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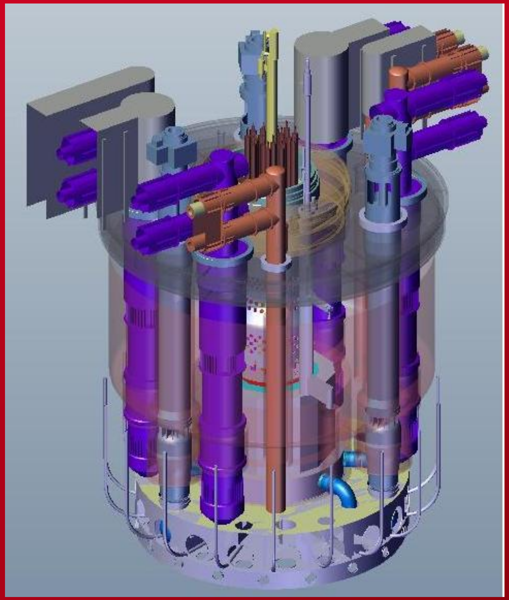

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SPECIFICATIONS FOR FUTURE FAST NEUTRON REACTORS

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INTRODUCTION

- **This presentation is inspired by the specifications for future sodium fast reactors by EDF, as transmitted to CEA in the framework of the ASTRID collaboration.**

- **However, additions, modifications or nuances were introduced to be more applicable to the different types of coolants considered in this seminar.**

- **The presentation does not aim to be exhaustive.**

EXPECTATIONS TOWARD 4TH GENERATION SYSTEMS

- **Sustainability**
  - Ability to recycle materials while making the best use of uranium or thorium natural resource. And, if this option is retained, ability to transmute certain minor actinides.
  - Need for fast neutron spectrum, and closed cycle.
  - The use of depleted uranium already mined and available on French territory could feed a fleet of fast neutrons reactors for several thousands of years at today's electricity production rate.
- **Safety**
  - Robustness of safety demonstration (uncertainties, margins, cliff edge effect)
  - Highest standards in terms of safety objectives, resulting from 3rd generation reactor safety demonstrations associated with the lessons from Fukushima accident.
- **Economy**
  - 4th generation systems shall be competitive, taking into consideration the same service rendered.
  - This means huge efforts on the reduction of the initial investment but also on operating costs (importance of availability factor).
- **Proliferation resistance**

PERFORMANCES

Specification	Comments
Power rate: first units [1000-2500 MWth], large deployment [3000-4000 MWth]	Achievable for sodium Possibly some limitations for other coolants
Breeding ratio: <1, =1 or >1	Depends on why FR are installed. High BR can be difficult to attain for certain choices of fuel, coolant and core design. Radial blankets ?
Lifespan: 60 years or more	Means that certain components need to be replaceable.
High burn-ups and long cycle (18 months)	Cladding material performances
High availability factor (>90%)	Short fuel handling outages (and robust fuel handling route), reliability of equipment, quick repair or replacement, short inspection periods.
Investment cost and cost per kWh as close to LWRs as possible	Significant improvements are needed to achieve this goal. Prototype and FOK effect.

SAFETY 1/

Specification	Comments
Safety level equivalent to Light Water Reactors that will be put into operation at the same time.	For 2020 prototypes: 3rd generation requirements (WENRA 2010 [1][2]) + lessons from Fukushima
Accidents with core melt: WENRA Objective O3.	• accidents with core melt which would lead to early or large releases have to be practically eliminated ; • for accidents with core melt that have not been practically eliminated, design provisions have to be taken so that only limited protective measures in area and time are needed for the public and that sufficient time is available to implement these measures.

