Proliferation issues related to the deployment of Fast Neutron Reactors (FNRs)

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Content

- ***General considerations***
- **Proliferation issues associated with FNRs**
- **Methodologies**
  - **Approaches drawn from nuclear safety analysis**
  - **The SAPRA methodology**
- **The path forward**
- **Conclusions**

Definitions

▶ Proliferation

Acquisition of nuclear weapons ("vertical" or "horizontal")

▶ Proliferation Resistance (PR)

Those characteristics of a nuclear energy system that impede the diversion or undeclared production of nuclear material, or misuse of technology, by States in order to acquire nuclear weapons or other nuclear explosive devices

▶ Physical Protection (PP)

Are those characteristics of a nuclear energy system that impedes the theft of materials suitable for an explosives or radiation dispersal devices, and the sabotage of facilities or transportations of nuclear materials, by sub-national entities and other non-host State adversaries.

▶ Proliferation risk

Include scenario studies (considering the whole spectrum of potential proliferation "pathways") which take into account specification of a potential "proliferator" (a state or a sub-national group)

Proliferation resistance and physical protection (PR&PP) : the actors

- **PR&PP issues covers a broad spectrum of activities and is a blend of 3 things:**
  - **Political actions:** UN resolutions, International treaties (NPT), …
  - **Institutional arrangements :** safeguard implementation (IAEA), Additional Protocol, export controls (NSG), national regulations,…
  - **Technical measures:** reduction of material attractiveness, design features to ease safeguard implentations or to enhance physical protection, NMC&A[1] , assessment methods,…

- **PR&PP issues are dealt by various bodies / entities in France :**
  - **Government :** President of the Republic, Prime Minister, ministries (➔ political + institutional)
  - **National bodies** such as CEA (Division for Security and non prolifération) and IRSN (➔ institutional + technical)
  - **Industrial actors :** AREVA, EDF (➔ mainly technical)

WE WILL FOCUSS HERE ON PROLIFERATION RISK OF FAST NEUTRON REACTOR SYSTEMS (FNRs)

(1) Nuclear Material Control and Accounting

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General considerations on proliferation risks of FNRs

- The deployment of any nuclear system present proliferation risks (more or less high) : as in safety, the « ZERO RISK » does NOT EXIST.

- FNRs systems could raise specific proliferation concerns mainly because their industrial deployment at a large scale would implies production, processing and handling of large amounts of plutonium (since plutonium is by far the best fissile material in fast neutron spectrums).

  In this sense, the whole FNR system (= Reactor + fuel cycle facilities) deserves specific analysis.

- However this would be balanced by the fact that :
  - FNRs would avoid the uranium enrichment plants at least in the long term
  - FNRs will be probably deployed only in countries that have large nuclear programs and that present very low proliferation risks (NWS or « De facto » WS, or states having strong non proliferation commitments)
  - Technically, a FNR is not the easiest proliferation pathway because it is a sophisticate technology

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Example of options to be assessed

	Alternative options / issues	comments
React.	Fresh and spent fuel handling and storage	Control and monitoring measures is of paramount importance for this system ("safeguard by design")
	MA : Homogeneous / heterogeneous recycling	This choice will <u>not</u> be imposed by PR concerns but its consequences will have to be assessed from PR point of view
	Blanket / no Blanket	<u>*See the next slide*</u>
	Burner / Breeder	Burners could only reduce (not suppress) Pu stockpiles. Same performances could be achieved with 100 % MOX – LWR.
Fuel	Adding MA or not	Same comment as MA in reactor (above) <u>*Note :*</u> PR issues are not very different than those of current LWR-MOX fuels
Repro.	Co-location (on site) / centralized (MNA)	Centralized facilities could raise PR problems due to transportation
	Pyro (dry) / Hydro (wet)	. Precise NMC&A for Pyro is very challenging . MUF is a concern for both processes
	Pu only separation / No Pu separation	. For the La Hague process (wet), COEX option will be assessed from PR point of view

