Probabilistic Risk Assessment of Seismic-Induced Fire and Flood: Report of Public Meeting

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." In SRM SECY 11 0137, the Commission directed the staff to initiate development of a probabilistic risk assessment (PRA) methodology to evaluate potential enhancements to plants' capability to prevent or mitigate seismically induced fires and floods as part of Tier 1 activities, while the broader evaluation (i.e., beyond the PRA methodology) of potential enhancements would remain a longer term Tier 3 activity.

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). A report documenting this feasibility will be one of the inputs to generate a staff recommendation to the NRC's Commissioners.

The public workshop was organized by BNL as part of this project 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 had prepared (attached as Appendix A). Their feedback was requested in the form of comments or preliminary responses to the questions to enhance the effectiveness of the workshop. Participants also were encouraged to raise any additional issues that they felt were relevant, but that were not covered in the questions.

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 the 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. A list of the attendees and their affiliations is attached as Appendix F.

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).

At the beginning on the morning of Wednesday 11, Kevin Coyne (NRC) made a presentation entitled "NTTF Recommendation 3: Seismically Induced Fires and Floods" (attached as

Appendix B). He pointed to the following challenges for PRA method that attempt 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., the findings from:

- 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 ASME/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.

Subsequent to this presentation, the main organizers of the workshop, Selim Sancaktar (NRC) and John Lehner (BNL), made further brief introductory remarks on the subject and on the workshop itself.

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)" (attached as Appendix C). He first 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 regarding 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 SI-F&IEF PRA is that, for an SSC of interest in such 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 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 cable type.

He also stated his belief that for seismically induced internal flooding there is a parallel to the problem noted for fire, i.e., that he was unaware of any information to support the development of fragility curves for SSCs that link the probability of creating a flood source with the magnitude of an earthquake (although it may not be that difficult to develop such a curve for some SSCs such as a water tank, a heat exchanger, or some piping).

For seismically induced external flooding he felt that the problem was different. In this case, one has to 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" (attached as Appendix D). He detailed a process to identify potential plant vulnerabilities after a seismic event and consequential internal fires or internal floods, focusing on seismically induced internal fires and internal floods that potentially might significantly affect the plant's seismic risk. He pointed out that although various guidance documents note the importance of performing such an assessment, little guidance is available.

He stated that attempting to quantify all seismically induced internal fire and internal flood scenarios is currently impractical, 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 one uses insights from plant earthquake experience and reviews of available internal flooding and fire PRAs, to look for significant fire or flooding sources 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 the application of 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. Workshop Discussion

With the presentations concluded, workshop participants turned their attention to discussion of the issues raised in the presentations and in the questions that had been sent to invited participants prior to the meeting. Responses to these questions were received before the workshop from several participants. BNL's staff consolidated and summarized these responses into several main points for each question, and the questions along with the preliminary responses were used as an outline to guide the workshop discussion. Appendix E includes the slides prepared by BNL containing these points.

After the discussion of the questions, the workshop participants focused on considering possible paths forward. Several ideas were posited for ways to move forward to better understand SI-F&IEF scenarios, thus helping to model and quantify the risk from SI-F&IEF scenarios.

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&IEF 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 SI-F&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. Development of small groups of expert panels was also suggested. Meetings of a relatively 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 of experts could discuss approaches for developing seismic-induced fire fragilities, another group 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. Screening of fire ignition source bins by an expert panel is another example, as is the expected operator response to fires/floods when the crew has to deal with many issues, including assuring the functionality of the safe shutdown equipment subsequent to an earthquake. The possibility of using an appropriate level of the Senior Seismic Hazard Analysis Committee (SSHAC) process, or some other kind of expert elicitation process, was discussed.

4. A number of participants also 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 safe shut down equipment are not very useful (an exception may be multiple fire scenarios).

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

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

It is expected that the activities for supporting the pilot(s) (e.g., developing the screening methods) would be accomplished within about two years, and that the pilot(s) would start sometime within this time frame.

References:

1. SECY-11-0137, "Prioritization of Recommended Actions to Be Taken In Response to Fukushima Lessons Learned," October 3, 2011.

2. SECY-12-0025, "Proposed Orders and Requests for Information in Response to Lessons Learned from Japan's March 11, 2011, Great Tohoku Earthquake and Tsunami," February 17, 2012,

3. SECY-12-0095, "Tier 3 Program Plans and 6-Month Status Update in Response to Lessons Learned from Japan's March 11, 2011, Great Tohoku Earthquake and Subsequent Tsunami," - Enclosure 3: "Program Plans for Tier 3 Recommendations," July 13, 2012. (ML12208A210.pdf)

4. JLD-ISG-2013-01 Guidance For Assessment of Flooding Hazards Due to Dam Failure *Interim Staff Guidance Revision 0,* July 29, 2013, ML13151A153.

