IAEA
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Atoms for Peace and Development

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Design of Nuclear Installations against External Events SSG-67 & SSG-68

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Objectives of the presentation

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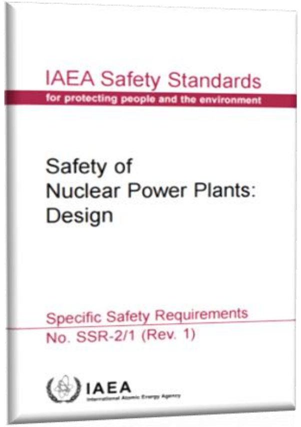
- Provide a deeper understanding of design of nuclear installations against external events presented in the IAEA Safety Standards No. SSG-67 and No. SSG-68.
- Provide what are the design requirements and guidance for the key elements of the design process for nuclear installations against external hazards.

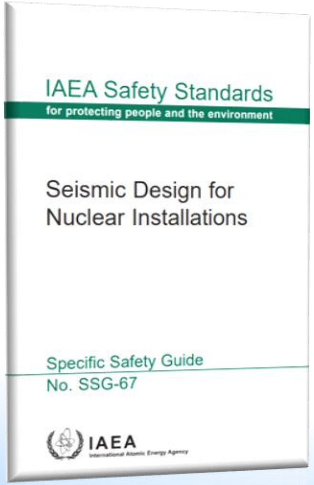
Outline

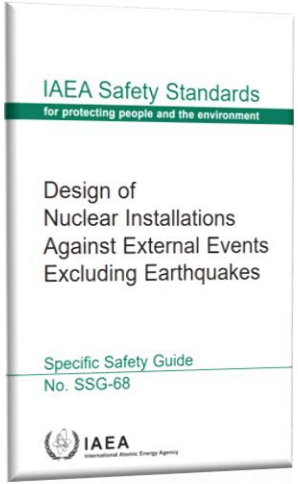
- Introduction
- Applicable Design Requirement (SSR-2/1) for External Events
- Seismic Design of Nuclear Installations: SSG-67
- Design of Nuclear Installations Against External Events Excluding Earthquakes: SSG-68
- Concluding Remarks

Introduction

IAEA Safety Standards related to design of nuclear installations against external events







Applicable Design Requirement (SSR-2/1) for External Events

Applicable Design Requirement (SSR-2/1 (Rev. 1)) for External Events

- **Requirement 17: Internal and external hazards**

  All foreseeable internal hazards and external hazards, including the potential for human induced events directly or indirectly to affect the safety of the nuclear power plant, shall be identified and their effects shall be evaluated. Hazards shall be considered in designing the layout of the plant and in determining the postulated initiating events and generated loadings for use in the design of relevant items important to safety for the plant.

Applicable Design Requirement (SSR-2/1 (Rev. 1)) for External Events

5.15A. **Items important to safety shall be designed and located**, with due consideration of other implications for safety, **to withstand the effects of hazards or to be protected**, in accordance with their importance to safety, against hazards and against common cause failure mechanisms generated by hazards.

5.15B. For **multiple unit plant sites**, the design shall take due account of the potential for specific hazards to give rise to impacts on several or even all units on the site simultaneously.

Applicable Design Requirement (SSR-2/1 (Rev. 1)) for External Events

5.17. **The design shall include due consideration of those natural and human induced external events** (i.e. events of origin external to the plant) that have been identified in the site evaluation process. Causation and likelihood shall be considered in postulating potential hazards. In the short term, the safety of the plant shall not be permitted to be dependent on the availability of off-site services such as electricity supply and firefighting services. The design shall take due account of site specific conditions to determine the maximum delay time by which off-site services need to be available.

5.19. Features shall be provided to minimize any **interactions between buildings** containing items important to safety (including power cabling and control cabling) and any other plant structure **as a result of external events** considered in the design.

