DE LA RECHERCHE À L'INDUSTRIE

A S T R I D

Advanced Sodium Technological Reactor for Industrial Demonstration

ASTRID safety approach and safety systems

5th IAEA-GIF Workshop on Safety of SFR

Vienna, June 23&24, 2015

Bernard CARLUEC, Pierre LO PINTO

bernard.carluec@areva.com

www.cea.fr

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GENERAL SAFETY APPROACH

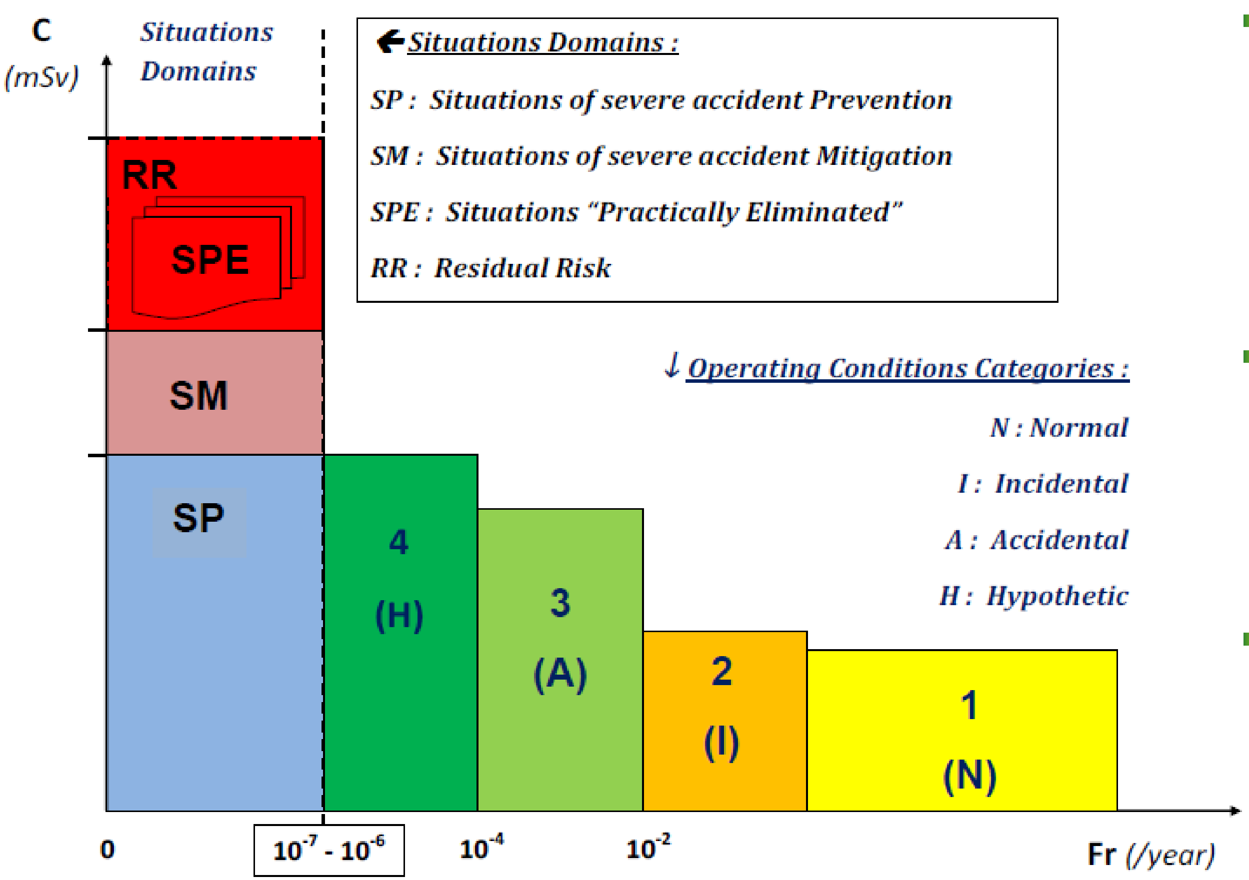
For the courant conceptual design stage of ASTRID:

