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Severe Accident Countermeasures of SFR

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Tsuruga, June 2012

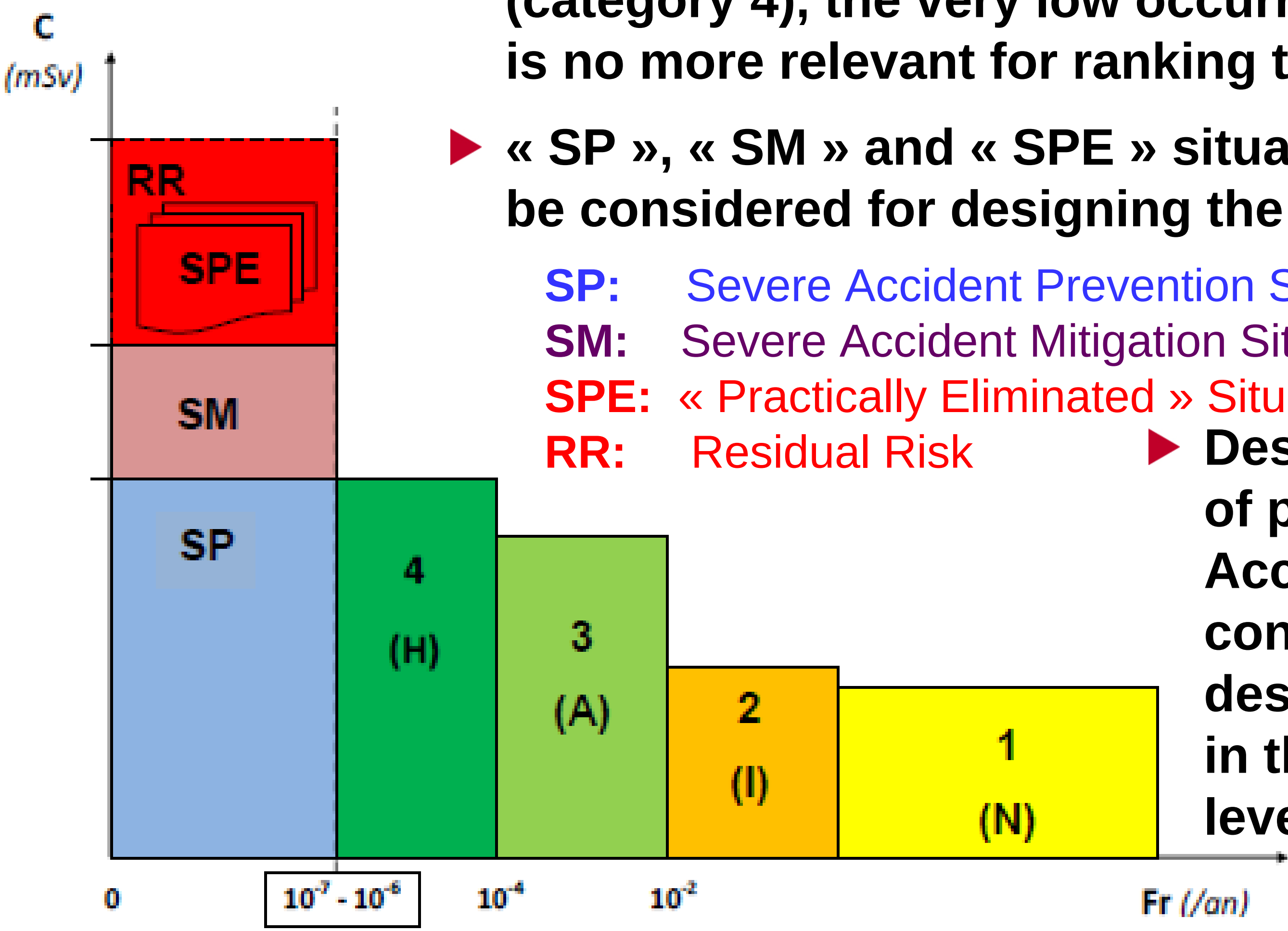
Objectives of the Presentation

- The main objective is to present the approach developed for designing the new French SFR with consideration to severe accident.
- The presentation is focused on the justification of mitigation measures, the prevention approach is not presented in detail.
- The role of the severe accident analysis in the design process.
- The approach is developed in the frame of the ASTRID project.