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FNRs : the blanket issue

- The concern : blankets made of U238 (or TH232) produce "weapon grade plutonium (or almost pure U233 with very low content of U233).
- However, breeding would very difficult to achieve without blankets
- Anyhow, it would be near impossible to prevent attempts to introduce fertile assemblies in the core. Taking such provisions at the design stage would be very risky as it would condemn the reactor to never reach a breeding state.
- Furthermore, the plutonium normally produced in blankets, is the "spent fuel standard" conditions : burnup > 30 GWd/t
- Thus, looking for a solution does not consist in suppressing the problem (blankets), the more so that there are several means to "denature" the Pu if needed : add to the fresh fuel LWR Pu (few %), add Np or U236 (RepU) to produce Pu238, add MA, add moderator elements, …
- In all cases, it is necessary to have a scale of value for estimating the "material attractiveness" (and calculate a "Figure of merit" of aech kind of material)

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Analogy of Proliferation Resistance (PR) and nuclear safety (NS)

In both cases :
one clear and well identified objective

▶ NS :

- **Ensure appropriate confinement of radioactivity in all circumstances**

▶ PR :

- **Prevent any acquisition of one or more nuclear weapons by a nation that currently does not have them**

Defense in depth (DiD) in PR

- **An internationally agreed principle**

  Proliferation resistance can be enhanced when complementary and redundant features and measures provide defense in depth (DiD)

- **For PR, there are two complementary sets of barriers**

  - **"Intrinsic" :**
    - ***Technical features :*** **Material attractiveness, NMC&A system, safeguard equipments, facility design to delay diversion or misuse, features that facilitate implementation of intrinsic measures themselves, ….**
    - ***Organizational features :*** **monitoring procedures, QA/QC implementation, NP "culture", education and training, …**
  - **"Extrinsic" :**
    - ***Institutional measures :*** **safeguards, additional protocol, export controls (NSG), …**
    - ***"Political" and diplomatic actions :*** **NPT and other international treaties (state commitments), UN "Sanctions",…**

PR will be most cost effective when an optimal combination of intrinsic features and extrinsic measures, compatible with other design considerations, can be included in a nuclear energy system.

The 5 levels in NS: a proposed analogy with PR

NS

1. Prevention of abnormal operation and failure
2. Control of abnormal operation and detection of failures
3. Control of accidents within the design basis
4. Control of severe plant conditions, …
5. Mitigation of radiological consequences of significant releases

PR

1. Prevention of misuse of facilities or diversion of nuclear materials
2. Implementation of verification regimes (safeguards)
3. Quick processing of detected anomalies and inconsistencies
4. Management of significant anomalies (established proliferation attempt), …
5. Mitigation of a clear breach of non-proliferation commitment

Each kind of barrier can play a role at each level of DiD

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Probabilistic Approach : tool for PR ?

- **Probabilistic approach in PR assessment involves :**
  - **Systematic in depth analysis of proliferation scenario**
  - **Quantification of events : mainly expert judgment**
  - **Estimation of uncertainties which are sometimes large**

- **It can be useful to identify strength and weakness of a system.**

- **It can be useful to assess effectiveness of a given improvement of a nuclear system.**

- **BUT : NOT to be used to assess overall performances of a system through a precise and unique value (only "figure of merits" can be sought in order to get a rough estimate of PR merits of a nuclear system on a scale of values, comparable to "event scale" utilized in NS)**

SAPRA[1] : general points

- SAPRA is a specific method developed by French nuclear partners (CEA, EDF, AREVA) to get a global view on proliferation resistance of a nuclear energy system
- It has been already presented in several conferences and to the GenIV-PR&PP expert group, and at the IAEA
- A report on SAPRA has been published and widely distributed in march 2007
- We only outline here some of the main features of this approach

(1) : Simplified Approach for Proliferation Resistance Assessment

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Outlines of the SAPRA methodology (1/2)

- **Four phases are distinguished in the proliferation pathway**
  - **Diversion by a state of nuclear materials (NM) either stolen in a facility of a foreign country or diverted (in a concealed way) in one of its own safeguarded facility.**
  - **Transport of NM to the location where NM will be processed (to make a nuclear weapon)**
  - **Transformation of original NM (stolen or diverted) to a direct usable material (that is HEU or pure metallic Pu)**
  - **Making of a nuclear weapon (using HEU or civilian Pu)**

