# EVALUATION OF AFTERSHOCKS IMPACT ON SEISMIC SAFETY OF POWER PLANTS BASED ON EXPERIENCE FEEDBACK

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**Abstract**: *Nuclear power plants (NPPs) are particularly vulnerable to the effects of aftershocks because they have complex and sensitive structures that require high levels of integrity to function safely. If the structural integrity of a nuclear power plant is compromised by an aftershock, it could lead to a serious accident with potentially catastrophic consequences for public health and the environment.*

*This paper focuses on work package 6 of Euratom METIS project, which concerns fragility analysis. One of the primary objectives of WP6 is to evaluate the impact of aftershocks and clustered seismicity on the seismic fragility and safety of NPPs.*

*In the clustered seismicity approach, seismic activity is modelled as dependent earthquakes categorized as foreshocks, aftershocks, triggered earthquakes, and mainshocks. Implementing aftershocks in seismic Probabilistic Safety Assessment (SPSA) for critical structures, such as NPPs, is challenging due to the lack of information on damage states of their components, which renders the full SPSA with aftershock consideration unfeasible. In this paper, influence of aftershocks on safety of NPPs based on experience feedback will be discussed. Specifically, our goal is to determine whether it is imperative to implement a comprehensive Seismic Probabilistic Safety Assessment (SPSA) of NPP structures subjected to aftershocks.*

*KEYWORDS: Aftershocks, Nuclear Power Plants (NPPs), Fragility, Seismic Safety.*

## 1 Introduction

Seismic Probabilistic Safety Assessment (SPSA) is a comprehensive methodology used to assess and quantify the risks associated with seismic (earthquake) events at complex technical systems such as nuclear power plants. It involves a systematic evaluation of how various components, systems, and structures within a nuclear facility would respond to earthquake-induced forces. Here's an overview of the key elements of seismic PSA of NPPs:

1. Hazard Assessment: The first step is to assess the seismic hazard at the specific location of the nuclear power plant. This involves analyzing historical earthquake data, studying the geological and tectonic characteristics of the region, and determining the probability of various levels of ground motion occurring.
2. Fragility Analysis: Fragility analysis examines the vulnerability of different plant components and systems to seismic forces. It assesses how likely these components are to fail or perform inadequately under various levels of ground shaking.
3. Event Tree and Fault Tree Analysis: These techniques are used to model and analyze the various pathways and sequences of events that can lead to core damage or other safety-related

consequences during an earthquake. Event tree analysis looks at the different possible accident scenarios, while fault tree analysis breaks down the events into their contributing causes.

In essence, seismic PSA provides a quantitative and probabilistic assessment of the safety of a nuclear power plant in the face of seismic events. It helps plant operators, regulators, and safety experts make informed decisions to enhance the resilience and safety of these facilities in earthquake-prone areas.

An aftershock is a seismic event that occurs in the aftermath of a larger earthquake, usually in the same general region as the mainshock. Aftershocks are typically smaller in magnitude than the mainshock but can still be significant and potentially damaging. Aftershocks can have various im-pacts on the safety of nuclear power plants. Aftershocks can exacerbate structural damage in nuclear power plants, potentially compromising their safety by affecting critical facilities like cooling towers, control rooms, and containment structures. The critical time for aftershock impact on the safety of nuclear power plants (NPPs) is typically in the immediate aftermath of the main earthquake event and during the subsequent hours and days. During this time, the plant is likely to be in a heightened state of alert, and safety systems may have already been activated in response to the main earthquake.

The choice between clustered and unclustered seismic event modelling depends on several factors, including the level of detail required in the analysis, the availability of empirical data on aftershock clustering behaviour in the region of interest, and the computational resources available for the analysis. In practice, clustered modelling is often preferred when more accurate and realistic representations of aftershock behaviour are needed, especially in regions with a history of significant seismic activity. Unclustered modelling may be used in cases where simplifications are acceptable, such as for screening-level assessments or when detailed aftershock data is limited.