Role of Severe Accident in the Design Process for New SFR

- **Beyond the design basis operating conditions (category 4), the very low occurrence frequency is no more relevant for ranking the situations.**
- **« SP », « SM » and « SPE » situations are also to be considered for designing the plant.**

SP: Severe Accident Prevention Situations
SM: Severe Accident Mitigation Situations
SPE: « Practically Eliminated » Situations
RR: Residual Risk



- **Despite the high level of prevention, Severe Accident is considered for designing the reactor in the frame of the 4th level of DiD.**

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Main Design Issues Related to Severe Accident Mitigation

- **Minimization by design of the potential mechanical energy release:**
  - **Assessment of mechanical energy release.**
  - **Design of specific devices if relevant, to minimize recriticality during the successive phases of the accident.**
- **Consideration of MFCI consequences.**
- **Design of containment capable to stand the potential mechanical energy release.**
- **Design of a core catcher capable to maintain the core debris in a safe state: sub-criticality and decay heat removal.**
- **Minimization of the consequences of possible sodium fire in the confinement due to ejection of primary sodium through the roof.**
- **Minimization of radiological releases in the environment:**
  - **Limited off-site countermeasures.**
  - **Minimization of confinement by-pass.**

Previous Safety Approach Concerning Assessment of Mechanical Energy Release

- **The very first studies of the consequences of severe accident were performed for the first SFR. They were based on arbitrary enveloping scenario corresponding to a molten core compaction (Bethe & Tait scenario).**
- **When large reactor such as Superphénix has been developed, because of the possibly high sodium void effect, the studies considered scenario for which the void effect occurs. In order to reduce unnecessary enveloping assumptions, a ”realistic” scenario was considered: “the unprotected trip of the primary pumps” (ULOF). The severe accident situation is initiated by an inconsistent sodium boiling leading to reactivity insertion (primary phase), followed by other reactivity effects due to core geometry modifications.**

Previous Safety Approach Concerning Assessment of Mechanical Energy Release

- **Later PRA showed that the ULOF scenario has a very low probability to occur compared to other initiating sequences such as local core melting. Nevertheless, the ULOF sequence continued to be assessed because its analysis covers any phenomena capable to lead to potentially damaging effects (i.e., void effect, core geometry modifications, material melting, MFCI).**

Previous Safety Approach Concerning Assessment of Mechanical Energy Release

- **The description and assessment of the ULOF scenario was not easy:**
  - **Because of the high reactivity effects, the calculation results are very sensitive to key parameters.**
  - **Fast kinetic and simultaneity of phenomena makes them difficult to be modeled (needs of coupling).**
  - **Some behaviors need representative experiments for quantification.**
  - **The results are dependent on computer codes.**
  - **The results related to a phase of the accident are sensitive to the previous phases.**
  - **Modeling of the more advanced accident phases is difficult.**
- **The description was focused on the primary phase. Some limitation of the void effect can be assessed for limiting the mechanical energy release: mitigation of core melt-down consequences with void effect higher than about 5$ is not reasonably achievable.**

Incentive for a new Approach Concerning Assessment of Mechanical Energy Release

- **Due to uncertainties, the containment design approach based on the results of a mechanistic analysis of a single scenario is questionable:**
  - **Due to the high prevention of scenarios leading to severe accident, the uncertainties lead to difficulty for defining a reference scenario (such as ULOF).**
  - **Due to the non-linear effects involved during the accident, in particular because of the high reactivity potentials, sensitivity studies are required.**
  - **Results could significantly be modified by the initial conditions.**
- **In the frame of the EFR project, the European licensing authorities recommended:**
  - **To pay similar attention to the advanced accident phases compared to the primary phase.**
  - **To assess accident scenarios other than ULOF (e.g., local core melting).**
- **The core and reactor designs could be performed in order to avoid core meltdown initiation in case of ULOF:**
  - **Improvement of the reactivity feedback effects.**
  - **Implementation of adequate devices if necessary.**

Incentive for a new Approach Concerning Assessment of Mechanical Energy Release

- **The previous mechanistic approach based on ULOF was supported by a significant experimental support which should be duplicated if new fuel concepts are developed.**
- **For new SFR, public acceptance requires to simplify the safety demonstration, particularly concerning the justification of the severe accident mitigation measures.**

Development of a more general approach for assessing the severe accident consequences is recommended.