- **In SAPRA all events of the proliferation pathway are supposed to occur in each phase and experts try only to determine how difficult it is for a proliferant state to overcome each of the barriers to reach its goal**

This is an extention of the TOPS[(1)] method which do not make this distinction explicitely and which consider mainly the diversion phase

(1) NERAC / CGSR, Report of the International Workshop on Technology Opportunities for Increasing the Proliferation Resistance of Global Civilian Nuclear Power Systems (TOPS), March 2000

Outlines of the SAPRA methodology (2/2)

- **TOPS barriers (technical, institutional) were rewieved and distributed in the 4 phases and some other barriers were added**
- **Each step of the fuel cycle are taken into account (from uranium mining to final disposal of waste)**
- **A scale of values is being defined for assessing the robustness of each barrier (for a given threat): from 0 (very weak barrier) to 4 (very high resistant barrier)**
- **Marks are alloted by « experts » for each square of the matrix (between 500 and 900 marks for a given case).**
- **Then, for each individual fuel cycle step, marks are being summed up and normalized to 1 for each set of barrier (material, institutional, …) and then for each phase (diversion, transport, …): this simple process provides « Proliferation Resistance Indexes » PRI**

			TOPS	SAPRA				Note
				Diversion	Transport	Transform.	Weapon fabricat.	
MATERIAL	Isotopic	Critical mass						1
		Isotopic enrichment						2
		Spontaneous neutron generation						
		Heat generation rate						
		Radiation (of the direct use material)						
	Dangerousness (=harmfullness other than irradiation)							
	Chemical							
	Radiological (other than the one of the material itself)							
	Mass and bulk							
	Physical form							
	Detectability							
TECHNICAL	Facility unattraciveness							3
	Facility accessibility							
	Available mass							
	Diversion detectability							
	Skill, expertise, knowledge							
	Time							
	Technical difficulty							
	Collusion level							
	Construction detectability							
	Signature of installation							
EXTRINSIC	Safeguards							
	Access / control / security							
	Location / distance (for transport phase)							

