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QUALITATIVE PRA INSIGHTS FROM SEISMIC EVENTS

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ABSTRACT

Probabilistic risk assessment (PRA) oriented reviews of historical operational events can help identify potential gaps where improved approaches can increase analysis realism. This paper summarizes observations from an exploratory project reviewing seismic events affecting nuclear power plant (NPP) operations. Observations regarding human and organizational factors, seismic/fire interactions, and reactivity effects indicate the importance of an integrated, multidisciplinary approach to seismic PRA.

BACKGROUND

As described by McCree (2018), the U.S. Nuclear Regulatory Commission (NRC) is seeking to increase its use of risk information in support of regulatory decision making. In support of this initiative, it is important to ensure that supporting probabilistic risk assessment (PRA) studies for nuclear power plants (NPP) provide treatments of the various contributing hazards, including seismic events, that are sufficiently realistic for the decisions at hand. PRA-oriented reviews of historical operational events involving these hazards can help identify and prioritize potential gaps where improved models, methods, tools, and/or data can improve analysis realism. Examples of such reviews are provided by Nowlen, et al. (2001), who looked at fires, by Siu et al. (2018) in an exploratory study of storms and flooding events, and in numerous papers following the March 2011 Fukushima Daiichi reactor accidents. See, for example, Siu et al. (2013, 2016a).

In addition to supporting the improvement of PRA models, operational experience reviews can provide an empirical view on key hazards that complements the decomposition-logic view of PRAs. The broadened perspective from these different views can be useful to decision makers as well as analysts. Thus, as the NRC staff ages and personnel knowledgeable of past events leave the agency, associated knowledge management activities, including "active learning" exercises involving reviews of events and the development of "smart search" tools as well as more conventional activities (e.g., training courses, seminars), are becoming increasingly important. In late 2018, encouraged by the lessons discussed by Siu et al. (2018), the authors of this paper initiated an exploratory project looking at historical seismic events.

OBJECTIVES AND SCOPE

The objectives of the ongoing, exploratory project are as follows:

1. Identify insights regarding seismic PRA methods, models, tools, and data potentially useful for seismic PRA analysts, reviewers, and/or developers.

2. Provide an educational experience for the authors that supports NRC's risk-informed initiatives.
3. Identify lessons regarding the mining of seismically-related operational experience that may be useful in the development of intelligent search tools.

The project scope is limited to seismic events affecting NPP operations. In particular:

- The project does not address seismic operational experience involving discoveries of plant conditions (perhaps identified by inspections) that can degrade a plant's response to a seismic event.
- The project does not address seismic effects on non-reactor facilities.
- The seismic PRA community routinely looks at hazard and fragility lessons from seismic events. See, for example, Swan (2018) and Li and Roche (1998). Our focus, therefore, is on the third major element of seismic PRA: plant response analysis.

It should be emphasized that the project is neither an attempt to engage in post-event fault finding nor an exercise to characterize the conditional likelihoods of key failures during postulated earthquakes. The focus is on identifying qualitative lessons for future PRA use and development.

This paper discusses the current results and insights associated with the first project objective. The complete set of project results will be documented in the final project report.

APPROACH

The project team started with three members with combined expertise in general PRA methods development and seismic fragility analysis. These team members are quite familiar with seismic PRA (e.g., as reviewers), but do not consider themselves to be experts in the performance of seismic PRA. As the project progressed, the team added staff with expertise in human reliability analysis (HRA) and fire PRA.

In order to develop desired insights, the project employed a straightforward two-step process. First, the team performed a literature search to identify candidate events for detailed review. This search involved the use of the NRC's Licensee Event Report (LER) search system (https://lersearch.inl.gov/Entry.aspx), the International Atomic Energy Agency's (IAEA) proprietary Incident Reporting System (IRS), the Institute of Nuclear Power Operations (INPO) proprietary INPO Consolidated Event System (ICES), the open database described by Wheatley et al. (2018), and various publicly available documents that can be identified through typical web search strategies. These latter documents included seismic analysis guidance documents that refer to actual operational events, notably Reed et al. (1988) and EPRI (2013), as well as industry publications, notably WNA (2019). As indicated earlier, the focus was on actual seismic events, as opposed to seismically-relevant degraded plant conditions (e.g., as identified during inspections and reported through LERs). We note the following.

