyst can perform this work, with no special training and only the minimal guidance that is readily available and easily learned.

IV. External Flooding

The scope of Chapter IV, “External Flooding,” “…covers external floods, meaning floods arising outside a nuclear power plant from external sources of water. The flooding phenomena under consideration mostly arise from "acts of god" such as high river or lake water, extreme precipitation, ocean flooding, tsunamis, seiche phenomena, and the like. A few man-made events can cause external flooding, principally due to the failure of dams, levees, and dikes…” Sections IV.A, “Summary Evaluation,” IV.B, “Introduction,” and IV.D.4, “Tsunamis,” are particularly relevant to seismic-induced external flooding, and they are reproduced below.

IV.A Summary Evaluation

Because PRAs have occasionally identified core-damage accident sequences Initiated by very high external flooding as among the important contributors at a few nuclear power plants, the analysis of flooding cannot be neglected as a part of external-initiators PRA. Fortunately, for most plants the analysis can be an abbreviated or screening analysis demonstrating that the plant layout and design are very well protected against flooding. For only a few plants will a more nearly full-scope analysis be required.

This summary will provide an overview evaluation of the reliability and usefulness of external-flooding PRA methods and results. Its summary statements are supported in the main text below.

1) How reliable is the flooding hazard methodology? The answer depends somewhat on the type of flooding phenomenon. For most of the phenomena, and for flooding heights up to or not too far above the historical record, the methodology can reliably provide site-specific answers to the question, "What Is the annual frequency of flooding (F_F) up to flood level X?" Extrapolation methods much beyond the historical record at a given site possess diminished reliability. Because our historical record is usually on the order of about one century (often less, if records are poor), calculated values of F_F much below about 0.01/year become increasingly difficult to support. Modest

extrapolations, of perhaps one order of magnitude to the range of 0.001/year, can be supported in some cases when the model for the flooding phenomenon is well understood.

In the above range (reliably down to F_F values near 0.01/year, less reliably down to about 0.001/year), the flood-hazard results are reliable. For F_F values much below about 0.001/year, the very broad uncertainties in the analytical models implies that the reliability of these values is much poorer.

For a few phenomena, the situation is somewhat better. Specifically, in analyzing local precipitation it is often feasible to obtain more reliable extrapolations at a specific site by using regional information. For dam failures, use of the very large data base on dams can sometimes allow reliable extrapolations of F_F down to quite small values if similarity arguments can be supported soundly. At some sites, extrapolation of F_F for other phenomena may be supportable.

<u>2) How reliable and useful are the flooding systems-analysis methodology and the consequence/release methodology?</u> These aspects of the methodology, which are broadly similar to the systems-analysis methods of internal-initiators PRA, are highly reliable and useful. Specifically:

- Given a postulated flood large enough to breach a barrier and damage some key equipment, the methodology can reliably quantify the conditional probability (P_{CD}) of core damage, its principal contributors, and their interactive roles, including equipment issues, operator-error issues, and operator recovery issues.

- Given a postulated core-damage accident the conditional probability of radioactive releases (P_R) can be reliably determined and the results are highly useful.

- It is fully feasible to identify flood-related specific vulnerabilities at a nuclear plant using this methodology. When a vulnerability is identified, the analysis is robust and can be used to suggest alternative approaches to reducing the vulnerability, including approaches that rely on operator recovery actions.

<u>3) How reliable and useful are "bottom-line numbers" for core-damage frequency and offsite risk and how reliable are the key engineering insights?</u> Because the flood-hazard methodologies are reliable only in the range above, say, about F_F = 0.001/year, core-damage frequencies dependent on smaller F_F values will have large uncertainties. Since the frequency of core damage, F_{CD}, is roughly the product of F_F times P_{CD}, values of F_{CD} are reliable and useful only if they are constituted from F_F values above about 0.001/year.

Despite possibly large uncertainties in the bottom-line risk results, these uncertainties should not generally invalidate any insights that may be obtained about flooding vulnerabilities. That is, if the analysis reveals combinations of failures that can give rise to a safety concern, these should be robust despite uncertainties in the numerical results.

IV.B Introduction

Different types of sites are prone to different external-flooding phenomena. The following … describes the wide range of flooding issues at different types of sites:

- <u>all sites:</u> flooding due to severe local precipitation and runoff effects on the site itself;
- <u>river sites:</u> flooding due to too much water in the river (from precipitation runoff, etc.)
- <u>river sites:</u> flooding due to a dam failure (which itself could be due to too much water in the river);
- <u>ocean, estuarine sites:</u> flooding due to combinations of high tides, wave effects, high wind-driven water levels, surges, seiches, etc.;
- <u>ocean sites:</u> flooding due to a tsunami;

- lake sites: flooding due to combinations of high lake water level, wave effects, high wind-driven water levels, surges, seiches, etc.;
- all sites: flooding due to earthquake-induced effects, such as landslides, dam failures, tsunami-type effects.

It is important to consider combinations of the above phenomena. At some sites, the very largest floods may not be due to an extremely unlikely occurrence of one of the phenomena, but rather to less extreme occurrences of more than one, in combination, at the same place and time. When considering the probabilities, the analyst and decision-maker must be cognizant of this issue.

As discussed in the introductory chapter, this paper is not intended to be an in-depth technical review of the subject matter, but rather an in-depth evaluation of the reliability and usefulness of the results and insights from external-initiator PRA.

The technical approach here, which builds on recent work accomplished under NRC support at Lawrence Livermore National Laboratory …, is to perform a more in-depth evaluation. The thrust is to identify and describe the principal aspects of the current state-of-the-art PRA methodology, what aspects are more robust and therefore provide the most reliable insights, what aspects are less robust and therefore provide less reliable insights, and why.

The product of the study is intended to be an evaluation of the PRA methodology for external flooding, concentrating on the sub-methodologies and on how these sub-methodologies are combined together to provide overall PRA results and insights. There is guidance in the literature about how to perform a flood PRA, which can be referred to for more details ...

IV.D.4 Tsunamis

Discussion of the Methodology: The issue here is to calculate the frequency per year that a tsunami might occur large enough to threaten the reactor site. Usually, a bounding analysis will be sufficient.

Although a tsunami can occur along any of the world's coastlines, the threat to U.S. reactors is generally considered greatest for those few reactor sites near the Pacific Ocean, where tsunami events are much more frequent than elsewhere. (However, tsunamis are not unknown in the Atlantic: the major earthquake in 1755 in Lisbon, Portugal produced tsunami effects along the entire American Atlantic coast).

The historical data base for tsunamis extends for several hundred years in both Pacific and Atlantic basins, with less reliable data going back somewhat further. Given a distant tsunami arriving at a specific location, it is feasible to determine how large a tsunami-induced flood will be, by considering the local offshore subsurface topography. Usually, a deterministic analysis is sufficient to assure that tsunami effects will not be troublesome at a given site: that is, F_F is usually acceptably small based on conservative or deterministic analysis. If not, it would be necessary to perform a response analysis, determining which safety equipment and structures might be damaged and the consequences for overall safe shutdown.

Evaluation: There exists no full-scope probabilistic tsunami reactor analysis in the literature. However, such an analysis would require a straightforward adaptation of PRA methods that are well known and well within the capability of PRA analysts, and of tsunami-flood-height methods routine used in the engineering community. Therefore, such an analysis should be both reliable and useful.

NUREG/CR-6544

NUREG/CR-6544, "A Methodology for Analyzing Precursors to Earthquake-Initiated and Fire-Initiated Accident Sequences," "…covers work to develop a methodology for analyzing precursors to both earthquake-initiated and internal fire-initiated accidents at commercial

nuclear power plants… The results of this project are that (i) an overall step-by-step methodology has been developed for precursors to both fire-initiated and seismic-initiated potential accidents; (ii) some stylized case-study examples are provided to demonstrate how the fully-developed methodology works in practice, and (iii) a generic seismic-fragility data base for equipment is provided for use in seismic-precursor analyses."

This NUREG's methodology analyzes precursors to earthquake-initiated accidents, but it does not address hazards that occur as a result of an earthquake, such as seismic-induced fires or floods. The following paragraphs from section 1.5, "Technical Approach to the Project," illustrate the NUREG's scope as far as earthquake-initiated accidents is concerned:

> …We believe it important to point out that the available precursor information that can cast light on potential earthquake-initiated accident sequences is quite different than for most other types of initiators. There have been no actual earthquake events of safety significance at any operating U.S. nuclear power plant (nor overseas either), and such earthquakes will never be frequent. The following discussion will show why. The PRAs reveal that the most seismically fragile aspect of the nuclear plants is their offsite power systems, because of the seismically weak ceramic switchyard insulators and offsite transmission lines. At typical eastern-U.S. sites the recurrence rate for seismic-caused loss-of-offsite power (LOSP) is analyzed to be in the range of about or below <u>0.001 per year</u>. Everything else of safety significance is generally found to be seismically stronger, requiring larger and hence rarer earthquakes to cause damage. This explains why damaging earthquake events <u>per se</u> even earthquakes that would only cause LOSP but no other damage, are thought to be very rare.
>
> However, one of the principal lessons from the seismic-PRA literature is that a large fraction (perhaps a majority, depending on how one counts) of the important seismic-initiated sequences involve a combination of seismic-caused failures <u>plus</u> non-seismic-caused failures or human errors ... A significant fraction of the "precursor events" relevant to earthquakes may turn out to be non-seismic events that compromise various safety functions, such that the plant is vulnerable and its ability to withstand a major earthquake is significantly degraded…

Similarly, the generic seismic-fragility data base for equipment in Chapter 6 of this NUREG is related to the loss of function of a component, not to the possibility of the component catching fire or causing a flood.

<u>NUREG/CR-6850</u>

An NRC/EPRI joint report titled "Fire PRA Methodology for Nuclear Power Facilities" (NUREG/CR-6850) "…documents state-of-the-art methods, tools, and data for the conduct of a fire Probabilistic Risk Assessment (PRA) for a commercial nuclear power plant (NPP) application. This report is intended to serve the needs of a fire risk analysis team by providing a structured framework for conduct of the overall analysis, as well as specific recommended practices to address each key aspect of the analysis…Methodological issues raised in past fire risk analyses, including the Individual Plant Examination of External Events (IPEEE) fire analyses, have been addressed to the extent allowed by the current state-of-the-art and the overall project scope…"

Chapter 13, "Seismic-Fire Interactions Assessment," of this NUREG addresses the following four seismic-fire interaction issues identified by the Fire Risk Scoping Study (NUREG/CR-5088):

- Seismically induced fires
- Degradation of fire suppression systems and features
- Spurious actuation of suppression and/or detection systems
- Degradation of manual firefighting effectiveness

Chapter 13 then recommends "…that a Fire PRA include a qualitative assessment of these issues. In this procedure, a recommended approach is given." The following paragraphs reproduce Chapter 13.

> This procedure does not provide a methodology for developing models and quantifying risk associated with fires caused by a severe seismic event. This is due to a combination of limitations in the state of the art, and the perceived low level of risk from these fires. The low risk is based on the low frequency of an earthquake that can initiate a challenging fire and degrade various plant fire protection defense-in-depth elements, and the general seismic ruggedness of the NPPs as part of their design basis. This procedure outlines a series of steps intended to verify this premise. If the verification steps outlined in this procedure do not preclude the risk significance, either a quantitative assessment or consideration of physical or procedural changes may follow…
>
> **13.2 Scope**
>
> Consistent with the recommendations of [the Fire Risk Scoping Study] and those outlined in the EPRI FIVE [EPRI 1993] and Fire PRA Implementation Guide [EPRI 1995], recommended practice in the seismic fire interactions assessment utilizes a qualitative, walkdown-based approach, rather than quantitative methods to estimated associated risk. This task provides a stand-alone study of the effects of a fire due to an earthquake. This task is not intended to develop quantitative estimates of the risk associated with seismic-fire interactions.
>
> **13.3 Background Information**
>
> *13.3.1 Seismically Induced Fires*
>
> There is a potential that a significant seismic event could trigger fires within or outside the plant. Postearthquake fires in typical urban and industrial settings are most often associated with pipes or storage tanks containing flammable gasses (e.g., natural gas, hydrogen) or liquids (such as gasoline, fuel oil, etc.). However, flammable liquids and gasses are not the only potential fire hazard.
>
> There is also a potential for fires arising from the failure of electrical equipment during an earthquake, even though these fires tend to have significantly less consequence due to the absence of large amount of flammable and/or combustible material. Unrestrained or inadequately restrained electrical equipment may be physically displaced or tip over during a seismic event. This could cause electrical fires through physical damage to, in particular, electrical cables and connections feeding power to the components. Furthermore, firefighting response may also be compromised and/or complicated by the seismic event (as discussed in the context of the other three seismic-fire interaction issues), so that if a fire occurs as the result of an earthquake, it would have a greater potential for long duration than general plant fires. A survey of over 100 plant and industrial facilities after 18 major earthquakes was conducted by EPRI in 1990 [8]. [The Fire PRA Implementation Guide] reviewed this study and reports that postearthquake fires in such facilities were not common. To date, no incidence of a post-earthquake fire impacting a NPP has been documented. Clearly, such events are rare, although no attempts have been made to estimate the likelihood of seismically induced fires in an NPP.
>
> *13.3.2 Degradation of Fire Suppression Systems and Features*

Elements of the plant fire suppression systems may or may not be designed to withstand the effects of an earthquake. The seismically induced failure of fire suppression system components could lead to general unavailability of one or more fire suppression systems or to the discharge of fire suppressant into an undesired location. The second effect will be discussed in the context of the SO of fire protection systems. This section deals primarily with the potential that fire suppression systems may be unavailable following a seismic event.

As reported in [the Fire Risk Scoping Study] and [the Fire PRA Implementation Guide], a study by Brookhaven National Laboratory (BNL) concluded that fire suppression systems installed in accordance with nationally recognized codes and standards generally provide an adequate level of support for piping under seismic conditions [BNL/NUREG-25101]. The most significant potential vulnerability identified in the BNL study was inadequate lateral constraint that could allow for movement of, and damage to, sprinkler heads, should they impact other nearby objects. [The Fire Risk Scoping Study] also identifies inadequate restraint of gaseous suppressant bottles as a potential concern. A final area of concern cited in [the Fire Risk Scoping Study] was the use of cast-iron fire mains, given that cast iron is known to be seismically weak.

[The NRC “Seismic Design Classification” (1978)] recommended the use of seismic category II-over-I design criteria for the installation of fire protection piping and components. Hence, depending on the specific plant design approach, it may be possible to demonstrate a reasonable level of assurance that fire suppression systems will be seismically robust.

In general, seismic design is more likely in areas prone to significant seismic activity. It is also likely that seismic restraints have been provided within the plant in cases where the rupture of the fire suppression system could compromise Class 1E safe shutdown equipment (e.g., the Seismic II/I designs). However, the seismic ruggedness of fire suppression systems should not be assumed without some review of plant-specific design practice.

Depending on where a failure occurs, one or more specific fire suppression systems or features may be compromised. (Systems could include local sprinkler systems, and features could include manual hose stations.) For example, ruptures in the firefighting water main piping system (e.g., the yard main) could render all water-based fire suppression (e.g., sprinklers and manual hose stations) unavailable until repair actions are taken to, e.g., isolate the ruptures. Even given successful isolation of the ruptures, portions of the firefighting water system could remain isolated pending major repairs.

13.3.3 Spurious Actuation of Suppression and/or Detection Systems

In the event of an earthquake, it is possible that one or more of the fixed-fire protection systems (detection and/or suppression) will actuate. It is also possible that fire suppressant may be released in unintended locations due to piping breaks.

Both ionization and photoelectrical smoke detectors are vulnerable to actuation from dust and/or steam. Note that systems designed to detect incipient fires may be relatively robust against such exposure, as they are designed specifically to filter out a potential false signal due to dust or steam. For example, the NFPA Fire Protection Handbook [1997] provides information on laser-based light scattering devices and air-sampling type smoke detectors designed to detect incipient fires. Heat detectors might also be activated given a substantial steam release. During a seismic event, it is likely that enough dust will be lofted to actuate any vulnerable detector. Steam may also be released in significant quantities given any ruptures to steam lines or piping. Hence, multiple detection signals are possible, if not likely. Sorting out valid from spurious fire detection signals could complicate the postearthquake response. In particular, multiple spurious detection signals could mask valid signals.

Similarly, some fire suppression systems may be vulnerable to spurious operation, including discharge resulting from physical damage to piping and control components.

- Relay chatter in non-seismically qualified fire protection system control panels could result in system actuation.

- A pipe break in a water-based system could cause the release of water in an unintended location and from an unexpected direction. Hence, equipment protected from sprinklers may still be sprayed by water.

- Deluge system trip valves may not be seismically robust and may spuriously open (or jam shut).

- Fusible links in sprinkler heads (and ventilation dampers) may actuate given a steam release.

- Systems tied to smoke detection (including cross-zone smoke detection) may receive actuation signals based on spurious actuation of the detectors.

- Spurious discharge of a gaseous suppression system could render a fire area (or zone) uninhabitable (e.g., CO_2).

In the event of a severe seismic event, multiple spurious operations or suppressant discharges could lead to potential flooding problems (e.g., water piping breaks), spraying of equipment from unanticipated directions, and/or diversion of suppressants away from actual fires.

13.3.4 Degradation of Manual Firefighting Effectiveness

A severe seismic event could impact plant operations, including actions associated with manual firefighting. As discussed above, there may be one or more actual fires initiated within the plant boundaries; there may be multiple fire detection signals (most of which may be false signals); one or more fire suppression systems may discharge (likely leading to additional alarms); and some elements of the fire suppression systems and features may be disabled.

In the postearthquake environment, it will be necessary for plant staff to assess the fire protection situation, in addition to other earthquake response activities. Depending on how the plant fire brigade is staffed, there may be conflicting assignments (e.g., security and maintenance personnel may be called on to perform other duties). If an actual fire does occur, some manual response will be required. Potential actions that may be necessary following a seismic event include the following:

- Respond to fire detection signals and reset detection systems,

- Confirm whether any actual fires exist and execute appropriate attack measures,

- Assess the condition of the fire suppression systems,

- Secure damaged fire suppression systems (e.g., leaking or broken pipes), and

- Ensure required access for safe shutdown response actions.

