# The Accident at the Fukushima Daiichi NPP and Severe Accident Management

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# Contents

- **Introduction**
  - *Safety is the first priority, Basic Safety Principles for Nuclear Power Plants (NPPs)*
- **Basic Safety Principles for NPPs***
- **Severe Accident Management**
  - *Severe Accident Management (SAM) at NPPs in Japan, PSA Analysis*
- **Safety Issues on Prevention of Severe Accident**
  - *Site selection, Safety Culture, Global approach, Improving Safety*
- **Remarks**

*) *Ref: INSAG-12 (75-INSAG-3 Rev.1)*

# Introduction

## *Safety is the first priority.*

- **“Nuclear energy”** plays an important role of sustaining human life and welfare as well as economic activities.
  - *433 NPPs in operation, 65 NPPs under construction (ref. IAEA)*
- **“Peaceful use”** of nuclear energy must be ensured.
  - *Safeguards and Security*
- **“Safety is the First Priority”** for the use of nuclear energy because of potential risk to health and environment if not adequately controlled.

# Introduction

## *Basic Safety Principles for NPPs*

- After the two severe accidents within less than ten years, **TMI-2 in 1979** and **the Chernobyl Accident in 1986**, the International Nuclear Safety Advisory Group (INSAG) of IAEA issued **"Basic Safety Principles for Nuclear Power Plants"** ***(INSAG-3)*** **in 1988** as a guide book to be referred by all who are engaged in nuclear power generation. INSAG-3 was revised as **INSAG-12 in 1999.**
- INSAG stated that two severe accidents within less than one decade are certainly not acceptable from safety point of view. The basic safety principles is intended to describe the state of NPP which meets the requirement for achieving high level of safety at all times until its end of operating life, i.e. *"Model Plant".*

# Basic Safety Principles for NPPs*

- **Objectives**
  - General nuclear safety, Radiation protection, **Technical Safety**
- **Fundamental Principles**
  - Strategy of defense in depth, General technical principles, Management responsibilities including **Safety Culture**
- **Specific Principles**
  - Site selection, Design, Manufacturing and construction, Commissioning, Operation, **Accident Management**, Decommissioning, Emergency preparedness

*) *Ref: INSAG-12 (75-INSAG-3 Rev.1)*

# Technical Safety Objective*

- **Prevention** of severe accident (SA)
  - ***Prevent with high confidence accident in nuclear power plants.***
- **Mitigation** of radiological consequence
  - Ensure that, for all accidents taken into account in the design of the plant, ***even those of very low probability, radiological consequences, if any, would be minor.***
- **Extremely small likelihood of severe accidents**
  - Ensure that ***the likelihood of severe accidents*** with serious radiological consequences is ***extremely small***.

** Ref: INSAG-12 (75-INSAG-3 Rev.1)*

# Technical Safety Objective

## *Observations at the Fukushima Dai-ichi NPP*

- **Prevention:**

**Failed** to prevent severe accident

- *Severe accidents occurred at the three units.*

- **Radiological consequences**:

**Failed** to prevent and mitigate consequences

- *Contamination was spread over from Fukushima to Tohoku and Kanto regions because the physical barriers lost their integrity.*

- **Likelihood of severe accident**:

**Failed** to meet the INSAG requirement

- *Three NPPs in the past 30 RY yield probability of severe accident as the orders of $10^{-2}$/RY at Fukushima alone, $10^{-3}$/RY for all NPPs in Japan, $10^{-4}$ for all NPPs in the world.*

# Technical Safety Objective

## *Likelihood of severe accidents* (1/2)*

** Ref: INSAG-12 (75-INSAG-3 Rev.1)*

- The target for existing nuclear power plants consistent with the technical safety objective is below about **$10^{-4}$ events per plant operating year.**

  *NOTE: At the time of the Chernobyl accident, world-wide accumulated reactor year was of the order of 5x* **$10^{3}$** *RY and the two severe accidents since 1963 yielded order of* **$10^{-3}$** */RY. INSAG did not accept the order of magnitude for existing NPPs and proposed at least about* **$10^{-4}$***/RY in the Basic Safety Principles.*

- Severe accident management and mitigation measures could reduce by **a factor of at least ten** the probability of large off-site releases requiring short term off-site response, i.e. **$10^{-5}$**/RY.