Applicable Design Requirement (SSR-2/1 (Rev. 1)) for External Events

5.21. **The design of the plant shall provide for an adequate margin** to protect items important to safety against levels of external hazards to be considered for design, derived from the hazard evaluation for the site, and **to avoid cliff edge effects.**

5.21A. **The design of the plant shall also provide for an adequate margin to protect items ultimately necessary** to prevent an early radioactive release or a large radioactive release in the event of levels of natural hazards exceeding those considered for design, derived from the hazards evaluation for the site.

Applicable Design Requirement (SSR-2/1 (Rev. 1)) for External Events

- **Requirement 18: Engineering design rules**

  The engineering design rules for items important to safety at a nuclear power plant shall be specified and shall comply with the relevant national or international codes and standards and with proven engineering practices, with due account taken of their relevance to nuclear power technology.

5.23. **Methods to ensure a robust design shall be applied**, and proven engineering practices shall be adhered to in the design of a nuclear power plant to ensure that the fundamental safety functions are achieved for all operational states and for all accident conditions.

Applicable Design Requirement (SSR-2/1 (Rev. 1)) for External Events

- **Requirement 20: Design Extension Condition**

  A set of design extension conditions shall be derived on the basis of engineering judgement, deterministic assessments and probabilistic assessments for the purpose of further improving the safety of the nuclear power plant by enhancing the plant's capabilities to withstand, without unacceptable radiological consequences, accidents that are either more severe than design basis accidents or that involve additional failures. These design extension conditions shall be used to identify the additional accident scenarios to be addressed in the design and to plan practicable provisions for the prevention of such accidents or mitigation of their consequences.

Applicable Design Requirement (SSR-2/1 (Rev. 1)) for External Events

- **Requirement 53: Heat transfer to an ultimate heat sink**

  The capability to transfer heat to an ultimate heat sink shall be ensured for all plant states.

6.19B. **The heat transfer function shall be fulfilled for levels of natural hazards more severe than those considered for design,** derived from the hazard evaluation for the site.

Applicable Design Requirement (SSR-2/1 (Rev. 1)) for External Events

- **Requirement 65: Control room**

  A control room shall be provided at the nuclear power plant from which the plant can be safely operated in all operational states, either automatically or manually, and from which measures can be taken to maintain the plant in a safe state or to bring it back into a safe state after anticipated operational occurrences and accident conditions.

6.40A. **The design of the control room shall provide an adequate margin against levels of natural hazards more severe than those considered for design,** derived from the hazard evaluation for the site.”

Seismic Design of Nuclear Installations: SSG-67

SSG-67

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Design Basis Earthquake (DBE)

- **Vibratory Ground motion Hazards**

SL-2: To ensure the safety of nuclear installation in the event of rare earthquake

- ✓ Defined as the maximum credible values of the parameters such as the peak ground acceleration and spectrum representation (Deterministic approach)
- ✓ Corresponding to a level with an annual frequency of exceedance in the range of 10^{-3} to 10^{-5} , typically (Probabilistic approach).

SL-1: To ensure the possibility of continued operation in the event of a less severe, but more probable, earthquake.

- ✓ Reasonably be expected to occur and affect the nuclear installation during its operating lifetime (Deterministic approach)
- ✓ Corresponding to a level with an annual frequency of exceedance in the range of 10^{-2} to 10^{-3} , typically (Probabilistic approach).

- **Detailed Geological, Geophysical and Geotechnical Characteristics**

SSG-67

Beyond Design Basis Earthquake (BDBE)

(a) The design should provide adequate seismic margins for those SSCs ultimately required to prevent core damage and to prevent an early radioactive release or a large radioactive release.

(b) The design should provide adequate seismic margins to the safety classified SSCs credited for mitigatory measures for Level 4 of the defence in depth concept.

(c) It should be demonstrated that cliff edge effects are avoided within the uncertainty associated with the definition of SL-2.

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Seismic Categorizations

- **Seismic Category 1:** Items that need to **remain functional during and/or after the occurrence of the SL-2** design basis earthquake.