13.4 Assumptions

No specific assumptions are made in the conduct of this task.

13.5 Task Interfaces

13.5.1 Input from Other Tasks

This task utilizes component and cable mapping information developed in support of the Fire PRA (Support Task B). In particular, the task will ask that, to the extent possible, components and cables credited in postearthquake safe shutdown are mapped to specific fire analysis compartments.

13.5.2 Additional Plant Information Needed to Complete this Task

Information relating to the plant seismic design basis, earthquake response procedures, and any seismic plant response analyses (as available) will be required to complete this task. Seismic plant response analyses of interest may include seismic margins analysis, seismic PRA, seismic IPEEE analysis, or other seismic response analyses, as available.

13.5.3 Walkdowns

The recommended approach is walkdown-based. Participants in the walkdown(s) should include staff knowledgeable of the plant fire protection systems and features; the results of the plant fire risk analysis, including the postulated fire growth and damage scenarios for key fire areas; and the plant's seismic design basis and the assessment of seismic restraints.

13.5.4 Output to Other Tasks

There is no direct output from this task to other tasks beyond documentation of the PRA findings (Task 16).

13.6 Assessment Procedure

The seismic-fire interaction assessment procedure includes the following seven steps.

Step 1: Identify key seismic-fire interaction analysis compartments

Step 2: Assess potential impact of seismically induced fires

Step 3: Assess seismic degradation of fire suppression systems and features

Step 4: Assess the potential impact of spurious fire detection signals

Step 5: Assess the potential impact of spurious fire suppression system actuations

Step 6: Assess the potential impact of a seismic event on manual firefighting

Step 7: Complete documentation

13.6.1 Step 1: Identify Key Seismic-Fire Interaction Analysis Compartments

- Determine what systems and components are credited for postearthquake safe shutdown. Information (such as Safe Shutdown Equipment List, SSEL) from plant Seismic Margin Assessment (SMA) or Seismic PRA may be used.
    - Review plant earthquake response procedures and identify key components and systems credited for safe shutdown.
    - Review any supplemental seismic plant response analyses (as available) to further identify components and systems important to postearthquake safe shutdown.
    - Identify any manual actions required to support postearthquake safe shutdown.

- To the extent possible, map the postearthquake safe shutdown systems and components to those circuits and systems credited in the Fire PRA Model.
  - Use the Fire PRA cable and component mapping information (developed under Tasks 2 and 3) and other plant cable and component mapping information, as available.
  - Consider additional cable and component routing efforts only if post-earthquake safe shutdown functions cannot be mapped to fire compartments with reasonable confidence.
- Identify key seismic-fire interaction compartments where seismic-fire interactions could be risk important.
  - Identify the fire compartments that house the components and cables credited for postearthquake safe shutdown.
  - Identify fire compartments where local manual control or repair actions may be needed in response to an earthquake.
  - Identify access paths within the plant required to support safe personnel passage and/or safe access following an earthquake.

13.6.2 Step 2: Assess Seismically Induced Fires

- For each key seismic-fire interaction analysis compartment identified in Step 1, assess whether or not fire ignition sources unique to a seismic event exist. Assess the acceptability/adequacy of existing seismic restraints for electrical equipment, flammable gas piping, and liquid or gaseous fuel storage tanks.
- Assess the potential for seismically induced fires to compromise postearthquake shutdown capability. Fire ignition source screening and analysis tools may be applied to support this assessment. Specifically, an ignition source screened in Task 8 may be excluded from consideration.
- If potentially significant seismically induced fires are identified, i.e., a fire compartment with a possible source and targets (i.e., targets identified in Step 1 of this task), consider providing additional protection. Possible measures may include:
  - Additional or upgraded seismic restraints,
  - Additional fire protection for either the exposing fire source or exposed safe shutdown targets (e.g., cables),
  - Enhancement of existing plant response procedures, and
  - Supplemental plant response procedures.

13.6.3 Step 3: Assess Seismic Degradation of Fire Suppression Systems and Features

- Review general plant practice regarding seismic restraints provided for fire suppression systems and components.
- Conduct a walkdown to assess the seismic ruggedness of plant fire protection systems and features.

  - Assess the seismic ruggedness of support items that could lead to a common-cause failure of multiple fire suppression systems. This would include fire pumps, primary firefighting water piping systems, standpipes, and firefighting water storage tanks/basins.

  - Assess the seismic ruggedness of the fire suppression capability for each of the key seismic-fire interaction analysis compartments identified in Step 1.

- Identify potential points of physical vulnerability for fire suppression systems and assess their impact on the availability of fire suppression following an earthquake.

- If potentially vulnerable fire suppression systems are identified in compartment(s) with the potential for significant seismically induced fires (from Step 2), consider measures to address any identified points of physical vulnerability. Possible measures may include:

  Upgrading the seismic ruggedness of key components in the fire suppression system(s),

  - Providing supplemental guidance in existing procedures or new procedures to ensure that the fire suppression capability is assessed and that leaks are secured promptly following a significant earthquake,

  - Providing a capability to isolate piping breaks,

  - Ensuring that there is a seismically robust source of manual firefighting water to key areas of the plant (e.g., seismically robust hose stations and adequate hose supply to reach key fire areas). This includes any backup water supplies that are used in the event that local hose stations are compromised by the seismic event.

13.6.4 Step 4: Assess the Potential Impact of Spurious Fire Detection Signals

- Identify fire detection systems that may be vulnerable to spurious actuation during a seismic event.

- Review plant postearthquake response procedures and determine if provisions are made for dealing with multiple fire alarm signals.

- Consider potential enhancements to the existing procedures if such provisions are lacking.

13.6.5 Step 5: Assess the Potential Impact of Spurious Fire Suppression System Actuations

- Identify fire suppression systems for the key seismic-fire interaction analysis compartments identified in Step 1 that may be vulnerable to spurious discharge through actuation of the system, damage to discharge heads, or a rupture in system piping.

- Assess the potential for spurious fire suppressant discharge to compromise components and systems credited for postearthquake safe shutdown (from Step 1).

- If system is vulnerable to seismic actuation in a compartment with systems credited for postearthquake safe shutdown (Step 2), consider potential measures to reduce component vulnerability.

13.6.6 Step 6: Assess the Potential Impact of a Seismic Event on Manual Firefighting

- For each key seismic-fire interaction analysis compartment identified in Step 1, identify and assess manual firefighting access routes.

  - Identify potential features that could compromise these access routes (e.g., unsecured storage panels that might block an access route following an earthquake, doors that might jam closed following an earthquake, etc.)

  - Determine if alternate access routes are available.

- For each analysis compartment identified in Step 1, identify and assess those assets that may be needed to support manual firefighting.

  - Assess seismic robustness of hose stations.

  - Determine if an alternate source of firefighting water is available if the primary source is compromised.

  - Determine if sufficient length of hose is available to support use of an alternate firefighting water source.

  - Assess the seismic ruggedness of prestaged firefighting equipment storage (e.g., turnout gear storage racks, portable fire extinguishing equipment storage racks, fire fighting equipment “cages,” etc.).

- Review and assess plant seismic event response procedures for relevance to manual fire fighting activities.

- If the above examination leads to the conclusion that the ability of the fire brigade to perform in the event of a severe earthquake may be compromised, consider potential upgrades to enhance the seismic robustness of the post-earthquake manual firefighting capability.

13.6.7 Step 7: Complete Documentation

Document the results of the seismic-fire interaction assessment consistent with the level of detail afforded other aspects of the analysis.

NUREG/CR-7046

The purpose of NUREG/CR-7046, “Design-Basis Flood Estimation for Site Characterization at Nuclear Power Plants in the United States of America,” “…is to describe approaches and methods for estimation of the design-basis flood at nuclear power plant sites…” This report states “…At the start of the estimation of design-basis flood hazards, it is very useful to list clearly all plausible flooding mechanisms that are capable of generating a severe flood at the site…” Accordingly, it considers an earthquake as a possible mechanism for external flooding.

On the other hand, this report also mentions “…This report briefly discusses the probabilistic approaches to estimation of design-basis floods. However, the deterministic approach currently in use is recommended for the near future because of two reasons: the lack of an overall framework that fully implements a Probabilistic Flood Hazard Assessment (PFHA) and to ensure consistency with current practices…” Accordingly, it acknowledges the absence of an overall framework for PFHA.

D.2.1.2 Commission Papers (SECYs)

Several U.S. Nuclear Regulatory Commission’s (NRC) Commission Papers (SECYs) and associated Staff Requirements Memoranda (SRMs), issued as a result of the seismic-induced

events at nuclear power plants (NPPs) in Japan in 2011, address seismic-induced fires and floods, and in particular, developing a PRA method for assessing the risk due to this hazard for a specific NPP. The following description summarizes the most relevant technical discussions on this subject from these SECYs and SRMs.

SECY-11-0093

SECY-11-0093, "Near-Term Report and Recommendations for Agency Actions Following the Events in Japan," states that on March 23, 2011, the NRC tasked the staff to establish a senior level agency task force to conduct a methodical and systematic review of NRC processes and regulations to determine whether the agency should make additional improvements to our regulatory system and make recommendations to the Commission for its policy direction. Consistent with that direction, this SECY included the Task Force Report, "The Near-Term Task Force Review of Insights from the Fukushima Dai-Ichi Accident," with its recommendations for agency actions following the events in Japan.

Subsection 4.1.2 of this SECY, "Protection from Concurrent Related Events," gives a summary of this type of events, and is reproduced next.

BACKGROUND

> The Task Force evaluated various related concurrent events and determined that fires and internal floods induced by design-basis earthquakes warranted further Task Force consideration.
>
> Seismically induced fires are frequent after earthquakes in urban areas. Seismic events have also resulted in fires at nuclear power plants. Seismically induced fires have the potential to cause multiple failures of safety-related systems and could create fires in multiple locations at the site. Fire protection systems are not required to be functional after a seismic event; therefore, efforts to fight seismically induced fires may be impaired by degraded fire protection equipment. A seismic event may also impede offsite fire crews from reaching the site, further challenging the capability to respond to such an event.
>
> This scenario occurred following the July 16, 2007, magnitude 6.6 Niigata-Chuetsu Oki earthquake that occurred 19 kilometers from the Kashiwazaki-Kariwa nuclear power plant, located in Niigata, Japan. Following the earthquake, a fire occurred in the Kashiwazaki-Kariwa Unit 3 electrical transformer. Sparks from a short circuit caused by large ground displacements of the transformer foundation caused the fire. The sparks ignited oil leaked from the transformer. Damage to the onsite fire protection equipment resulting from the seismic event included multiple failures of the firefighting water system in Units 1, 2, 3, and 4; failure of one of the fire water storage tanks; and failure of other fire suppression systems. Attempts by the plant fire brigade to extinguish the fire were unsuccessful. The local municipality fire brigade eventually extinguished the fire approximately 2 hours after it began. The fire was contained by fire protection walls and did not affect any plant safety equipment. However, the event provided important insights into vulnerabilities from seismically induced fires.
>
> The 2007 Japanese earthquake event also revealed insights regarding seismically induced flooding. The plants experienced flooding from sloshing of the spent fuel pool, fire suppression piping failure outside the Unit 1 reactor building that flowed into the plant through cable penetrations, and a condenser flexible connection failure. While there were no safety consequences, these flooding failures led to water flow to various portions of the plant that could have caused SSC functional failures.

TASK FORCE EVALUATION

The staff initiated Generic Safety Issue (GSI)-172, "Multiple System Responses Program (MSRP)," to address 21 potential safety concerns that were raised by the Advisory Committee on Reactor Safeguards (ACRS) during the resolution of USI A-17, "Systems Interactions in Nuclear Power Plants"; USI A-46, "Seismic Qualification of Equipment in Operating Plants"; and USI A-47, "Safety Implications of Control Systems." GSI-172 included the ACRS concern that the resolution of USI A-46, other seismic requirements, or fire protection regulations did not adequately address seismically induced fires. This concern was identified as Item 7.4.16 in NUREG/CR-5420, "Multiple System Responses Program—Identification of Concerns Related to a Number of Specific Regulatory Issues," published October 1989. ACRS was also concerned that previous internal flooding studies had examined events such as pipe ruptures (and subsequent flooding) as single events and that the nature of a seismic event could cause such problems in multiple locations simultaneously. This concern was identified as Item 7.4.18 in NUREG/CR-5420.

The staff developed guidance for the review of the safety concerns of GSI-172 in the IPE and IPEEE programs. As a result, the IPEEE program subsumed the issues related to seismically induced fires and floods.

With regard to seismically induced fires, NUREG-1742 states the following:

> All of the IPEEE submittals reported that the licensees qualitatively examined seismically induced fire interaction issues as part of the treatment of Sandia fire risk scoping study issues. A few licensees performed a PRA study for seismically induced fire-initiating events; albeit the level of detail varied from a simplistic probabilistic analysis to inclusion in their plant's seismic or fire PRA.
>
> In most of the submittals, licensees included seismically induced fire considerations within the scope of their overall seismic walkdown. The level of effort, scope, and detail directed toward addressing seismically induced fire issues varied significantly among the IPEEE submittals. One licensee did not discuss seismically induced fire evaluations in their IPEEE submittal. In most other cases, licensees limited their seismically induced fire evaluations exclusively to assessing direct impacts on safe shutdown equipment.

Seismically induced flooding events can potentially cause multiple failures of safety-related systems. The rupture of small piping could provide flood sources with the potential to affect multiple safety-related components simultaneously. Similarly, nonseismically qualified tanks are a potential flood source of concern. While some licensees proposed plant improvements to address related issues, NUREG-1742 states that the level of effort, scope, and detail directed toward addressing seismically induced flooding issues varied significantly among the IPEEE submittals. Some plants did not provide any information in their IPEEE submittals to verify this issue.

The GSI-172 issue regarding seismically induced fires and floods was closed based on the IPEEE results, and the NRC established no new requirements to prevent or mitigate seismically induced fires or floods. The Task Force concludes that the agency should reevaluate the closure of GSI-172 in light of the plant experience at the Kashiwazaki-Kariwa nuclear plant and the potential for common-mode failures of plant safety equipment as the result of seismically induced fires and floods.

Recommendation 3

The Task Force recommends, as part of the longer term review, that the NRC evaluate potential enhancements to the capability to prevent or mitigate seismically induced fires and floods.

SECY-11-0137

The NRC's Near Term Task Force (NTTF) recommendation 3 of SECY-11-0093 was prioritized as Tier 3 in SECY 11-0137 because longer-term staff evaluation was required to support a regulatory action. The Tier 3 consists of those NTTF recommendations that require further staff study to support a regulatory action, have an associated shorter-term action that needs to be completed to inform the longer-term action, are dependent on the availability of critical skill sets, or are dependent on the resolution of NTTF Recommendation 1. Recommendation 1 is "The Task Force recommends establishing a logical, systematic, and coherent regulatory framework for adequate protection that appropriately balances defense-in-depth and risk considerations."

In the Staff Requirements Memorandum (SRM) to SECY 11-0137, the Commission agreed with the Tier 3 prioritization of Recommendation 3, but directed the staff to initiate a PRA methodology to evaluate potential enhancements to the capability to prevent or mitigate seismically induced fires and floods as part of Tier 1 activities. The Tier 1 consists of those NTTF recommendations which the staff determined should be started without unnecessary delay and for which sufficient resource flexibility, including availability of critical skill sets, exists. Therefore, the prerequisite activity to initiate development of an appropriate PRA methodology should be started without unnecessary delay, while the remainder of Recommendation 3 activities remained prioritized as Tier 3. In addition, insights gained from the development of this methodology will be useful to implementation of other NTTF recommendations.

SECY-12-0025

In SECY-12-0025, the NRC's staff summarized the pre-planning activities needed for devising a detailed project plan for formulating a PRA method for seismically induced fires and floods. Pre-planning activities addressed several key aspects of this work, including the objectives of the methodology, intended users, stakeholder involvement, information gathering, coordination with other initiatives, resource needs, and proposed schedule.

Specifically, Enclosure 8 to SECY-12-0025, under the heading "Resource Estimate and Schedule for Probabilistic Risk Analysis Methodology on Seismically Induced Fires and Floods," mentions, in part, the following:

> Background
>
> As described in the NTTF Report, seismically induced fires have the potential to cause multiple failures of safety-related systems and induce separate fires in multiple locations at the site. Additionally, it has been recognized that events such as pipe ruptures (and subsequent flooding) could cause such problems in multiple locations simultaneously. Although these issues have been examined to a limited degree in the Generic Issues Program and Generic Letter (GL) 88-20, Supplement 5, "Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities," the NTTF concluded that the staff should reevaluate the potential for common-mode failures of plant safety equipment as the result of seismically induced fires and floods. Although this recommendation (NTTF Recommendation 3) was categorized as a Tier 3 item (identified for long-term evaluation), SRM-SECY-11-0137 directed the staff to initiate a probabilistic risk assessment (PRA) methodology to evaluate potential enhancements to the capability to prevent or mitigate seismically induced fires and floods as part of Tier 1 activities. Furthermore, the staff was asked to include a discussion of the resource estimate and schedule to develop the PRA methodology in the next 6-month status update to the Commission, as required by SRM-SECY-11-0117.

Staff Recommendation

The staff recognizes that the development of a PRA methodology to address seismically induced fires and floods represents a complex challenge. The scope of this effort is expected to cover seismically induced fires internal to the nuclear power plant, internal seismically induced floods (e.g., piping and tank ruptures), external seismically induced floods (e.g., upstream dam failures), and seismically induced losses of heat sink (e.g., downstream dam failures). There are significant challenges associated with this effort including, but not limited to the following:

- hazard definition and characterization
    - quantification of seismically induced fire ignition
    - quantification of site-specific seismically induced flooding frequencies
    - treatment of uncertainties
- modeling concurrent and subsequent initiating events
- treatment of systems interactions
- human reliability analysis applicability to seismically induced hazards
- multiunit risk considerations

SECY-12-0095

Enclosure 3, "Program Plan for Tier 3 Recommendations," to SECY-12-0095, offers a "Program Plan for Potential Enhancements to the Capability To Prevent or Mitigate Seismically Induced Fires and Floods." This program states, in part, the following:

Regulations and Guidance

- GDC 2, "Design Bases for Protection Against Natural Phenomena," of Appendix A to 10 CFR Part 50 requires, in part, that SSCs important to safety be designed to withstand the effects of natural phenomena such as earthquakes, floods, tsunami, and seiches without loss of capability to perform their safety functions.