The presence of a high number of Structures, Systems, and Components (SSCs) in a nuclear power plant (NPP) and the need for detailed understanding of their structural behaviour present additional challenges in conducting a Seismic Probabilistic Safety Assessment (SPSA) with clustered seismic event modelling. In other words, the large number of SSCs in nuclear power plants (NPPs) can render it infeasible to conduct a comprehensive Seismic Probabilistic Safety Analysis (SPSA) for NPPs.

In a Seismic Probabilistic Safety Analysis (PSA) for a nuclear power plant, a comprehensive list of seismic equipment is compiled to assess the plant's vulnerability to seismic events. This equipment list typically includes a wide range of components and systems throughout the plant that are important for maintaining safety during and after an earthquake. Instead, it’s more feasible to do SPSA of NPPs considering more critical SSCs. Conducting a Seismic Probabilistic Safety Assessment (SPSA) of a Nuclear Power Plant (NPP) without explicitly considering the safety of each individual Structure, System, and Component (SSC) can involve a more simplified and high-level approach. While this approach may not provide a detailed evaluation of each SSC's safety, it can still yield valuable insights into the overall seismic risk and help identify areas where further analysis or safety enhancements may be needed. It means, perform a probabilistic risk assessment (PRA) at a system or functional level rather than an SSC-specific level. This involves modelling the response of critical systems or functions to seismic events without considering the detailed behaviour of individual com-ponents.

Identifying critical Structures, Systems, and Components (SSCs) for a Seismic Probabilistic Safety Assessment (SPSA) of a Nuclear Power Plant (NPP) is a crucial step in the analysis. Critical SSCs are those whose failure during a seismic event could lead to significant safety consequences or impair the functionality of the plant. One way to identify critical SSCs is by reviewing any existing PRA or safety analysis reports for the NPPs. These analyses typically identify and assess SSCs based on their contributions to risk. Critical SSCs are often those that have a high likelihood of failure or a significant impact on risk when they fail. Another way is by reviewing any existing experience feedback reports regarding observed aftershock’s impacts on safety of NPPs. In this report, our goal is to evaluate whether the aftershock effect on nuclear power plant safety can be disregarded or not, based on existing feedback and experience. Moreover, this report facilitates the identification of SSCs of greater importance for inclusion in the Seismic Probabilistic Safety Analysis (SPSA) of a nuclear power plant.

This research is part of work package 6 of METIS which is a EURATOM project. This project has the goal to improve seismic Probabilistic Safety Assessment (PSA) methodology and to develop open-source tools in line with industrial needs and in agreement with recent scientific advances in earth-quake engineering and data science.

## 2 Methodology

Comprehensive reports that investigate the assessment of aftershock impacts on the safety of power plant structures and components are currently in short supply. To compile a thorough dataset, we conducted an exhaustive review of various databases, including SQUG, EPRI, SMIRT, HAL, WGIAGE, and NEA. Unfortunately, despite our rigorous search, the results yielded only a limited number of reports that singularly addressed the evaluation of aftershock effects on power plant safe-ty.

Our collected reports offer vital insights, thoughtfully categorized into distinct sections:

1. *Mainshock properties:* These initial powerful earthquakes triggering aftershocks are explored, shedding light on their properties, providing a foundational understanding essential for assessing their impact on power plant structures.
2. *Aftershock properties:* Reports delve into aftershock properties, including magnitude, location, frequency, and duration. This analysis enhances comprehension of aftershock characteristics, enabling better assessment of their potential safety implications for power plants.
3. *Structural Descriptions*: Comprehensive information on power plant structures, encompassing design, materials, and overall integrity, forms another significant section. This data is critical for evaluating vulnerability to seismic events and subsequent aftershocks.
4. *Mainshock Damage Assessment:* Detailed examination of the damage inflicted by mainshocks on power plant structures and components, including integrity assessment, weak point identification, and damage extent evaluation, is vital for anticipating aftershock consequences.
5. *Facility Performance:* Insights into power plant performance during mainshocks, including critical system responses, emergency shutdown protocols, and safety measure effective-ness, help identify areas for enhancement to bolster resilience against seismic events and aftershocks.
6. *Aftershock-Induced Damage*: Reports discuss the specific damages caused by aftershocks, encompassing evaluation of additional stress, identification of potential vulnerabilities stemming from mainshock damage, and overall safety impact assessment.