# Technical Safety Objective

## *Likelihood of severe accidents* (2/2)*

** Ref: INSAG-12 (75-INSAG-3 Rev.1)*

- Application of all safety principles and the objectives to future plants could lead to the achievement of an improved goal of **not more than $10^{-5}$** per plant operating year.
- Another objective for these future plants is the practical elimination of accident consequences that could lead to large early radioactive releases.

**Observation**: *Based on the likelihood of severe accidents observed at the Fukushima NPPs, all NPPs in Japan must be re-examined for their actual strength against severe accident conditions.*

# Levels of Protection and Barriers

## *Objective and essential features**

** Ref: Fig.3 INSAG-12 (75-INSAG-3 Rev.1)*

### Protection

1. Prevention of abnormal operation and failures
   - *Conservative design and quality in construction and operation*
2. Control of abnormal operation and detection of failures
   - *Control, limiting and protection systems and other surveillance features*
3. Control of accidents below the severity level within the design basis
   - *Engineered safety features and accident procedures*
4. Control of severe plant conditions, including prevention of accident progression and mitigation of the consequences of severe accidents
   - *Complementary measures and **accident management**, including containment protection*
5. Mitigation of radiological consequences of significant releases of radioactive materials
   - ***Off-site emergency response***

### Barriers

- *Fuel matrix, Cladding, Primary boundary, Confinement*

# **Severe Accident Management** (SAM)

## *Prevention and mitigation of severe accident*

- Severe accident management as a component of accident prevention includes the actions taken by operators during the evolution of an accident sequences beyond the design basis.
- The past experience proved that accident progression can be terminated and radiological consequence can be minimized by adequate accident management.
- Severe accident management procedure and facilities are now included in design and/or operation procedures as additional safety features of existing nuclear power plants.

# **Severe Accident Management** (SAM)

## *SAM at NPPs in Japan*

- Introduction of SAM to enhance safety of NPPs was recommended by **NSC in 1992** as an action taken by utilities;
  - *To reduce the risk even lower level and prevent severe accidents (Phase-1), To mitigate consequences arising from NPPs to avoid serious consequences (Phase-2).*
- SAM has been adopted by all utilities for all NPPs by 2004 and reviewed by NISA. The results were reported to NSC for their review.
  - *2002 SAM report for all NPPs with PSA for limited NPP*
  - *2004 SAM report for all NPPs with PSA for all*

# Important design modifications for severe accident scenarios*

** Ref: Table II. INSAG-12 (75-INSAG-3 Rev.1)*

| Severe accident scenarios | Most frequent modifications |
|---|---|
| Reactivity accidents | • Enhanced makeup system<br>• Enhanced or fast acting boron system<br>• Automated dilution control |
| Release of combustible gases | • Nitrogen inerting<br>• Igniters<br>• Catalytic devices |
| High pressure core melt: DCH | • Enhanced RCS depressurization |
| High pressure core melt: SGTR | • Enhanced RCS depressurization |
| Impact on vessel support structure | • Physical barrier<br>• Cavity flooding |
| Vessel penetration | • External vessel cooling |
| Direct contact with containment boundary | • Physical barrier; flooding |
| Slow containment overpressurization | • Filtered venting<br>• Alternate cooling sources |
| Basemat melt through | • Cavity flooding<br>• External vessel cooling |
| Containment bypass | • Eliminate high/low pressure interface<br>• Additional isolation valves |
| Containment isolation | • Reduce risk of impaired containment |
| CANDU severe accident | • Increase availability of moderator/ shield tank heat sinks |

**Note:** CANDU: Canadian deuterium uranium reactor; RCS: reactor coolant system; DCH: direct containment heating; SGTR: steam generator tube rupture.