- GDC 3, "Fire Protection," of Appendix A to 10 CFR Part 50 requires, in part, that fire detection and fighting systems of appropriate capacity and capability shall be provided and designed to minimize the adverse effects of fires on SSCs important to safety and that fire fighting systems be designed to assure that their rupture or inadvertent operation does not significantly impair the safety capability of SSCs.

- 10 CFR Part 50, Appendix R, "Fire Protection Program for Nuclear Power Facilities Operating Prior to January 1, 1979," Section III.O, "Oil Collection System for Reactor Coolant Pump," requires, in part, that the oil collection system be designed, engineered, and installed such that there is reasonable assurance that the system will withstand a safe shutdown earthquake (SSE).

- 10 CFR Part 100, "Reactor Site Criteria," Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Plants," provides detailed criteria to evaluate the suitability of proposed sites and the suitability of the plant design basis established in consideration of the seismic and geologic characteristics of the proposed sites. Appendix A, which applies to stationary reactor site applications before January 11, 1997, provides a deterministic approach for developing the seismic plant design basis. In contrast, 10 CFR 100.23, which applies to applications on or after January 11, 1997 and is being used by new reactor applicants to develop seismic design bases, requires that uncertainties inherent in the estimates of the SSE be addressed through appropriate analysis, such as probabilistic seismic hazard analysis.

- NUREG-0800, Section 2.4.2, “Floods,” issued November 1975 and updated June 1978, July 1981, April 1989, and March 2007; Section 2.4.10, “Flooding Protection Requirements,” issued November 1975 and updated May 1978, July 1981, and March 2007; and Section 2.5.2, “Vibratory Ground Motion,” issued November 1975 and updated July 1981, August 1989, March 1997, and March 2007 provide general review guidance related to site characteristics and site parameters together with site-related design parameters and design characteristics associated with the ground motion response spectrum and flooding hazards.

- RG 1.29, “Seismic Design Classification,” issued June 1972 and updated August 1973, February 1976, September 1978, and March 2007, describes one acceptable method for use in identifying and classifying those features of nuclear power plants that must be designed to withstand the effects of the SSE ground motion.

- RG 1.59, “Design Basis Floods for Nuclear Power Plants,” issued August 1973 and updated April 1976 and August 1977, discusses the design-basis floods that nuclear power plants should be designed to withstand without loss of capability for cold shutdown and maintenance thereof.

- RG 1.60, “Design Response Spectra for Seismic Design of Nuclear Power Plants,” issued October 1973 and updated December 1973, describes a procedure for defining the response spectra for the seismic design of nuclear power plants.

- RG 1.102, “Flood Protection for Nuclear Power Plants,” issued October 1975 and updated September 1976, describes the types of acceptable flood protection for the safety-related SSCs identified in RG 1.29.

- RG 1.125, “Physical Models for Design and Operation of Hydraulic Structures and Systems for Nuclear Power Plants,” issued March 1977 and updated October 1978 and March 2009, describes the detail and documentation of data and studies that an applicant should include in the preliminary and/or final safety analysis report to support the use of physical hydraulic model testing for predicting the performance of hydraulic structures and systems for nuclear power plants that are important to safety.

- RG 1.200, “An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities,” issued February 2004 and updated March 2009, describes one acceptable approach for determining whether the technical adequacy of the PRA, in total or the parts that are used to support an application, is sufficient to provide confidence in the results, such that the PRA can be used in regulatory decision-making for LWRs.

- Generic Letter (GL) 87-02, “Verification of Seismic Adequacy of Mechanical and Electrical Equipment in Operating Reactors, Unresolved Safety Issue (USI) A-46,” dated February 19, 1987, requested licensees to review the seismic adequacy of certain equipment in operating nuclear power plants against seismic criteria not in use when these plants were licensed.

- GL 88-20, Supplement 4, “Individual Plant Examination Of External Events (IPEEE) for Severe Accident Vulnerabilities,” dated June 28, 1991, and Supplement 5, “Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities - 10 CFR 50.54(f),” September 8, 1995, requested licensees to perform an IPEEE for plant-specific severe accident vulnerabilities initiated by external events and to submit the results to the NRC.

<u>Staff Assessment and Basis for Prioritization</u>

…No current state-of-practice PRA methods are capable of supporting a quantitative assessment of seismically induced fires and floods for nuclear power plants. Although the RG 1.200 regulatory positions addressing an acceptable approach for defining PRA technical adequacy do consider seismic/fire interactions, only a qualitative assessment is needed. Specifically, RG 1.200 states that a

qualitative assessment should be performed to verify that such seismically induced fires have been considered and that steps are taken to ensure that the potential risk contributions are mitigated. Current PRA standards do not specifically address seismically induced fires and floods. However, the American Society of Mechanical Engineers and the American Nuclear Society Joint Committee on Nuclear Risk Management recently formed a working group to investigate approaches for quantitatively addressing multiple concurrent hazards (including seismically induced fires and floods).

Staff Plan

Because of staffing limitations and because significant plant-specific information related to seismic and flooding hazard evaluations will not be received for several years, the staff plans to defer the evaluation of NTTF Recommendation 3 until 2016. However, the staff also believes that some supporting information to facilitate this evaluation can be developed during the next several years. The staff plans to engage in the following activities during FY 2012 through FY 2016 to address NTTF Recommendation 3:

- Initiate the development of a PRA methodology for addressing seismically induced fires and floods. As initially described in SECY-12-0025, the staff has completed a detailed plan for developing this method ... It should be noted that the staff has limited resources available to support new fire and external hazard PRA activities. Therefore, until it obtains sufficient information from ongoing activities supporting NTTF Recommendation 2.1, 2.3, and 4.2, the staff plans to dedicate resources to this method development activity at a level that will not preclude accomplishment of other high-priority work in the fire and external hazard area (e.g., development of new NFPA 805 fire and external hazard SPAR models). The staff plans to focus method development activities in two areas:

  (1) Coordination with standards development organizations (e.g., American Society of Mechanical Engineers and American Nuclear Society) and developing more generalized approaches for assessing concurrent hazards. This will help identify the technical elements and associated high-level and supporting requirements for a suitable PRA method, and will suggest specific areas where detailed guidance is needed.

  (2) Performance of a feasibility scoping study to identify issues associated with the risk assessment of multiple concurrent hazards and evaluation of available PRA methods within this context. This study would provide information regarding the capabilities of traditional and advanced risk assessment methods (e.g., linked event tree and fault tree, dynamic simulation-based approaches) for accident scenarios where issues such as event timing, dependencies, and concurrency can influence risk significance. This study would also include an evaluation of the current state of the art for addressing seismically induced fires and floods and, more generally, concurrent hazards…

D.2.1.3 Other Relevant NRC Publications

Workshop on "Probabilistic Flood Hazard Assessment (PFHA)"

A workshop on PFHA was organized by the U.S. Nuclear Regulatory Commission's (NRC's) Offices of Nuclear Regulatory Research (RES), Nuclear Reactor Regulation (NRR), and New Reactors (NRO), in cooperation with Federal agency partners: U.S. Department of Energy (DOE); Federal Energy Regulatory Commission (FERC); U.S. Army Corps of Engineers (USACE); U.S. Bureau of Reclamation (BoR); and U.S. Geological Survey (USGS). It was "…a research workshop devoted to the sharing of information on probabilistic flood hazard assessments for extreme events (i.e., annual exceedance probabilities much less than 2.0 E-3

per year) from the Federal community. The organizing committee has chosen the presenters and panelists who have extensive knowledge and experience in the workshop topics…"

The workshop goals were "…to assess, discuss, and inform participants on, the state-of-the-practice for extreme flood assessments within a risk context with the following objectives:

- Facilitate the sharing of information between both Federal agencies and other interested parties to bridge the current state-of-knowledge between extreme flood assessments and risk assessments of critical infrastructures.
- Seek ideas and insights on possible ways to develop a probabilistic flood hazard assessment (PFHA) for use in probabilistic risk assessments (PRA). Flood assessments include combinations of flood-causing mechanisms associated with riverine flooding, dam and levee safety, extreme storm precipitation, hurricane and storm surges, and tsunami.
- Identify potential components of flood-causing mechanisms that lend themselves to probabilistic analysis and warrant further study (i.e., computer-generated storm events).
- Establish realistic plans for coordination of PFHA research studies as the follow-up to the workshop observations and insights.
- Develop plans for a cooperative research strategy on PFHA for the workshop partners."

Though the workshop encompassed all causes of external floods, some of the presentations may be relevant to seismic-induced external floods. The workshop had 9 panels, and several presentations within each panel, as follows. The panels that seem more relevant to seismic-induced external floods are highlighted in bold font.

<u>Panel 1: Federal Agencies' Interests and Needs in PFHA</u>

"Panel 1 will be a forum to highlight the participating Federal agencies' interests and needs regarding Probabilistic Flood Hazard Assessments (PFHA). The presentations will include NRC staff's perspectives on the development of a PFHA approach within a risk context. Other presentations will focus on probabilistic approaches presently used or under development by the participating agencies, as well as ongoing efforts to develop consensus standards."

- NRC Staff Needs in PFHA (Fernando Ferrante, NRC)
- Probabilistic Hazard Assessment Approaches: Transferable Methods from Seismic Hazard (Annie Kammerer, NRC)
- Reclamation Dam Safety PFHA Perspective (John England, BoR)
- FERC Need for PFHA (David Lord, FERC)
- American Nuclear Society Standards Activities to Incorporate Probabilistic Approaches (John D. Stevenson, chair of ANS-2.31; Ray Schneider, Westinghouse)

<u>Panel 2: State-of-the-Practice in Identifying and Quantifying Extreme Flood Hazards</u>

"Panel 2 focuses on the state-of-the-practice in identifying and quantifying extreme flood hazards including their frequency and associated flood conditions within a risk context. Additional discussion on how extreme events (i.e., with an annual exceedance probability of much less than 2E-3 ranging to 1E-6) not historically observed or normally anticipated (i.e., "black swans") could be estimated. The panel will also discuss uncertainties in the estimation of flood levels and conditions."

- Overview and History of Flood Frequency in the United States (Will Thomas, Michael Baker Corp.)
- Extreme Flood Frequency: Concepts, Philosophy, Strategies (Jery Stedinger, Cornell University)
- Quantitative Paleoflood Hydrology (Jim O'Connor, USGS)
- USACE Methods (Douglas Clemetson, USACE)
- Hydrologic Hazard Methods for Dam Safety (John England, BoR)

Panel 3: Extreme Precipitation Events

"Panel 3 focuses on extreme precipitation events and their impacts on flooding due to local or watershed-scale responses. Antecedent conditions such as snowpack releases and combination of extreme storms (e.g., the possibility of sequential hurricanes or extratropical storms) will be included, as well as, various data sources and climate perspectives."

- Introduction of Panel, Objectives, and Questions (John England, BoR)
- An Observation-Driven Approach to Rainfall and Flood Frequency Analysis Using High-Resolution Radar Rainfall Fields and Stochastic Storm Transposition (Daniel Wright, Princeton University)
- Regional Precipitation Frequency Analysis and Extremes including PMP – Practical Considerations (Mel Schaefer, MGS Engineering Consultants)
- High-Resolution Numerical Modeling As A Tool to Assess Extreme Precipitation Events (Kelly Mahoney, NOAA-ESRL)
- Precipitation Frequency Estimates for the Nation and Extremes – A Perspective (Geoff Bonnin, NWS-OHD)
- Extreme Precipitation Frequency for Dam Safety and Nuclear Facilities – A Perspective (Victoria Sankovich, BoR)

Panel 4: Flood-Induced Dam and Levee Failures

"Panel 4 focuses on defining the current state-of-the-art and –practice, and research needs, related to estimating probabilities of failure and flooding associated with dams and levees. Presenters will address methods for estimating probabilities of failure, making probabilistic assessments of flood hazards, and determining inflow design floods. The emphasis will be on potential failure modes tied to hydrologic events and the associated erosion of embankments/foundations, not limited to overtopping failures."

- Risk-informed Approach to Flood-induced Dam and Levee Failures (David Bowles, RAC Engineers & Economists)
- Dutch Approach to Levee Reliability and Flood Risk (Timo Schweckendiek, Deltares Unit Geo-engineering)
- Risk-Informed Decision-Making (RIDM) Approach for Inflow Design Flood (IDF) Selection and Accommodation for Dams: A Practical Application Case Study (Jason Hedien, MWH)
- Incorporating Breach Parameter Estimation and Physically-Based Dam Breach Modeling into Probabilistic Dam Failure Analysis (Tony Wahl, BoR)
- USACE Risk Informed Decision Framework for Dam and Levee Safety (David Margo, USACE)

Panel 5: Tsunamis Flooding

“Panel 5 focuses on Probabilistic Tsunami Hazard Analysis (PTHA) as derived from its counterpart, Probabilistic Seismic Hazard Analysis (PSHA) to determine seismic ground-motion hazards. The Panel will review current practices of PTHA, and determine the viability of extending the analysis to extreme design probabilities (i.e., 10^{-4} to 10^{-6}). In addition to earthquake sources for tsunamis, PTHA for extreme events necessitates the inclusion of tsunamis generated by submarine landslides, and treatment of the large attendant uncertainty in source characterization and recurrence rates. Submarine landslide tsunamis will be a particular focus of Panel 5.”

- Probabilistic Tsunami Hazard Analysis (Hong Kie Thio, URS Corp.)
- Recent advances in PTHA methodology (Randy LeVeque, University of Washington)
- Landslide Tsunami Probability (Uri ten Brink, USGS)
- Modeling Generation and Propagation of Landslide Tsunamis (Pat Lynett, USC)

Panel 6: Riverine Flooding

“Panel 6 focuses on riverine flooding including watershed responses via routing of extreme precipitation events and antecedent conditions such as snowpack releases. This session is linked to Panel 3 and 4. {Flood-induced dam and levee failures will be addressed separately in Panel 4.}”

Riverine PFHA for NRC Safety Reviews – Why and How? (Rajiv Prasad, PNNL)
Flood Frequency of a Regulated River - the Missouri River (Douglas Clemetson, USACE)
Extreme Floods and Rainfall-Runoff Modeling with the Stochastic Event Flood Model (SEFM) (Mel Schaefer, MGS Engineering)
Use of Stochastic Event Flood Model and Paleoflood Information to Develop Probabilistic Flood Hazard Assessment for Altus Dam,Oklahoma (Nicole Novembre, BoR)
Paleoflood Studies and their Application to Reclamation Dam Safety (Ralph Klinger, BoR)

Panel 7: Extreme Storm Surge for Coastal Areas

“Panel 7 focuses on extreme storm surge for coastal areas due to hurricanes, extratropical cyclones and intense winter storms. The panel will also discuss seiche flooding on closed or semi-closed water bodies.”

- Coastal Flood Hazard in the Netherlands (Joost Beckers, Deltares)
- Recent Work and Future Directions in Coastal Surge Modeling within NOAA (Stephen Gill, NOAA)
- FEMA’s Coastal Flood Hazard Analyses in the Atlantic Ocean and Gulf of Mexico (Tucker Mahoney, FEMA)
- Modeling System for Applications to Very-Low Probability Events and Flood Response (Ty Wamsley, USACE)
- Coastal Inundation Risk Assessment (Jen Irish, Virginia Polytechnic Institute (VPI))

Panel 8: Combined Events Flooding

“Panel 8 focuses on identifying and evaluating combined event scenarios within a risk-informed framework. Combined events can include flooding caused by seismically-induced dam or levee

failure; flooding caused by combinations of snowmelt, rainfall and ice; flooding caused by combinations of coastal and riverine events; basin or system-wide performance and impacts; human and organizational factors; and other scenarios."

- Combined Events in External Flooding Evaluation for Nuclear Plant Sites (Kit Ng, Bechtel Power Corp.)
- Assessing Levee System Performance Using Existing and Future Risk Analysis Tools (Chris Dunn, USACE)
- Seismic Risk of Co-Located Critical Infrastructure Facilities – Effects of Correlation and Uncertainty (Martin McCann, Stanford University)
- Storm Surge - Riverine Combined Flood Events (Joost Beckers, Deltares)
- Combining Flood Risks from Snowmelt, Rain, and Ice – The Platte River in Nebraska (Douglas Clemetson, USACE)
- Human, Organizational, and Other Factors Contributing to Dam Failures (Patrick Regan, FERC)

Panel 9: Summary of Significant Observations, Insights and Identified Opportunities for Collaboration on PFHA

"Panel 9 will be a forum to provide summaries of significant observations and insights from the previous technical panel presentations and discussions."

NRC Generic Issue 204

Seismically induced external flooding (such as failure of upstream dams) was the subject of a recent NRC generic issue, GI-204, Flooding of Nuclear Power Plant Sites Following Upstream Dam Failure.

The latest information on this GI that was available to this literature search is the "Generic Issue Management Control System Report for Fiscal Year 2014 2nd Quarter" by the Office of Nuclear Regulatory Research (RES), and it is reproduced next.

