

## Severe Accident Training

### Technical Support for Staff and Shift Personnel

Raising awareness by learning from the past to improve your nuclear power plant's safety in the future

#### Challenge

Several severe accidents with core damage have occurred in the past. Beside technical issues, these events also demonstrated operational challenges to emergency organizations, internal and external crisis communication and detrimental working conditions for field operators.

Plant operators need to be aware of these hard and soft lessons learned to support their staff in the best manner and to avoid and manage such issues in a possible future crisis situation.

#### Solution

We offer a comprehensive severe accident training program, based on class-room trainings as well as emergency drills.

Our trainings can be held as individual modules, as full-day or multi-day events, based on your specific needs. All Framatome instructors are recognized severe accident experts being able to address specific questions of the audience.

#### Classroom trainings

We offer the following classroom training modules:

- **Introduction to Severe Accidents**  
(Length about 1 hour. Introduction to the severe accident related physical/technical basics for e.g. shift personnel)
- **The Accident in Fukushima Daiichi**  
(Length about 4 hours. Discusses the expectable working conditions and personal challenges to operators and support organizations)
- **The Three Mile Island Unit 2 (TMI2) Accident**  
(Length about 4 hours. Reviews the lessons learned with respect to installed base plants – boiling water reactors and pressurized water reactors)
- **The Chernobyl Disaster**  
(Length about 3 hours. Includes a basic introduction into neutronics)
- **Severe Accident Control in the EPR Reactor**  
(Length about 4 hours. Gives a review about state-of-the-art severe accident control)

The length and technical depth of the class-room trainings can be adapted to best suit the anticipated audience.

#### Customer benefits

- Improved understanding about the occurred nuclear accidents supports the personnel of a nuclear power plant to anticipate and deal with challenges unique to a severe accident
- Efficient preparation of personnel for a worst-case scenario is a fundamental aspect of nuclear safety
- Gaining insights in the know-how and know-why of up-to-date severe accident mitigation systems and guidance schemes allows utilities to make informed decisions about possible plant modifications

#### (C.2) Human Response

- Situation of the operators
  - ◆ Fear for their families (no cellphones)
  - ◆ Knew about escalation into a nuclear accident
  - ◆ No useable operational manual
  - ◆ No guidance / never trained this situation
  - ◆ Work in darkness
  - ◆ Lack of suitable tools / resources
  - ◆ Later: work in heavy protection gear in high dose rate environment
  - ◆ Frequent aftershocks
  - ◆ Ongoing tsunami warnings



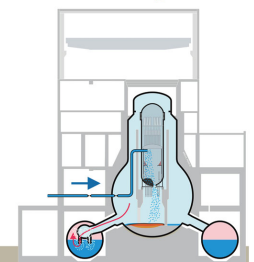
The Accident in Fukushima Daiichi – October 2018

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#### (D.23) Unit 1 Accident Progression

- 3/12 2:45 - Reactivation of pressure gauges
  - ◆ RPV pressure ~9 bar
  - ◆ PCV pressure ~9.4 bar (design 5.4 bar)
  - ◆ Explainable by compression of PCV atmosphere plus 700 kg H<sub>2</sub> in wet well (→ RPV failure)
- 3/12 4:00 - Water injection into RPV with fire engines



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Excerpts from the Fukushima course material

**Your performance**  
is **our** everyday **commitment**

## Exercise drills

To ensure a long-lasting success of the classroom trainings, we recommend a subsequent emergency drill, where trainees can practically apply the theoretically acquired knowledge in a simulated environment.

The scope of drills strongly depends on the existing structures within the plant organization, such as, accessibility of simulators and implemented severe accident management procedures. Framatome offers severe-accident drills as primary organizer with shared responsibilities or to send only observers to provide you with qualified feedback.

## Objectives of a special severe accident training for operators

- The severe accident background education enables to anticipate an accident development and evaluate information to identify false or misleading data.
- The proper training of accident sequences enables to develop a basic understanding of relevant time periods during the progression of a severe accident.
- The ability to assess accident situation relieves stress and enables for more focused work.
- The knowledge about radiological consequences on-site and in nearby communities enables the educated decision making about relevant actions.

Naturally, the plant staff is mostly focused on operational occurrences training. Hence, training experiences with regard to beyond design severe accident situations is often rather theoretical.

A severe accident training with our Framatome experts, who work extensively in the field of severe accident research, methodology development and accident simulations and evaluations, targets to help your crew to immerse into very extraordinary situations and to gain first-hand knowledge from our experts.

## Prompt / Delayed Criticality (II of V)

- By splitting of an U235 nucleus neutrons are emitted...
  - ◆ Mostly prompt → generation life time ~1 ms = time for moderation
  - ◆ Rarely delayed → generation life time ~0.1 s due to delayed neutron release
  - ◆ Fraction of delayed neutrons is called  $\beta$ 
    - 0.65% for U235
    - 0.2% for Pu239
    - The higher the burn-up, the smaller  $\beta$
- Distinguish supercriticality into
  - ◆  $1 < k < 1 + \beta$ : delayed critical → power raise <10% per second  
How one wants to operate a power reactor
  - ◆  $k > 1 + \beta$ : prompt critical → power raise >100% per second  
**Risk that power excursion is too fast to stop it by injecting control rods**

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## 4.1) Hydrogen Mitigation

- During core oxidation, 1000 kg to 1500 kg H<sub>2</sub> gets released into the EPR containment
- Hydrogen combustibility shown by Shapiro diagram
  - ◆ Yellow region: Hydrogen burns slowly
    - 4 vol% flame can only travel upward
    - >6 vol% flame can travel sideways
    - >8 vol% flame can travel downward
  - ◆ Red region: Hydrogen may detonate (high dynamic loads – to be avoided)
- To mitigate the hydrogen the EPR has
  - ◆ CONVECT system → Fast dilution of hydrogen
  - ◆ Passive autocatalytic recombiners → (Slow) consumption of H<sub>2</sub> and O<sub>2</sub>
  - ◆ Hydrogen measurement system → Confirming H<sub>2</sub> mitigation

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## 3.11) Accident Progression

- 01:13 Recirculation pumps Loop B stopped
- 01:40 Recirculation pumps Loop A stopped
  - ◆ In accordance to the OM pump limits and precautions
  - ◆ Phase separation (~50% void in coolant) → Sudden breakdown of the loop flows
  - ◆ Siphon-like surge line prevents drainage of PZR
  - ◆ Low condensation in SG due to equal p/T
- 01:51 Loop A and B hot leg temperatures rising
  - ◆ Indicates start of core exposure
  - ◆ Going off-scale (> 620 F = 327°C) within 40 mins
  - ◆ Cold-leg temperatures off-scale low
- 02:15 In-core (self-powered) neutron detector readings rise rapidly
  - ◆ Likely effect of rising core temperatures
  - ◆ Confused the operators further

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Excerpts from Chernobyl, TMI2, and EPR course material

## References

- Emergency drills in Germany, Brazil, Spain, Finland and Switzerland
- Participation in several industry- and university-based educational programs
- OECD observer mission
- Performance of multi-week trainings of emergency organization in new-build plants

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