(a) Items whose failure could directly or indirectly cause accident conditions;
(b) Items that are necessary for shutting down a reactor and maintaining a reactor in a safe shutdown condition, including the removal of decay heat;
(c) Items that are necessary to prevent or mitigate unintended radioactive releases, including SSCs in spent fuel storage pool structures and fuel racks;
(d) Items that are necessary to mitigate the consequences of design extension conditions and whose failure would result in consequences of a high level of severity, as defined in IAEA Safety Standards Series No. SSG-30, Safety Classification of Structures, Systems and Components in Nuclear Power Plants;

- **Seismic Category 2:**

(a) Items that might have spatial interactions or any other earthquake induced interactions with items in seismic category 1, including effects on any safety related action by personnel at the installation;
(b) Items not included in seismic category 1 that are necessary to mitigate design extension conditions;
(c) Items relating to the infrastructure needed for the implementation of the emergency evacuation plan.

- **Seismic Category 3**

Other Items

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Selection of Seismic Design and Qualification Standards

- Engineering design rules are based on relevant national or international codes, standards and proven engineering practices and should be applied, as appropriate, to the seismic design of items in each seismic category.

- Experience from the design and construction of nuclear installations indicates that codes, norms and standards of different origin (i.e. different country or different type of installation) are often used. Even within a State, codes or standards for the different design disciplines (i.e. mechanical, civil and electrical) are not always based on compatible safety criteria. Therefore, consistent acceptance criteria should be established, and good engineering practices should be used, to provide consistency in the application of selected codes and standards in seismic design.

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Seismic Design of SSCs

- ✓ Layout of the Installations
- ✓ Buildings and Civil Structures
- ✓ Engineered earth Structures and Buried Structures
- ✓ Seismically Isolated Structures
- ✓ Mechanical Equipment
- ✓ Storage tanks
- ✓ Piping
- ✓ Buried Pipes
- ✓ Electrical Equipment, Control and Instrumentation
- ✓ Cable Tray and Conduits
- ✓ Heating, Ventilation and Air-Conditioning Ducts
- ✓ Seismic Capacity

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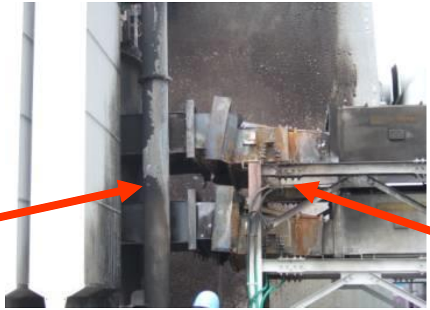
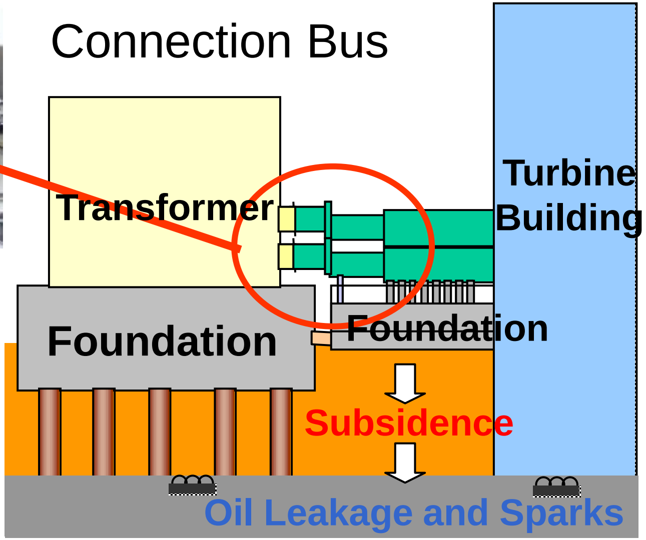
Seismic Design of SSCs

House Transformer Damage and Fire KK NPP (TEPCO) at the 2007 NCOE.





Plant Layout

Rigid connections should be avoided between different building structures or between equipment of different seismic categories and dynamic behaviours.

