THE COLLABORATIVE PROJECT ON THE EUROPEAN SODIUM FAST REACTOR AND ITS PROLIFERATION RESISTANCE EVALUATION

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ABSTRACT

The collaborative project on the sodium fast reactor (CP-ESFR) is an international project where 25 European partners develop R&D solutions for a European Sodium Fast Reactor concept. The Project is funded by the 7th EU Framework Programme and covers topics such that the fuel, the fuel element and the fuel cycle, the safety concepts, the reactor architectures and components and the balance of plant. Within the sub-project 3, dedicated to safety, a task, addresses proliferation resistance issues. In the paper some of the core features and the so called working horses, for a loop and a pool Sodium fast reactor concept are presented, by highlighting those more relevant for the proliferation resistance aspects. Some of the activities carried out in the project for its proliferation resistance evaluation are then illustrated, in particular those related to material type considerations on the possible diversion targets.

1. Introduction

The collaborative project on the sodium fast reactor (CP-ESFR) is an international project where 25 European partners develop R&D solutions for a European Sodium Fast Reactor concept [1]. The Project explores aspects related to the main design aspects of the system, with particular focus on the core features. Within sub-project 3, dedicated to the system’s safety concepts, a dedicated task led by JRC-ITU, with contributions of EdF, ENEA and AREVA, addresses proliferation resistance issues. The objective of this task is to make considerations on the resistance to nuclear proliferation of a Sodium Fast Reactor design. The Generation IV International Forum (GIF) Proliferation Resistance & Physical Protections (PR&PP) Evaluation Methodology [2] has been chosen as the general framework for this work, complemented by punctual aspects of other evaluation methodologies and studies. In particular, some of the indications contained in the International Atomic Energy Agency (IAEA) International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) PR assessment manual [3] have been considered to make Material Type attractiveness considerations on the core options under investigation by the CP-ESFR analysts. This paper will first briefly illustrate some aspects of the ESFR design relevant to proliferation resistance and then will present selected aspects emerged by the analysis carried out.

2. Aspects of the ESFR design relevant to proliferation resistance

Two concepts of 1500 MWe reactors called “Working Horses” have been proposed in the context of CP ESFR: a pool type and a loop type design. For both designs, two core options are proposed: one with U and Pu oxide fuel and the other with U and Pu carbide fuel. For both carbide and oxide cores, the inner and outer fuel regions have different Pu mass content in order to flatten the core power shape. The reactor architectures and the core of the working horses are shown in Fig 1.

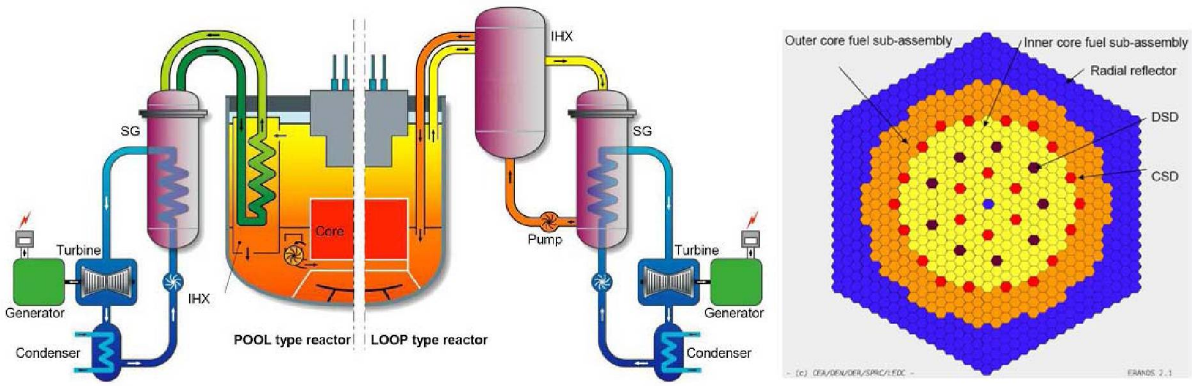

Fig 1. Schematic diagram of reactor architectures of the two ESFR working horses [4] and the SFR core with oxide fuel, no blanket case. [5]