# Important design modifications for severe accident scenarios* *(from Table II, INSAG-12)*

** Ref: Table II. INSAG-12 (75-INSAG-3 Rev.1)*

- Release of combustible gas:
  - ***Nitrogen inerting**, **Igniters, Catalytic devices***
- Impact on vessel support structure:
  - ***Physical barrier, Cavity flooding***
- Vessel penetration: ***External vessel cooling***
- Direct contact with containment boundary:
  - ***Physical barrier, flooding***
- Slow containment over-pressurization:
  - ***Filtered venting**, **Alternate cooling source***
- Basemat melt-through: ***Cavity flooding, External vessel cooling***
- Containment isolation: ***Reduce risk of impaired containment***

# Severe Accident Management

## *PSA analysis by utilities*

- Reduction of severe accident frequency by about one order of magnitude or less
  - External events except earthquake were not considered.
  - Credits were given to multiple unit site on availability of off-site power even if once assumed lost, but recovers within about 11 hours and EDG recovers within several hours.

**Observation:**

- ***No external events other than earthquake were taken into account.***
- ***Recent technology and scientific knowledge were not adopted in the analysis, i.e. tsunami, earthquake etc.***

# Safety Issues on Prevention of Severe Accident

## *Site Selection*

- **External factors**
  - The choice of site takes into account the results of investigation of local factors that could adversely affect the safety of the plant including natural factors and manmade hazard, e.g. geological and seismological characteristics.
- **Radiological impact**
  - Sites are surveyed from the viewpoint of radiological impact of the plant in normal operation and in accident conditions on the public and the environment.
- **Feasibility of emergency plan**
  - Emergency plan must be feasible in the case of severe accident to protect the public and the environment.
- **Ultimate heat sink provisions**
  - Heat removal should be secured to maintain coolability of NPS.

# Safety Issues on Prevention of Severe Accident

## *Safety Culture**

* Ref: 75-INSAG-3 (1988)

- The important role of safety culture was described in the INSAG report, "Basic Safety Principles of Nuclear Power Plants" (75-INSAG-3 in 1988, revised as INSAG-12 in 1999).
- Safety culture is to be cultivated, maintained and strengthened continuously by all who are engaged in use of nuclear energy, individuals and organizations, owners and regulators.

***General Observation:* *Safety Culture*** *has remained as one of key principles for safe operation of NPPs. Weakening of safety culture must be prevented and strengthening safety culture must be promoted. Management is responsible.*

# Safety Issues on Prevention of Severe Accident

## *Global Approach for Nuclear Safety*

- International Harmonization
  - IAEA Conventions on Safety
    - *CNS for nuclear facilities, Joint Convention for spent fuel and radioactive waste management , Early notification of incidents*
  - Promotion of international activities
    - *IRRS: Mutual review of regulatory activities*
- Exchange of information, share experiences, transfer technology through regional and/or international frameworks, bilateral agreements etc. in order to ensure and enhance safety of use of nuclear energy.

# Safety Issues on Prevention of Severe Accident
## *Continuous Improvement*

- Approach to improve safety
  - *First priority: Prevent occurrence of any accident*
  - *Second: Maintain plant at the best condition as designed*
  - *Third: Maintain technical staff at the best condition as required*
  - *Fourth: Safety conscious approach must be taken all the time until the end of plant life.*
- Maintain transparency, honesty, motivation for workers, Safety culture, etc.
- Secure expertise, knowledge and technology base

# Remarks

## *Safety issues from the Fukushima NPP*

- Safety Issues on multiple unit sites
  - Advantage and disadvantage of multiple unit NPPs
  - Independency and Interdependency
  - Common cause failures among multiple units.
- Emergency preparedness
  - Multiple occurrence of natural hazards
  - Multiple occurrence of national emergency
- Investigation of the NPPs at Onagawa and Tokai
  - Those survived plants provide valuable information for improving robustness against tsunami for future.

# Remarks

## *Improving safety for next generations*

- All international community must be in collaboration to minimize any accident
- Coordinated effort should be continued further via international organizations such as IAEA, NEA, Private sectors organizations as well.
- Safety is the top priority and keep improving safety

***"One accident anywhere in the world will have global effect to the world."*** ***NO MORE SEVERE ACCIDENT!***