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Post-Fukushima lessons and safety orientations for ASTRID

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Introduction

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- **The earthquake and tsunami leading to the accident of Fukushima Daiichi nuclear plants occurred on March 11th, 2011 while the preconceptual phase of ASTRID was being to be launched.**
- **A first analysis of the accident has been performed and the safety orientations used for this design phase were reoriented.**
- **The analysis of the accident and its integration in the design are a continuous process which is not yet completed.**
- **The safety orientations for the ASTRID preconceptual phase are being examined by the French Safety authority**

Overview of the safety orientations for the preconceptual phase of ASTRID

- **ASTRID (*Advanced Sodium Technological Reactor for Industrial Demonstration*) is a project sponsored by the French Government and leaded by CEA.**
- **Main characteristics at the beginning of the preconceptual phase:**
  - **Sodium-cooled Fast Reactor**
  - **Capability for minor actinide transmutation**
  - **Technology taking advantage of feedback from earlier SFR, but improved by innovative options**
  - **Potential for experiments**

  - **Pool-type primary circuit**
  - **Oxide fuel**
  - **600 MWe**

The main design options will be selected at the end of 2015

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Favorable safety characteristics of SFR

Phénix (1973-2010)

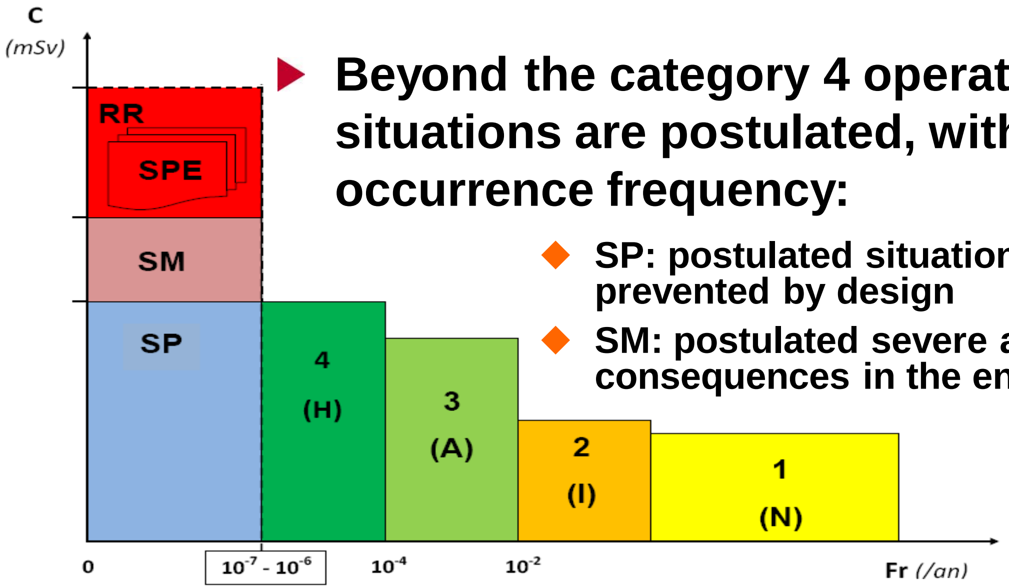
Super-Phénix (1985-1998)

- **No pressurization of the primary coolant, high thermal inertia, no xenon effect**
- **High radioprotection level**
- **Limited effluents**
- **High thermal efficiency**
- **Large sodium boiling margin**
- **Natural convection capability**
- **Atmosphere as heat sink for removing the decay heat**

Overview of the safety orientations

- **A major place is allocated to safety in the preconceptual phase:**
  - **Acceptance of future SFR will depend notably on public perception of the safety**
  - **The Fukushima accident leads to reconsider the safety approach and the plant design approach**
- **From these incentives, two main safety orientations are considered for ASTRID:**
  - **Improvement of the design in comparison with previous SFR (*i.e.*, Superphénix and EFR), even if their safety level were judged to be acceptable**
  - **Development of a simple and “robust” safety demonstration**

Overview of the safety orientations



- **Beyond the category 4 operating conditions, hypothetical situations are postulated, without consideration of their occurrence frequency:**
  - **SP: postulated situations for which severe accident shall be prevented by design**
  - **SM: postulated severe accident situations for which the consequences in the environment shall be limited**
- **The limited number of situations which cannot be reasonably mitigated shall be "practically eliminated" (SPE)**
  - **Exhaustive identification of such situations**
  - **Design driven by the need to practically eliminate such situations**
  - **Robust demonstration of their practical elimination**