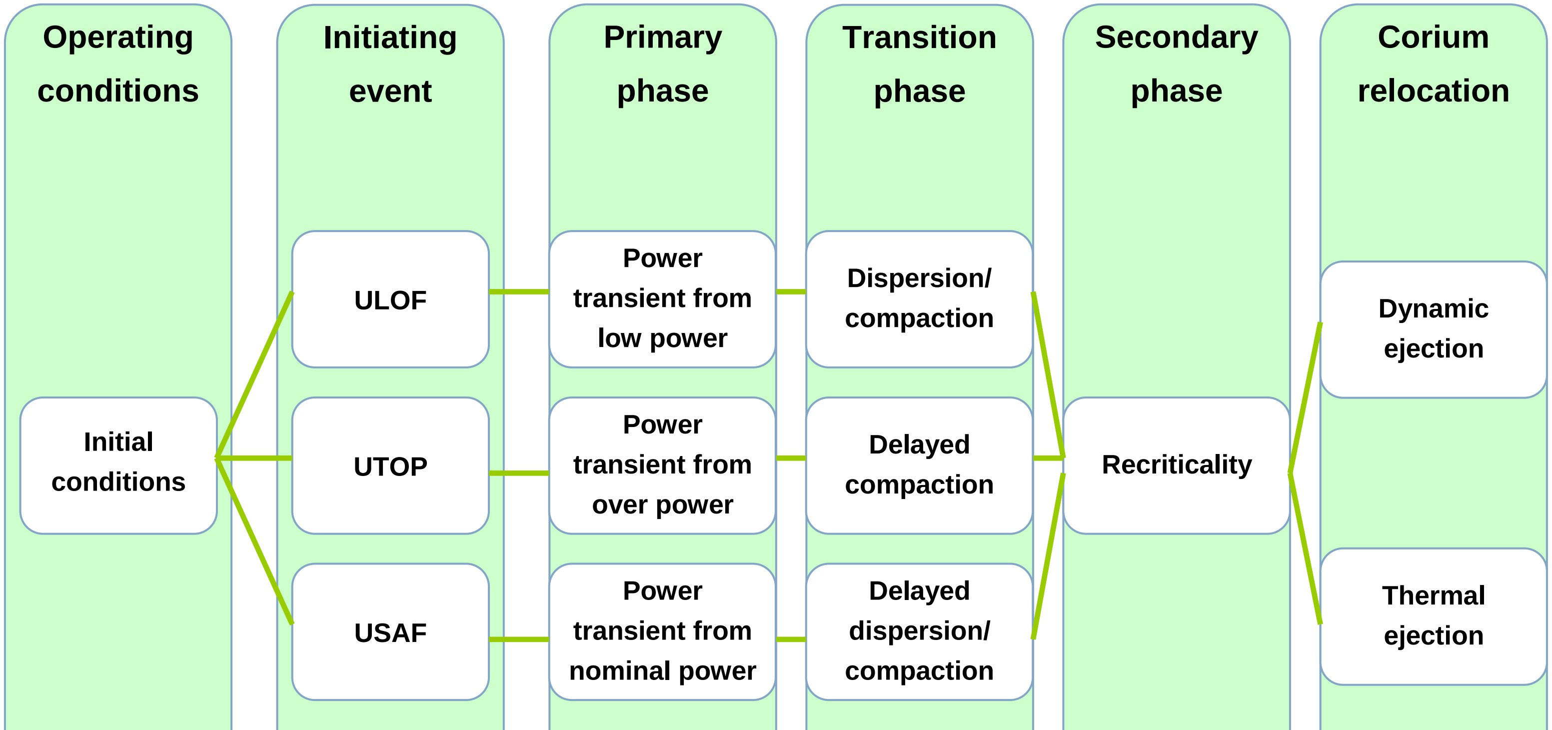
This has to be complemented by:

- **an enhanced prevention of the severe accident by design**
- **a “top-down” approach for designing the mitigation measures.**

Innovative Approach for Assessment of Mechanical Energy Release

- **To consider the different families of severe accident initiators, if they are physically possible.**
- **For each family, to assess the ranges of the key parameters which can be associated to acceptable consequences.**
- **For each family, justification that the design ensures that the realistic values are situated in the acceptable ranges.**
- **To minimize the need for experimental validation (other than the existing ones):**
  - **To take benefit of the large experimental programs performed for the previous plants.**
  - **To use advanced computer codes modeling simultaneously the phenomena (e.g., thermohydraulic, neutronic, mechanic).**
  - **Nevertheless, minimum number of experiments should be needed due to the possible evolution of the fuel design.**

Innovative Approach for Assessment of Mechanical Energy Release



- **Identification for each event family of the relevant phenomena physically possible.**
- **Merging of similar states.**

Mitigation Measure Design for Mechanical Energy Release

- **Using directly the result of mechanical energy release assessment for designing the structures could be insufficient:**
  - **Uncertainties for justifying that the calculated scenarios are sufficiently enveloping.**
  - **Uncertainties in the modeling.**
- **The design approach is based on disconnection of design from results of core accident calculations, as far as possible.**

Mitigation Measure Design for Mechanical Energy Release

- **Severe accident is highly improbable and cannot be based on a credible scenario.**
- **The core is designed to verify the low mechanical energy release for a large range of scenarios.**
- **The structures are designed in order to provide resistance to mechanical energy release, significantly higher than the values assessed by calculations.**
- **The possible mechanical weak points are identified and the structures are strengthened in order to provide an homogeneous behavior, as far as reasonably feasible.**

Top-down approach consistent with the DiD philosophy: disconnection from the initiating scenario.

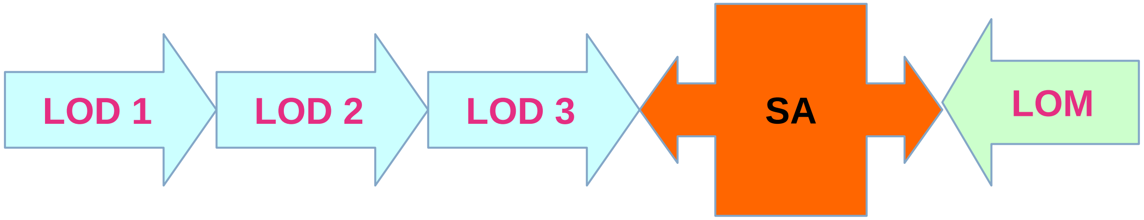
Mitigation Measure Design for Mechanical Energy Release

Severe accident prevention

- Lines of Defense (LOD)
- Bottom-up approach
- Independence and reliability of LOD

Severe accident mitigation

- Line of Mitigation (LOM)
- Top-down approach
- Homogeneous behavior and margins



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Core Catcher Design Approach

- **Implementation of a high capacity core catcher.**
- **Minimization of possible core catcher damage due to severe accident effects:**
  - **Resistance to possible mechanical energy release.**
  - **Resistance to possible thermal loadings due to high temperature of molten materials (dynamic and steady state).**
- **Minimization of possible damage of the core catcher cooling system due to severe accident effects.**
- **Maintaining sub-criticality at very long term and in cold conditions.**
- **Minimization of the risk of recriticality during the molten core relocation phase.**

Mitigation of Consequences of Sodium Fire

- **In case of severe mechanical energy release, primary sodium can be ejected through the roof leading to sodium fire capable to damage confinement structures.**
- **Top-down approach: the design of the confinement structures should be disconnected from the scenario associated to sodium ejection.**
- **If necessary adequate measures are implemented.**
- **Possible weak points are enhanced. Design margins are expected.**

Consideration of Fukushima Accident

- **The measures necessary for the severe accident mitigation (i.e., necessary for avoiding large or early radiological releases) shall be classified as “hardened safety core”:**
  - **Protection against extreme natural hazards.**
  - **Significant margins beyond the loadings resulting to design basis hazards.**
  - **Consideration of events induced by extreme natural hazards.**
- **Monitoring of plant states resulting from severe accident.**