- Most of the seismically-induced transients identified in our search were relatively minor events and so little detailed plant response information is readily available. Many of the detailed insights reported in this paper are therefore based on lessons from three well-documented events: the July 16, 2007 Niigataken Chuetsu-oki Earthquake that involved the Kashiwazaki-Kariwa NPP, the March 11, 2011 Great East Japan Earthquake that involved multiple NPPs, and the August 23, 2011 Mineral, Virginia Earthquake that involved the North Anna NPP.[1]

[1] For brevity, the remainder of this paper uses "Kashiwazaki-Kariwa" to refer to the events associated with the 2007 Niigataken Chuetsu-oki Earthquake, "3/11" to refer to the 2011 Great Eastern Japan Earthquake, "Fukushima Daiichi" to refer to the 2011 Fukushima Daiichi reactor accidents, and "North Anna" to refer to the events associated with the 2011 Mineral earthquake.

- As a scoping study, we did not attempt to develop a comprehensive event database in the spirit of that described by Wheatley et al. (2018), nor did we exhaustively review the voluminous literature on Fukushima Daiichi. The potential value of such follow-on activities will be assessed at the completion of this project.

GENERAL OBSERVATIONS

Our literature search has identified 50 earthquakes of potential interest. These include events that actually affected power operation (e.g., by triggering a reactor trip), events that could have affected power operation but didn't (e.g., events that might have triggered a reactor trip but didn't because the plant was not yet operating or was already shutdown for other reasons), and events involving large earthquakes that were documented as having little or no actual effect on NPPs nearby or in the general region. (The last category of events was included in case there was useful information to be gleaned.)

Table 1 provides some summary statistics for the 50 earthquakes. It should be emphasized that this table only characterizes our dataset. Given the exploratory nature of our project, it should not be used as quantitative basis for decision support. We note following.

- A number of earthquakes have exceeded the NPP's Operating Basis Earthquake (OBE) and/or Safe Shutdown Earthquake (SSE) for at least part of the ground motion response spectrum. In a number of cases, this occurred before the plant had started commercial operation. Note that per Reed et al. (1988), Regulatory Guide (RG) 1.166 (NRC, 1997) and empirical experience, simple exceedance of the OBE/SSE is not necessarily a good indicator of onsite damage. In our project, OBE/SSE exceedance is only an indicator of an event of potential interest for deeper review.
- Per USGS (2007), the highest peak ground accelerations (PGA) reported for Kashiwazaki-Kariwa in the free-field and near the foundation levels were around 0.88g in a downhole array in the proximity of the Unit 1 Reactor Building. Both of these foundation level PGAs were less than 1.0g. At the ground surface, a PGA of about 1.25g was reported in the proximity of Unit 5. In this paper, the PGAs at the foundation levels are taken as those of reference for the Kashiwazaki-Kariwa event.
- Some of the larger earthquakes had large (moment magnitude – M_w – greater than 6.0) aftershocks. For one event (3/11), the main shock was preceded by a number of large foreshocks. One event (Kashiwazaki-Kariwa) was followed by an independent, large earthquake (M_w 6.8) some distance away. The potential PRA-significance of multiple shocks is discussed later in this paper
- Earthquakes affecting one unit on a site generally affected other units at the same site. (In some cases where a multi-unit impact is not indicated, it is not clear from the event description if the other units were already shutdown.)

Table 1: Summary Statistics for 50 Reviewed Earthquakes (1975-2019)

Earthquakes	**Japan**	**Other**
Earthquakes exceeding then-current OBE/SSE	3	7
Earthquakes with large aftershocks ($M_w > 6$)	4	3
Earthquakes felt at multiple sites	7	9
Earthquakes causing at least one reactor trip	7	4
Reactor Effects	**Japan**	**Other**
Seismically-induced reactor trips[a]	25	7
Seismically-induced "complicated events" [b]	12[c]	6

[a]Includes trips due to seismically-induced tsunamis.
[b]See Footnote 2.
[c]Eleven of these transients occurred on March 11, 2011.