APPENDIX A

The following introductory list of topics for discussion in the form of 15 questions, classified into three broad categories (Issues and Methods, Probabilistic Data, and Resources and Value Added) was sent to the meeting invitees:

Issues and Methods

1. What are the PRA-related issues for obtaining meaningful estimates of risk from SI-F&IEF scenarios?

2. Are the key mechanisms of failure understood well enough so they can be modeled, or at least estimated with expert judgment?

3. Do you believe that one or more of the current PRA methods can be used satisfactorily to assess SI-F&IEF scenarios? Or is it necessary to develop new or enhanced methods or approaches for this purpose?

4. Could the current PRA standard activities for inclusion of concurrent events in the standard be used for addressing your identified issues?

5. Can the actions associated with other NTTF Recommendations 2.1, 2.3, and 4.2 be used or enhanced to support the PRA methods development activity? For example: can walkdowns document specific High Confidence of Low Probability of Failure (HCLPF) values of equipment that could cause or lead to fire or floods if failed? What feedback can be expected from this activity?

6. Could the current work on re-evaluation by the utilities in response to the NRC request factor into a PRA method? For example, could JLD-ISG-2013-01 Guidance for Assessment of Flooding Hazards Due to Dam Failure Interim Staff Guidance Revision 0 (Reference 4) and a utility response based on this reference be factored into a PRA Method?

7. Because of the general low frequencies that are expected for SI-F&IEF, how can one appropriately distinguish which low frequency events should be included and which should be screened out? Do you consider it possible to screen low frequency sequences while still adequately addressing rare events with high consequences?

8. Assuming a plant has a seismic and an internal fire PRA, can it perform a seismically-induced Fire PRA today, using the available guidance? Is such a project expected to uncover new insights or change the assessment of current risk?

9. Assuming a plant has a seismic and an internal flooding PRA, can it perform a seismically-induced Internal Flooding PRA today, using the available guidance? Is such a project expected to uncover new insights or change the assessment of current risk?

10. Assuming a plant has a seismic PRA and an assessment of external floods in response to the NRC request for reevaluation, can they perform a seismically-induced External Flooding PRA today, using the available guidance? Is such a project expected to uncover new insights or change the assessment of current risk?

Probabilistic Data

11. A risk assessment typically involves a quantitative (e.g., frequency of occurrence) or at least a semi-quantitative assessment of the risk. Such quantification requires, in turn, probabilistic data such as frequency of earthquakes and probability of failure of a structure, system, or component (SSC) given a SI-F&IEF. What specific data sets are needed (for example, seismic fragilities of SSCs for seismically-induced floods)?

12. There is a recognized lack of data, such as seismic-induced fragilities of SSCs, that is, the likelihood that specified ground motions will result in the movement or failure of an SSC in a mode that creates a flood. What can be done with limited data available for these events? Are there sufficient data available for quantifying risk from SII&EF events? What sources of probabilistic data for this purpose are you aware of, if any?

Resources and Value Added

13. What are the implications of cost versus value-added for satisfying the data needs referred to above? i.e., for obtaining such information generically or plant-specifically?

14. If a new set of data needs to be assembled for use in a SI-F&IEF PRA, who should spearhead this effort; NRC, EPRI, international organizations?

15. What are the resource estimates for carrying out the PRAs assumed in Questions 8, 9, and 10 above?

APPENDICES B TO E: PRESENTATIONS

A 70-page pdf file separately compiled.

Public Meeting on Probabilistic Risk Assessment of Seismic-Induced Fire and Flood - December 11 to 12, 2013

APPENDIX F: LIST OF PARTICIPANTS

	Name	Affiliation
1	Ali Azarm	IESS
2	Paul Amico	Hughes Associates
3	Vince Anderson	ERIN
4	Rick Anoba	Hughes Associates
5	Bob Budnitz	LBNL
6	Kevin Coyne	NRC
7	Beth Faber	US Army Corps of Engineers
8	Fernando Ferrante	NRC
9	Ray Gallucci	NRC
10	David Gennardo	NRC
11	Michelle Gonzalez	NRC
12	Bruce Henley (by phone)	Comanche Peak
13	Dennis Henneke	GE-Hitachi
14	Joseph Kanney	NRC
15	John Lehner	BNL
16	Andrea Maioli	Westinghouse
17	Gerardo Martinez-Guridi	BNL
18	Nicholas Melly	NRC
19	Agnes Moisin	OPG
20	Zoran Musicki	EMS
21	Thomas Nicholson	NRC
22	Steve Nowlen	SNL
23	Jacob Philip	NRC
24	Bob Rishel	Duke Energy
25	Selim Sancaktar	NRC
26	Nathan Siu	NRC
27	Barry Sloane	ERIN
28	Alexander Trifanov	Kinectrics
29	Smain Yalaoui	CNSC