

Assessment of a French scenario with the INPRO methodology

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Abstract – *This paper presents the French contribution to the Joint Study of the IAEA's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO).*

It concerns the application of the INPRO methodology to a French scenario, on the transition from present LWRs to EPRs in a first phase and to 4th generation fast reactors in a second phase during the 21st century.

The scenario also considers the renewal of the present fuel cycle facilities by the third and the fourth generation ones.

Present practice of plutonium recycling in PWR is replaced by the middle of the century by a global recycling of actinides, uranium, plutonium and minor actinides in fast reactors.

The status and the evolution of the INPRO's criteria and the corresponding indicators during the studied period are analyzed for each of the six considered areas: economics, safety, environment, waste management, proliferation resistance and infrastructure.

Improvements on economic and safety are expected for both the EPR and the 4th generation systems having these improvements among their basic goals.

The use of fast reactors and global recycling of actinides leads to a significant improvement on environment indicators and in particular on the natural resources utilization.

The envisaged waste management policy results in significant reductions on mass, thermal loads and radiotoxicity of the final waste which only contains fission products. The use of fuels that do not rely on enriched uranium and separated plutonium increases the proliferation resistance characteristics of the future fuel cycle.

The paper summarizes also some recommendations on the data, codes and methods used to support the continuous improvement of the INPRO methodology and help future assessors.

I. INTRODUCTION

One of the IAEA INPRO main objectives is to develop a methodology for the assessment of innovative nuclear reactors and fuel cycles (INS) at the national, regional and global level, with respect to a number of important

performance characteristics in the areas of economics, safety, environment, waste management, proliferation resistance and infrastructure. This assessment process ultimately should provide information about the potential sustainability of any INS evaluated.

INPRO in its initial Phase, called Phase 1A, has developed a set of Basic Principles, User Requirements, Indicators, and Acceptance Limits in the different areas [1]. In the following phase, called Phase 1B (first part) this set of requirements was tested by several national case studies, and studies performed by individual experts. The methodology was then updated [2].

During the ongoing phase of INPRO, called Phase 1B (second part), this methodology is applied to assess several complete INS. Several Case Studies are implemented by INPRO Member States with the objective to assess national INS and to identify the role and potential of innovative nuclear energy systems in satisfying the conditions for sustainable development and contribution to the solution of energy problems at global, regional and national level during the 21st century;

The French contribution to this work does address the application of the INPRO methodology to the “French case”. The assessed scenario covers the transition from present LWRs fleet to the one with EPRs in a first phase and to the generation IV fast reactors deployment in a second phase, during the 21th century [3].

The scenario also considers the renewal of the present fuel cycle facilities during this century.

II. THE CURRENT FRENCH NUCLEAR FLEET

The present French nuclear fleet is composed of 58 PWRs with at total capacity of about 60 GWe and a total electricity production of about 400 TWh per year. The total cumulated operation is about 1200 reactor x years (cf. figure 1).

Most of the reactors were started up during a short period of less than twenty years and, even if it is expected that the lifetime will be extended, at least for some of them, beyond 40 years, their partial replacement by EPRs (European Pressurized Reactor) will start around 2020.

Concerning the fuel cycle facilities, the present situation and their expected evolution are presented in the next chapter.

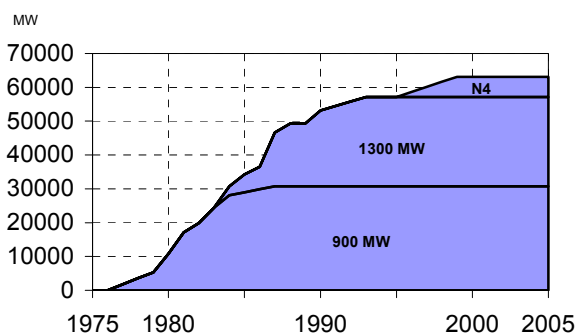


Fig. 1. The present French fleet deployment

III. THE TRANSITION SCENARIO

III.A. Description of the reference scenario assessed and hypothesis

The starting point of the scenario is the year 2010, and it is supposed that the energy supplied by a 60 GWe reactor fleet is constant and equal to 400 TWh per year.

About 91% of this energy is produced by UOX fuels and 9 % by MOX fuels at 45 GWj/t mean burnup.

By the year 2010 the total Plutonium Inventory is 250 tons with

- ✓ 180 tons stored in spent fuels,
 - 115 tons in UOX fuels
 - 60 tons in MOX
 - 5 tons in spent URT fuels
- ✓ 20 tons in fuel cycle plants
- ✓ 50 tons in reactor cores

Average burnup of UOX and MOX fuels are increased to 60 GWD/t by 2013.