The systems could be used for minor actinide management (MA), either in homogeneous or heterogeneous mode. Homogeneous MA management basically consists in replacing part of the uranium of the fresh fuel elements with minor actinides (4% MA), while heterogeneous MA management considers that an additional ring of fuel assemblies (FA) is added with respect to the specified ‘Working Horse’ core [6]. These additional ring assemblies form the radial blanket. Fresh radial blanket assemblies, when present, are always composed of depleted UO_2 (80%) and MAs (20%). The group investigated the possibility to perform MA management only for the oxide core.

3. Proliferation resistance evaluation framework

The GIF PR&PP Evaluation Methodology framework [2] is illustrated in Fig 2.

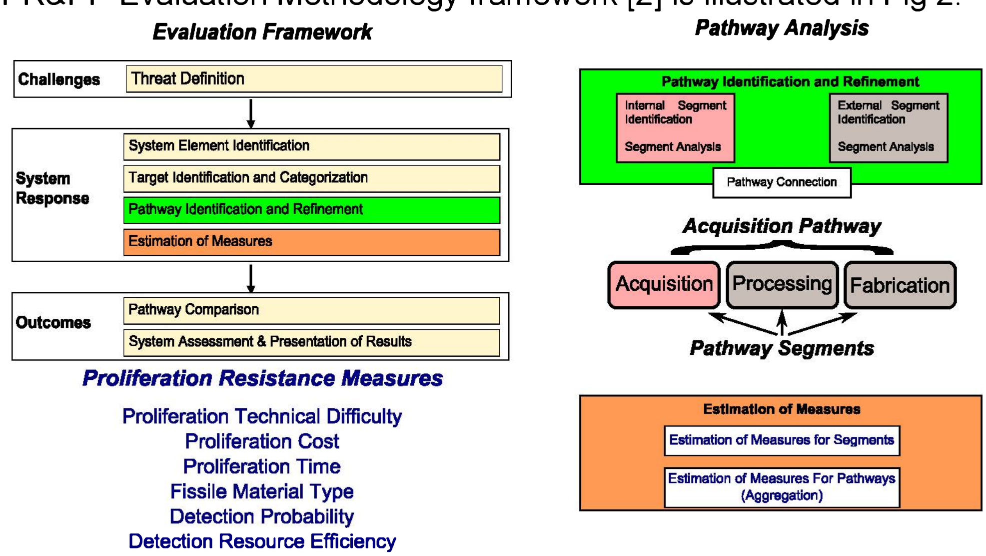

Fig 2. The GIF PR&PP methodology framework

The GIF defines proliferation resistance as “that characteristic of an NES that impedes the diversion or undeclared production of nuclear material or misuse of technology by the Host State seeking to acquire nuclear weapons or other nuclear explosive devices”[2]. The threats to be considered according to the methodology are 1) *Concealed diversion,* 2) *Concealed production of nuclear material,* 3) *Breakout* and 4) *Production in clandestine facilities*.

A full PR evaluation of the systems design was beyond the scope of the project. The GIF PR&PP methodology framework has been used to decompose the system into system elements and to identify potential diversion targets. The analysis then focused on the aspects that were considered to be more relevant for the project, i.e. targets characterizations in terms of nuclear material attractiveness for a proliferator, Safeguards by Design (SbD) considerations, high-level considerations on the four above-mentioned threats. Although the in vessel fuel handling systems of the reactors are different for pool and loop reactor types, both designs share the same conceptual system elements, shown in the left hand-side part of Fig 3. The right hand-side of Fig 3. shows the possible diversion target types (in red) corresponding to all the cases simulated for the oxide and carbide cores by the other project partners [6], [7].