In conclusion, despite limited available reports, our categorized information provides essential in-sights into assessing aftershock effects on power plant safety. This knowledge is indispensable for enhancing power plant resilience and safety in the face of seismic events.

## 3 Examining the Safety Consequences of Aftershocks on Power Plants

In the upcoming section, we delve into a review of reports discussing the effects of aftershocks on the safety of power plants. Given the scarcity of available reports and common structure, systems, and components (SSCs), we extend our analysis to encompass various types of power plants be-yond just nuclear facilities. This broader perspective will enhance our comprehension of the potential impact of seismic events on the overall security and stability of these facilities.

### 3.1 Investigation of the 1999 Chi Chi Taiwan earthquake, EPRI (2001)

- *Mainshock properties*: The Chi Chi Earthquake, with 7.3 ML or 7.6 MW, occurred on September 21, 1999, near Chi Chi, Nantou County, at 1:47 AM (local time), with a hypocentre about 7 km below ground.
- *Aftershock properties:* Over 10,000 aftershocks followed within a month, with five exceeding magnitude 6 on the Richter scale. One of these, a 6.7 magnitude aftershock on June 11, 2000, caused additional damage, primarily on the east side (hanging wall) of the Chelungpu Fault.
- *Structural Descriptions:* Taiwan Power Company (Taipower) operated various power plants, including hydroelectric, thermal (oil, coal, LNG), and nuclear, with a total capacity of 26,680 MW. Power from the southern and central parts of Taiwan was transmitted to the north via a 345-kV transmission system (Figure 1).
- *Mainshock Damage Assessment:* The Chi Chi Earthquake severely damaged the 345-kV and 161-kV systems due to slope failures around the epicentre. Substations suffered extensive damage, but the nuclear power plants, located about 150 km from the epicentre, remained undamaged. Some fossil plants and transmission towers near Taichung harbour suffered earthquake damage.
- *Facility Performance:* Nuclear generating stations, such as Chinshan and Kuosheng, over 100 km from the epicentre, experienced reactor trips due to power grid instability caused by transmission tower

damage. All units were back online within one to four days after the earthquake. Maanshan Nuclear Generation Station remained operational throughout the earthquake.

- *Aftershock-Induced Damage:* There is no investigation in this report regarding additional damages caused by aftershocks.