Until 2020, the UOX spent fuels processing addresses the partitioning of plutonium alone, under “just-in-time” Pu flow conditions (processing, manufacturing, reactor) are extended, thus not all spent fuel assemblies are processed. The produced glasses contain FPs, MA, and Pu processing losses (0.1%).

In a later period, around 2040, Gen IV fast neutron systems, designed for an grouped recycling of all actinides appear as the best candidate nuclear systems. They will efficiently use natural uranium and will be environmentally friendly thus contributing, among other energy sources, to the sustainable development.

This leads to develop interesting scenarios taking benefit from industrial plant renewal (reactors and fuel cycle plants), while optimising the utilization of existing plants and taking benefit from their replacement to implement innovative processes and technologies. The reference scenario considers grouped recycling of all actinides (U-Pu- MA). It foresees around 2040, both the deployment of Fast Reactors in the French generating fleet (sodium or gas cooled), and the start up of a new spent fuel treatment plant, superseding the existing plant of La Hague.

The effective deployment of this scenario is linked to the progress sought on the quality of ultimate waste forms, and the technical and economical optimisation of the geological repository (the design of which depends on the long term decay heat).

Main trends for reactors and associated fuel cycle are summarized in figure 2.

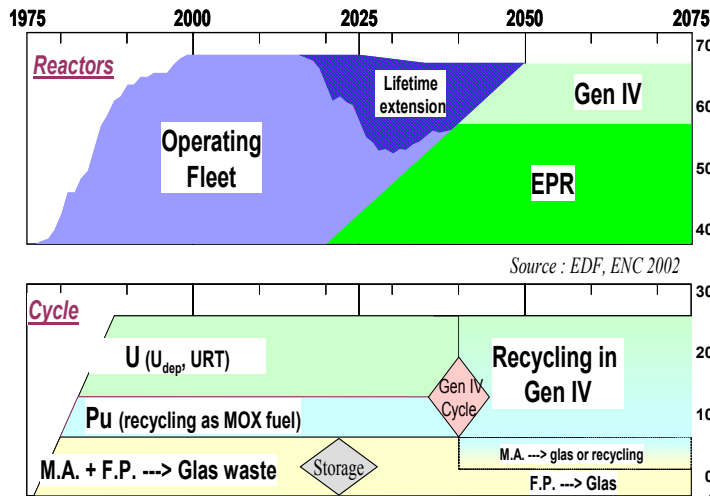


Fig. 2. Evolution of the French nuclear reactors and fuel cycle facilities

For simplification and modelling purposes, the reference scenario for the transition phase is considered as follows:

✓ 2020 – 2035

Start of renewal of 50% of the fleet with EPR reactors; this renewal relates to the end of the service life of the first PWR plants introduced in 1975/1985 and is carried out, depending on EDF prospects, at the rate of 2 GWe per year.

✓ 2035 – 2040

Start of renewal of the remaining 50% reactors of the previous generation by 4th generation fast neutron systems. Implementation of the advanced processing of spent MOX fuel for plutonium and minor actinides recycling in 4th generation fast neutron systems.

✓ 2080

Start of renewal of the EPRs which were first introduced in 2020 by 4th generation FRs.

The following deployment scheme (Figure 3) was modelled by the COSI code [4] for the period 2000 – 2100.

