



International Atomic Energy Agency

***Impact of Extreme Events on
Nuclear Facilities following Fukushima***

by

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(based on a paper produced by A. Lyubarskiy, I. Kuzmina and M. El-Shanawany)

IAEA Peer Review Service being developed for Extreme Events

**IAEA views on where
PSA methodology
needs to be enhanced
following Fukushima**

Current State-of-the-Art in PSA

PSA methodology well established; 40 years of experience in producing PSAs

Current standard is to produce Level 2 PSAs for all types of nuclear facilities that address a wide range of internal and external events

Standards/ guidance available for producing/ reviewing PSAs including IAEA Specific Safety Guides (SSGs)

IAEA has considerable experience in reviewing PSAs for nuclear power plants (IPSART reviews)

Need to Enhance PSA Methodology

Fukushima accident indicated areas where current PSA methods need to be enhanced

➤ **Assessment of the hazards in the PSA**

- 1] External hazard screening
- 2] Correlated hazards

➤ **Plant response to the hazards**

- 3] External hazard impact assessment
- 4] Multi-unit sites
- 5] Mission time
- 6] Human reliability assessment
- 7] Failure probability of qualified equipment
- 8] Hydrogen explosion following station blackout
- 9] Transient hazardous materials
- 10] Connections between plant buildings and compartments
- 11] Spent fuel pool; waste treatment facilities
- 12] Severe accident management guidelines

Assessment of the Hazards in the PSA

1] External hazard screening

- ✓ Hazards screened so that the detailed analysis focuses on those with the highest risk significance; involves qualitative and quantitative screening
- ✓ Hazards making a relatively low contribution to risk screened out
- ✓ Screening process/ criteria need to be revisited
- ✓ Screening needs to take account of correlated hazards

2] Correlated hazards

- ✓ Need to identify all correlation mechanisms including:
 - Source correlated hazards (seismic + tsunami)
 - Phenomenologically correlated hazards (strong winds and heavy rain)
 - Duration correlated hazards (hazards occurring during a long hot summer period)
 - Induced hazards (seismically induced fire or flood)
- ✓ Frequency assessment needs to take account of correlation mechanisms

Plant Response to the Hazards (1)

3] External hazard impact assessment

- ✓ Need to take account of all potential impacts of hazards
- ✓ Need to take account of combined impact of correlated hazards
- ✓ Impacts of correlated hazards may be different
 - Seismic event + prolonged period of high temperatures (effect on ultimate heat sinks)
 - High wind + high precipitation (structural damage + equipment submerged)

4] Multi-unit sites

- ✓ Interactions between plant units often not taken into account in PSA
- ✓ Could arise due to: shared buildings, off-site power systems, spatial interactions, radiological releases, operator availability, etc.
- ✓ All these effects need to be taken into account

Plant Response to the Hazard (2)

5] Mission time

- ✓ Mission time often taken as 24 hours; IAEA SSG states that longer mission times need to be considered where there is a potential “cliff-edge”
- ✓ Further consideration needs to be given to mission times for success sequences where systems are restored/ required to operate for a long time
- ✓ Could be done using Markov modelling

6] Human reliability assessment

- ✓ HRA needs to include a more realistic assessment of the effect of hazards on human performance and take account of:
 - Accident sequences where information not available
 - Actions carried out in adverse environmental conditions
 - Availability of operators for multi-unit sites

Plant Response to the Hazard (3)

7] Failure probability of qualified equipment

- ✓ Random failures only are considered for qualified equipment within design basis
- ✓ Need to consider enhanced failure where environmental conditions approach design basis (fragility)

8] Hydrogen explosion following station blackout

- ✓ Potential for hydrogen explosion needs to be considered

9] Transient hazardous materials

- ✓ Transient flammable materials usually considered in fire PSA
- ✓ Transient hazardous (flammable, explosive, etc.) materials also need to be considered for other hazards

Plant Response to the Hazard (4)

10] Connections between plant buildings and compartments

- ✓ Need to take account of all such connections, their status during different operating modes and their failure due to hazards

11] Spent fuel pool; waste treatment facilities

- ✓ Usually addressed in shutdown PSAs; also need to be considered in at-power PSAs

12] Severe accident management guidelines

- ✓ SAMGs provided for most plants to mitigate the consequences of severe accidents
- ✓ Methodology needs to be enhanced for modelling SAMGs in PSA

**IAEA Peer Review Service
being developed for
Extreme Events**

Issues Raised by the Fukushima Accident

Is the level of protection provided at nuclear facilities adequate for extreme events?

Are the reviews/ stress tests being carried out in the member states adequate to identify vulnerabilities to extreme events?