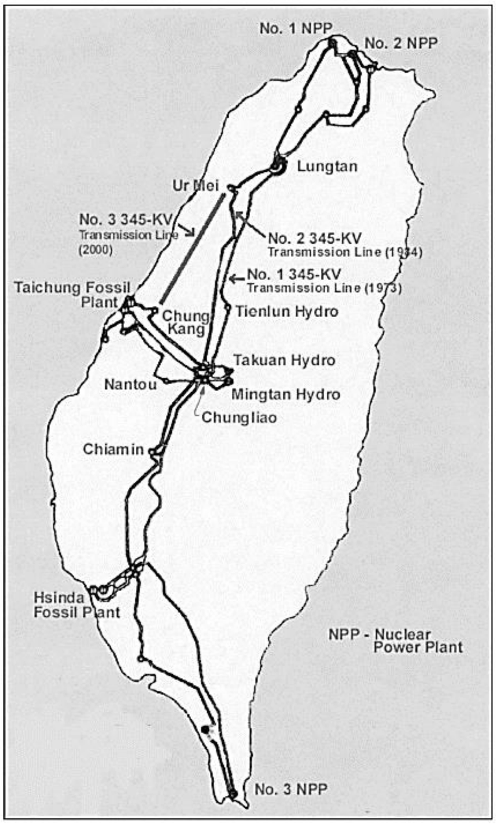

*Figure 1: Taipower 345-KV Transmission Lines*

## 3.2 Evaluating Raceway System Performance During Strong-Motion Earthquakes: THE CHILE EARTHQUAKE, EPRI (1991)

- *Mainshock properties:* The Chile earthquake, occurring at 7:47 P.M. local time on March 3, 1985, registered a magnitude of 7.8. Striking 15 miles offshore in central Chile, including Santiago with 6 million inhabitants, it resulted in 180 deaths, over 2,500 serious injuries, and the destruction of 45,000 dwellings, with estimated direct damage near $2 billion (U.S.). The earthquake lasted about 2 minutes, with up to 40 seconds of strong ground motion. Modified Mercalli intensities reached IX along the coast and VII to VIII over a wide area.
- *Aftershock properties:* The main earthquake triggered significant aftershocks, including a magnitude 7.0 event one hour later and a 7.2 magnitude event on April 9.

In following, inspection report on different facilities is reviewed:

### 3.2.1 RENCA POWER PLANT

- *Structural Descriptions:* The Renca Power Plant, situated 85 miles east of the earthquake's epicentre in Santiago, Chile. It comprises two 50 MW coal-fired boiler units and two turbine generators on reinforced concrete pedestals, all with steel-framed structures. The site includes cooling towers, a switchyard, a concrete-frame Dispatch Centre building, a coal conveyor system, and a water treatment facility. The plant is located on a flat site on deep alluvium and utilizes 18-inch-wide cable trays with rod-hung trapeze supports spanning 8 to 10 feet.
- *Mainshock Damage Assessment:* Seismic damage included bent boiler restraints, tube leaks, anchor bolt failures on tanks, and fractured transformer base bolts. Two unanchored motor control centers shifted but stayed put due to conduit connections. Remarkably, cable trays remained undamaged throughout.

- *Facility Performance:* Neither unit was operating at the time of the earthquake. Unit 1 was undergoing maintenance. Unit 2 was brought on-line after a superficial inspection within 5 hours of the earthquake. It operated through several aftershocks.
- *Aftershock-Induced Damage:* There is no investigation on further damages due to aftershocks in this report.

### 3.2.2 RAPEL HYDROELECTRIC PLANT

- *Structural Descriptions:* The Rapel Hydroelectric Plant, situated 65 miles southeast of the earthquake epicentre, features a large concrete arch dam with five 75 MW generators. The 345-foot-tall, 1,150-foot-long dam rests in a river gorge on steep terrain, while the switchyard and control building sit atop an adjacent hill. The generators were commissioned between 1968 and 1970.
- *Mainshock Damage Assessment:* During the earthquake, none of the five turbines were in operation. Afterward, a minor inspection revealed only slight damage to the dam. The emergency diesel ran for 24 hours until three units were brought online; two remained offline due to foundation movement. The delayed startup was mainly due to 220 kV switchyard damage. Equipment in the control building suffered minor damage, while cable trays and conduit remained unscathed.
- *Aftershock-Induced Damage:* In the days following the earthquake, more damage to the dam was discovered. The direct cost of damage at the facility was estimated at $20 million with an additional loss of approximately $11 million due to the unavailability of Units 3 and 5. Little or none of the damage was attributed to the aftershock.

*Figure 3: Rapel Hydroelectric*

## 3.3 Evaluating Raceway System Performance During Strong-Motion Earthquakes: THE MEXICO EARTHQUAKE, EPRI (1991)

- *Mainshock properties:* The Mexico earthquake occurred on September 19, 1985, at 7:17 A.M. (local time) and had a magnitude of 8.1. The epicentre was approximately 25 miles northwest of the industrial town of Lazaro Cardenas. The main earthquake was felt throughout southwestern Mexico and as far away as Galveston, Texas.
- *Aftershock properties:* On September 20 at 7:34 P.M., a 7.5 aftershock struck about 70 miles southwest of the main shock epicentre.
- *Structural Descriptions:* There are two major hydroelectric plants in the epicentral area. The 1000 MW El Infiernillo plant is located approximately 40 miles from the main shock and the 300 MW La Villita plant is located only 25 miles from the epicentre.
- *Mainshock Damage Assessment*: Damage to the dams was limited to superficial damage at the dam crests. An oil leak occurred in a high-voltage transformer in the switchyard at El Infiernillo, and a few ceiling panels in the control room at La Villita fell.
- *Aftershock-Induced Damage:* There is no investigation on further damages due to aftershocks in this report.