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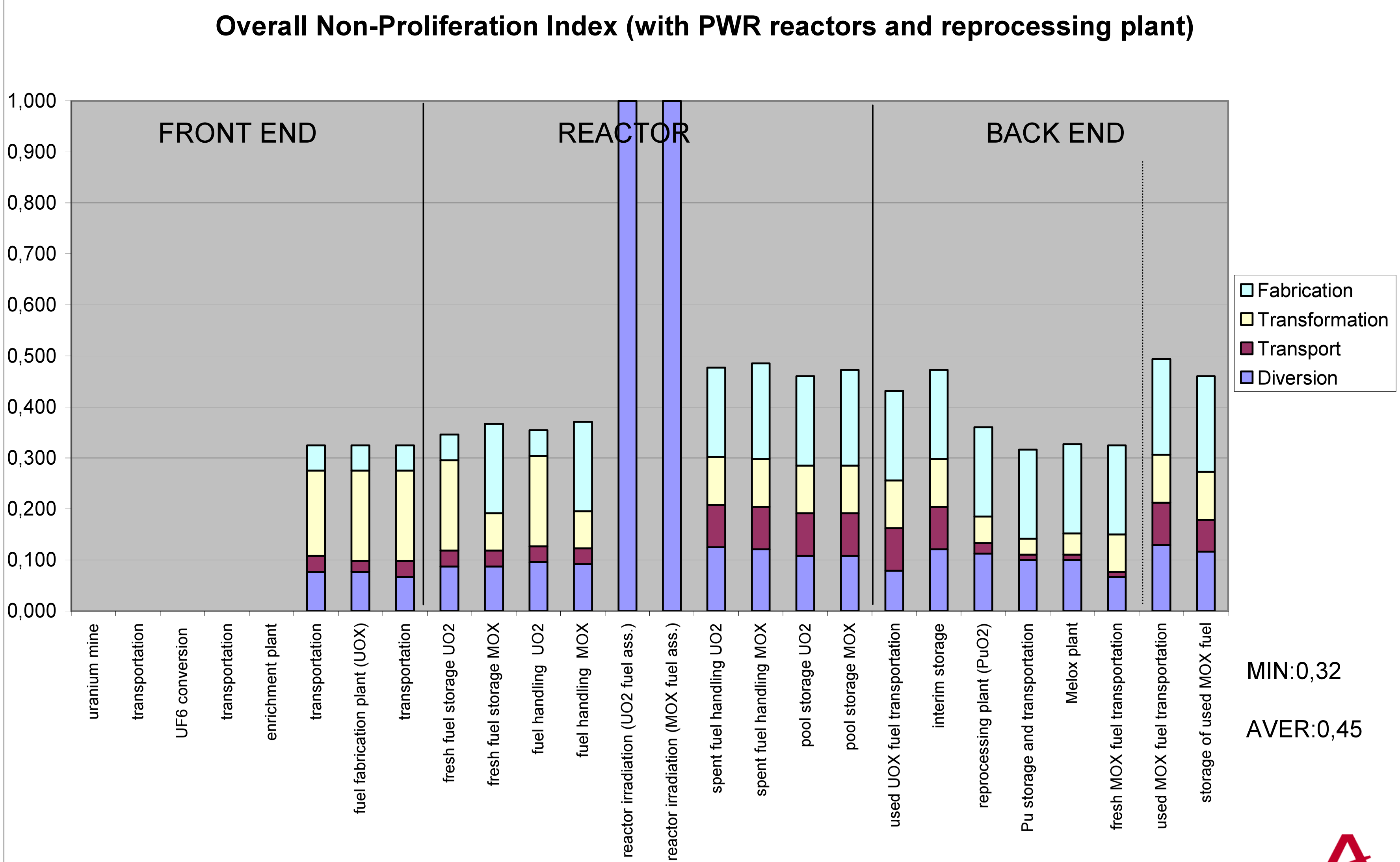
Example of SAPRA results



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Analysis of the proliferation risk of FNRs systems : the pathforward (1/2)

- **Indentification of a comprehensive set of proliferation scenarios :**
  - Concealed diversion of nuclear material (either at once or protracted)
  - Concealed misuse of a process or facility (ex: introduce undeclared fertile assemblies in a reactor core)
  - Overt diversion of nuclear materials or overt misuse of a facility
  - "Breaking" scenario (country which denounce its non proliferation commitments)

  Also, assumptions concerning "country profile" will be needed (technical and scientific capabilities, infrastructures, strategies, status of its nuclear program, …)

- **Implementation of the SAPRA methodology (modifies and improved, if needed), for a first overall assessment aimed at identifying weak points**

- **In parallel, application of the "defense in depth" approach to check the robustness of the system against proliferation attempts**

- **Refinement of the analysis using Gen-IV PR&PP methodology for some particular segments of the FNR systems (ex : reprocessing plant)**

Analysis of the proliferation risk of FNRs systems : the pathforward (2/2)

▶ Anticipated Outcomes :

- Identify strength and weaknesses of FNRs with regard to Proliferation risk, and mitigate weaknesses with adequate intrinsic and extrinsic measures
- Compare FNRs merits / Disadvantages with regard to other nuclear systems
- Propose possible R&D to enhance proliferation resistance of FNRs,
- Recommend safeguard, control and monitoring measures ("Safeguard by design")

More generally, this kind of study could contribute to define <u>CRITERIA</u> that could be discussed and then approved at an international level

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CONCLUSION

- As for any other nuclear system, the industrial deployment of FNRs raises a proliferation risk which must be assessed comprehensively (even if this risk is very low when efficient safeguard are implemented)

- All nuclear actors and relevant international organization such as IAEA must be part of this process in order to take into account ALL ASPECT of the problem (which is a blend of political, institutional and technical issues)

- This analysis is in progress in France, using in particular approaches drawn from those used in Nuclear Safety and implementing specific assessement tools such as SAPRA and « PR&PP » methodologies.