- A few earthquakes affected operations (e.g., through the triggering of some alert level) at multiple sites, some of which were separated by significant distances. It appears that only three events involved a system response (e.g., reactor trip) at multiple sites. The 3/11 event, which affected the Fukushima Daiichi, Fukushima Daiini, Onagawa, Tokai, and Higashidori sites – the last two separated by over 500 km – is the only event involving serious challenges across multiple sites.
- None of the earthquakes appear to have caused damage to major mitigating systems (e.g., emergency diesel generators, emergency core cooling systems, auxiliary feedwater) due to ground motion. Onsite equipment losses and other complications (e.g., debris, heavy smoke) during 3/11 were caused by induced hazards, namely seismically-induced tsunamis and fires. A few earthquakes resulted in very low (0.01 to 0.03g) PGAs at the plant but nevertheless triggered reactor trips or safety system actuations (for shutdown plants).
- Beyond 3/11, other earthquakes causing "complicated events"[2] are as follows.
    - Chi Chi (Taiwan) Earthquake (1999) – failure of 345 kV transmission line offsite led to grid instability and automatic shutdown of Chinshan 2-3 and Kuosheng 1-3. Per EPRI (2001), the onsite PGAs (less than 0.05g) were significantly smaller than the OBE (Chinshan: 0.15g; Kuosheng: 0.20g).
    - Sumatra-Andaman Earthquake (2004) – tsunami flooding and debris failed seawater pumps, complicating shutdown of Madras 2.
    - Kashiwazaki-Kariwa (2007) – an onsite large transformer fire at Unit 3 (caused by differential ground subsidence) led to complications in event response. Per IAEA (2007), the maximum onsite PGAs at the foundation levels were around 0.88g in the free field and 0.69g in reactor building basements.
    - North Anna (2011) – the earthquake induced dual-unit reactor trips and LOOP. The reactor trips were due to high neutron flux rate; the LOOP was due to actuation of sudden pressure relays for multiple transformers (i.e., due to ground motion but not actual damage). Per VEPCO (2011), the spectral accelerations exceeded the OBE and design basis earthquake (DBE). However, post-event walkdowns and inspections found no significant physical or functional damage to safety related structures, systems, and components (SSCs). These appear to be the only seismically-induced commercial NPP reactor trips in the U.S.

DETAILED OBSERVATIONS (PLANT RESPONSE)

It is well recognized that, in addition to causing SSC failures by ground motion, earthquakes can influence the progression of an accident scenario by affecting plant operators and/or by causing induced (sometimes called secondary) hazards such as seismically-induced fires and floods that, in turn, can cause additional SSC failures. Perhaps less well recognized within the NPP PRA community, earthquakes can also cause reactivity excursions that might trigger a class of scenarios (anticipated transients without scram – ATWS).

In this section, we provide some PRA-relevant observations regarding these potential effects based primarily on the descriptions of the Kashiwazaki-Kariwa, 3/11, and North Anna events. We recognize that these events have been extensively studied and some of the following are not new or unique.

Human and Organizational Factors

In NPP PRAs, the influence of human and organizational factors on accident progression is modelled through human failure events (HFEs), i.e., basic events representing the failure of needed human actions. (In a few cases, inappropriate actions, called errors of commission, are also modelled.) The role of HRA is,

[2] For the purposes of this paper, a "complicated event" involves a reactor trip and potentially significant additional failures (e.g., partial or complete loss of offsite power – LOOP).

as part of an integrated PRA effort, to identify which actions should be included in the PRA model, determine whether these actions are feasible under various conditions specified in the PRA model, and, if so, determine the likelihood of failure. The last step, typically referred to as "quantification," requires a qualitative analysis of the actions (What tasks need to be performed? What are the specific conditions of performance and how might these conditions affect performance?) as well as quantification.

The general principles of NPP HRA are agreed upon by the HRA community (see, for example, Kolaczkowski et al., 2005), but there are many different HRA methods and models, and, consequently, a variety of ways of looking at operational experience. The following observations are organized following the Information-Detection-Action-Crew (IDAC) cognitive framework developed by Mosleh (e.g., see Chang and Mosleh, 2007) and adapted by the NRC's Integrated Human Event Analysis System – General (IDHEAS-G) methodology (NRC, 2019). This framework is based on five macro-cognitive functions underlying human decision making and action: information noticing/detection, sensemaking and understanding, decision making, action, and teamwork. Note that the following observations are focused on impacts particularly relevant to seismic PRA. There are, of course, many more lessons (particularly from 3/11) regarding human and organizational lessons. See, for example, GoJ (2011), INPO (2011), TEPCO (2012), NAS (2014) and IAEA (2015). HRA-specific lessons are also available in the literature. See, for example, Siu et al. (2013) and Siu et al. (2016a).[3]