- Implementation of all levels of the Defense-in-Depth principle, with additional provisions for both SA prevention and mitigation;
  according to WENRA advice →
- Consideration of non-radiological risk involved by sodium; complying with the recent French regulation
- Complementary Domain accounting for natural hazards more severe than the Design Basis hazards; as for lessons learnt from Fukushima accident
- Safety demonstration of Practically Eliminated Situation for some accident situations leading to cliff edge effect (i.e., early or large radiological release)
- PSA insights where relevant
- ISI capability for the main safety relevant structures (e.g., core support)

Levels of defence in depth		Objective	Essential means	Radiological consequences
Level 1		Prevention of abnormal operation and failures	Conservative design and high quality in construction and operation, control of main plant parameters inside defined limits	No off-site radiological impact (bounded by regulatory operating limits for discharge)
Level 2		Control of abnormal operation and failures	Control and limiting systems and other surveillance features	
Level 3 (1)	3.a	Control of accident to limit radiological releases and prevent escalation to core melt conditions (2)	Reactor protection system, safety systems, accident procedures	No off-site radiological impact or only minor radiological impact (4)
	3.b		Additional safety features(3), accident procedures	
Level 4		Control of accidents with core melt to limit off-site releases	Complementary safety features(3) to mitigate core melt, Management of accidents with core melt (severe accidents)	Off-site radiological impact may imply limited protective measures in area and time
Level 5		Mitigation of radiological consequences of significant releases of radioactive material	Off-site emergency response Intervention levels	Off site radiological impact necessitating protective measures(5)

Specific ASTRID approach beyond the DB domain:

- Classification of hypothetical situations, not based on frequency ranges :

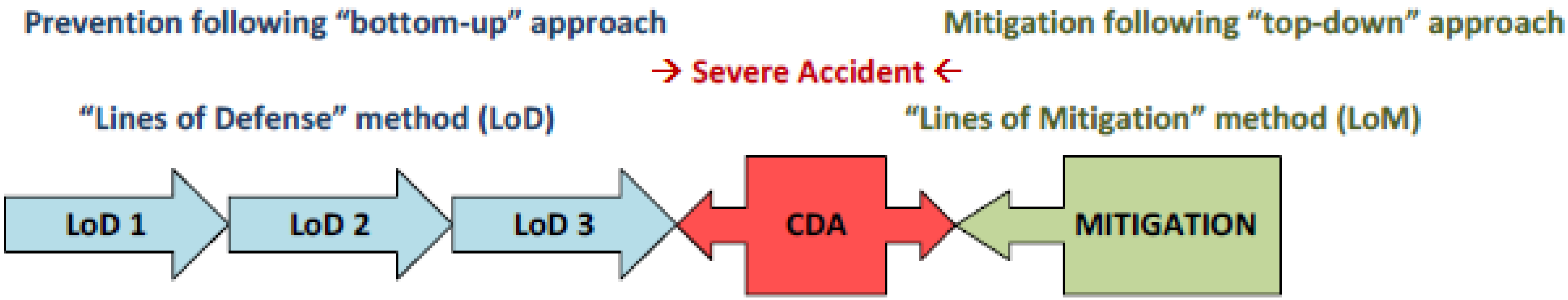


- SP: all postulated multiple failure events that could reasonably prevent escalation to core melt accident are taken into account
- SM: all events sequences leading to SA, consequences of which could be reasonably mitigated, are taken into account
- SPE: some situations leading to SA but consequences of which cannot be efficiently mitigated, must be strongly prevented.