> The Nuclear Regulatory Commission has started a formal evaluation of potential generic safety implications for dam failures upstream of U.S. commercial nuclear power plants. The complete scope of the generic issue includes the effects of flooding from upstream dam failures on nuclear power plants sites, spent fuel pools, and sites undergoing decommissioning with spent fuel stored in spent fuel pools. The NRC began examining this issue after inspection findings at two plants. Staff completed a draft of the screening assessment in July 2011. The issue was officially declared as Generic Issue (GI) 204 in February 2012.
>
> While this screening assessment did not identify any immediate safety concerns, inspections or other reviews at individual plants have led to those plants taking actions regarding flooding scenarios on site-specific basis. Generic Issue 204 has been subsumed as part of the implementation of the recommendations from the agency's Japan Near-Term Task Force (NTTF), which was assembled in response to the earthquake/tsunami and reactor accident at the Fukushima Dai-ichi site.
>
> While the NTTF used preliminary information from the screening assessment and discussed flooding in its July 2011 report (Agencywide Documents Access and Management System (ADAMS) accession number ML111861807), the issue related to flooding from the upstream dam failure came to the staff's attention long before the earthquake/tsunami and reactor accident at the Fukushima Dai-ichi site. New sources of information on this issue have accumulated over the past few years. This

information includes inspections of flood protection and related procedures, as well as recent re-evaluations of dam failure frequencies and possible flood heights at some U.S. nuclear power plants, suggesting that flooding effects in some cases may be greater than previously expected.

The NTTF's review of the Fukushima accident led to recommendations regarding the potential for flooding from all hazard mechanisms at operating reactors. In March 2012, letters were sent by the NRC to holders of operating licenses and construction permits, which requested the reevaluation of all floods hazards (including dam failures) using present-day guidance and methodologies. (Note: Sites undergoing decommissioning, which are part of the generic issue, are not included in the NRC's activities related to reevaluation of flood hazards.)

Nuclear power plant designs include protection against serious but very rare flooding events, including flooding from dam failure scenarios. Dam failures can occur as a consequence of earthquakes, overtopping, and other mechanisms such as internal erosion and operational failures. A dam failure could potentially cause flooding at a nuclear power plant site depending on a number of factors including the location of the dam, reservoir volume, dam properties, flood routing and site characteristics.

Documentation related to the Generic Issue can be found in ADAMS. The July 2011 screening assessment of potential nuclear plant safety issues from upstream dam failures is available in ADAMS under accession number ML113500495. The March 2012 transfer of the Generic Issue from the Office of Research to the Office of Nuclear Reactor Regulation for regulatory office implementation is available in ADAMS under accession number ML120261155.

The March 2012 request for information letters related to the reevaluation of flood hazards are available in ADAMS under accession number ML12053A340. Finally, the May 2012 letter stating the flood hazard reevaluation due dates are available in ADAMS under accession number ML12097A509. This letter describes the criteria used to place each site into one of three completion date categories. All hazard reevaluations are due to the NRC by March 12, 2015.

Out of the 22 sites that must submit by March 2013, the Recommendation 2.1 flood hazard reevaluation reports (FHRRs), 16 sites have submitted the FHRR on time. One site requested an extension and submitted the FHRR on May 2013. The remaining five sites requested an extension, which the NRC approved. The FHRRs are currently under review by Staff. All other sites are on schedule in submitting the FHRRs by their prioritized response due dates.

Section 5.0, "Seismically-Induced External Floods," of Appendix A of the NRC/RES "Plan for the Development of a Methodology for Seismically Induced Fires and Floods," mentions, in part, the following about these floods:

This generic issue has been transferred to NTFF Recommendation 2.1. After completion of this activity, the impact of the seismic event that caused the dam failure on the plant to cause internal fires and or internal floods should be examined in the context of Recommendation 3 work.

It is worth mentioning that the actuarial data and dam hazard statistics (as reported by Bureau of Reclamation database) indicate that the contribution of seismic events to dam failures is insignificant, as a percentage. Overtopping and other failures dominate the failure frequency. However, the point mentioned above should be examined in risk perspective. The following reference is included as a starting point for dam failures.

http://www.usbr.gov/ssle/damsafety/Risk/pfma/TabJ-SeismicFailureModes.pdf

However, the above internet address was not functional when it was exercised.

NRC Interim Staff Guidance JLD-ISG-2013-01

The NRC's Japan Lessons-Learned Project Directorate issued the Interim Staff Guidance (ISG) "Guidance for Assessment of Flooding Hazards Due to Dam Failure," (JLD-ISG-2013-01) "…to provide guidance acceptable to the staff of the U.S. Nuclear Regulatory Commission (NRC) for re-evaluating flooding hazards due to dam failure…" Chapter 5, "Seismic Dam Failure," of this ISG gives information on external flooding due to dam failure that is relevant to the probabilistic analysis of seismic-induced external flooding. The following paragraphs reproduce subsection 5.1.3, "Probabilistic Seismic Hazard Analysis." The reader is referred to that chapter for the details on this subject.

5.1.3 Probabilistic Seismic Hazard Analysis

A probabilistic seismic hazard analysis (PSHA) involves relating a ground-motion parameter to its probability of exceedance at the site. The value of the ground-motion parameter to be used for the seismic evaluation is then selected after defining a probability level, applicable to the dam and site considered. PSHA considers the contributions from all potential sources of earthquake shaking collectively. Uncertainty is treated explicitly, and the annual probability of exceeding specified ground motions (commonly expressed as response spectra acceleration(s) at the period of interest), are computed. Alternatively, the analysis may be performed for a specified duration of time (such as the operating life of the dam). PSHA involves a thorough mathematical and statistical process that takes into account local and regional geologic and tectonic settings, as well as applicable historic and geologic rates of seismic activity. The results are typically expressed in terms of peak ground acceleration (PGA), peak ground velocity (PGV), or spectral amplitudes at specified periods.

Whereas in the past deterministic approaches have been favored in dam engineering, there has been a gradual shift to probabilistic methods for determining ground-motion parameters. Therefore, the rest of this document will concentrate on the PSHA approach. Any PSHA study has three basic components: 1) seismic source characterization, 2) development of ground-motion estimates, and 3) development of the site response. Additional steps include the development of uniform hazard spectra and development of acceleration time histories.

Staff Position:

- PSHA is considered the state of practice for evaluating seismic hazards for dam failure.

NRC Interim Staff Guidance JLD-ISG-2012-04

The NRC's Japan Lessons-Learned Project Directorate issued the Interim Staff Guidance (ISG) "Guidance on Performing a Seismic Margin Assessment in Response to the March 2012 Request for Information Letter," (JLD-ISG-2012-04) "…as supplemental guidance to nuclear power reactor licensees on an acceptable method for performing a seismic margin assessment (SMA)…" The ISG is a reference on carrying out such assessment, but it does not specifically discuss seismic-induced fires or floods.

NRC Interim Staff Guidance JLD-ISG-2012-05

The NRC's Japan Lessons-Learned Project Directorate issued the Interim Staff Guidance (ISG) "Guidance for Performing the Integrated Assessment for External Flooding," (JLD-ISG-2012-05) "…to describe to stakeholders methods acceptable to the staff of the U.S. Nuclear Regulatory Commission (NRC) for performing the integrated assessment for external flooding…" The ISG is a reference on external flooding that may be relevant when performing a probabilistic analysis of seismic-induced floods.

NRC Information Notice (IN) No. 94-12: Insights Gained From Resolving Generic Issue 57: Effects of Fire Protection System Actuation on Safety-Related Equipment

This IN states "…The resolution of GI-57 involved gaining a detailed understanding of the potential safety significance of fire protection system intended and inadvertent actuations at U.S. commercial nuclear power plants. During the resolution process, the NRC staff reviewed operational experiences involving fire protection system actuations and developed a methodology for quantifying the effects of such actuations on safety-related equipment. The staff applied this methodology to one boiling-water reactor (BWR) and three pressurized- water reactors (PWRs). In doing this, the staff conducted extensive plant walkdowns and detailed reviews of plant documentation. Building on the insights gained from the analysis of these four plants, the staff also performed a generic risk assessment…"

The insights from this IN that appear to be most relevant to seismic-induced fires and floods are the following quotes:

1. Mercury Relays

   a. Mercury relays were present in the fire protection control systems for a diesel generator (DG) room. These relays are susceptible to seismic actuation. If present in common with any of the following features (identified on other plants), the potential for station blackout during a seismic event is increased:

      1) Water deluge-type FPSs in the DG rooms with nozzles aimed at the DG control panel, diesel air intake, or generator cooling air intake.

      2) Fire protection control systems that lock out the diesel generators and/or isolate the diesel generator rooms' cooling when the FPS is actuated in the DG rooms.

      3) A CO_2 FPS in a DG room where the DG control system is designed to shut down the engine due to presence of high CO2 or low oxygen in the engine air intake.

   b. Mercury relays were present in an auxiliary FPS control circuit designed to isolate cooling in a high-pressure coolant injection (HPCI) pump room. This design could result in the loss of the HPCI pump as the room overheats following a seismic event.

   c. Mercury relays were present in the actuation circuits for a control room Halon FPS. An inadvertent release of Halon could require either donning of emergency breathing apparatus (thus compounding communications problems and increasing the probability of human errors) or abandoning the control room following a seismic event.

2. Seismic Dust/Smoke Detectors

   Smoke detectors present in the fire protection actuation systems in many plants will likely be actuated by the dust that rises during a seismic event. When a fire protection control system is actuated by smoke detectors alone, a seismic event has the potential to lead to an inadvertent release of suppressant. A design of this type was observed for the CO2 FPS in a cable spreading room…

4. Fire Suppressant Availability During a Seismic Event

    a. One water FPS was installed with one pump driven by an electric motor and the other driven by a diesel engine. During a seismic-related loss of offsite power, the electric pump's non-vital power source could be lost, and the diesel-driven pump might not start because the lead-acid batteries powering its starter could become disconnected (the batteries were located on a weakly anchored metal storage rack, and were not fastened to the rack). Thus, in a seismic event, the fire main could fail to remain pressurized. At this plant, water was the agent used in the FPSs for the cable spreading room, the emergency diesel generator rooms, and many other areas (a seismic event potentially increases the likelihood of a fire in those and other critical areas of the plant).

    b. The supply reservoir for one CO2 FPS was a non-seismically mounted tank, and the batteries that supplied power to the tank outlet valve were weakly anchored to a shelf that had no end restraints. The tank outlet piping could be damaged and/or valve power could be unavailable during a seismically induced fire. In this plant, CO2 was the FPS agent for the cable spreading room, the emergency diesel generator rooms, and other plant areas.

    c. The supply bottles for one Halon FPS were attached to a non- seismically qualified wall by a single metal strap, providing a high likelihood that the bottle outlet piping could be damaged and the Halon could fail to be distributed if demanded by a fire during a seismic event. In this plant, the Halon was the suppressant agent for the cable spreading room.

5. Switchgear Fires

    Seismic/fire interaction is a contributor to risk in the emergency electrical distribution rooms due to the presence of a fire source (the switchgear itself). In some switchgear rooms, many critical cables are routed along the tops of the switchgear cabinets so that large numbers of these cables are vulnerable to a fire in any cabinet subdivision. To reduce the potential risk associated with these areas, some licensees have implemented the following options:

    a. Reduction of fire probability by securing the cabinets with seismic anchors to prevent tipping or sliding.

    b. Distancing the safety-related cables from the fire source or separating safety-related equipment cables by distance or physical barriers.

    c. Routing some cables out of the switchgear cabinets through locations other than the top of the switchgear to reduce the likelihood that a fire in a single cubicle could damage a large number of safety-related cables.

6. Electro-Mechanical Components in Cable Spreading Rooms

    Many cable spreading rooms contain electrical cabinets, increasing the risk due to seismic/fire interaction in these rooms. When such cabinets are present, fire probability can be reduced by securing the cabinets with seismic anchors to prevent tipping or sliding.

NRC Interim Staff Guidance JLD-ISG-2012-06

The NRC's Japan Lessons-Learned Project Directorate issued the Interim Staff Guidance (ISG) "Guidance For Performing a Tsunami, Surge, or Seiche Hazard Assessment," (JLD-ISG-2012-06) "…to describe to stakeholders methods acceptable to the staff of the U.S. Nuclear Regulatory Commission (NRC) for performing a tsunami, surge, or seiche hazard assessment for external flooding …" The ISG is a reference on external flooding due to this type of hazard that may be relevant when performing a probabilistic analysis of seismic-induced floods.

D.2.2 Individual Plant Examination of External Events (IPEEE)

Three IPEEEs were surveyed to get an idea of the extent to which seismically induced fires and floods were analyzed in this type of document. The IPEEEs studied were Diablo Canyon (a PWR), Limerick (a BWR), and Palo Verde (a PWR); the insights gained are described next for each plant.

Diablo Canyon IPEEE

Seismically-induced fires and floods are discussed in the following subsections of the Diablo Canyon IPEEE:

3.1.3.8 Seismically-Induced Fires

3.1.3.10 Seismically-Induced Floods

4.8.1 Seismic/Fire Interactions

5.2 External Flooding

Text from these subsections is reproduced next.

3.1.3.8 Seismically Induced Fires (page 3-14)

Seismically induced fires were assessed as part of the LTSP.[18] The potential for seismically induced fires was also considered in the fire risk scoping study evaluation (Section 4.8)[19] following the approach outlined in the EPRI Fire-Induced Vulnerability Evaluation final report (Reference 3-19).

3.1.3.10 Seismically Induced Floods (page 3-15)

The internal flooding scenarios previously analyzed (Reference 3-20) were reviewed and none was determined to present unique seismic problems. Additionally, a number of the seismic top events include contributing causes of piping failure or other component failures which considers potential seismic flooding scenarios. Seismically induced fires, seismic actuation of fire suppression systems, and seismic degradation of fire suppression systems are addressed in Sections 4.8.1.1 to 4.8.1.3.

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[18] LTSP stands for Long Term Seismic program.
[19] The references are to the Diablo Canyon IPEEE.

4.8.1 Seismic/Fire Interactions (pages 4-105 to 4-111)

The EPRI-suggested response to the Sandia Fire Risk Scoping Study issue related to seismic/fire interactions consists of the following three aspects:

1. Seismically Induced Fires
2. Seismic Actuation of Fire Suppression Systems
3. Seismic Degradation of Fire Suppression Systems

The IPEEE fire walkdown discussed in Section 4.2 included a seismic/fire component. This portion of the walkdown activities verified, through visual examination, the pertinent details in identified fire areas relevant to each of the three aspects identified above.

4.8.1.1 Seismically Induced Fires

The seismically induced fires aspect of the IPEEE fire walkdown focused on the potential hazards of flammable liquids or gases during a seismic event. The IPEEE walkdown team considered flammable liquids or gases within tanks, vessels, piping, cylinders, or other storage vessels that might be subject to leakage or failure.

Plant operating procedures specify that after a seismic event, a thorough inspection of all plant areas be conducted to assess and, if possible, remedy any damage that might have occurred to plant components as a result of the seismic event. Any earthquake-induced fire or potential fire hazard created by the earthquake would be identified during this inspection and, if necessary, the plant fire brigade would be dispatched to the fire. This inspection of all plant areas would be completed within two hours after a seismic event.

Bulk gas storage is not permitted inside structures housing safety-related equipment. A separate chemical and gaseous storage vault is provided for storage of hydrogen. Bulk hydrogen storage tanks are located outside, east of the auxiliary building. At the hydrogen bulk storage vault, the hydrogen system is equipped with excess flow automatic shutoff valves which will shut off hydrogen supply if system demand exceeds 50 cfm. The valves are inherently reliable passive elements, and the light weight internals and housings would not be vulnerable to damage from a seismic event since the valves are rigidly supported in place. These valves would provide protection against and indication of a significant hydrogen leak.

To further minimize hazards from a hydrogen explosion, hydrogen lines are enclosed within a guard pipe where it runs in areas containing safety related equipment. The guard pipe is vented to the outdoors and has been pressure tested to verify that it is leak tight. The guard pipe is constructed of carbon steel piping and fittings. Hydrogen leakage in safety related areas would require failure of both the hydrogen piping and the guard piping. This could be postulated to occur only in the event of complete collapse of the piping system. If this were to occur, hydrogen flow would be sufficient to trip the excess flow valves. A small hydrogen leak (insufficient to close the trip valves) is unlikely to occur in safety related areas and, as described below, would not create a hazard.

Fire zones containing safety related equipment in which the hydrogen piping (within guard pipe) runs are as follows:

1. Fire Pump Room (fire zone 3-R) elevation 115'.
2. Penetration Areas (fire zone 3-BB), elevations 115' and 100'.
3. Auxiliary Building, elevation 100' (fire zone 3-X).

In summary, large hydrogen leaks in safety-related areas are unlikely, and if such a leak occurred, the excess flow trip valves would prevent hydrogen build up. Small hydrogen leaks in safety-related areas cannot be reasonably expected to occur, and even if such a leak were to occur, an explosive concentration of hydrogen could not build up since these areas are properly ventilated to purge any hydrogen leakage.

The IPEEE fire walkdown also focused on the storage and use of compressed gas cylinders. Procedure AP C-763, "Compressed Gas Cylinder Control," includes the following requirement for storage of flammable gases:

> "Flammable gases (hydrogen, butane, propane, acetylene, etc.) and oxygen cylinders in storage shall be separated from each other by 20 feet or by an approved 5-foot high barrier that has a 1-hour fire rating."
>
> "When cylinders are used outside of an approved designated storage location, the cylinders shall be secured in an upright position to a structural member. Cylinders shall be secured to structural members in two places (e.g., top and bottom) using an approved strap specifically made for this or 1/2" thick rope minimum."

A complete welding and open flame permit system exists and is governed by the referenced administrative procedure. Oxygen and acetylene are stored in the hot shop and warehouse areas. Fuel gases are also used routinely in the machine shop area and hot shop. The fire hazards analyses of these areas considered the contribution of fuel gases to the overall combustible loading. Safety-related equipment is not present in any of these areas. The warehouse area and machine shop are protected by hose reels and backed up by portable fire extinguishers. Permits are required whenever welding or cutting is done outside established shop areas.

Flammable liquids containers are stored in flammable materials storage cabinets that meet the intent of NFPA 30, "Flammable and Combustible Liquids Code." Procedure OM8.1D1, "Fire Loss Prevention," includes instructions on controls for flammable liquids and temporary storage locations.

In addition to the controls and mitigating features applied to flammable gases and liquids, electrical switchgear is secured and supported such that it is unlikely to represent a seismic-induced fire hazard.