Information Detection/Noticing. Information needed by decision makers has been directly hampered by earthquake ground motions and/or induced hazards (e.g., flood, fire). The hazard impacts include:

- Unavailability of instrumentation and control (including the seismic event detection system)
- Spurious alarms
- Degraded and dangerous site conditions (e.g., debris, damaged roads, uncovered manholes, onsite flooding[4]) that hampered surveys and, in combination with loss of communication systems, delayed relaying of field information to decision makers

Sensemaking and Understanding. The ability of the operating crew to understand plant status and event progression is naturally affected by the severity of the seismic event. In addition to the information issues mentioned above, seismic events can raise stress levels and impact cognitive processing. For example, in the case of Fukushima Daiichi, operators were highly stressed not only because of plant conditions but also because of concerns of offsite conditions affecting family, friends, etc. We note that operators were initially confident in their response to the earthquake shock, but became increasingly stressed after the second tsunami struck and reactor units lost power.[5]

It should be recognized that such cognitive effects are not mentioned for the other seismic events reviewed in this project. However, in most cases, it can be reasonably assumed that the effects (if any) were minor, due to the minor ground motions at the site. Furthermore, in at least one case involving more severe shaking (North Anna), the effects also appear to have been minor, as evidenced by the Shift Manager's appropriate decision to enter the Emergency Action Level matrix despite the lack of indication from the Seismic Monitoring Instrumentation Panel (which had lost power). Appropriate actions were also performed at Onagawa on 3/11, despite control room distractions caused by falling ceiling tiles and spurious

[3] Most HRA-related observations derived from the events of March 11 emphasize negative aspects. Given our interest identifying areas of potential PRA improvement, this paper has a similar emphasis. However, it should be recognized that, in spite of the enormous challenges facing operators, there were also significant human action successes (e.g., the prevention of damage to other reactor units, including Fukushima Daiichi Units 5 and 6).

[4] Note that two workers died at Fukushima Daiichi while performing a field survey. See TEPCO (2012).

[5] Per GoJ (2011), the staff at the Emergency Response Center "was lost for words at the ongoing unpredicted and devastated state."

fire alarms. It would be interesting to investigate the reactions and performance of the operating crews at the Kashiwazaki-Kariwa plant during the 2007 earthquake, given the significant ground accelerations (greater than those experienced by Fukushima Daiichi on 3/11) and offsite damage caused by that earthquake.

Decision Making. Of the events reviewed, naturally the greatest decision making challenges were posed by the multiple unit accidents at Fukushima Daiichi. Given the lack of preparation and resources for such events, decision makers, particularly the Site Superintendent, had to decide upon and prioritize recovery activities (in a situation where key plant status information was unavailable). We note that post-shock tsunami warnings apparently affected the superintendent's accident management plans, focusing concern on the potential loss of the seawater pumps (the plant's ultimate heat sink). This is an illustration of how the anticipation of seismically-induced events (whether or not they actually occur) might need to be considered in an HRA and is related to the topic of aftershocks discussed below.

Action. As discussed earlier, onsite conditions induced by the seismic shock and induced hazards hampered the performance of needed actions. In addition to debris and flooding at Fukushima Daiichi and road damage at Kashiwazaki-Kariwa, Fukushima Daiichi, and Onagawa, the following are worth noting.

- Access system failure (loss of power to a security gate) at Fukushima Daiichi
- Heavy smoke from a high energy arc fault (HEAF) at Onagawa on 3/11
- Multiple major aftershocks and tsunami warnings at Fukushima Daiichi

Regarding aftershocks and warnings, these are important because associated concerns with worker safety: a) delayed the initiation of needed activities (e.g., plant damage surveys), and b) interrupted ongoing work activities.

Although not seismic-specific, it is interesting to note that understaffing played a role during the Kashiwazaki-Kariwa event (the earthquake occurred on a national holiday) as well as during the Fukushima Daiichi reactor accidents. In the latter case, self- and directed evacuation of some onsite personnel contributed to the lack of organizational knowledge (e.g., operation of equipment, location of items).

Teamwork. Coordination challenges arose during responses to the Kashiwazaki-Kariwa and 3/11 events. The following are noteworthy from the standpoint of seismic PRA.