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Seismic Design of SSCs

Damage of anchorage bolts and brackets of filtered Water tanks KK NPP (TEPCO) at the 2007 NCOE.

Mechanical Equipment

Most of the reported failures of mechanical equipment are associated with a lack of anchorage or with insufficient capacity at the anchorage.

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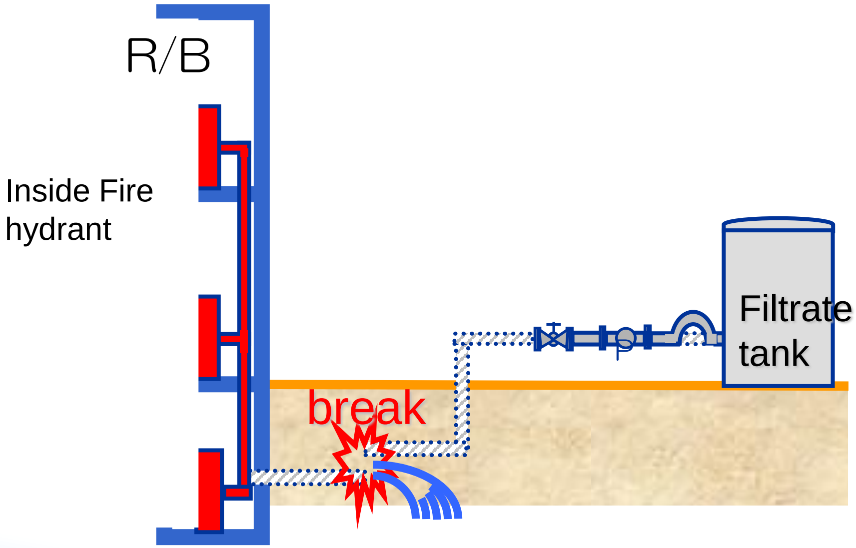
Seismic Design of SSCs



Rupture of Buried Piping
KK NPP (TEPCO) at the 2007 NCOE.

Buried Pipes

Buried pipes are a special type of piping that is continuously supported by the ground. The main seismic design principle for this kind of piping is to make it sufficiently flexible to follow the ground deformation during seismic shaking.