[1]	Western European Nuclear Regulator's Association, "WENRA Statement on Safety Objectives for New Nuclear Power Plants", November 2010
[2]	Western European Nuclear Regulator's Association, "Safety Objectives for New Power Reactors - Study by WENRA Reactor Harmonization Working Group", December 2009

SAFETY 2/

Specification	Comments
Decay heat removal: practical elimination of total loss of DHR function over a long period of time	Risk of coolant freezing in circuits Diversification Active/passive Special attention for GFR
Compatibility of secondary coolant with primary coolant	Risk of precipitates Chemical reactions Gas entrainment into core Vapor explosion?
Purification	Corrosion of steels Blockage of subassembly
Elimination of big sodium fire, big sodium-water reactions and big sodium-water-air reactions	Specific Na issues
Very high reliability of shut-down system	Redundant systems, 3rd shut-down system, diversification…

SAFETY 3/

Specification	Comments
Protection against large airplane crash	Feedback from 9/11 events. Always a confusion between probabilistic approach (small aircrafts) and act of malevolence (possibly large aircraft)
Earthquake, flooding…	Following Fundamental Safety Rules Earthquake issue for LFR ?
All states of operation, all parts of the installation shall be taken into consideration	Including fuel storage
Coolant leaks: early detection, quick localization and repair	/
Probabilistic Safety Analysis: level 2 required	/

SAFETY 4/

Specification	Comments
Radiation protection for the workers : overall annual collective dose < 100 man.mSv/y per installed GW(e) and maximum individual dose < 2.5 mSv	~10 times lower than current 2nd generation LWRs.
Waste minimization Special issue of tritium	Solid waste is preferable. Tritium is produced inside the fuel or the absorbers, but also inside the coolant itself in large quantities in case of molten salts.
Dismantling - Waste minimization: low activation of structures when possible, decontamination, tritium - Minimization of dose to the workers - Availability of dismantling technics - Availability of final disposal for generated waste	Including disposal of coolant itself.

FAST NEUTRON CORE ISSUES

Specification	Comments
Coolant void reactivity effect as low as possible	Heterogeneous core for SFR (ASTRID) Limitation for large LFRs?
Core compaction: prompt-criticality to be practically eliminated	Design provisions to be taken for SFR, GFR, LFR. Understanding of Phenix negative reactivity events in 1989-90. Issue for MSR ? (stability/homogeneity of salt)
Control rod withdrawal: no fuel failure even if undetected	Possibility of core design with low loss of reactivity per cycle
Energetic events below a given threshold	Demonstration of margins with regard to containment
Need for core catcher	With as little impact as possible on normal operation
Strategy for cladding failure: detection, localization…	“clean coolant” strategy

FUEL HANDLING

Specification	Comments
Whole core discharge (fast ?)	Depends on safety objectives and design options with regard to loss of primary coolant. Depends also on operator’s objective with regard to possible reuse of fuel. Impact on external vessel storage tank.
Elimination of fuel handling mistake	Requires redundant possibilities of fuel subassembly identification.
Decontamination / Cleaning	Effectiveness (no remains of coolant)
Reliability of fuel handling route	Concerns SFR, GFR, LFR but also MSR (fuel cycle)

INSTRUMENTATION - INSPECTION

Specification	Comments
In-service inspection All structures inside the primary circuit shall be inspectable: • Visually • Volumetrically	Some areas might be highly radioactive, sensors do not work for long. Temperature for “cold” state of the reactor. Opacity of liquid metals Ultrasound technics Under sodium viewing
But all efforts are made in the design to avoid such inspections under normal circumstances.	/
Need for post-accidental instrumentation	Lesson from Fukushima
Suitable instrumentation	

OTHER IMPORTANT CONSIDERATIONS

Specification	Comments
Simple, robust design Standardization of equipment	/
Possibility to replace equipment	Upper core structure Heat exchangers Steam generators Pumps …
Availability / Cost of coolant	Bi: availability issue He: expensive, need for very good leak tightness
Use of critical materials	To be checked regularly

CONCLUSION

- **Impossible to be exhaustive. Many items were not addressed.**
- **The step to reach 4th generation criteria at once without continuous feedback of experience is much more challenging today as technological experiments that were conducted in the pioneer times (1960s-70s).**
- **There is a link between the technical maturity and the safety level.**

ASTRID	Advanced Sodium Technological Reactor for Industrial Demonstration
BR	Breeding ratio
DHR	Decay Heat Removal
FOK	First of a kind
FR	Fast-neutron reactor(s)
GFR	Gas-cooled Fast-neutron Reactor
LFR	Lead-cooled Fast-neutron Reactor
LWR	Light Water Reactor(s)
MS(F)R	Molten Salt (Fast) Reactor
SFR	Sodium-cooled Fast-neutron Reactor
WENRA	Western European Nuclear Regulator’s Association