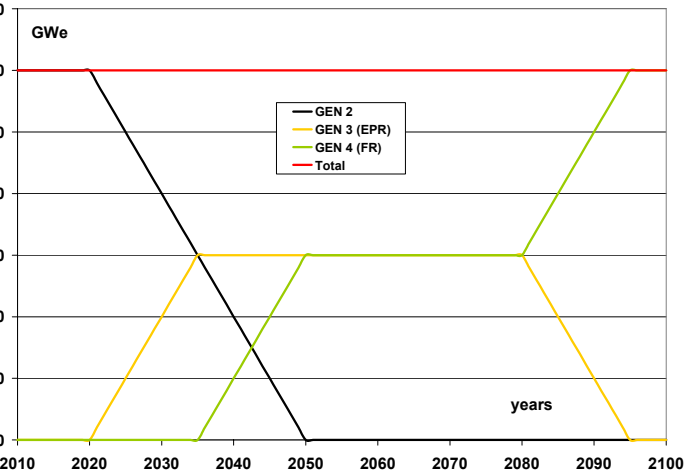


Fig. 3. Simulated transient scenario

Additional assumptions

- ✓ Constant 60 GWe installed capacity producing 400 TWh/year during the period.
- ✓ The order in which existing PWRs are decommissioned is CP0, MOXed CPY, unMOXed CPY, P4, P4' and finally N4.
- ✓ The minimum spent fuel (SF) cooling time before processing are:
 - 5 years for PWRs SF
 - 2 years for 4th generation fast neutron systems, which are considered in the study to be self breeders or slight breeders.
- ✓ Two types of fast reactors were considered in this study:
 - SFR (Sodium Fast Reactor)
 - GFR (Gas Cooled Fast Reactor)
 In both cases closed fuel cycle with global actinides recycling is assumed.
- ✓ Advanced partitioning or grouped partitioning is started in 2020, at the same time as:
 - Interim storage of minor actinides,
 - Production of so-called « low thermal and low radiotoxicity» glass, for storage in a small area (volume),
 - Processing of spent UOX fuel,
 - Processing of spent MOX fuel if necessary.

- ✓ From 2020 to 2025, plutonium is recycled using single plutonium recycling in PWRs. From 2025 to 2035, UOX and MOX spent fuels are put into interim storage and processed. Plutonium and minor actinides are recycled in GFR fuels.
- ✓ From 2035 to 2050: GFRs uniformly recycle all actinides and resorb the stock and production of the previously existing 2nd generation PWR fleet in 15 years.
- ✓ In 2080: Second phase in renewal of the reactor fleet, since the firstly implemented EPRs in 2020 will have reached the end of their 60-year life and will be replaced by GFRs.

III.B. Results of the scenario's analysis in terms of materials flows and inventories

Results obtained for this reference scenario are summarized on Table 1.

Table 1. Mass inventories (tons) in the fuel cycle.

	2035	2050	2070	2100
Natural U (annual, t)	7850	4200	4200	0
Natural U (cumulated ¹ , kt)	430	515	600	660
SWU (annual, M SWU/yr)	6	3,2	3,2	0
Pu (Total, t) ²	455	576	685	848
Np	22	28	30	22
Am	50	61	65	47
Cm	4	7	10	17
MA (Total)	76	96	105	86
TRU total	531	672	790	934
Fuel with TRU in fleet (%) ³	0	50	50	100
TRU in storage ⁴	27	28	29	30

¹ Cumulative needs for natural uranium since 1980, in tonnes. World reserves are conventionally accepted at 4 million tonnes, the world resources are estimated at 11.4 Mt (<130 \$/kg) (cf. Red Book of the AIEA/OECD)

² Total = Temporary storages, Reactors, Factories, Disposal – These values include the Pu from the decay of Cm in temporary storage. Pu production by the stored Cm later recovered is high above all for alternatives 2 (20 tonnes in 2100) and 3 (32 tonnes in 2100).

³ Reactor fraction in the fleet containing actinides (Pu or minor actinides).

⁴ Inventory of TRU in tonnes (Pu, Np, Am and Cm) in ultimate storage (vitrified waste), in long-term storage of non-recyclable irradiated fuels according to the scenario or specific materials (for instance: Cm in the case of alternative 3). The loss rate during spent fuel processing is 0.1% for all actinides.

IV. THE ASSESSMENT WITH THE INPRO METHODOLOGY

On each one of the six INPRO areas, economics, safety, environment, waste management, proliferation resistance and infrastructure, different Basic Principles are considered and divided in User Requirements with their corresponding criteria. At each criteria corresponds an acceptance limit and one indicator value. Almost one hundred criteria are defined to assess a nuclear system.

We present here the main trends of the assessment under way on the previously presented French scenario.

IV.A. Economics

The cost of energy from innovative nuclear energy systems, in our case EPR in the first phase of the scenario and FRs in the second phase, taking all relevant costs and credits into account, is competitive with that of alternative energy sources available

EPR offers several advantages:

- shorter construction time (57 months) and lower construction costs,
- longer service life of 60 years,
- increased availability, reaching more than 90% over the entire service life of the plant,
- lower operating costs,
- optimised use of fuel resulting in 15% savings on Uranium,

This means that a reactor series of this type would generate base-load electricity at a cost of almost 20% less than that of the most advanced high-efficiency, high-output combined cycle gas power stations.

For the EPR, the total cost is assessed considering the Investment (17.0), the Operation & Maintenance (5.8), the Fuel (4.2 €/MWh), Dismantling (0.1 €/MWh) and the R&D (0.6 €/MWh). The total cost is 27.7 €/MWh. The same for the Gas Combined Cycle (GCC) gives 33.9 €/MWh.

The cost of the electricity produced by the EPR is around 10 to 20 % less than the one for the GCC. The cost for the EPR does consider the externalities not taken into account for the GCC.

For the GFR/SFR the objective is to achieve a design the cost of which has to be comparable or less than the one of the innovative LWR (EPR). Obviously the uncertainties are larger.