SAFETY ANALYZE METHODS

Basic safety principles and rules are translated into practical methods:

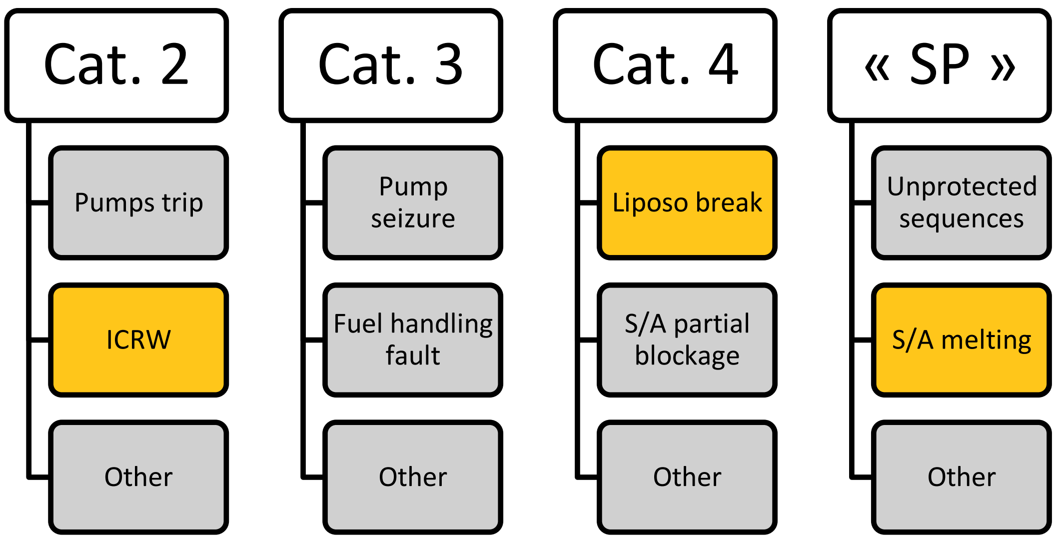
- Deterministic methods are applied in order to set convincing safety demonstrations:
  - LoD: “lines of defense” method for prevention; involving several, independent, diverse, reliable and successive LoDs
  - LoM: “line of mitigation” method for SA mitigation; assuring design margins by Top-Down approach (e.g., core catcher with high capacity) and homogeneous containment behavior (e.g., HX versus reactor vessel)
  - Complementary methods for specific demonstration in particular SPE
- Further, criteria for safety classification of SSC are based on their importance within the safety demonstrations (e.g., LoD) and then correlated to Design Standards



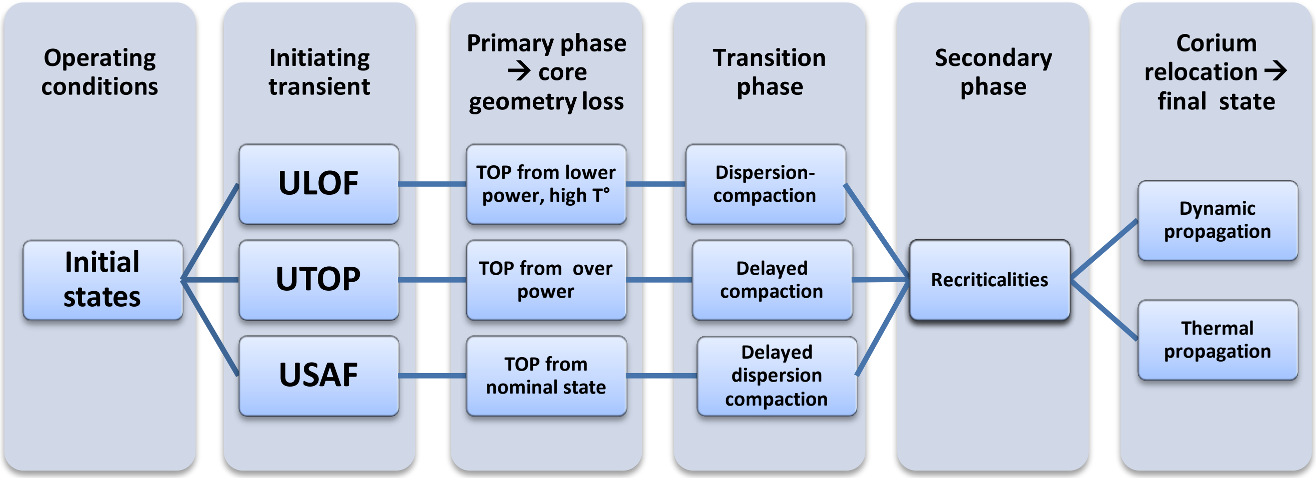
S.A. PREVENTION APPROACH

Progressive and extensive approach is implemented:

- Despite taking account of CDA within the design, prevention provisions are enhanced as far as reasonably feasible:
  - Redundant and diversified safety systems
  - Enhanced inherent reactor behavior, following event scenario approach
  - Complementary safety devices (CSD-P), not specific to any event scenario
- Each event family (either global or local) is analyzed from frequent initiating event (I) up to postulated multiple failures sequence whatever its low frequency (SP)



CDA MITIGATION APPROACH



Some features of the approach:

- CDA studies not based on only one scenario but from each initiating transient family
- Two CDA calculation methods:
  - ✓ Mechanistic analysis of each initiator
  - ✓ Identification of key parameters by accident phase and then conceptual design enhancement for reducing the sensibility
- Objective of “non energetic” CDA by conceptual core design (e.g., low sodium void core)
- SA management by LoM e.g., devices surrounding the core for limiting possible radial propagation of molten materials
- Separation between CDA analysis and LoM design (Top-Down approach) for more confidence as regards safety demonstration

LOD AND LOM PRESENTATION

	S.A. Prevention	S.A. Mitigation
Method:	**Lines of defense** (LoD)	**Lines of Mitigation** (LoM)
Application domain:	Prevention including SPE	Confinement barrier analysis and associated provisions assessment
Approach type:	”Bottom-Up”	“Top-Down”
Objective:	Probabilistic targets	Consequences reduction
Criteria:	Number of lines, reliable, independent, common mode absence	Each LoM is necessary for safety demonstration. LoM homogeneous behavior: ‘’no weak link’’
Demonstration:	Equivalent to ‘’2 strong + 1 medium’’ lines	Minimization of radiological release with ‘’top-down’’ approach
Safety classification:	SSC involved as LoD	SSC involved as LoM
SSC of the complementary domain against natural hazards:	Demonstration based on availability of 1 LoD per SPE and per hazard	Availability of each LoM is required

COMPLEMENTARY DOMAIN AGAINST NATURAL HAZARDS (CD-NH)

Implementation of the lessons learnt from FKS accident:

- The DB-hazard features must be suitable to prevent SA sufficiently, in comparison with the risk induced from other initiating families
- Natural hazards beyond the DB-hazards are assessed to prevent cliff-edge effect (early or large radiological release)
- SSC concerned by the CD-NH are: SSC acting as LoM or some LoD for SPE
- Cliff-edge effect prevention is provided by the Design margins of the CD-NH SSC

		S.A. objective ↑	Cliff-edge effect ↑
External hazards (EH) :	Design Basis (DB)	Complementary Domain (CD-H)	SPE

DB domain :	DB-H	10^{-4} (ex : earthquake)		
SSC classified :	Design loading	Design margin		
If SA risk too high → DB-H change for only « weak link » SSC		Design margin of the « weak link » SSC		
CD-H domain : analyses beyond the DB-H				
identification of necessary SSC :		SA meeting →	Cliff-edge effect →	
If cliff-edge effect meeting → DB-H change for "weak link" SSC			Design margin from DB-H of the « weak link » SSC	SPE

SITUATIONS PRACTICALLY ELIMINATED (SPE)

Safety demonstration with high level of confidence for each SPE:

- The number of SPE has to be reduced, that means any postulated accident sequence, consequences of which could be reasonably mitigated, has to be taken into account (SP or SM)
- Prevention of each SPE must be based on deterministic evidence and probabilistic insight if relevant.
  - ✓ General approach for ASTRID considers implementation of three independent and diverse LoD without possible common mode failures.
  - ✓ Some specific SPE demonstration needs additional methods. For example: Reactor support structures involve singular components (diagrid, strongback, skirt, vessel); for example for the strongback the demonstration is based on an adequate design providing internal redundant and independent structures with early failure detection.