- For Kashiwazaki-Kariwa, the arrival of the local (offsite) fire department was delayed. Given the scale of offsite destruction caused by the earthquake, it seems possible that offsite needs for emergency services played a role in this delay.
- For 3/11, this was a regional event with widespread impact on emergency response systems (including a key offsite emergency response center as well as communications).[6]
- For 3/11, coordination difficulties also arose due to the involvement of multiple offsite organizations which demanded information and provided suggestions and directions. Such difficulties are not unique to seismic events, but could have been amplified by the regional scale of the event (which is characteristic of a major earthquake).

[6] From a positive standpoint, despite these coordination challenges, Fukushima Daiichi did receive assistance from offsite organizations, including less-affected NPPs.

Seismic/Fire Interactions

In 1989, Sandia National Laboratories performed a Fire Risk Scoping Study that identified seven potential "seismic/fire interactions" based apparently on general principles and supported by non-nuclear seismic experience (see Lambright et al., 1989):

- Cable pulling
- Flammable liquid spills
- Flammable gas release
- Spread of fire from non-Category I SSCs
- Failure of suppression systems
- Spurious suppression actuation (leading to loss of suppressant inventory as well as SSC wetting)
- Degradation of fire recognition and fire fighting in a post-earthquake environment (including spurious fire alarms, aftershocks, LOOP, loss of non-emergency lighting)

NPP operational experience in the 30 years since then provides examples for some of these interactions. It also introduces an interaction – seismically-induced HEAFs – not explicitly identified by the scoping study. The following discussion of observations is structured using the fire PRA framework discussed by Siu et al. (2016b): fire initiation, fire-induced damage to SSCs (considering fire detection and suppression as well as fire growth), and plant response.

<u>Fire Initiation</u>. Seismically induced fires occurred at Kashiwazaki-Kariwa and at Onagawa (on 3/11).

- Both events involved HEAFs.
    - The Kashiwazaki-Kariwa HEAF involved a large station ("house") transformer at Unit 3. It was caused by differential ground subsidence leading to vertical displacement of the transformer relative to its secondary connection bus, leading to one or more ground and/or short circuit faults.
    - The Onagawa HEAF involved a non-emergency, 6.9 kV switchgear cabinet in the Unit 1 Turbine Building. It was caused by seismic shaking of Magne-Blast breakers, which have vertically oriented breaker stabs and are hung by buses in the cabinet (i.e., they are not fixed to the floor).
- No other seismically-induced fires have been reported for Kashiwazaki-Kariwa and 3/11.[7]
- Seismically-induced fires have not been reported in any of the other event descriptions reviewed.

We recognize the possibility that: (a) our dataset might not include all significant seismic events involving NPPs, and (b) the reports reviewed (many of which are high-level summaries) might not mention induced or coincident fires if they are considered to be minor. Nevertheless, we think that for at least the PGA ranges observed, considering the large number of potential fire initiation sites at any NPP, a seismically-induced NPP fire at any specific initiation site is certainly possible but not highly likely.[8]

<u>Fire Growth, Detection, and Suppression</u>. Our observations regarding the extent of seismically induced fires and associated fire fighting efforts are as follows.

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[7] Reactor Building fires at Fukushima Daiichi Unit 4 were apparently initiated by a hydrogen explosion.

[8] A similar inference, with similar caveats, can be made considering non-nuclear industrial facilities with electric power components analogous to those at NPPs. See, for example, Li and Roche (1998), who provide a photograph of damage caused by a seismically-induced fire at the Kobe Substation. From the information presented, it appears that the fire might have been due to fracturing of anchor bolts for a 275/77 kV 300 MVA transformer and subsequent transformer movement.

- At Kashiwazaki-Kariwa, the HEAF-induced fire involved leaking transformer oil from a failed bushing, but did not spread further due to existing fire walls.
- At Onagawa, the HEAF-induced fire affected all ten sectors of the switchgear cabinet. It also involved some vertical cables rising from the cabinet but did not spread further.
- Dust re-suspended by seismic shaking led to spurious fire detection alarms at Kashiwazaki-Kariwa, Onagawa, and Fukushima Daiichi.[9]
- At Onagawa, dense smoke filled large portions of the Turbine Building and hindered identification of the fire location.
- Fire suppression efforts were affected by the previously discussed coordination issues and broken underground fire lines (at Kashiwazaki-Kariwa)[10] and damaged roads (at both Kashiwazaki-Kariwa and Onagawa). The Kashiwazaki-Kariwa fire lasted 2 hours; the Onagawa fire lasted 7 hours.