The first lesson of the Fukushima accident confirms and reinforces the approach:

- ***Severe accident situations must be considered in the design process***
- ***The design must allow a robust demonstration of practical elimination of unacceptable situations***

Main safety issues raised by the Fukushima accident
Consideration of natural hazards

- **Before the Fukushima accident, the natural hazards are considered in the design process through:**
  - **Conventional definition of the amplitude of natural hazards (*e.g.*, based on historical evidence)**
  - **Conventional design methods which require design margins**
- **"Extreme" natural hazards (*i.e.*, with an amplitude higher than the one conventionally defined) are potential initiator of common mode failures inside and outside the plant**
- **This reinforces some design orientations for ASTRID:**
  - **To implement seismic protection devices in order to reduce the uncertainties related to the amplitude of earthquakes**
  - **To deterministically combined to any operating condition and situation, the loss of off-site supports (*i.e.*, loss of off-site electrical supply and loss of feedwater)**
  - **To implement diversified Lines of Defense for prevention of severe accident based on active and passive provisions**
  - **To improve the capability for sodium circuit, including primary circuit, to remove the decay heat by natural circulation**
  - **To consider the total loss of AC power as a category 4 operating condition, at least**

Main safety issues raised by the Fukushima accident
Multiple-failure situations

- **The safety approach considers that situations with multiple failures. Basically, the multiple failures were associated to the Lines of Defense required for preventing the consequences of the initiating event.**
- **The Fukushima accident requires to re-assess the identification of multiple failure situations by consideration that natural hazards may be a common mode, even on diverse equipment (*e.g.*, occurrence of simultaneous leakages on different sodium circuits should be assessed).**

Main safety issues raised by the Fukushima accident
Post-accident management

- **Post-accident emergency procedures have to consider situations beyond the situations considered for the design:**
  - **The design shall facilitate the capability to repair the main safety systems**
  - **The design shall provide grace times for allowing corrective measures**
- **In accident situations the accessibility of the plant could be limited:**
  - **The autonomy of the plant in accident conditions has to be re-inforced**
- **Situations which could be difficult to manage (e.g., loss of primary sodium) have to be excluded by design**

Consideration of the stress tests

- **Main conclusions relevant for ASTRID issued from the French stress tests:**
  - ***Severe accident can result from an extreme natural hazard***
  - ***Any accident can never be excluded***
    - This reinforces deterministic considerations
    - The Defense-in-Depth principle remains the basis for the design
    - “Practical elimination” is still relevant, but this reinforces the necessity to include considerations on loadings higher than the design basis in the demonstration
  - ***“Cliff-edge effects” shall be identified***
  - ***Implementation of additional equipment classified as “hard safety core” on the existing plants***

Lessons learned from the Fukushima accident

- **Reinforcement of demonstrations of "practical elimination" of situations leading to important radiological releases in the environment**
- **Reinforcement of consideration of loss of some supplies, the objective is to prevent severe accident:**
  - **Loss of all AC power**
  - **Loss of I&C**
  - **Failure of operator action**
- **Reinforcement of the capability to prevent severe accident by natural behavior:**
  - **Favorable neutronic feedback effects**
  - **Natural circulation capability to remove the decay heat**

Lessons learned from the Fukushima accident

- Consideration of severe accident initiated by an extreme natural hazard
- No need of operator actions at short term for managing severe accident
- Design improvement for achieving significant grace time in degraded situations
- Design improvement for facilitating emergency actions
- Design improvement for achieving the autonomy of the plant

Lessons learned from the Fukushima accident

- **Implementation of monitoring dedicated to severe accident situation**
- **The assessment concerns the reactor and any zone with severe radiological risk (e.g., fuel handling and spent fuel storage)**
- **The assessment concerns also the risks resulting from the chemical characteristics of sodium (e.g., mechanical effects of a large sodium-water reaction, hydrogen production)**

Preliminary identification of the "hard safety core"

- **Identification of the situations leading to important radiological releases in the environment**
- **Identification of the equipment necessary for avoiding important radiological releases in the environment, i.e.,:**
  - **Equipment necessary for mitigation of severe accident**
  - **Equipment necessary for "practical elimination" of situations which cannot be mitigated**
- **For these equipment qualified as "hard core" by extrapolating the notion defined for the existing plants, identification of the margins against loadings beyond the design basis. If necessary, enhancement of their design**