- ✓ **Concerns highlighted at IAEA Ministerial Conference**
- ✓ **DG proposed that an enhanced nuclear safety framework is established**
- ✓ **IAEA activities to be strengthened in areas of plant design and safety assessment**
- ✓ **IAEA Safety Assessment Section are developing a Peer Review Service to address extreme events explicitly**

Extreme Event

An internal or external event (or combination of events) that is more severe than the initiating events taken into account in the design (design basis events)

Has the potential to lead to widespread damage to structures, systems and components (SSCs) and prevent operator actions being carried out

Provides a severe challenge to the ability of the plant to carry out the Fundamental Safety Functions (FSFs)

- ✓ ***Criticality control (of the reactor and stored fuel)***
- ✓ ***Residual heat removal (from the reactor and stored fuel)***
- ✓ ***Confinement (of radioactive material)***

Extreme Event Damage State

Damage to SSCs that has occurred due to a specific extreme event

Includes the damage due to the immediate impact of the extreme event plus any consequential failures that could occur

Damage state will change with time as further failures occur and operator actions are carried out to mitigate the consequences of the extreme event

Scope of the Peer Reviews

To include a wide range of extreme events (both internal and external)

To include the threat to all sources of radioactive material

- ✓ ***Reactor core***
- ✓ ***Stored irradiated fuel***
- ✓ ***Radwaste***

To include all modes of operation

- ✓ ***Operation at power***
- ✓ ***Low power and shutdown***
- ✓ ***Refuelling and fuel storage***

To include all aspects of “stress tests”; to play a role in their development and harmonisation

Does not include security threats to the plant

Specific Objectives

To enhance IAEA Design and Safety Assessment Review services to address extreme events explicitly

To take into account the lessons learned from Fukushima

To add a new component to IAEA's peer review services

To provide an input into the updating of IAEA Safety Standards on design and safety assessment

To provide a forum for the dissemination and sharing of information amongst Member states; harmonisation of approaches

Recommendation Made

To enhance the current IAEA peer reviews (IPSART, RAMP, GRSR, PSRS) to include extreme events explicitly

The work will be carried out in co-operation other peer reviews:

- ✓ ***Siting of nuclear facilities/ site specific characteristics***
- ✓ ***Operational aspects/ management aspects of recovery procedures and guidelines following an extreme event***

Aim of the Peer Reviews

To determine the potential impact of extreme events on nuclear facilities

To determine if there are weaknesses in the existing protection where improvements need to be considered

Peer reviews will focus on the design and safety assessment aspects of the protection:

- ✓ *Effect on: Fundamental Safety Functions, defence-in-depth, safety margins, robustness, cliff edge effects, multiple failures, prolonged loss of support systems, recovery actions carried out by the plant operators, etc.*

Activities Considered in the Peer Reviews

- 1. Review design basis of the nuclear facility for internal and external events; justification for the selection of the design basis events; treatment of beyond design basis events***
- 2. Identify potential extreme events that could occur; use of a generic list (to be defined)***
- 3. Identify impact of extreme events, damage to SSCs, impact of the extreme event on the ability of the operating staff/ recovery actions, extreme event damage states***
- 4. Determine if remaining plant is adequate to carry out the Fundamental Safety Functions***
- 5. Determine if existing Emergency Operating Procedures (EOPs) and Severe Accident Management Guidelines (SAMGs) are sufficient for extreme events***
- 6. Identify examples of good practice; identify vulnerabilities in the protection provide for extreme events where additional protection required***



Possible Approaches

Stepwise Increase in Load approach

Looks at the adequacy of the protection provided for increasingly severe extreme events

Configuration Matrix approach

Looks at the impact of extreme events on defence in depth for Level 3 (protection for design basis accidents) and Level 4 (mitigation of severe accidents)

Fault Sequence Analysis approach

Looks at the adequacy of the protection provided using the linked Event Tree/ Fault Tree (PSA) models defined for the plant

Emergency Operating Procedures/ Severe Accident Management Guidelines

Reviews the basis for the existing EOPs/ SAMGs and their applicability to the damage states that occur following extreme events

Common features of different approaches

These approaches all consider:

- ✓ **Wide range of extreme events of increasing magnitude**
- ✓ **Damage caused to SSCs; extreme event damage states**
- ✓ **Damage to front line safety systems and support systems**
- ✓ **Plant realignments/ reversionary modes**
- ✓ **Ability of the plant operators to respond**
- ✓ **Effect on Fundamental Safety Functions, defence in depth**
- ✓ **Long term development of the extreme event damage state**
- ✓ **Looks for cliff edges**

Work Being Carried Out

- Task 1: Develop the approach for a peer review of the impact of extreme events on nuclear facilities**
- Task 2: Develop guidelines/ methodology to carry out a comprehensive, systematic peer review**
- Task 3: Carry out benchmark reviews; identify good practices**
- Task 4: Provide feedback into the IAEA Safety Standards relating to extreme events**
- Task 5: Provide feedback to other IAEA peer review services on extreme events**
- Task 6: Hold workshops/ seminars to disseminate the insights from the peer reviews carried out**