4.8.1.2 Seismic Actuation of Fire Suppression Systems

At the October 10, 1991, Advisory Committee on Reactor Safeguards (ACRS) meeting on the Long Term Seismic Program, several questions were raised regarding the PRA and the risk impact of inadvertent actuation of fire suppression systems during a seismic event. On October 11, 1991, PG&E and NRC Staff met with ACRS members to answer these questions. All questions were answered to the satisfaction of the ACRS members.

The ACRS questioned whether seismically induced inadvertent actuation of fire suppression systems had been considered in the PRA for fire water wet-pipe systems and fire water deluge systems. These systems had been considered in the PRA in the spatial interactions analysis and during the seismic walkdowns. As a result of the seismic walkdowns, it was concluded that seismically induced inadvertent actuation of these systems was not a significant contributor to risk.

In areas with safety-related equipment, wet-pipe systems are used with sprinkler heads. A fragility was developed for the sprinkler heads of the fire water wet-pipe system and was found to have a median seismic capacity greater than 10 g spectral acceleration. Therefore, it was concluded that it would be very unlikely for the sprinklers to actuate during a seismic event. Additionally, if the sprinklers did actuate, no single sprinkler can affect more than one train of safety-related equipment because of physical separation (either the trains are too far apart or located in separate compartments). Sprinkler heads deliver water at a rate of 20-30 gpm, covering an area 10-12 feet in diameter. Each sprinkler head actuates individually. Also see Section 4.3.5 for a discussion of fire water suppression system induced equipment damage.

Fire water deluge systems are used in a few select places in the plant. Specifically, DCPP[20] Unit 1 has 11 (10 in Unit 2) deluge valves for protection of the following systems:

- turbine bearings,
- hydrogen seal oil unit,
- main feedwater pump turbines,
- lube oil reservoir,
- main and startup transformers.

These systems are actuated in a variety of ways, such as mechanical linkage or by a control system. The only PRA equipment in locations where deluge systems are used, is the startup transformer. While the startup transformer is a source of offsite power, loss of the startup transformer alone would not result in core damage. Therefore, it was concluded that the fire water deluge systems would not contribute to risk. It is judged that even if there were an inadvertent actuation, the quantity of water would not be enough to affect other equipment. If one of these deluge systems were to actuate, it could result in an initiating event, but the frequency of occurrence would be small compared to the regular initiating event frequencies for these initiators.

One goal of the IPEEE fire walkdown team was to visually verify, where possible, the train separation for safety-related equipment with respect to wet-pipe sprinkler coverage. The walkdown also served to verify the absence of fire water deluge system impact on safety-related equipment. The walkdown also served to verify the presence and distribution of drains in relation to both types of fire water systems.

4.8.1.3 Seismic Degradation of Fire Suppression Systems

NRC Regulatory Guide 1.29, "Seismic Design Classification" provides guidance for identifying and classifying structures, systems, and components which should be seismically qualified. Among other things, this Regulatory Guide specifies that nonsafety-related structures, systems, and components should be seismically designed if their failure could jeopardize the functioning

[20] DCPP means Diablo Canyon Power Plant.

of safety-related components in a seismic event. Many nuclear power plants comply with Regulatory Guide 1.29 by virtue of a "Seismic II over I" program; i.e., Class II (nonsafety-related) components above Class I (safety-related) components are installed with seismic design considerations.

As a condition for the issuance of an Operating License (OL) for Diablo Canyon, PG&E implemented the Seismically Induced Systems Interaction Program (SISIP) to address this issue. During the pre-OL SISIP, extensive walkdowns of the Diablo Canyon Units 1 and 2 were performed to identify postulated seismically induced interactions created by nonsafety-related sources that could potentially jeopardize safety-related targets. Approximately 3800 seismically induced interactions were identified as a result of these walkdowns. Approximately one-third of these postulated interactions were of an inconsequential nature and were documented and dis positioned by the walkdown team with no further action required. Another one-third of the postulated interactions were resolved by various engineering analyses. In some instances, the analysis was a detailed seismic qualification; in other instances, the analysis might have been an evaluation of the consequences of the postulated interaction. The remaining one-third of the identified interactions were resolved by plant modification. The modification usually provided seismic qualification to the identified source. In some instances, targets were relocated or shielded. In a few instances, interactions were resolved by revising plant operating procedures.

The results of the Program conducted prior to the issuance of OLs for Units 1 and 2, including a computer database printout listing the 3,800 postulated interactions, are documented in the ten-volume SISIP Final Report (Reference 4-31). The SISIP Final Report includes the results of the pre-OL SISIP, the program manual for the pre-OL SISIP (Appendix B), and the interactions documented by the pre-OL SISIP (Attachment 13 for the Unit 1, Attachment 16 for Unit 2).

To ensure that the objective of the SISIP is met on an ongoing basis, plant modifications and housekeeping and maintenance activities are reviewed for their potential to create seismically induced systems interactions (SISI). The SISI Manual (Reference 4-32) provides the technical guidance to design engineers to perform SISI evaluations. Specifically, fire protection system modifications are evaluated to ensure that in the event of a seismic disturbance, the fire protection system as modified will not adversely affect safety-related equipment. This may be accomplished by supporting fire system components such that the components will not endanger safety-related equipment in the area.

The SISIP defines component failure as a failure of connections, structural members, and non-structural members (the component undergoes failure as opposed to failure of the components' supports). Connections to evaluate include welded or bolted connections. Failure of structural members can result from tensile loads, and compressive loads that can cause buckling, bending, shearing, torsion, or combined loads. Failure of nonstructural members includes failure of component accessories or appurtenances, equipment panels, or casings. If component failures occur, falling and/or gross deflections need to be considered. Degraded operation of the source component is not a concern unless environmental effects result from such degraded operation.

In most instances, the evaluation of failure potential component's also requires a concurrent evaluation of the component's support capability. The SISIP defines a component to include equipment, piping, ducting, raceways, tanks, panels and cabinets, and architectural features.

In addition to the failure of a component or its supports, deflection of piping is also considered in the SISIP analysis. Finally, if a component is assumed to fail or rupture, the following possible environmental effects are considered in the SISIP process:

- line break causing flooding or jet impingement
- steam line break creating a high temperature, high humidity environment
- chemical spills, such as acid, caustic or hydrazine
- hydrogen explosion
- toxic gas release
- oil spills and resulting fire
- switchgear failure resulting in explosion or fire

Fire suppression capability after a safe shutdown earthquake consists of manual hose reels and portable extinguishers. Hose reels have been provided throughout the plant so that all areas of the plant containing safety-related equipment are accessible by at least one hose stream. Portions of the fire water system have been seismically qualified so that all hose reels in safety-related areas of the plant, with the exception of the intake structure where the safety-related equipment is enclosed within fire barriers, will be available following a safe shutdown earthquake. The qualified system consists of the 300,000 gallon fire water tank, two motor-driven fire pumps, and fire mains and piping required to provide water to the hose reel stations in safety-related areas of the plant. Cross-ties exist between the auxiliary building and the turbine building so that the fire pumps can supply water to any fire system component within the plant without the use of the yard loop. Check valves in the six yard loop feeder lines into the plant prevent water loss out of the yard loop (which could conceivably be damaged as a result of an earthquake). The check valves have normally closed, manual by-passes to ensure availability of a backup water supply for the transformer deluge systems.

The seismically qualified portion of the fire water system can be readily isolated from the rest of the fire water system. Procedure EP M-4 (Reference 4-33) instructs operators as follows:

> "Within two hours following an earthquake > 0.02g, inspect all zones listed in Technical Specifications Table 3.3-11 for fires. If a portion of the Fire Protection System is earthquake damaged as ascertained by visual inspection or flow annunciator, isolate that portion from the remainder of the system (refer to Appendix 7.5 for Post-Earthquake Fire System Isolation Valve numbers and locations)."

The existing turbine building sprinkler systems can be isolated from the rest of the system by closing two valves per unit. Reactor coolant pump sprinklers can be isolated from the seismically qualified portion of the fire system by closing valves in the lines to the sprinkler systems or by closing containment fire system isolation valves inside or outside of containment. The existing auxiliary building sprinklers can be isolated by closing one valve. All sprinkler systems have flow alarms to provide control room annunciation of system actuation and/or leakage. Sufficient fire water would be available for multiple hose streams even considering the water that could be lost from breaks in nonqualified sprinkler piping prior to plant operators isolating the leaks. Backup fire protection capability is provided by three 250 gpm, portable, engine-driven fire pumps. Connections are available from the ASW (at the CCW heat exchanger) to provide suction to the portable pumps. The pump discharge can be tied into a fire main to resupply the fire water tank or to pressurize the fire system for long-term fire fighting. The portable pumps are stored in a suitable area to ensure that they will not be affected by a seismic event.

All buildings in which the qualified fire system piping is run have been reevaluated for the Hosgri earthquake and, where necessary, were strengthened as a result of the analysis. The qualified fire system piping runs in the vicinity of some non-Class I equipment in the turbine building; however, as a part of the Hosgri reevaluation, supports for major non-Class I equipment were reanalyzed and modified where necessary.

The IPEEE fire walkdown team observed examples of the following degrees of support for fire water suppression systems:

- seismically qualified
- seismically supported
- installed in accordance with NFPA 13

The IPEEE fire walkdown team verified that the various fire suppression systems installations throughout the plant did not introduce new seismically induced vulnerabilities to safety-related equipment.

5.2 EXTERNAL FLOODING (pages 5-2 and 5-3)

The external flooding hazard was evaluated by reviewing the FSAR Update, Sections 2.4, 3.4 (Reference 5-5), and the appropriate SRP criteria for the external flooding (Reference 5-2). This includes flooding from a maximum probable hurricane, tsunami, high tide, storm waves, probable maximum precipitation (PMP), and a severely degraded breakwater. The review concluded that DCPP conforms to the SRP criteria; therefore, there are no vulnerabilities. Reference 5-5 also shows that heavy rains will not cause sufficient ponding on the plant site to flood safety-related buildings; nor will it cause the only stream near the site (Diablo Creek) to overfill. The roofs of the safety-related buildings are designed to handle a PMP of 4 inches per hour. If the rainfall intensity should exceed this drain capacity, overflow scuppers will still prevent ponding on the roof. Yard areas around safety-related buildings are also sloped to keep water away from the buildings.

Another possible flooding source considered in Reference 5-1 is the raw water reservoirs located on the hill behind the plant at Elevation 310 feet. There are two reservoirs, each holding about 2.25 million gallons. Each reservoir is roughly egg-shaped, with major and minor dimensions of approximately 270 feet and 190 feet. It is unlikely that the reservoirs can fail in such a way to pose a threat to the plant. However, a worst case scenario was evaluated in Reference 5-1 and the study concluded that the depth of flooding is not expected to cause serious damage to the plant. In addition, the flood will only be temporary and not sustained.

The other issue for external flooding (Le., Section 2.4 of Reference 5-7) is Generic Letter 89-22 (Reference 5-10), in which the NRC adopted the latest National Weather Service (NWS) Probable Maximum Precipitation (PMP) criteria for future plants. It was indicated in the letter from the National Weather Service that the PMP for California, which is presently defined by Hydrometeorological Report (HMR) # 36 (Reference 5-11), is still valid. Thus, the present analysis in DCPRA for external flooding, which is based on HMR # 36, is still valid.

The only safety-related equipment needing special protection from external flooding are the auxiliary saltwater (ASW) pumps located within the intake structure. There are two ASW pumps per unit. Each pump is housed in its own room. Each room is equipped with a normally closed watertight door. The pump rooms are equipped with snorkels to allow air in the room to remove

heat from the ASW pump motors. These snorkels allow the pump rooms to be waterproof up to + 48 feet above the mean lower low water level (MLLW).

Two cases were evaluated for possible flooding of the ASW pump rooms (Reference 5-1). One case considers when one or more pump room doors being left open or failing during a tsunami event. In this case, flooding of the pump rooms will occur if the water level reaches the main deck level of the intake structure, which is at +20 feet MLLW. The other case considers the pump room doors being closed but the combined tsunami-storm wave height exceeding +48 feet MLLW.

The total frequency of flooding all four ASW pumps was calculated to be 5.7E-5 per year (Reference 5-1). However, loss of all ASW pumps does not automatically lead to core damage since there is a possibility of aligning fire water to the charging pumps, thus preventing RCP seal failure. The flood-initiated core damage failure frequency was therefore calculated to be 7.2E-7 per year, which is small compared with other contributors, and less than the 10E-6 per year suggested for screening in NUREG-1407 (Reference 5-7).

No significant items were noted for external flooding during the plant walkdown. Based on the review and walkdown, there have been no significant changes that would adversely affect the external flooding design basis at DCPP since issuance of the operating licenses.

In conclusion, the DCPP design basis for external flooding satisfies the SRP criteria. Also an assessment of Generic Letter 89-22 shows that the revised NWS PMP criteria does not impact DCPP. No potential vulnerabilities were identified with regard to external flooding.

Limerick IPEEE

Seismically-induced fires and floods are discussed in the following subsections of the Limerick IPEEE:

4.8.2.1 Seismic/Fire Interactions

5.2.2 Plant Design Basis

Text from these subsections is reproduced next.

4.8.2.1 Seismic/Fire Interactions (pages 4-58 to 4-61)

The seismic/fire interactions issue consists of three elements:

(1) seismically induced fires;

(2) seismic actuation of fire suppression systems;

(3) seismic degradation of fire suppression systems;

Seismically Induced Fires

As outlined in section 10.5 of the FIVE methodology, walkdowns were performed to address potential seismic/fire interaction. The results of these walkdowns show that one condition could

potentially result in a seismically induced fire. The condition involves the sight glasses on the diesel generator lube oil make up tanks in the diesel day tank rooms.

These sight glasses do not have isolation valves; therefore, should they fail during a seismic event, the oil in the lube oil make up tanks would drain out onto the day tank room floor. This condition is not considered to be a significant issue for the following reasons:

(1) The lube oil make up tanks are not needed to maintain operability of the diesels.

(2) Should the sight glass fail and release oil onto the floor of the day tank room, the room design will contain the oil within the room.

(3) Also, ignition of the oil is not postulated due to the lack of ignition sources (the postulated fire for this fire area is a fuel oiler lube oil leak from the diesel engine onto the floor of the diesel engine compartment, with subsequent ignition).

(4) Should a fire occur in the day tank room, it would be contained by the 3 hour rated fire barriers that make up the day tank room walls and it would be controlled by the pre-action sprinkler system which protects the diesel generator compartment (including the day tank room).

No other situations were discovered by the seismic/fire interaction walkdown team where flammable gas or liquid storage vessels could create a significant fire hazard due to a seismic event.

Seismic Actuation of Fire Suppression Systems

The seismic/fire interaction walkdown also investigated the impact of inadvertent actuation of fire suppression systems on plant equipment. As discussed in Section 9A.3.1.2 of the LGS[21] UFSAR, the suppression systems at LGS have been designed and located so that inadvertent operation of or a crack in the systems will not cause damage to redundant trains of safety related equipment that is needed for safe shutdown of the plant.

Seismic Degradation of Fire Suppression Systems

Fire suppression systems at LGS are designed and installed in accordance with the applicable NFPA [National Fire Protection Association] code. This code provides for an adequate level of support based on the geological characteristics of the region. In addition, systems located in safety related areas are designed and installed with the II1I design criteria for seismic conditions as required by PECO Energy specification M-400, (ref. 3.1-16, 3.1-17)[22] Safety Impact Review and Commodity Clearance/Structural Walkdown Program. Based on these conditions, hazards due to seismic degradation are not anticipated. Mercury switches are a special concern since they can cause equipment to spuriously operate during a seismic event. The fire protection systems were reviewed to determine if mercury switches are used. The following mercury switches were found on the fire system:

Electric motor driven fire pump (00-P512) discharge pressure switch. The pressure switch is designed to start the electric motor driven fire pump should the fire system header pressure

[21] LGS stands for Limerick Generating Station.
[22] References are to the Limerick IPEEE.

drop to 100 psig. A seismic event could cause the 00-P512 to start spuriously which would result in the pump running at minimum flow. However, since there is a relief valve on the pump discharge piping, no damage to the pump would result. A seismic event could also prevent 00-P512 from starting. However, should this occur the diesel driven fire pump (00-P511) would still be capable of starting at 95 psig. The fire system is designed such that only one pump is required to maintain system operability. The seismic event that is postulated for LGS is expected to last less than a minute; therefore, the impact of 00-P512 possibly being unavailable is considered to be insignificant, since it is expected that the pump would resume normal operation after the seismic event ends and 00-P511 would be available throughout the entire event.

This pressure switch is only capable of starting the fire pump on low fire system pressure, spurious actuation of this pressure switch would not result in shutting down the fire pump should the pump be operating at the time of the seismic event. Spurious actuation of this pressure switch would not result in actuation of any water suppression systems.

CO_2 system refrigeration system control pressure switch. A seismic event could cause the compressor to not operate on demand, or to operate spuriously. The seismic event that is postulated for LGS is expected to last less than a minute; therefore, the impact of the CO_2 system compressor operating or not operating is considered to be insignificant, since it is expected that the system would resume normal operation after the seismic event ends. Spurious actuation of this pressure switch would not result in actuation of any CO_2 suppression systems. Based on these conditions and the seismic walkdowns performed for fire suppression system, hazards due to seismic degradation are not anticipated.

5.2.2 Plant Design Basis

Potential Dam Failures, Seismically Induced (page 5-27 and 5-28)

UFSAR Section 2.4.4 discusses the potential failure of three major dams upstream of LGS whose seismic failure could generate significant waves in the LGS reach of the Schuylkill River. Table 2.4-2 lists minor dams that are either too small or too remote to cause significant flooding at LGS in the event of seismic failure. Table 2.4-3 lists the three major dams of concern. The dams are: Ontelaunee, Blue Marsh and Maiden Creek dams. Due to their design parameters, these dams cannot be considered seismic qualified. Their failure is considered simultaneously with the LGS SPF [Standard Projected Flood].

Sections 2.4.4.1 through 2.4.4.3.2 provide detailed discussions and analysis sequences on the potential dams' failure. Dam failure permutation and unsteady flow analysis was performed with a final conclusion that the most severe seismic dam break permutation of the three dams: Blue Marsh, Ontelaunee and Maiden Creek, would not endanger safety-related structures. A simplified analysis, presented in the UFSAR, is justifiable because the plant area is high above the Schuylkill River.