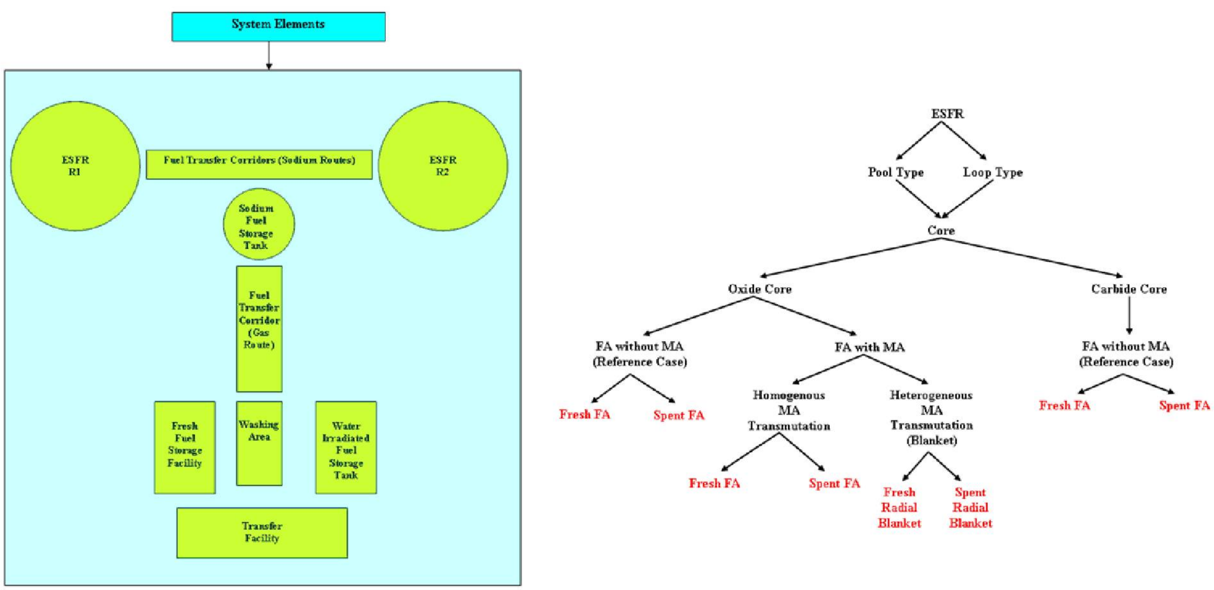

Fig 3. ESFR system elements and possible diversion targets in different cases

To analyse the nuclear material attractiveness of the identified diversion targets, several literature studies have been reviewed and applied. The following paragraph illustrates the outcome of the material type analysis performed by applying User Requirement 2 of the INPRO Proliferation Resistance (PR) manual (The attractiveness of nuclear material and technology in an INS for nuclear weapons programme should be low) [3].

4. Material type analysis according to INPRO PR UR 2

User Requirement [UR] 2 of the INPRO PR manual provides 3 indicators and related evaluation parameters (EP) for the attractiveness of Nuclear Material [3]. Fig 4. shows the quantification of nine of them when applied to the ESFR possible diversion targets.

	EP2.1.1 Material type/ category						EP2.1.2 Isotopic composition						EP2.1.3 Radiation field					
	VW	W	M	S	VS	MT type	VW	W	M	S	VS	Pu-239/Pu (%)	VW	W	M	S	VS	Dose (mGy/hr)
Fresh oxide FA	■					UDU				■		47.76		■				173
Fresh carbide FA	■					UDU				■		47.76	■					145
Fresh oxide FA with 4% MA	■					UDU				■		47.76				■		3330
Spent oxide FA		■				IDU		■				62.41					■	4.13E+06
Spent carbide FA		■				IDU		■				62.96					■	4.63E+06
Spent oxide FA with 4% MA		■				IDU		■				58.82					■	3.86E+06
Spent Blanket with 20% MA		■				IDU				■		48.57					■	2.29E+06