Atoms for peace !

Thank you

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Why AREVA is concerned by non proliferation issues ? (1/2)

- **Globalization :** nuclear is becoming a « GLOBAL industry » and AREVA is a worldwide leader in this sector. Its activities can be affected by events occuring in another country
- **Regulation :** more and more national and international constraints on non proliferation grounds : nuclear commercial activities and trade are strickly regulated and subject to governmental approvals and specific constraints such as international safeguards and export controls
- **Transparancy :** Support and acceptance of the public is needed for the deployment of nuclear energy but nuclear activities are subject to public scrunity and contest: proliferation risk serves as argument against the use of nuclear power and development of industry.

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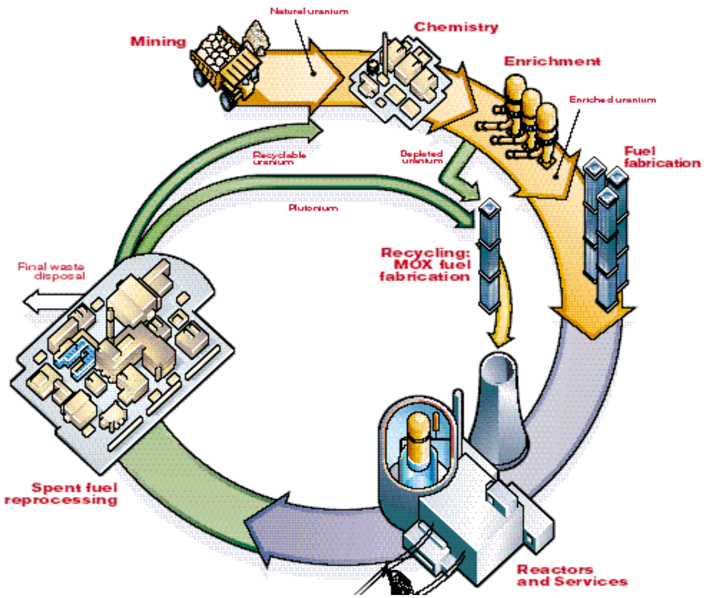
Why AREVA is concerned by non proliferation issues ? (2/2)

- **Governance and Ethic :** compagnies are valued and assessed with regard to the respect of their values chater and sustainability commitments, among which non proliferation is an important contributor in nuclear business
- **Contribution of Industry to non proliferation efforts**
  - as a designer of nuclear facilities (« safeguard by design »)
  - as a technology and material holder,
  - as a supplier of surveillance and safeguards equipements
  - as an exporter of materials, equipments and technologies
  - As a contributor to counter proliferation efforts (securing sensitive materials from the military sector)

Addressing the challenges; Multi-National Approaches (MNA)

- **The Multinational Approach applied to recycling**
  - **Limit the number of facilities worldwide**
  - **Limit the risks of misuse of facility if political changes**
  - **Limit the safeguards efforts**
  - **Limit the security risks**
  - **Guarantee access to treatment and fuel fabrication when needs are proven, on a timely manner**
  - **Guarantee access to treatment services when recycling is guaranteed abroad**
  - **Return of waste is of no proliferation concern**

The COSI computer code



- **COSI is a code simulating a pool of various kinds of NPPs, with its associated nuclear fuel cycle facilities.**
- **It is designed to study various short, medium and long term options that include combinations of various types of NPPs and NFC that evolve with time.**
- **Calculates the mass and flows, as well as isotopic composition of all materials, in each part of the nuclear fleet, at any time.**

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« Charlton » method is being integrated as a post processing in COSI

Main functions implemented are :

- Proliferation resistance data (**which are out puts of the COSI calculations, such as type of materials, mass, flows, ….)**