Palo Verde IPEEE

Seismically-induced fires and floods are discussed in the following subsections of the Palo Verde IPEEE:

3.1.1 Review of Plant Information, Screening and Walkdown

4.8.1 Seismic/Fire Interactions

Text from these subsections is reproduced next.

3.1.1 Review of Plant Information, Screening and Walkdown (page 3-5)

…The fifth column [of an abbreviated Walkdown form] pertained to flooding system interaction concerns, and is also intended to cover spray issues. Spray or flood issues typically arise from broken piping or failure of tanks and heat exchangers. These types of failures almost always are caused by poor anchorage, which upon failure results in excess movement which cannot be accommodated by the attached piping. These issues were also covered in the PVNGS[23] design to satisfy the requirements of RG 1.29, so the emphasis during the walkdown was on looking for issues that may have been overlooked or appeared marginal…

4.8.1 Seismic/Fire Interactions (page 4-20)

Seismic/fire interactions were addressed in Section 3.3 of Reference 4.10.11,[24] "Prescreening and Walkdown of Palo Verde Nuclear Generating Station for Seismic IPEEE." No concerns or vulnerabilities were identified.

In addition, NRC Information Notice 94-12, Effects of Fire Protection System Actuation on Safety-Related Equipment," was addressed. No lessons learned applicable to Palo Verde were identified. See Ref. 4.10.12, which is also appended to Ref. 4.10.6.

D.2.3 Electric Power Research Institute (EPRI)

EPRI Report NP-6989

The document "Survey of Earthquake-Induced Fires in Electric Power and Industrial Facilities" examined 18 earthquakes and 108 facilities. There were 4 sites where a fire ignition followed an earthquake. As discussed during the workshop of experts on the feasibility of developing a PRA method, expanding the time period of this report through 2014 could be useful.

The report conclusion states:

"Of the 108 power or industrial operation sites investigated, there are four instances of earthquake-induced fire. Two of the instances involve electrical fires caused by arcing in high voltage equipment. One instance is a chemical fire in a laboratory, and one (perhaps the least well understood), appears to be ignition of oil-soaked insulation on a steam line in a power

[23] Palo Verde stands for Palo Verde Nuclear Generating Station.
[24] References are to the Palo Verde IPEEE.

plant. The incidents of fire identified were all localized events within the facilities in which they occurred and did not appear to result in significant damage."

EPRI Report NP-6041-SL, Revision 1

The report "A Methodology for Assessment of Nuclear Power Plant Seismic Margin (Revision 1)" states "EPRI's seismic margin methodology enables utility engineers to quantify a nuclear power plant's ability to withstand an earthquake greater than design and still safely shut down for at least 72 hours. This cost-effective, practical methodology uses generic screening of systems and component seismic ruggedness and does not require probabilistic calculations. The revision adds depth, detail, and more complete procedures to the original report but does not change the basic method." The objective of this report is "To develop practical methods of assessing nuclear plant seismic margins."

The report further mentions "The original project team developed systems and experience-based seismic ruggedness screening guidelines, detailed plant walkdown procedures to verify component screening, and analytic methods for evaluating unscreened components. These methods are used to determine the seismic capacity for which there is a high confidence of a low probability of failure (HCLPF). The revision team incorporated detailed HCLPF calculational guidance for specific component types and included lessons learned from trial plant evaluations completed after report NP-6041 was issued."

The results documented in the report are "The seismic margin methodology enables engineers to choose a functional success path and several alternatives to shut down the plant and to identify the subset of plant structures and components associated with the path selected. The methodology further provides guidelines for screening the seismic ruggedness of subset components and structures. Components that satisfy screening criteria require no further evaluation. Remaining components require deterministic evaluations using in-structure motions calculated for the earthquake being assessed. The seismic margin earthquake (SME) is chosen to be sufficiently larger than the SSE to establish a significant seismic margin. Methodology procedures determine the weakest link components and establish the HCLPF level of ground motion for which the plant can safely shut down. Plant walkdowns ensure component compliance with screening guideline conditions. The revision gives detailed methods for calculating HCLPF values for an extensive variety of components."

EPRI Report 3002000709

The objective of report "Seismic Probabilistic Risk Assessment Implementation Guide" is "…to provide utilities with implementation guidelines for performing state-of-the-art [seismic probabilistic risk assessments] SPRAs. This report updates the initial version of the Electric Power Research Institute (EPRI) report Seismic Probabilistic Risk Assessment Implementation Guide (1002989) … to provide updated guidelines and approaches for seismic SPRAs…"

Appendix G, "Seismic Fire and Flood," "…describes a process to identify potential plant vulnerabilities, given the combined effects of a seismic event and consequential internal fire or internal flood hazards (that is, hazards that occur as a direct result of the seismic event), with a focus on seismically induced internal fires and internal floods that may have the potential to significantly affect the plant seismic risk. The results of this process provide insights that may be used to determine whether enhancements to the plant seismic probabilistic risk assessment (SPRA) or PRA-based seismic margins assessment (PBSMA) … are appropriate to explicitly

address individual consequential hazards." Accordingly, the scope of this Appendix' process does not include seismic-induced external floods.

The process described in Appendix G appears to be essentially the same approach proposed by Sloane, True, Andersen, et al. in their paper "Process for Identifying and Addressing Potential Seismically-Induced Internal Fires and Internal Floods in a Commercial NPP Seismic PRA or PRA-Based SMA."

D.2.4 International Atomic Energy Agency (IAEA)

IAEA-TECDOC-724

The IAEA Technical Document IAEA-TECDOC-724, "Probabilistic Safety Assessment for Seismic Events," mentions the following related to seismic induced fires and floods:

2.3. SEISMIC RESPONSE OF STRUCTURES, SYSTEMS AND COMPONENTS AND FRAGILITY DETERMINATION

…Ideally, the structural and system analysis should include definition of earthquake induced failure mode for each safety related structural element and component. One should also consider the possible systems interactions inside the plant. That is, failure of non-safety systems and components could induce the failure of safety related systems and components. Also other seismic secondary effects (like failure of a dam and possible flood at the site) may require modelling to obtain seismic response…

4. SECONDARY SEISMIC EFFECTS

4.1. INTRODUCTION

PSAs including seismic loads have been generally limited to the direct influence of the vibratory ground motion to different safety related items in the nuclear power plant, and the resulting influence of these to the annual frequency of core damage which is the major content of the subsequent sections. The concern for seismic loads in PSAs is their potential to initiate common cause failures or/and dependent failures.

The purpose of this section is to give some recommendations for identifying secondary effects which may appear as consequences of earthquakes.

Secondary seismic effects are often dismissed deterministically either as not being credible or because it is cumbersome to include these into the already complex framework of a PSA. This section will address some of the issues related to secondary seismic effects. Recent field observations have demonstrated the importance of secondary seismic effects in the damage distribution and subsequent impairment of function of plant systems. The most common secondary effects are what is termed as systems interactions. Other types of secondary effects include fire following an earthquake, inadvertent activation of fire protection systems and plant specific secondary effects such as flooding due to dam failures.

4.2. SYSTEMS INTERACTIONS

The inclusion of many types of systems interactions is common practice in current seismic PSAs. Systems interactions result when seismic failure of a non-safety system or component affects the performance of a safety related component or system. These interactions may be spatial or systematic. Spatial interaction includes falling, hammering, spray and internal flooding. A very common spatial interaction is failure of unreinforced masonry walls which may impact essential equipment.

Systematic interactions include such scenarios as failure of a non-safety heat exchanger which breaks the closed loop component cooling water systems resulting in loss of CCW. Modern plant designs preclude most potential systems interactions but they are quite common in earlier NPPs.

4.3. SEISMIC FIRE INTERACTIONS

This is currently a subject of interest and has been studied by USNRC contractors ... Fire protection systems are typically not designed for earthquakes and are often damaged in earthquakes. If a seismic event initiates a fire and the fire protection system is unavailable, the plant may be severely damaged. Fire protection system failures are often examined as a spatial system interaction source of spray or falling but in the event of a fire, the unavailability becomes even more important. Another current issue with fire protections systems is activation resulting from an earthquake. This is often a source of water damage to equipment in non-nuclear facilities and a potential threat in nuclear facilities.

Other consequences which could result from inadvertent activation of fire protection systems are uninhabitability of the control room and shutdown of emergency diesel generators upon a fire signal. These fire and fire protection systems issues are often difficult to identify and model.

4.4. PATHWAYS FOR OTHER SEISMIC SECONDARY EFFECTS ON NUCLEAR FACILITIES

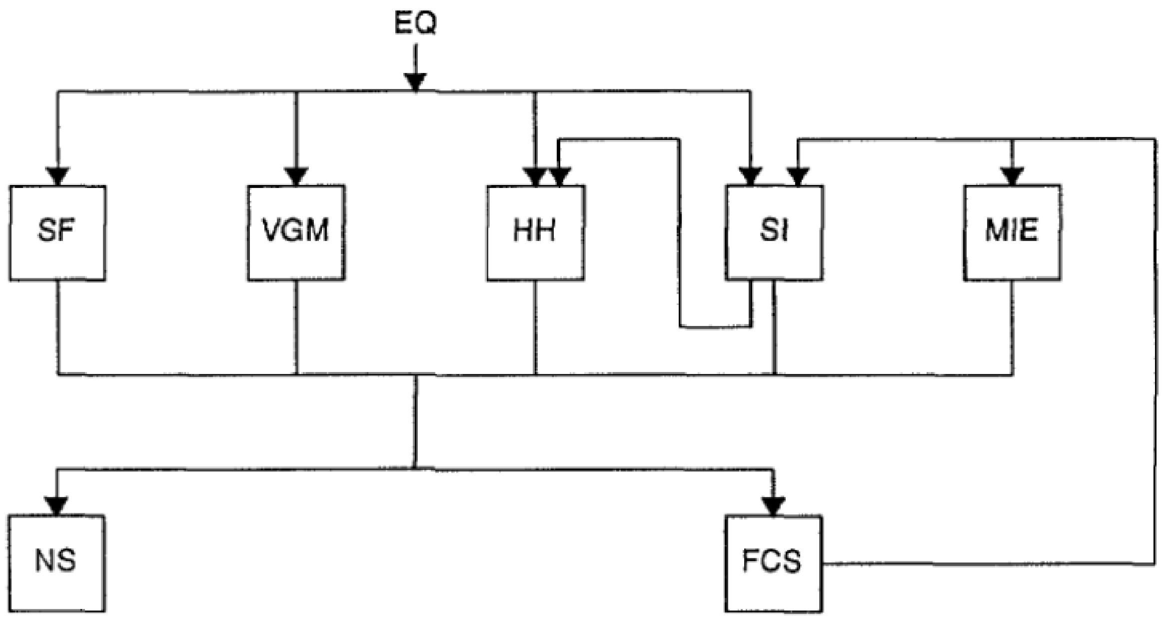
Seismic events may initiate an accident in various ways because of the number of intermediate effects which finally cause failure or loss of function of NPP components.

Figure 5 gives a condensed version of these possible pathways. Various elements may be located in each block; see the legend of Fig. 5.

It should be noted that many of the seismically induced secondary events may not constitute an immediate input into a 'seismic' PSA. For example consider the pathway EQ → VGM → FCS → MIE → NS, i.e. vibratory ground motion due to earthquake causes the failure of a dam and consequently the nuclear power plant site is flooded. Although the original trigger is seismic, the eventual effect to the nuclear power plant site is in the form of a flood and the additional due risk can be accounted for within the framework of a 'flood' PSA.

It may be necessary to produce a new seismic hazard curve for some secondary effects if they take place some distance away from the site. For example, the loss of off-site power might be initiated at a switching station remote from the NPP. The time aspect of secondary effects should not be forgotten; the most obvious example is impact due to aftershocks. Some of these possible pathways are discussed in more detail in the following sections.

In practice, most of the pathways which can be generated using Fig. 5 would have such a low probability of occurrence that these scenarios would be considered 'impossible' and taken out of further consideration. However, in performing a PSA it may be discovered that secondary effects have not been excluded when siting the plant.



EQ: Earthquake
VGM: Vibratory ground motion
SF: Surface faulting
HH: Hydrological hazards; Tsunami, Seiche
SI: Soil instabilities: Liquefaction, slope instability, subsidence, collapse
MIE: Man-induced events: Flood, fire, drifting cloud, explosion
FCS: Failure of conventional structures (dams, pipelines, storage facilities for explosive material)
NS: Nuclear structures (containment, reactor building, buildings neighbouring reactor, power lines, switchyard, water intake structures, ultimate heat sink, diesel generator building, fuel storage facility).

Hazards considered for NS: Fire, explosion, flood, settlement, uplift, loss of bearing capacity, overturning, tilting, sliding, foundation rupture, impact due to collapse of other structures, drawdown.

FIG. 5. Block diagram for pathways.

Some of the reasons are as follows:

- New (i.e. after design/construction of the nuclear power plant) information and evidence may be revealed indicating an increase in a particular natural hazard. An example of this is the discovery of a fault in the site vicinity.
- New general information and evidence may lead to a different interpretation of seismic hazard at the site. This may be due to more data in terms of additional epicentres in the site region or strong motion records obtained elsewhere but which may have applicability to the site. This could lead to a higher design acceleration or higher design spectral ordinates.
- The above items also apply to conventional structures in the site vicinity whose failures may adversely affect the nuclear power plant safety. Furthermore, safe siting criteria for these structures are generally less strict and the design basis vibratory ground motion for these is lower in comparison with nuclear power plants.
- There may also have been construction of new conventional structures in the site vicinity whose failure may adversely affect nuclear power plant safety, such as a pipeline, petrochemical facility or a dam.
- Finally, new understanding and interpretation of nuclear safety concepts may also initiate considerations for earthquake levels beyond design basis.

4.5. EXAMPLE SCENARIOS FOR OTHER SEISMIC SECONDARY EFFECTS

Ten example scenarios have been compiled in Table I. This is not an exhaustive list and the analyst must insure that all possible sequences for any specific sites are covered.

Each of the sequences could be developed into an event tree…

Although all the pathways are initiated by seismic events, this does not mean that the risk from all of the pathways is in all cases appropriately included in the estimation of the seismic risk increment for the facility; nor does it mean that a detailed analysis of a seismically initiated pathway need necessarily be performed as part of the seismic PSA. It would be perhaps more appropriate for several of the indirect pathways to be evaluated as part of other external event analyses.

For example, if a seismic PSA is being performed for a nuclear facility which is in the flood plain of a dam, then it is almost certainly the case that a flood analysis for the facility is being performed as well. This flood analysis will consider non-seismically induced modes of flooding arising from such phenomena as random failure of the dam, dam failure due to severe weather, improper operation of the dam, etc. It would be entirely possible to increase the frequency of the gross failure of the dam by the amount due to seismic events and, in this way, account for the risk to the nuclear facility from seismically induced dam failure. In fact, this seems to be a much more desirable approach since the analysis of plant damage will be similar for seismically induced failure of the dam as for non-seismically induced modes of failure.

The word similar is used because there is one important distinction between seismically induced flooding at a nuclear facility site and other flood events at the site, and that is the fact that the facility will also very likely be subjected to some seismic loading as well as flood damage, depending on the epicentral location of the earthquake, the proximity of the dam to the facility, the surrounding geology, etc. This problem of having to consider two simultaneous or closely sequenced external events impacting a facility is a very difficult one. It has not been extensively

addressed and may, in fact, defy adequate treatment. One may wish, instead, to calculate the probability of sustaining two severe external events simultaneously and assume some maximum damage state to result. The frequency of such a damage state arising from this simultaneous occurrence would then be simply equal to the expected frequency of simultaneous occurrence of the two external events. This frequency may be well within whatever is deemed to be an acceptable level of risk for the facility. If so, then no further analysis would be necessary. If not, then it might be necessary to reevaluate the situation to reduce conservatism and, possibly, resort to a specialized analysis which deals with the effects of two simultaneous external events.

TABLE I. EXAMPLES OF SCENARIOS FOR OTHER SEISMIC SECONDARY EFFECTS

SECONDARY SEISMIC EFFECT	CONSEQUENTIAL EFFECTS
1A. Soil liquefaction under NPP structures IB. Soil liquefaction not under NPP structures	Severe structural damage leading to core damage Loss of off-site power Loss of cooling water Worsened access
2. Slope instability, subsidence or ground collapse	Direct damage to NPP structures Blockage of river causing flood Damage to water retaining structures
3. Surface faulting	Direct damage to NPP structures Loss of ultimate heat sink
4. Structural damage to power lines, switchyards, etc.	Loss of off-site power
5. Tsunami, seiche or dam failure	Flooding of safety related items Damage to power lines, etc. — loss of off-site power Damage to NPP structures
6. Damage to pipelines or hazardous storage	Fire Explosion Toxic effects Missiles

4.6. RISK CATEGORIES

Once all of the consequential effects have been considered and event trees prepared, the risks can be categorized and ranked in order of probability. Then each one can be considered for inclusion in the PSA, or eliminated if the risk is acceptably small.

6.2.1. Initiated plant states

…In Section 4, discussion was made of the many types of indirect failures, such as those produced by systems interactions, tsunami flood, avalanche, etc., which might also be induced by the seismic event. For other than the systems interaction case these indirect failures, although caused by the earthquake, are (typically) not treated in the accident sequence resulting from the seismic initiators. They are usually treated in the external initiator PSA using methods which have been developed for them specifically. The effects of a seismically induced flood may be quite different from those of other external floods because the plant may be

subjected to more than one threat to safety. Thus, the damage to the plant due to the combination of seismic and flood effects may be greater than that arising from either occurring separately. Perhaps more important and more problematical than the possible associated external initiators are internal initiators, such as fire and possibly also floods, which may be initiated by the seismic event. In the case of fires, the seismic initiator may fail fire barriers and fire detection/mitigation systems, and the combination of fire and structural motion may together produce more damage in other safety systems than if they had occurred separately. This aspect of indirect seismic failures is obviously quite complex and has yet to be fully modelled.