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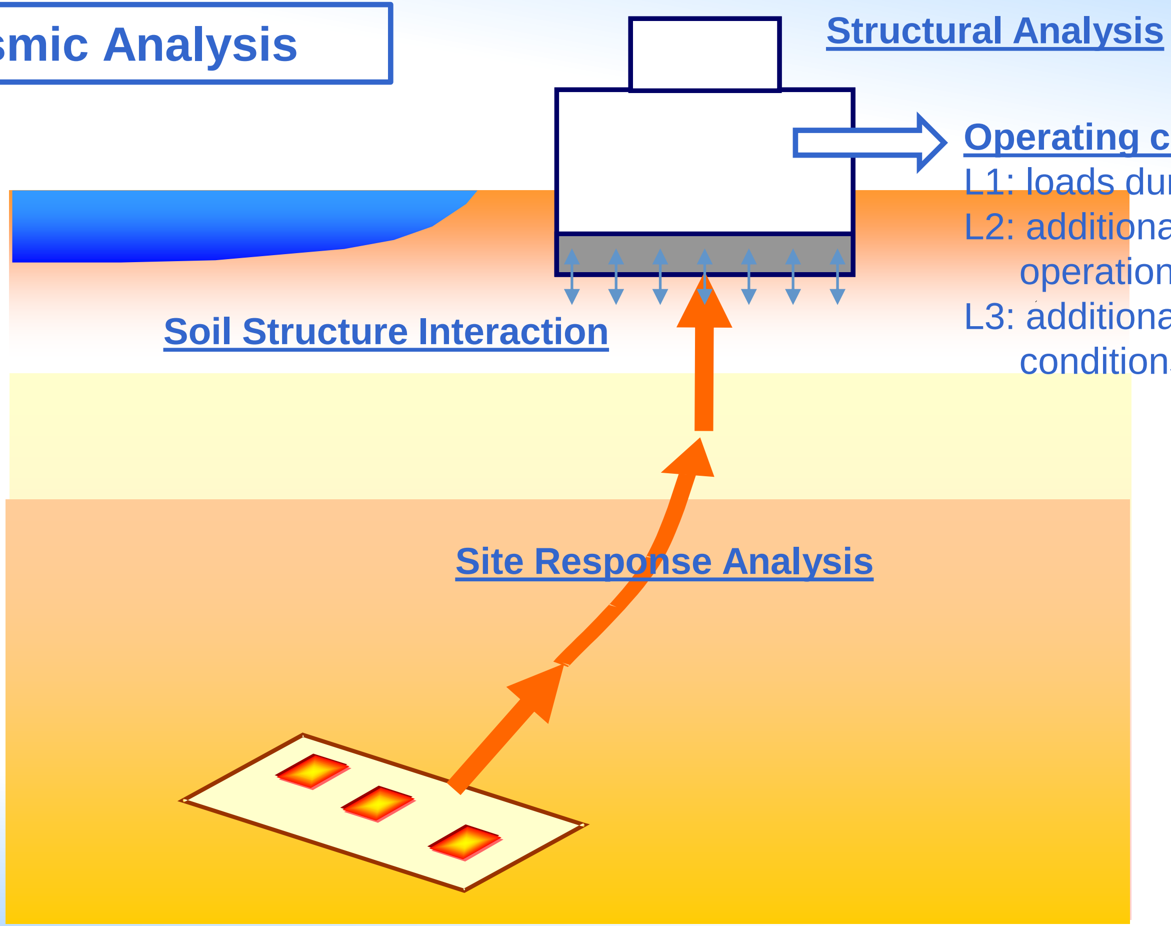
Seismic Analysis



Operating condition loads

L1: loads during normal operation;

L2: additional loads during anticipated operational occurrences;

L3: additional loads during accident conditions.

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Seismic Qualification

Seismic qualification is **the process of verification** — through testing, analysis or other method — of the ability of an SSC to perform its intended function during and/or following the designated earthquake. Seismic qualification should be carried out for **seismic category 1** and **seismic category 2** components.

Qualification Methods

- **Analysis**
- **Testing**
- **A combination of analysis and testing**
- **Indirect methods (e.g. similarity)**

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Seismic Margin to be Achieved by the Design

- **Concept of Seismic Margin**

The design should provide adequate seismic margin:

- ✓ To protect items important to safety and **to avoid cliff edge effects**;
- ✓ To protect items ultimately necessary **to prevent an early radioactive release, or a large radioactive release**,

in the case that levels of natural hazards greater than those considered for design occur.

- **Adequate Seismic Margin**
  - ✓ Less than 10^{-5} (CDF) / 10^{-6} (LERF) : Probabilistic method
  - ✓ SMA (Seismic Margin Analysis) : Deterministic method

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Seismic Design for nuclear installations other than Nuclear Power Plants

Seismic Design Category	Design Codes and Standards	Seismic Hazard Level	Target Seismic Performance Goal
SDC1: High hazard nuclear installations	Nuclear	SL-2 / 1.0E-4	< 1.0E-5
SDC2: Medium hazard nuclear installations	Nuclear	SL-2 / 1.0E-3	< 1.0E-4
SDC3: Low hazard nuclear installations	Conventional	1.5 × NSC*1	< 5.0E-4
SDC4: Conventional installations	Conventional	NSC	< 1.0E-3

*1 NSC: National Seismic Codes

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Seismic instrumentation and post-Earthquake Actions

Application of the Management System

Design of Nuclear Installations Against External Events Excluding Earthquakes: SSG-68