UDU: Un-irradiated Direct Use Material
IDU: Irradiated Direct Use Material

	EP2.1.4 Heat generation rate						EP2.1.5 Spontaneous neutron gen. rate						EP2.2.1a Mass of an item (kg)					
	VW	W	M	S	VS	Pu-238/Pu (%)	VW	W	M	S	VS	(Pu-240+Pu-242)/Pu (%)	VW	W	M	S	VS	Mass of one item (kg)
Fresh oxide FA		■				3.60		■				40.35				■		500 - 750
Fresh carbide FA		■				3.60		■				40.35				■		500 - 750
Fresh oxide FA with 4% MA		■				3.60		■				40.35				■		500 - 750
Spent oxide FA		■				1.94		■				30.37				■		500 - 750
Spent carbide FA		■				1.37		■				30.22				■		500 - 750
Spent oxide FA with 4% MA		■				6.68		■				29.50				■		500 - 750
Spent Blanket with 20% MA				■		37.79		■				13.47				■		500 - 750

	EP2.2 No. of items for SQ						EP2.2.3 No. of SQ (material stocks or flow)						EP2.3.1 Chemical/ physical form					
	VW	W	M	S	VS	No. of SQ in FA	VW	W	M	S	VS	No of SQ in NES	VW	W	M	S	VS	Form
Fresh oxide FA	■					3.45	■					>100			■			Pu compounds
Fresh carbide FA	■					2.90	■					>100			■			Pu compounds
Fresh oxide FA with 4% MA	■					3.45	■					>100			■			Pu compounds
Spent oxide FA	■					4.83	■					>100				■		Spent Fuel
Spent carbide FA	■					2.52	■					>100				■		Spent Fuel
Spent oxide FA with 4% MA	■					5.26	■					>100				■		Spent Fuel
Spent Blanket with 20% MA		■				0.83		■				69.72				■		Spent Fuel

Fig 4. Comparison of the cases with respect to nuclear material attractiveness study in INPRO UR2. Very Weak (VW), Weak (W), Medium (M), Strong (S), Very Strong (VS).

Fig. 4 shows that the "Spent Blanket with 20% MA" dominates or equals the other targets in all the considered indicators, making it nominally the least attractive nuclear material target in the system. This would seem to hint at the fact that the heterogeneous transmutation of minor actinides in the radial blanket would not pose additional diversion hazards. In addition, the possibility to recycle minor actinides in the blanket instead of recycling them in fresh fuel elements would avoid incurring in "safeguardability" issues for the fresh fuel elements [8]. On the other hand, it has to be noticed that the presence of a radial blanket would open up potential misuse scenarios that might worsen the overall PR of the reactor core.

There is no substantial difference between diversion targets in the oxide and the carbide options. The only indicator that scores differently is the radiation field for fresh oxide and fresh carbide fuel assemblies. The difference stems from the different amount of nuclear material available inside the elements, but this difference (173 mGy/h vs 143 mGy/h) has no real life impact.

In the case of homogeneous minor actinide management, the minor actinides are added to the fresh fuel. As can be seen from the indicators, this leads to a difference in the quantification of the radiation field indicator related to the fresh fuel targets. In this case the difference is substantial and points at a higher difficulty in handling MA-bearing fresh fuel. It has to be noticed that the presence of MA in the fresh fuel assemblies might have negative impacts on the safeguardability of these items, as the current verification activities might be hindered by the strong radiation emission of the actinides (for additional details on this aspect see [8]).

5. Conclusions

This paper presented selected aspects of the CP-ESFR proliferation resistance evaluation, the evaluation framework and then some outcomes stemming from the application of User requirement 2 of the INPRO PR manual. In summary:

- Both loop and pool type working horses share the same core configuration. Although being item facilities and therefore not posing particular problems in terms of safeguards accounting and reporting, liquid sodium is a hostile environment and an opaque coolant that makes the verification of the sodium-immersed nuclear inventory more problematic than in typical LWRs.
- The addition of MA to the fuel and/or blankets might have proliferation resistance and safeguardability implications that need to be thoroughly assessed adopting a systemic point of view.
- For a diversion strategy there is no big difference in terms of material type attractiveness between the oxide and the carbide fuel assemblies.
- Blanket assemblies (where present) could be composed by depleted uranium or by more complex mixtures. Irradiated blanket assemblies could have a relatively low burn-up and, depending on the initial mixture, may contain weapons-grade plutonium. The addition of MA to the blanket mixture strongly affects the irradiated assemblies' plutonium isotopic composition.

6. References

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