SITUATIONS PRACTICALLY ELIMINATED (SPE)

List of SPE:

Not mitigable accident sequence	Scenario of SPE
S.A. leading to LoM failure	Core compaction
	Gas passage through the core
LoM failure leading to S.A.	Loss of DHR function
	Reactor support structure failure
	(Water ingress into the primary circuit)* (Hydrogen explosion)*
SA with inefficient LoM	Core loading mistake
	Fuel melting in the fuel handling facility

* Specific requirement from Licensing authority

NON-RADIOLOGICAL RISK MANAGEMENT

Off-site release of aerosols from sodium reactions is prevented by conceptual design:

- French regulation relating to nuclear facilities, requires design provisions against non-radiological risk, with a deterministic approach similar to the nuclear risk's approach (in comparison, the approach applied by the chemical industry is more probabilistic).
- Approach of ASTRID is based on the Defense-in-Depth principle, from the sodium leakage up to the aerosols release out of the facility.
- No outlet devices and provisions for avoiding overpressure; e.g.,
  - several communicating rooms containing sodium circuits able to limit overpressure
  - inert zone able to stand pressure and thermal loading
- In case of remaining risk of aerosols release (e.g., leak of sodium/air HX), the phenomena kinetics has to be simulated (sodium oxides→ soda→ sodium carbonate→ sodium bicarbonate) for the short term effect assessment. International data concerning health effects are needed.

REACTIVITY CONTROL FUNCTION

Enhancement of the two main shutdown systems and additional means in the DB and BDB fields:

- Background of the previous SFRs introduced into the redundant main systems :
  - More extended diversification for protection against each type of event (e.g., physical parameters monitoring)
  - Enhanced monitoring capability and reliability in particular for local faults
  - Improvement of reliability, e.g., avoid inhibition devices
- Investigation for Complementary safety devices in addition to the inherent behavior. e.g.,
  - "Thermal" shutdown ('Curie' point): all types of global transient can be protected (except very fast fault)
  - "Hydraulic" shutdown ('floating' rod): designed for postulated fast ULOF
  - "Over-power" shutdown ('neutron fusible' concept): not implemented for ASTRID; large fast UTOP must be prevented by design (SPE approach)
  - "Stroke limitation" device (limitation of control rod withdrawal): not implemented for ASTRID (prevention is based on natural behavior taking advantage of the low reactivity decrease during core cycle)
  - "Electric" shutdown by self reactor shutdown in case of LOSSP

DECAY HEAT REMOVAL FUNCTION

Loss of the DHR function is ranked as SPE because LoM (primary structures) can be damaged prior SA occurs:

- Thus, three independent DHR systems (LoD) are implemented:
  - Each reactor operating condition should be protected by sufficient LoD.
  - Large primary sodium loss should be eliminated by design.
- The two main redundant and diversified DHR safety systems are:
  - “Active” DRCS: 2 independent circuits (2 x 100% function) from the primary ‘cold’ plenum, with emergency electrical supply
  - “Passive” DRCS: 3 independent circuits from the primary ‘hot’ plenum (3x 50% function in natural circulation) and possible natural convection in the primary circuit
- Equivalent to the third LoD:
  - At short time: normal DHR system via the SG (water supply)
  - At long time: via the reactor vault (RVACS) i.e., oil cooled circuits with a water heat sink. RVACS is ‘active’ for performance purpose but with possible backup and repair of the ‘active’ components within the grace delay.
- Additionally, probabilistic assessment including reparability is in progress

Post-CDA heat removal function:

- Available DRC circuits + RVACS are involved in the LoM approach

CONFINEMENT FUNCTION

Barriers and related systems are designed to delay and minimize any off-site radiological release, in particular in case of SA:

- Limited number of internal release-ways, mainly the primary argon system
- Intermediate volumes, between the 2nd and the last barrier, are devoted to delay off-site release and minimize pressurization of the last barrier. As for benefit:
  - 'Source term' is reduced (FP decay effect + lower leakage of the last barrier)
  - Delay could be used for implementing off-site measures
- Additional safety provisions are implemented for managing potential bypasses of the barriers