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General Concepts

➢ Human Induced External Events

i. Accidental aircraft crashes;
ii. Explosions (i.e. deflagrations and detonations) with or without fire and with or without secondary missiles;
iii. Release of corrosive or hazardous gases or liquids (e.g. asphyxiant, toxic) from off-site or on-site storage or during transport;
iv. Release of radioactive material from off-site sources or from the site;
v. Fire generated off the site or from on-site sources;
vi. Collision of ships or floating debris with safety related structures, such as water intakes or structures associated with the ultimate heat sink;
vii. Collision of vehicles with SSCs;
viii. Electromagnetic interference from off-site or on-site sources;
ix. Floods resulting from the rupture of external pipes;
x. Any combination of the above resulting from a common initiating event, for example an explosion with fire and a release of hazardous gases and smoke.

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General Concepts

➢ **Natural Events**

i. Floods due to events such as tides; tsunamis; seiches; storm surges; wind generated waves; precipitation causing flooding of nearby rivers and streams; dam forming and dam failures; bores and mechanically induced waves; channel migration; and high groundwater levels;
ii. Extreme meteorological conditions (of temperature, snow, hail, frost, subsurface freezing and drought);
iii. Extreme winds, including straight line winds, winds due to tropical storms (e.g. cyclones, hurricanes, typhoons) and tornadoes;
iv. Dust and sandstorms;
v. Lightning;
vi. Volcanism;
vii. Biological phenomena;
viii. Collision of floating objects (e.g. ice, logs) with safety related structures such as water intakes and components of the ultimate heat sink;
ix. Geotechnical hazards (not associated with seismic loads);
x. Any combination of the above.

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General Concepts

- Design Basis for External Events: Derivation of Design Basis External Events (**DBEE**) and Beyond Design External Events (**BDBEE**) (2.9 and Section 3)
- **Installation Layout** and **Design Approach** (Section 4):
  - ✓ Installation Layout
  - ✓ Approach to Structural Design
  - ✓ Approach to Structural Assessment for Beyond Design Basis External events
- **Design Provisions** against External events (Section 5)
- Safety Design Provision for Nuclear Installations other than Nuclear Power Plant: (**Graded Approach**) (Section 6)
- Application of the **Management System** to the Design of a Nuclear Installation against External Events (Section 7)

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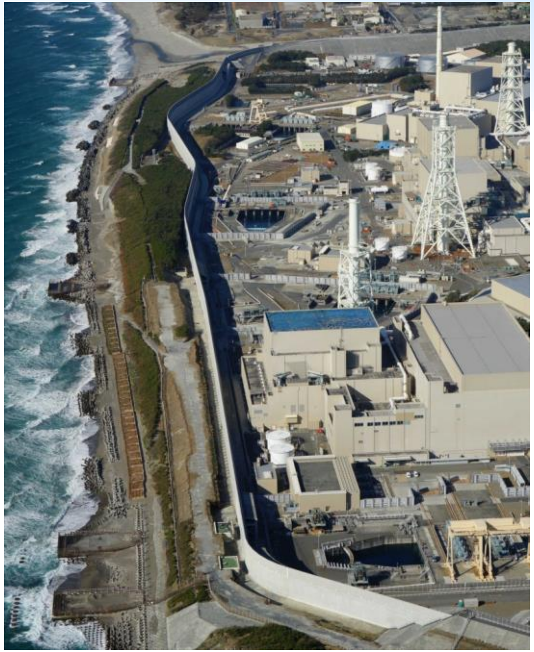
Installation Layout and Design Approach

Design Approach

- **Barrier**
  - ✓ Passive barrier (e.g. a dry site),
  - ✓ Dykes or sea walls for floods
  - ✓ External shields for an aircraft crash
  - ✓ Barriers for explosions



Seawall at the Hamaoka NPS (Japan)

https://www.at-s.com/news/article/shizuoka/992478.html

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Installation Layout and Design Approach