## 3.4 Evaluating Raceway System Performance During Strong-Motion Earthquakes: THE ADAK, ALASKA, EARTHQUAKE, EPRI (1991)

- *Mainshock properties:* On May 7, 1986, a magnitude 7.7 earthquake struck southeast of the Andreanof Islands chain, approximately 90 miles southeast of Adak, Alaska. Preceding the main event, three foreshocks of magnitudes 4.5, 6.0, and 5.0 occurred within the 3 hours prior. Shaking intensity ranged from V to VII on the Modified Mercalli Intensity Scale, with estimated PGAs between 0.15g and 0.25g.

- *Aftershock properties:* Two significant aftershocks, registering magnitudes 6.2 and 6.5, were recorded on May 8 and May 17, respectively. Despite a tsunami warning, no significant wave heights occurred, though water levels dropped in Sweeper Cove.
- *Structural Descriptions:* Adak's structures include timber-frame, reinforced masonry, precast reinforced concrete, and numerous steel structures, mostly three stories or lower. The island hosts diesel generators, steam plants, electrical substations, and various facilities housing computer equipment and emergency power facilities.
- *Mainshock Damage Assessment:* The power plant sustained minor earthquake damage with no impact on cable raceways or cables. Only minor floor slab cracking occurred.
- *Aftershock-Induced Damage:* About a week post-main shock, an outboard bearing on one diesel generator was damaged, likely due to earthquake or aftershock-induced misalignment.

### 3.5 **Earthquake of October 9, 1995: Effects at the Manzanillo Power Plant,** EPRI (1997)

- *Mainshock properties:* A magnitude 7.6 earthquake in the subduction zone off the Pacific Coast of Mexico caused serious damage to the Manzanillo Power Plant, one of the largest thermoelectric generating plants in the nation’s power system.
- *Aftershock properties:* On Monday, October 9, the Manzanillo instrument detected 16 aftershocks with peak ground acceleration ranging from 0.005 to 0.03g. Small aftershocks continued through Tuesday and Wednesday. A magnitude 5.0 aftershock on Tuesday, October 10, had a peak ground acceleration of 0.15g.

  A significant event occurred on Thursday, October 12, with a magnitude 5.6 aftershock at 10:53 a.m., recording a peak ground acceleration of 0.15g. This strong aftershock alone could serve as a valuable representation of a design basis earthquake for nuclear power plants in the eastern United States.

- *Structural Descriptions:* The Manzanillo Power Plant experienced a level of ground shaking among the most severe ever recorded beneath a large modern power facility. Motions of about 0.40g peak ground acceleration were recorded in the plant’s substation in each of two horizontal directions. Resulting building and equipment motions were also recorded.
- *Mainshock Damage Assessment:* Intense ground motion, lasting about 30 seconds with a broad frequency range, caused significant damage. The 400-kilovolt substation switchyard collapsed, and the plant's buried concrete cooling water intake system structures experienced localized liquefaction. However, most other systems in the modern power plant remained robust, and the plant restarted smoothly after bringing the generating units back online, reaffirming power stations' resilience to strong ground motion.
- *Facility Performance:* Manzanillo, the largest and most modern plant, faced considerable ground motion. It incurred more damage than almost all other power plants in the EPRI database, except for the U.S. Navy steam plant in Guam during the 1993 magnitude 8.0 earthquake. Both plants suffered liquefaction damage to their saltwater intake structures, leading to buried concrete piping collapse serving plant condensers. Repairs kept the largest unit of the Navy plant offline for three months post-earthquake.
- *Aftershock-Induced Damage:* Effects to the two Manzanillo plants from the magnitude 5.6 aftershock, however, were of no consequence. All generating units were shut down and already under repair from damage sustained from the main shock three days before.