IAEA Safety Standards Series No. NS-G-2.13

The IAEA Safety Standards Series No. NS-G-2.13, "Evaluation of Seismic Safety for Existing Nuclear Installations", mentions the following related to seismic induced fires and floods:

2.13. The final documentation to be produced at the end of the evaluation should be identified from the beginning in agreement with the regulatory body and should be consistent with the established purpose of the programme. The end products of these evaluations may be one or more of the following:

…(e) Identification of interactions with fire prevention and protection systems, etc…

3.17. All available information relating to actual earthquake experience at the site or at other industrial installations in the region should be obtained. Special attention should be paid to earthquake induced phenomena such as river flooding due to dam failure, coastal flooding due to tsunami, landslides and liquefaction.

4.1. An initial step of any programme for seismic safety evaluation — in parallel with the collection of related data as indicated in Section 3 — should be to establish the seismic hazard with regard to which the seismic safety of the existing installation will be evaluated. In this regard, the seismic hazard specific to the site should be assessed in relation to three main elements:

a) Evaluation of the geological stability of the site … with two main objectives:…
b) Determination of the severity of the seismic ground motion at the site…
c) Evaluation of other concomitant phenomena such as earthquake induced river flooding due to dam failure, coastal flooding due to tsunami, and landslides.

5.2. The SMA [Seismic Margin Assessment] methodology comprises a number of steps. One description of these steps is as follows:

1) Selection of the assessment team;
2) Selection of the review level earthquake (see Section 4);
3) Plant familiarization and data collection (see Section 3);
4) Selection of success path(s) and of selected SSCs3;
5) Determination of the seismic response of selected SSCs for input to capacity calculations;
6) Systems walkdown and seismic capability walkdown;
7) HCLPF determination for selected SSCs;
8) HCLPF calculations for the installation;
9) Enhancements to the programme (e.g. seismic induced fire and flood evaluations, detailed relay reviews);

10) Peer review (see Section 8);
11) Documentation (see Section 8).

5.9. The systems walkdown is aimed at reviewing preliminary success path(s), and it should be performed by an assessment team that, as indicated in para. 5.4, includes systems engineers, operations personnel and seismic engineers. Operations personnel should ensure that the selected paths are compatible with plant operating procedures. Seismic engineers should review the candidate SSCs for robustness and for ease of demonstrating high capacities. This latter review includes the SSCs and the immediate surrounding areas for the purpose of considering potential sources of failure of SSCs due to the effects of seismic induced system interactions. The end result of the systems walkdown is the selection of the final success path(s) and the set of selected SSCs to be evaluated.

5.20. The SPSA [Seismic Probabilistic Safety Assessment] methodology has evolved over the past three decades following the development of PSA methodologies for internal events. The SPSA methodology comprises a number of steps. In general, an SPSA should include:

1) Selection of the assessment team;
2) Seismic hazard assessment (see Section 4);
3) Plant familiarization and data collection (see Section 3);
4) Systems analysis and accident sequence analysis leading to event tree and fault tree modelling and identification of the selected SSCs;
5) Determination of the seismic response of structures for input to fragility calculations;
6) Human reliability analysis for seismic events;
7) Walkdowns for seismic capability;
8) Fragility calculations for the selected SSCs;
9) Risk quantification for the installation;
10) Enhancements to the programme (e.g. seismic induced fire and flood evaluations, detailed relay reviews);
11) Peer review (see Section 8);
12) Documentation (see Section 8).

5.31. Depending on the final objective of the evaluation, the regulatory body and the operating organization should consider aspects such as:

a) Analysis of non-seismic failures. The analysis of non-seismic failures is treated easily in the SPSA, since the system models are derived from the internal event models, which were developed to represent non-seismic failures. Those SSCs having low non-seismic reliability should be included in the quantification of risk, and their effects on the end metrics may be quantified with sensitivity studies.
b) Global behaviour of structures such as uplift, drift, overturning and settlement, and the modelling of these in the PSA (e.g. singletons).
c) Human actions (see para. 5.18).
d) Evaluation of the containment and containment systems (see para. 5.19), including fragility functions developed (HCLPF values).
e) Evaluation of electrical devices (see para. 5.48).
f) Evaluation of interactions due to seismically induced fire and seismically induced flooding.

5.33. Plant walkdowns are one of the most significant components of the seismic safety evaluation of existing installations, for both the SMA and the SPSA methodologies. Plant

walkdowns should be performed within the scope of the seismic safety evaluation programme. The term ‘plant walkdown’ is used here to denote the ‘seismic capability walkdown’ for the SMA approach and the ‘fragility walkdown’ for the SPSA approach. These walkdowns may serve many purposes, such as: gathering and verifying as-is data; verifying the screening-out of SSCs due to high capacities on the basis of engineering judgement; verifying the selection of safe shutdown paths for the SMA; evaluating in-plant vulnerabilities of SSCs, specifically issues of seismic system interaction (impact, falling, spray, flooding); identifying other in-plant hazards, such as those related to temporary equipment (scaffolding, ladders, equipment carts, etc.); and identifying the ‘easy fixes’ that are necessary to reduce some obvious vulnerabilities, including interaction effects. Walkdowns should also be used to consider outage configurations that are associated with shutdown modes. Detailed guidance on how to organize, conduct and document walkdowns should be developed or adapted from existing walkdown procedures.

5.39. The walkdown should also be aimed at identifying spatial interactions, which have the potential to adversely affect the performance of the selected SSCs. The following are major issues of seismic system interactions that should be addressed:

a) Falling interaction is a failure of the structural integrity of a non-safety-related item or a safety related item that can impact on and damage one or more selected SSCs…
b) Proximity interactions are defined as conditions in which two or more items are in close enough proximity that any unsafe behaviour of one of them may have consequences for the other. The most common example of a proximity interaction is the impact of an electrical cabinet containing sensitive relays with adjacent items.
c) Spray and flooding can result from the failure of piping systems or vessels that are not properly supported or anchored. Inadvertent spray hazards to selected SSCs arise most often from wet piping systems for fire protection. Impact and fracture or leakage of sprinkler heads is the most common source of spray. If spray sources can spray equipment sensitive to water spray, then the source should be backfitted, usually by adding support to reduce deflections and impacts or stresses. Large tanks may be potential flood sources. If a flood source can fail, the walkdown team, with the assistance of plant personnel, should assess the potential consequences, taking into account the flow paths and dispersion of liquid through penetrations, drains, etc.

Seismic induced fire and flood

5.49. Seismic safety reviews should include seismic induced events such as fire and flood. Such reviews should be performed by a team that comprises seismic engineers and fire engineers, in particular those who have been involved in the evaluation of the installation’s fire risk analysis. These reviews should be performed principally by means of plant walkdowns focused on area reviews, that is, the review for ignition sources and combustibles in areas or compartments containing components important to the success path or the SPSA. Ignition sources are those potentially initiated by the earthquake induced shaking. Combustibles in the area where ignition occurs and in adjoining areas should be reviewed with respect to fire protection and possible fire spread due to the failure of boundaries. Potential impacts on the success paths chosen (for SMA) and on the risk quantification (for SPSA) should be incorporated into the evaluations and should be adequately documented.

5.50. Experience from past earthquakes has demonstrated that numerous configurations of fluid retaining components are susceptible to damage from earthquake induced shaking. Examples include unanchored tanks, non-ductile piping, mechanical couplings for piping systems (fire protection systems) and sprinkler heads for wet systems. The need to review local sources of

spray and flooding when evaluating items on the list of selected SSCs is discussed in paras 5.32–5.40 on plant walkdown. Overall area walkdowns covering buildings and yards should be performed to evaluate other sources of flooding, for example, sloshing of water in spent fuel pools, failure of tanks at higher elevations in a building with flow paths available through penetrations in the floor and failure of yard tanks with flow paths available to building levels below ground level. A further specific evaluation should cover inadvertent actuation of the fire protection system. Potential impacts on the success paths chosen (for SMA) and on the risk quantification (for SPSA) should be incorporated into the evaluations.

5.51. Influences of tsunami hazards on the safety functions of nuclear installations located near coastlines, for example, the malfunctioning of equipment located at a low level, such as seawater pumps, should be evaluated...

8.4. The peer review should be conducted by experts in the areas of systems engineering, operations (including fire prevention and protection specialists), earthquake engineering and relay circuits (if a relay review is performed). Peer review should be performed at different stages in the evaluation process, as follows:

1) The systems and operations review should be performed first, coinciding with the selection of the success paths for SMA or the tailoring of the internal event system models for the SPSA.
2) Seismic capability peer reviews should be performed (a) during and after the walkdown and (b) after a majority of the HCLPF values (for SMA) or fragility functions (for SPSA) for the SSCs have been calculated. The seismic capability peer review should include a limited plant walkdown, which may coincide with a part of the plant walkdown or may be performed separately.

The findings of the performed peer reviews should be documented in specific reports.

8.6. Typical documentation of the results of the seismic safety evaluation should be a report documenting the following:…

m) Treatment of non-seismic failures, relay chatter, dependences and seismic induced fire and flood…

8.7. In addition to the above information, the following detailed information should be retained:…

c) Detailed documentation of all walkdowns performed, including SSC identification and characteristics, screening (if appropriate), spatial interaction observations for the seismic system, and area walkdowns usually performed for systems such as cable trays and small bore piping, and to evaluate seismic induced fire or flood issues…

IAEA SSG-3

The IAEA Specific Safety Guide No. SSG-3, "Development and Application of Level 1 Probabilistic Safety Assessment for Nuclear Power Plants", mentions the following related to seismic induced fires and floods:

6.13. The general approach used for the identification of a realistic set of combinations of hazards should be based on a systematic check of the dependencies between all internal and external hazards. The following causes for combinations of hazards should be considered:

a) Hazards have the potential to occur under the same conditions and at the same time (e.g. high winds and snow precipitation).
b) One external hazard can induce other hazards (e.g. a seismically induced external flood accompanied by dam failure).
c) External hazards can induce internal hazards (e.g. seismically induced internal fires or floods).
d) One internal hazard can induce other internal hazards (e.g. internal floods induced by internal missiles).

The impact of combinations of hazards on safety functions should be reassessed as they may affect different safety functions or the same function in a more severe manner than a single hazard.

8.8. As seismic hazards appear to be important contributors to core damage frequency in many Level 1 PSAs, a detailed analysis should be performed. However, in order to limit the effort required for Level 1 PSA for seismic hazards, it is possible to perform a bounding analysis for seismic hazards of a certain range. The secondary effects of seismic hazards (e.g. seismically induced fires and floods) should also be considered at this stage.

8.66. The potential for seismically induced fires and floods should also be included in the focus of the walkdown.

8.89. The model for seismically induced damage of structures, systems and components should thoroughly take into account all dependent failures of the equipment located in the building after damage of the building due to a seismic event. If dependencies of this type are to be eliminated from the model or if their significance in the model is to be decreased, this should be justified.

8.91. A thorough check and associated adjustment should be performed in relation to recovery actions and probabilities of human errors. Recovery actions that cannot be performed due to the impact of seismic events of certain magnitude should be removed from the Level 1 PSA model or probabilities of failure whilst performing the action should be increased. All post-initiator human errors that could occur in response to the initiating event, as modelled in the Level 1 PSA for internal initiating events, should be revised and adjusted for the specific seismic conditions. As a minimum, the following seismically induced effects on the operators' performance shaping factors should be taken into account:

a) Availability of pathways to specific structures, systems and components after a seismic event;
b) Increased stress levels;
c) Failures of indication or false indication;
d) Failure of communication systems;
e) Scenarios with consequential fire and flood;
f) Other applicable factors impacting the operators' behaviour.

8.92. Seismically induced fires and floods should be included in the Level 1 PSA model for seismic hazards, unless it is clearly justified that other seismic damage bounds additional effects from seismically induced fire and floods.

8.98. Uncertainties, dependencies and correlations should be thoroughly accounted for in developing accident sequence models for initiating events induced by external floods.

D.2.5 Canadian Nuclear Safety Commission (CNSC)

REGDOC-2.4.2

This regulatory document is part of the Canadian Nuclear Safety Commission's (CNSC) Safety Analysis series of regulatory documents, and it sets out the requirements of the CNSC with respect to the probabilistic safety assessment.

Issued as REGDOC-2.4.2, this document is the second version of Probabilistic Safety Assessment (PSA) for Nuclear Power Plants. It supersedes the previous version of the same title that was identified as S–294. REGDOC-2.4.2 includes amendments to reflect lessons learned from the Fukushima nuclear event of March 2011, and to address findings from the CNSC Fukushima Task Force Report, as applicable to S–294.

As stated in its Introduction, "The purpose of this regulatory document, when incorporated into a licence to construct or operate a nuclear power plant (NPP) or other legally enforceable instrument, is to assure that the licensee conducts a probabilistic safety assessment (PSA) in accordance with defined requirements." However, it gives little guidance on how to implement a PSA. Nevertheless, Section 4.8, "Site-specific initiating events and potential hazards," states, in part:

> Include all potential site-specific initiating events and potential hazards, namely:
>
> - internal initiating events and internal hazards
> - external hazards, both natural and human-induced, but non-malevolent
>
> Include potential combinations of the external hazards…
>
> **Guidance**
>
> Examples of external hazards are seismic hazards, external fires (e.g. fires affecting the site and originating from nearby forest fires), external floods, …

D.2.6 Los Alamos National Laboratory

LA-UR-11-01857

The report "Modeling the Number of Ignitions Following an Earthquake: Developing Prediction Limits for Overdispersed Count Data," "…describes an approach for modeling the number of ignitions (fires) following an earthquake. The modeling is not meant to be exact, but to provide a context for assessing the likelihood of various fire scenarios. The first component of the approach is a statistical model to predict the number of ignitions for a new earthquake event. This model is based on data for ignitions following earthquakes from 1906 to 1989 in Alaska and California. These U.S. fire data are taken from reports by fire departments on the fires they responded to immediately after the earthquakes and for several days thereafter. These data are for fires in the general built environment, including residential, commercial and industrial structures. The data contain estimates for the mean peak ground acceleration (PGA) for each earthquake, an estimate of the built area affected in million square feet (MMSF) for each earthquake, and the number of ignitions within the estimated affected area (IGNS). The statistical model uses negative binomial regression to estimate the expected number of ignitions

as a function of the explanatory variables, PGA and MMSF. The associated upper confidence and prediction limits are derived from the statistical model using only spreadsheet technology. The upper prediction limit is used to determine a conservative estimate of the probability of a specified number of ignitions following a future earthquake event. The results from the spreadsheet technology are compared to more exact results based on numerical integration. The spreadsheet probability estimates are shown to be conservative.

However, these fire data are limited in two ways. First, there are no estimates of the number of fires that may not have been responded to by the fire department, e.g. unreported fires following an earthquake. Second, the terms “fire” and “ignition” are used interchangeably; there are no data on the number of ignitions causing the fire. The second component of the approach provides methods for adjusting the statistical model to account for these limitations of the data. This report also provides an example of an application of this approach to a large single structure.

LA-UR-06052

The document “A Method for Evaluating Fire After Earthquake Scenarios for Single Buildings,” was a handout for the Department of Energy (DOE) Natural Phenomena Hazards Workshop, that took place in Washington, D.C., on October 25, 26, 2011. It states

> Department of Energy Standard DOE-STD-3009-94 Change Notice 3 (DOE-STD-3009), Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses … directs that earthquake induced fires be evaluated for non-reactor nuclear facilities. The standard also allows a probabilistic frequency cutoff for natural phenomena hazards, i.e. it is not a Design Basis Accident, if the annual probability of occurrence is less than 10^{-6} based on a conservative calculation. The challenge is to be able to defend the conservatism of the calculation, yet provide a calculation that is not so overly conservative that it is not useful.
>
> The statistical method developed in Modeling the Number of Ignitions Following an Earthquake: Developing Prediction Limits for Overdispersed Count Data … provides a context for assessing the conservatism of various fire scenarios. The statistical method uses data for fires following earthquakes from 1906 to 1989 in Alaska and California. This method is applied to an example facility to evaluate the probabilities of the number of randomly occurring ignitions after an earthquake of a given intensity affecting an area of a specified size.
>
> In addition to the randomly occurring fires, an evaluation is conducted to determine processes and/or activities unique to the facility. These processes and activities are reviewed to identify associated ignition mechanisms. Should the ignition potential be judged to be highly probable if an earthquake occurs, these ignitions are assumed to occur in addition to any randomly occurring ignitions.
>
> Finally, the detailed fire modeling for the facility is discussed and a procedure for establishing fire parameters is offered. The DOE Toolbox fire modeling code, CFAST …, is used to model temperatures in the hot gas layer and fire driven gaseous flows for the example facility.

D.2.7 Conference Papers

Paper by Sekizawa et al., "Development of Seismic-induced Fire Risk Assessment Method for a Building"

This paper states "Post-earthquake fire risk can be different from other design scenarios because fire protection systems can be non-functional even when a building itself is structurally sound. We have developed a prototype of a seismic-induced fire risk assessment method to evaluate fire risk based on factors such as size and type of buildings, installed fire protection systems, and the intensity of input earthquake motion. This paper describes the outline of the framework and examples of results from a case study applying a tentative simplified model. Results from our study show that sprinkler systems that are designed to be seismically resistant have a significant effect in mitigating fire risk associated with earthquakes…"

Paper by Lee, R. Davidson, N. Ohnishi, et al., "Fire Following Earthquake—Reviewing the State-of-the-Art of Modeling"

This paper states "Models for estimating the effects of fire following earthquake (FFE) are reviewed, including comparisons of available ignition and spread/suppression models. While researchers have been modeling FFEs for more than 50 years, there has been a notable burst of research since 2000. In particular, borrowing from other fire modeling fields and taking advantage of improved computational power and data, there is a new trend towards physics-based rather than strictly empirical spread models; and towards employing different simulation techniques, such as cellular automata, rather than assuming fires spread in an elliptical shape. Past achievements include identification of the factors affecting FFE, documentation of historical events, and years of FFE model use by practitioners. Opportunities for future advances include continued development of physics-based spread models; better treatment of slope, water and transportation system functionality, and suppression by fire departments; and more validation and sensitivity analyses…"

The paper concludes:

"Fire Following Earthquakes has accounted for the largest single earthquake-related losses in both the U.S. and Japan, and continue to be a source of potentially catastrophic risk. Modeling of FFE began with Hamada more than 50 years ago, and the 1970s and 1980s saw the main factors affecting FFEs identified and many historical and contemporary events increasingly better documented. In the 1980s and 1990s, several integrated FFE models emerged that have been used by, for example, the Tokyo Fire Department, the Federal Emergency Management Agency, the insurance industry, and practitioners.