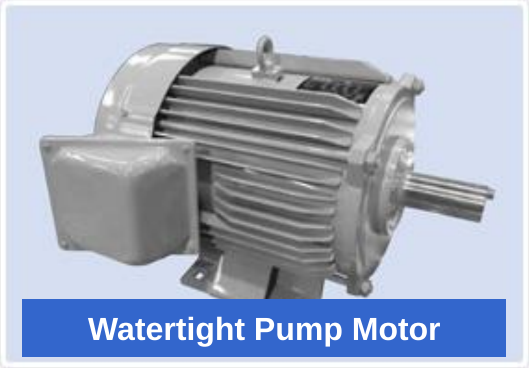
- **Effective Resistance**
  - ✓ The concepts of diversity
  - ✓ Redundancy
  - ✓ Physical separation
  - ✓ Functional independence

- **Withstanding in the external event conditions**

- **Administrative measures**

Firebreak in Hamaoka NPP

https://www.chuden.co.jp/resource/energy/nuclear/hamaoka/anzen/gakujutsukaigi/gakujutsukaigi_05.pdf



Watertight Pump Motor

https://www.mitsubishielectric.co.jp/fa/products/drv/i_motor/pmerit/toprunner/sf_prp.html

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Installation Layout and Design Approach

- **Cliff Edge Effect**

For each external event of interest, the possibility of **the loading conditions creating a cliff edge effect** should be assessed. The assessment should include **the identification of the cliff edge effect** (e.g. overtopping of a flood protection structure), **the probability of the occurrence of such an effect**, **the consequences of the cliff edge effect** on SSCs and on the installation, and **methods of mitigating** these effects.

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Installation Layout and Design Approach

- **Secondary Effect**

- Failure and collapse of nearby structures
- Secondary missiles generated from nearby SSCs
- Flooding from failure of liquid retaining structures, not necessarily close to the building
- Chemical releases from failure of containers or deposits of material
- Secondary fires or explosions, as a result of failures in tanks containing flammable or explosive material
- Electromagnetic interference generated by electrical faults.

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Installation Layout and Design Approach

- **Assessment for BDBEE**

Assessment against beyond design basis external events to demonstrate an adequate margin and avoidance of cliff edge effects:

- Items that are ultimately necessary to prevent an **early radioactive release** or a **large radioactive release**
- Items that ensure heat transfer to an **ultimate heat sink**
- Items that ensure the functions of the **control room** and, if the main control room is not available following the beyond design basis external event, items that ensure the functions of the **supplementary control room**.

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Design Provisions against External Events

- **External Floods, including Tsunami (Example)**

Phenomena

- Storm surges
- Wind generated waves.
- Tsunamis
- Seiches
- Flooding of rivers and streams
- Extreme precipitation events: local intense precipitation
- Floods due to the sudden release of impounded water from the following
  - ✓ Dams (i.e. due to dam failure)
  - ✓ On-site water storage (ultimate heat sink), etc.
- Bores and mechanically induced waves
- Channel migration
- High groundwater levels

Parameters

- Hydrostatic load
- Hydrodynamic load
- Wave load
- Buoyancy
- Debris load
- Erosion and sedimentation, etc.

Countermeasures

- The ‘dry site’ concept
- Permanent barriers
- Breakwaters
- Site grading and drainage systems
- Watertight doors and penetrations
- Temporary watertight barriers
- Watertight components

Concluding Remarks

Concluding Remarks

- **External events including natural phenomena are subject to uncertainty.** We must consider that actual phenomena may exceed Design Basis Parameters predicted by current regulation and technology.
  - ✓ Always strive to collect knowledge about natural phenomena and improve your technology for assessment of the external hazards.
  - ✓ Don't become too attached to Design Basis Parameters. It is more important to prepare for beyond design situations.

- The impacts on nuclear installations from external events will **vary and evolve sequentially in variable directions**.
  - ✓ Use your maximum imagination to predict how Nuclear Installations would be affected if a natural phenomenon were to strike.
  - ✓ Experimental tests may also provide good insight.

- Continue to think about what countermeasures are effective against the impacts of external events, and consider **systems, procedures and culture that allows for immediate improvements or additions to SSCs** if necessary.

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Thank you!