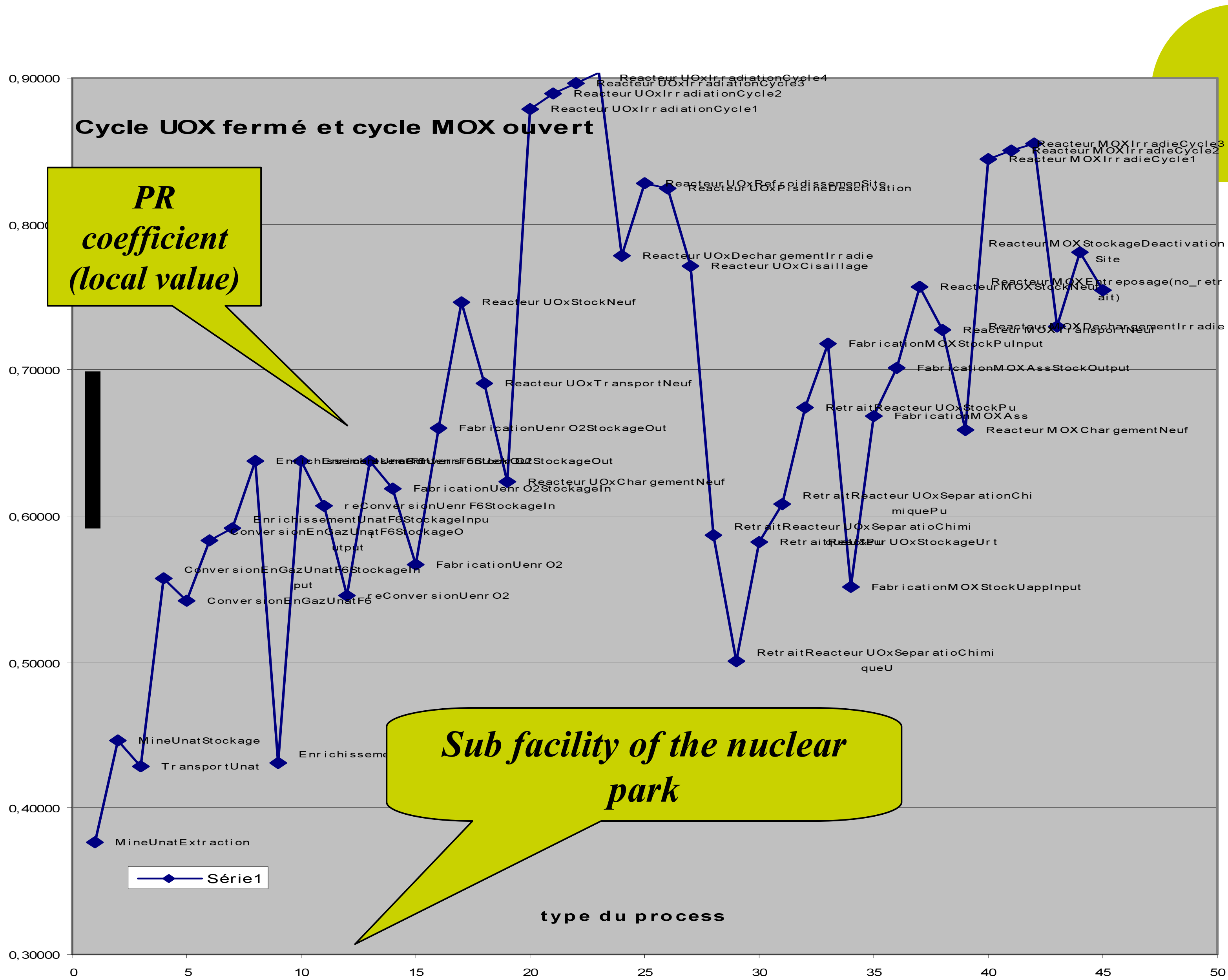
- Proliferation resistance calculations :

➔**Each facility is divided in several sub-facility, or process in sub set of elementary process steps (Example : reprocessing plant sub facilities : FA dismatling,dissolutionSeparation, Glass fabrication)**

➔**A transit time of each material through each of these sub facility or sub process is allocated**

➔**« Nuclear security » measure (NS) is calculated using the Charlton methodology : 14 « attributes », utility functions, weights, ….**

- Graphical presentation of the results



Example of results

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