Opportunities to improve FFE modeling remain, as reflected in a notable increase in research in the field since about 2000. Data from recent earthquakes is being used to update empirical ignition models, and significant advances are emerging in urban fire spread modeling as researchers adapt ideas from other fire modeling arenas, and take advantage of improved computational power and data availability. The trend is towards spread models based on physical laws, often modified by historical experience, rather than strictly empirical models; and towards models that use different simulation techniques, such as cellular automata. Spread models will likely become more physics-based, making them more generally applicable and scientifically defensible. Important factors not yet included explicitly or needing better modeling are slope, vegetation, and building damage; the effects of suppression efforts by fire departments; and the functionality of water supply and transportation systems. Lastly, more

effort should be made to open and verify existing models, and to improve our understanding of them via sensitivity and other analyses."

Paper by Eide and Young, "Identification of Seismic-Fire and Seismic-Flood Interaction Events" [7]

This paper states "When developing a seismic probabilistic risk assessment (SPRA), the ASME/ANS PRA Standard lists two supporting requirements related to the identification of seismic-flood and seismic-fire interaction events, SFR-E4 and SPR-B11. Guidance for identifying such events is found in various documents (NUREG-1407, NUREG/CR-5088, EPRI NP-6041-SL, NUREG/CR-6850, and EPRI 1002989). Using these documents and the ASME/ANS PRA Standard requirements, a structured approach to identifying seismic-flood and seismic-fire interaction events for the Fermi 2 SPRA seismic walkdowns was developed. That approach includes walkdown lists covering the rooms and areas of interest. Those lists were filled out by PRA engineers who assisted the structural engineers during the seismic walkdowns. The result of this process is a well-documented approach that meets the ASME/ANS PRA Standard requirements. Documentation of the effort is important in demonstrating that the requirements have been met. Lessons learned from this exercise indicate areas where changes can be made to increase the efficiency of the process…"

The paper concludes:

"…The structured approach to the identification of seismic-flood and seismic-fire interaction events outlined in this paper results in a well-documented process that meets the ASME/ANS PRA Standard requirements for this activity. Lessons learned from applying this approach at Fermi 2 as part of the SPRA development should help to streamline the process for future SPRA efforts…"

Paper by Sloane et al., "Process for Identifying and Addressing Potential Seismically-Induced Internal Fires and Internal Floods in a Commercial NPP Seismic PRA or PRA-Based SMA"

This paper "…describes a process to identify potential plant vulnerabilities given the combined effects of a seismic event and consequential internal fire or internal flood hazards (i.e., hazards that occur as a direct result of the seismic event), with a focus on seismically-induced internal fires and internal floods that may have the potential to significantly affect the plant seismic risk. Although various guidance documents note the importance of performing such an assessment, little actual guidance is available. The results of the process described herein serve to provide insights that may be used to determine if enhancements to the plant's seismic probabilistic risk assessment (SPRA) or PRA-Based seismic margins assessment (PBSMA) are appropriate to explicitly address individual consequential hazards. Insights from application of this process to a multi-unit CANDU plant SPRA and a multi-unit CANDU plant PBSMA are summarized…"

The paper concludes:

"…A process has been defined to identify potential plant vulnerabilities given the combined effects of a seismic event and consequential internal fire or internal flood hazards, with the objective of identifying seismically-induced internal fires and internal floods with the potential to significantly affect the plant seismic risk. Two applications of the process have been prepared, one involving application to a seismic PRA and the other involving application to a PRA-based seismic margin assessment. The results of these applications validate the feasibility of the

proposed process, and its ability to provide insights into significant potential impacts on the seismic risk assessment of these particular combined hazards. It is hoped that additional applications will be attempted, to test the process on light water reactor plant designs where the design seismic response, and therefore the potential for impacts of internal fire or flood hazards, may be somewhat different…"

Paper by Lin et al., "Screening of Seismic-Induced Fires"

This paper states "Seismic-induced fire has been an issue not addressed quantitatively in both the nuclear plant seismic [probabilistic risk assessments] PRAs and fire PRAs mainly because of the lack of data and a method to estimate the likelihood of a seismic-induced fire. One approach to identify the seismic-induced fire scenarios and evaluate the occurrence frequencies of these scenarios is to perform a screening analysis based on both the likelihood and the impact of such scenarios. Based on frequency of seismically induced fire initiation, there are two aspects to screening fire scenarios: (1) to assess the subset of seismic failure modes that may contribute to fires, the fragility for the structural failure modes including support/anchorage failures conservatively bounds the seismic failure potential; (2) the other factor that can be considered is the conditional probability of potential fire ignition. The seismic screening capacity can be determined by identifying an assumed fragility with which a convolution of the seismic hazard exceedance curves will result in a frequency of [structures, systems, and components] SSC failure integrated over the entire seismic hazard acceleration range below an acceptable screening value. For the remaining SSCs that survive the seismic capacity screening, additional screens based on fire consequences can be performed to reduce the number of scenarios to a minimal set for further detailed, quantitative evaluations."

The paper concludes: "…Seismic-induced fire scenarios can be evaluated by first performing identification and screening of the potential scenarios. Both qualitative and quantitative screening can be conducted. Qualitative screening can be based on the potential for the types and locations of equipment that may cause a seismic-induced fire as well as the potential impacts that may result. Quantitative screening can be performed using the frequency of seismic-induced fire initiation to determine screening seismic capacity value for a single SSC which should be noticeably lower than the screening seismic capacity for direct seismic failure contributors to core damage frequency (CDF)/ large early release frequency (LERF) because a conditional ignition probability can also be considered. Quantitative screening can also use the fire consequence reflected by the fire compartment [conditional core damage probability] CCDP and [conditional large early release probability] CLERP as additional criteria.…"

Paper by Oppenheim, "Modelling Earthquake-Induced Fire Loss"

This paper states "Fire loss following earthquake is influenced by three vectors: ignition frequency (number of fires started initially), conflagration potential ("free-field" fire spread) and fire loss suppression (actions of firefighters). Procedures available for modelling each of the three influences are reviewed, and an ignition frequency estimate for west coast construction is presented. The key influence is the conflagration potential, and urban areas may fall into three categories. Many have such a low potential that serious loss is unlikely. Other have an intrinsically high potential and nothing short of rezoning can prevent serious fire loss. Finally, there is a middle ground, in which engineering actions may be effective at mitigating loss…"

The paper concludes: "…The elements governing fire loss have been reviewed, and some sample modelling procedures have been described. We do not have, at present, a model which would yield a meaningful analysis for any urban area. However, the most important determinations can be made without a precise analytical model. Our recommendation is that an urban area first be evaluated for conflagration potential, as judged by an experienced fire scientist. The following actions are the recommended:

- Areas with high conflagration potential: These areas face high loss if struck by a damaging earthquake. Estimation of ignition frequency … would be a sufficient scenario to convince most experienced fire safety professionals. The remedies include rezoning, emergency response plans (as in wartime to combat incendiary bombing raids), or other strategic planning.

- Areas with low conflagration potential: It is likely that fire loss will not be high, and is probably not a top priority for seismic safety planning. However, circumstances which may alter the conflagration potential should be carefully monitored.

- Other areas: Planners should try to identify which elements are on the "critical path" for loss reduction. While water supply comes to mind for most engineers there are several other effects (saturation, dispatch and transportation delays, etc.) which may govern instead."

<u>Slides by Li et al. on "Recent Advances in Post-Earthquake Fire Modeling: An Urban Fire Simulation Model (UFS),"</u>

These are the slides for a presentation at the 2011 Pacific Earthquake Engineering Research (PEER) annual meeting. As the name of the presentation implies, the focus of this work is on urban fires, but some of the material may be applicable to seismic-induced fires at NPPs.

Appendix E Consolidated Comments Received from NRC Staff Members on the Draft BNL Report Titled “Scoping Study for a PRA Method for Seismically Induced Fires and Floods”, Issued April 2015. (Added July 8, 2015)

A request was made for informal feedback from selected NRC staff members on a draft of BNL’s report on the “technical feasibility” of a PRA approach to seismically-induced fires and floods entitled “Scoping Study for a PRA Method for Seismically Induced Fires and Floods.” In response comments were received from several NRC staff members.

Appendix E While there were aspects of the report that all responders commented on, each staff member also made numerous comments on individual aspects not covered by the other reviewers.

Global Comments

There were a number of global issues that the commenters seemed to agree on.

1) The staff members agreed that many technical challenges remain for developing and implementing a PRA methodology for seismically-induced fires and floods. In this respect one staff member pointed out that the SRM providing the Commission’s direction to the staff on the seismically-induced fire and flood issue stated that the staff should “initiate a PRA methodology to evaluate potential enhancements….” Therefore, the question to be considered is: do the technical challenges prevent a “good enough” evaluation, not do they prevent an accurate assessment of risk. The staff member felt the nuance of this directive was not sufficiently emphasized in the introduction of the report and suggested this should be corrected.

2) The reviewers generally agreed with the use of a graded approach advocated in the report, which put much emphasis on the use of screening methods to reduce (or eliminate) the number of seismic-induced scenarios which need to be explored in greater detail. (However, there was disagreement on the feasibility and efficacy of ‘generic’ screening, given the current state of knowledge, as discussed further below.)

3) The report’s separation of the discussions of seismically-induced fires, internal floods, and external floods was considered appropriate, since each topic provides its own context and challenges. (One commentator pointed out the lack of consideration of seismically-induced external fires, as noted further below.)

4) The report’s workshop summary and other discussions of key sources of information provided a useful overview of the current state of available analysis technology and where major gaps in the technology exist. The report appropriately noted the potential value of data mining from past events.

Other global comments expressed by at least one of the commenters, and without apparent disagreement, are the following:

- The scope of the project should not cover basic development of fire, seismic or flooding PRAs. The methodology should be developed with the presumption that a plant has a seismic PRA, a fire PRA, an internal flooding PRA, and an external flooding PRA. The commenter believed more plants will have seismic PRAs, several plants have (or will have) NFPA 805 fire PRAs, many/most plants have internal flood PRAs, and perhaps recent work will prompt more external flooding PRAs. The report should focus on the unique, additional challenges arising from seismically triggered hazards. These aspects can include seismically-induced failures of fire- and flooding-barriers as well as "cliff edge" scenarios where the extra effects of a fire or flood (e.g., SSC failures, degraded environments, operator workload) takes a seismically-degraded plant "over the edge" with non-negligible likelihood.

- Developing appropriate treatment of human-reliability analysis for scenarios involving combined seismic failures and seismic-induced fire or flood failures, including those from multiple seismic-induced fires and floods, should be deferred to other ongoing efforts by NRC/RES and industry, and not be part of the scope of the report.

- One commenter noted the failure to address seismically-induced "external" fires in the scope of the work. He noted that for "technology islands," there may be several "outside" sources of hazardous materials (e.g., oil, natural gas) potentially ignited by an earthquake and thereby posing an external fire hazard to a co-located reactor (e.g., switchyard, outside transformers). Therefore this aspect should be considered in the report as well.

- The report is written at a largely generic level. It would be useful to provide an appendix (potentially sensitive) with some plant specific information on the issues (e.g., which plants have or will have modern seismic PRAs, NFPA 805 fire PRAs, internal flooding PRAs, and external flooding PRAs; which ones appear to be of heightened interest given current seismic and external flooding information). This latter information can help to identify plants where, based on hazards considerations alone, seismically-induced fires or seismically-induced floods might be a concern.

- The report makes heavy use of text extracts from source reports (especially in Appendix D but also in the main report). Reduced use of quotes and increased synthesis and analysis by the authors was recommended

- The report briefly mentions the EPRI finding (four out of 108 sites with seismically-induced fires); more details (e.g., the characteristics of the particular earthquakes, the types and extent of fires) would be informative.

There were differing opinions among the commenters regarding some of the near term recommendations in the report for continued development of screening methods, largely with the help of expert elicitation, and including the use of a pilot plant implementation. Several of the reviewers largely agreed with the suggestions in the report on a number of near term future steps. They felt the use of appropriately constituted expert panels to be a reasonable way to quickly focus attention on crucial issues with the possibility of some resolution. In some cases these commenters elaborated somewhat on the suggestions in the report. These suggestions included:

1) Holding a meeting of the responders to the questions discussed in Section 4 of the report (and possibly include some additional 'experts') to resolve differences and to perhaps arrive at an agreed-upon list of fire sources that can be screened from further consideration in a seismically-induced fire analysis, as well as a list of fire sources that always should be considered in this type of analysis.

2) Using the same panel (or other appropriately qualified experts) to discuss and reach some consensus on additional qualitative screening criteria and rules for seismically-induced fire as well as flood scenarios. It may be possible to build on experience (not necessarily limited to nuclear plants) from real earthquakes to obtain insights on ways to screen efficiently. While this may be quite difficult at present for seismic-induced fire, it may be less so for seismically-induced floods where the ruggedness of piping and other structures can be taken into account, and screening is already part of the seismic PRA framework. Furthermore it may be possible, pursuing a balanced approach between fragility assessment and impact quantification to transition the seismic impact into an internal flooding PRA or an internal flooding piece to the seismic PRA.

3) Expert panels could also be formed to agree upon a methodology on dealing with unscreened seismically-induced fire scenarios where a risk estimate, and its uncertainty, is needed. Such a panel could also make recommendations on estimating ignition fragilities for identified critical items through shake tests or other means.

4) With respect to seismically-induced external flooding a panel may also be useful to discuss and hopefully achieve some consensus about the circumstances under which the various correlation/dependence factors must be accounted for (such as quake magnitude, distance of each site to the earthquake, distance between the plant and the flood source).

One reviewer felt strongly that further development of generic screening methodologies would be premature for seismically-induced hazards like fires (including external fire) and, to a lesser extent, floods. He believes that much too little is known about the "fragility" aspects of interest arising from these seismically-induced phenomena to generically, or a priori, screen out anything. He felt that only if the component has already failed or done its maximum possible damage due to the earthquake alone, such that any additional detriment from fire or flood would be extraneous, should it be screened.

He believes any substantial progress in this area has to be on hold until research, including testing, is done to estimate “fragilities” due to seismically-induced “collateral damage,” and only conservative quantification should be used. Since little is currently known regarding the “fragility” of components to seismically-induced fires, or even the nature of the phenomenology, generic screening may be inappropriate and only plant-specific screening makes sense. Likewise for floods, even if a component’s fragility to an earthquake is high, this fragility may be lowered by the presence of a “sloshing liquid” inside of it. So again, generic or a priori screening may be inappropriate, and only plant-specific screening should be applied.

This commenter also felt that even relying on historical data for a frequency estimate could be inadequate because of the variability among earthquake effects within a plant, let alone between sites. More appropriate would be some sort of testing to determine what components are susceptible to seismically-induced fires, at what ground motions, and with what seismic phenomenology.
In summary, this commenter felt that “expert” consensus in the absence of any data is not the proper path forward. Until the data are collected (via testing), expert consensus should be deferred. He also felt that any pilot study would be premature.

Specific Comments

- Section 1.1. It would be useful to provide a brief summary of what has been learned from the IPEEEs regarding seismically-induced fires and floods.

- Section 1.2. The discussion of value could be read as an objection to the Commission’s direction.

- Section 2.0. The discussion raises the question of “sufficient value” but doesn’t indicate how this will be determined.

- Section 2.3. This section (or Appendix D) should provide more discussion of what sources were reviewed. (Did the project look at the LER database? IAEA’s event database?)

- Section 3.2. The focus of the discussion (and other parts of the report) is on fire sources. Earthquakes can also affect fire barriers (note that “fire barriers” include constructed enclosures within a room as well as room walls), might trigger suppression systems, and of course can affect operators. The latter effects go beyond direct shaking – they can include work interruptions (e.g., personnel accounting after major aftershocks), access limitations due to power losses and debris, and psychological effects (considering the offsite effects of a major earthquake). There may also be multiple demands for fire equipment (to provide alternate ECCS as well as firefighting support).

- Section 4. The title should be broadened – this is the section discussing the questionnaire results.

- Section 4.1. A review of past events (including North Anna) might inform a discussion of the potential ignition sources listed in Table 4.1.

- Section 4.1. It would have been useful for the respondents to self-rate themselves in terms of their experience and expertise. Future efforts should involve more experts who have observed the effects of real earthquakes.

- Section 4.2. Although not directly stated, it appears that the report is focusing on SSC inundation due to rising water levels. Other modes of wetting (e.g., due to falling water streams from broken pipes) are possible in some plants.

- Section 5.1. The report notes that the EPRI survey was published in 1990. It would be useful to provide some discussion indicating if there is any reason to expect that the situation is dramatically different now.

- Section 5.4. Although wall collapse could connect two rooms, the failure mode need not be so dramatic.

- Section 5.5. Although a "high-intensity" earthquake may cause core damage directly, it's reasonable to ask if a lower intensity earthquake coupled with an induced fire might do the same with higher likelihood. This line of argument may be fruitful and it appears to be worth some additional thought.

- Section 5.5. Regarding the suggestion that a process similar to the Multiple Spurious Operations (MSO) process may serve in screening SSCs in seismic-induced fire and flood scenarios: This is less likely to be productive for seismically-induced fires and floods given the need for plant-specific considerations as the primary, rather than secondary, step, unlike for MSOs.

- Section 5.7. The specific walk-downs already completed for NTTF 2.3, and being undertaken for NTTF 2.1, not only are unlikely to capture the insights needed for seismic-induced fire/flood scenarios; these walkdowns may not even be adequate for seismic issues alone, as phenomena such as soil liquefaction have been excluded and deferred to the PRA phase.