### 3.6 **Northridge Earthquake: Effects on Electric Power and Industrial Facilities,** EPRI (1997)

- *Mainshock properties:* On Monday, January 14, 1994, at 4:31 AM (PST), a moment magnitude 6.7 (MW) earthquake struck the Northridge area of metropolitan Los Angeles, California. It caused approximately $20 billion in damage, one of the highest insured losses due to natural disasters in U.S. history.
- *Aftershock properties*: Aftershock activity was high, with 13 aftershocks of magnitude 4.0 or greater between January 18 and 28. It followed a pattern consistent with other significant California earthquakes.

- *Structural Descriptions*: The Valley Generating Station, closest to the epicenter, comprises four thermal generating units. Units 1 and 2 were placed in operation in 1954 and later mothballed in 1994. Units 3 and 4 had not operated since November 1993.
- *Mainshock Damage Assessment:* The facility experienced minor damage, including cracks in steel struts, distorted insulation panels, damaged piping supports, and superficial building element damage. Protective relays remained functional. Damaged apparatus included 230KV equipment, transformers, and building infrastructure.
- *Facility Performance:* Unit 3 was on reserve shutdown, while unit 4 was unavailable during the earthquake. Plant power was lost due to a grid blackout, and restarting auxiliary systems took several hours.
- *Aftershock-Induced Damage:* A magnitude 5.1 aftershock on January 19 triggered unit 4's trip offline due to relay actuation. Additionally, a transformer fire occurred at receiving station S following an aftershock, attributed to misaligned bushing.

### 3.7 **Investigation of the 1999 Kocaeli Turkey Earthquake,** EPRI (2001)

- *Mainshock properties:* On August 17, 1999, a magnitude 7.4 (MW) earthquake struck the city of Izmit in the province of Kocaeli in western Turkey, causing over 20,000 buildings to collapse, killing 17,000 people, injuring 44,000, and causing an estimated economic loss of US $16 billion.
- *Aftershock properties:* At 8:54 AM, a strong aftershock caused the entire grid to de-energize again and the step-by-step restoration process had to start over.
- *Structural Descriptions:* The Ambarli Fuel Oil Power Plant, situated west of Istanbul, about 130 km from the epicentre, consists of five units with a combined capacity of 630 MW. Built between 1967 and 1971, it experienced peak horizontal ground acceleration of 0.25g, causing an off-line trip due to offsite power loss. Within six days, all units were operational under controlled conditions.
- *Mainshock Damage Assessment:* Despite the earthquake, the plant had no significant damage to its boilers, turbine generators, or support structures. Minor issues included spring support damage on condensers (Units 4 and 5), elevated vibration in the Unit 4 turbine generator, slight stretching of anchor bolts (Units 4 and 5) and pounding damage to floor slabs (Units 4 and 5). Elevators in Units 4 and 5 also suffered damage, including snapped cables, braking system issues, and deformation of counterweight guide rails. The brick enclosure atop the reinforced concrete stacks of Units 4 and 5 sustained damage.
- *Facility Performance:* On the day of the earthquake, local grids were re-energized, providing electricity at 34.5 kV. Most distribution service was restored by the evening of August 17th, except for areas with damaged circuits. It's worth noting that the Turkish electrical transmission system was expanding significantly at the time, which facilitated the restoration effort with readily available equipment and materials.
- *Aftershock-Induced Damage:* The brick enclosure collapsed around noon on the day of the earthquake, during an aftershock, causing damage to gas isolation equipment housed in the building located below the brick enclosure.