Plant Response. It does not appear that the seismically-induced HEAFs at Kashiwazaki-Kariwa and Onagawa, by themselves, led to major complications in plant response. Of course, in the case of the latter, the seismically-induced partial LOOP and the following (seismically-induced) tsunami provided significant challenges.

Comment – Seismically-Induced HEAFs. The HEAFs at Kashiwazaki-Kariwa and Onagawa did not have significant nuclear safety impacts. However, it is important to recognize that HEAFs can be safety-significant. A HEAF was a major contributor to a 2-hour station blackout at the Maanshan (Taiwan) NPP in 2001 (see AEC, 2001),[11] and recent research activities have identified a HEAF-related damage mechanism (the creation of a cloud of conductive aluminum particles) that, for certain plants, have the potential to affect SSCs outside of previously assumed zones of influence. See Boyce (2016).

Current PRA standards (e.g., ASME/ANS, 2013) and guidance (e.g., EPRI, 2013; EPRI/NRC 2005) indicate there are significant challenges in quantitatively treating seismically-induced fires (including HEAFs) and rely heavily on walkdowns to qualitatively identify potential scenarios. Given our observation of the potential significance of seismically-induced HEAFs, we have performed a quick review of 24 HEAF events (all non-seismically initiated) experienced by U.S. NPPs. Our review identified several HEAF root causes (including loose or degraded connections, foreign material) that might be triggered or exacerbated by a seismic event. It is not clear if many of these root causes are readily identifiable by visual inspection conducted as part of a typical seismic PRA walkdown. However, HEAF-targeted preventative maintenance activities described in EPRI (2019), including bolted connection torque checks, foreign material exclusion (FME) measures, stab connection thermography and corona tracking efforts would likely be effective.

Reactivity Effects

Earthquakes in our dataset led to neutron-flux related reactor trips at the Onagawa (1993) and North Anna (2011), rather than trips due to ground motion. (In the case of North Anna, the Seismic Monitoring Instrumentation Panel was unavailable.) The fact that earthquakes have caused reactivity excursions: a) may not be widely recognized in the PRA community, and b) might be an important observation in the development and analysis of new reactor designs.

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[9] This phenomenon is not mentioned in the Kashiwazaki-Kariwa documents that we've reviewed, but is mentioned in GoJ (2011) as something the Fukushima Daiichi shift supervisor knew about based on Kashiwazaki-Kariwa experience. As with our discussion of seismically-induced fires, it should be cautioned that when an event report doesn't mention a particular phenomenon, this is not definitive proof that the phenomenon didn't occur.

[10] Interestingly, fire protection lines moved aboveground at Fukushima Daiichi as a result of the Kashiwazaki-Kariwa experience were exposed to and damaged by the tsunami on 3/11.

[11] Note that during the 1999 Maanshan event, heavy smoke from the HEAF was a key factor in preventing operator actions needed to terminate the SBO.

CONCLUDING REMARKS

To date, we have reviewed descriptions of 50 seismic events that potentially affected NPP operations and have developed a number of qualitative observations relevant to seismic PRA methods and models. Given the variety of sources consulted, we are reasonably confident our search has captured most significant events relevant to U.S. NPPs. We recognize that there are likely many minor events (e.g., low intensity earthquakes felt but not affecting NPP SSCs) that we have not captured, but expect that they will add few insights to those developed from more severe events.

To provide a more complete set of insights from our observations, we recognize that the observations need to be compared against current seismic PRA standards and guidance, and against the findings of recent analyses. This comparison will be performed in the next phase of our study. In the meantime, we note that several observations concern factors, mechanisms, and scenarios of interest to the human and organization, fire protection, and reactor physics technical communities. This points out the importance of an integrated, multidisciplinary approach to seismic PRA. It also emphasizes the need to ensure that seismic event reports address these other phenomena, going beyond descriptions of ground motion and direct effects on SSCs.[12]

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[12] Note that from a PRA perspective, it is important to have information on successes (e.g., definitive statements that an earthquake did not cause a fire at a particular location) as well as failures.

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