*Figure 4: Stack for Units 4 and at Ambarli Fuel Oil Plant*

### 3.8 Initial Discoveries and Insights from the Earthquake at Kashiwazaki-Kariwa Nuclear Power Plant on July 16, 2007, IAEA (2007), Kayen et al (1997)

- *Mainshock properties:* The Niigata Chuetsu Oki earthquake, with a magnitude of 6.6, struck offshore Kariwa at 10:13 a.m. local time on July 16, 2007. It had an estimated focal depth of 10 km and resulted in a seismic intensity of 6+ (IX in MMI) in several areas.
- *Aftershock properties:* The Niigata Chuetsu Oki earthquake was followed by a sequence of aftershocks. The largest aftershock as of 10:00 on July 17, was a M5.8 (preliminary) earthquake that occurred at 15:37 on July 16, with maximum seismic intensity 6 Lower.
- *Structural Descriptions:* The Kashiwazaki-Kariwa nuclear power plant, operated by Tokyo Electric Power Company (TEPCO), is the world's largest nuclear power plant site. It consists of seven units with a total net installed capacity of 7,965 MW. This includes five BWR-type reactors (1,067 MW net capacity each) and two ABWR-type reactors (1,315 MW net capacity each). The units entered commercial operation between 1985 and 1997.
- *Mainshock Damage Assessment:* The earthquake resulted in automatic shutdown of operating reactors, a fire in Unit 3's in-house electrical transformer, limited release of radioactive material, and damage to non-nuclear structures, systems, components, and outdoor facilities. Preliminary data suggested potential exceedance of the design basis ground motion with possible effects on plant SSCs.
- *Facility Performance:* 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 mode but not connected to the grid, while Units 1, 5, and 6 were in shutdown mode for planned maintenance. Despite the earthquake exceeding the plant's seismic design parameters, the facility responded safely. Reactors 3, 4, 7, and 2 (in start-up) successfully auto-shutdown.
- *Aftershock-Induced Damage:* There is no investigation on further damages due to aftershocks in this report.

## 4 Conclusion

In conclusion, the existing literature highlights a significant gap in our understanding of how after-shocks precisely affect power plants and their associated structures, systems, and components (SSCs). While current research suggests that aftershocks typically do not cause direct damage to the primary reactor structures, they tend to worsen preexisting vulnerabilities within subsystems that were already weakened by the initial mainshock. This is particularly noticeable in masonry structures or subsystems that experienced misalignment during the mainshock.

As a result, aftershocks often exacerbate the problems within these subsystems, making it more challenging to swiftly restore power plant operations after a mainshock-induced safety shutdown. In light of these findings, there is a clear need for more comprehensive investigations into the specific mechanisms underlying the impact of aftershocks on power plant SSCs. Such research is crucial for improving the resilience and safety of power plants in regions prone to seismic activity.

## 5 Acknowledgment

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## 6 References

EPRI, *"Investigation of the 1999 Chi Chi Taiwan Earthquake."* Palo Alto, CA (2001).

EPRI, *"The Performance of Raceway Systems in Strong-Motion Earthquakes"*, Palo Alto, CA (1991).

EPRI, *"Earthquake of October 9, 1995: Effects at the Manzanillo Power Plant"*, Palo Alto, CA (1997).

EPRI, *"The January 17, 1994, Northridge Earthquake: Effects on Electric Power and Selected Industrial Facilities"*, Palo Alto, CA (1997).

EPRI, *"Investigation of the 1999 Kocaeli Turkey Earthquake: Effects on Power and Industrial Facilities"*, Palo Alto, CA (2001).

IAEA, *"Preliminary Findings and Lessons Learned from the 16 July 2007 Earthquake at Kashiwazaki-Kariwa NPP"*, AT (2007).

Kayen, R., Collins, B.D., Abrahamson, N., Ashford, S., Brandenberg, S.J., Cluff, L., Dickenson, S., Johnson, L., Kabeyasawa, T., Kawamata, Y., Koumoto, H., Marubashi, N., Pujol, S., Steele, C., Sun, J., Tanaka, Y., Tokimatsu, K., Tsai, B., Yanev, P., Yashinsky, M., and Yousok, K., *"Investigation of the M6.6 Niigata-Chuetsu Oki, Japan, Earthquake of July 16, 2007"*, U.S. Geological Survey, Open File Report 2007-1365, 230pg, (2007).