Concerning the total investment required to design, construct, and commission innovative nuclear energy systems, including interest during construction, it should be such that the necessary investment funds can be raised.

Among the relevant figures of merit, the total investment required should be compatible with the ability to raise capital in a given market climate.

The comparison focused on the capital cost between a nuclear system and a fossil conventional system is systematically unfavourable to the nuclear. The competitiveness is found on the cost of the KWh.

With regard to the current situation, it is reasonable to consider that this established fact should improve by means of the reduction of the durations of construction. This duration is estimated in 57 months for the EPR and it is aimed 48 months for the Gen IV concepts. This situation is acceptable for a developed country like France and there are no economic showstoppers for the deployment of nuclear systems.

An important aspect in economic area is the risk of investment in innovative nuclear energy systems, it should be acceptable to investors taking into account the risk of investment in other energy projects.

Considering the past large experience gained in France, no major issues are expected to license both the EPR and the Innovative Gen IV Systems GFR or SFR. The rationale of the statement is that even if an innovative safety approach is considered for the Gen IV systems the foundation of this approach remain conventional and coherent with the current key principles. Moreover an effort is planned within the Gen IV context to improve the degree of harmonisation for the national licensing constraints.

The project construction and commissioning times should be comparable with those for other energy supply alternatives.

As indicated above, the construction time expected for the EPR is 57 months. The experience gained through the construction of the French fleet lead to consider the figure as realistic. Uncertainties are still present for Gen IV systems but the improvement of the construction techniques within the next 30 years can contribute to consider that the objectives for the construction time (48 months) will be met.

Concerning the political environment, relevant indicators show long-term support for nuclear power.

The flexibility of the INS is also considered in this area. Two sort of "flexibility" have to be considered : the capability to answer different types of markets and the possibility to achieve different modes of energy production: base load or load following.

The EPR being a large size plant can easily fit with markets/grids able to accept such a large plants. Finland and France are very different in terms of global electricity production capability but the EPR can answer the expectation of two markets.

The EPR is able to answer the two function modes : base load or load following. Obviously this will be done with different performances in terms of maximum burn up : 57 GWd/t for the base load and 52 GWd/t for the load following mode.

Analogous requirements will be answered by the Gen IV systems. Moreover the range of Gen IV plant size is larger (300 – 1200 MWe) opening the possibility for wide market applications.

With a strategy of fuel recycling, the current installations for the fuel cycle do not present the same flexibility. Large plants as La Hague have to be considered for large national markets (as French one) or on a regional basis.

With the Gen IV systems the situation can evolve toward a greater flexibility. The Gen IV requirements for fast reactors systems asks for on site fuel cycle installations and an R&D effort is implemented to look for compactness of the process and of the installations.

IV.B. Safety

The development of the EPR safety approach was founded on a joint safety approach of French and German safety authorities for future PWRs in parallel with the development of the EPR design. The initial safety goals were the following: Safety improvement compared to existing PWRs; Design to be licensable in France and Germany; Evolutionary design; Harmonisation between two countries' approaches.

Among the important EPR's General Safety Objectives it seems important to recall : A further reduction of the core melt frequency ; The "practical elimination" of accident situations which could lead to large early releases of radioactive material ; For low pressure core melt situations the design has to be such that the associated maximum conceivable releases would necessitate only very limited protective measures in area and time; No permanent relocation and no need for emergency evacuation outside the immediate vicinity of the plant; Limited sheltering and No long-term restriction in food consumption

The approach for the definition of the safety related architecture lies on the following Safety Principles: Defence-in-depth remains the fundamental principle but must be extended with the independence between the different levels of defence; Design should be made on a deterministic basis, supplemented by probabilistic methods; Utilization of operating experience and results of in-depth safety studies in France and Germany; Utilization of results of research and development work.

The greater independence between the different Levels of Defence is achieved through : Diverse systems for each level; Highly reliable support systems; Diesel generators; Containment heat removal cooling chain; Spatial separation of redundant trains as a measure against internal hazards (fire, flooding). Moreover, operating and safety functions are separated to simplify system layout; together, the operating and safety provisions provide progressive responses commensurate with any abnormal occurrences. One of the EPR's main features is its simple design based on the 4 primary loops and 4 safety trains concept which applies to mechanical equipment as well as the electrical

power supply and the associated instrumentation and control (I&C).

The achievement of the above goals and objective as well as the implementation of the above principles lead the EPR to meet the highest level of safety required worldwide for future nuclear power plants.

For the Gen IV systems the details for the safety approach are still under discussion. The basic idea - from French side - is to try improving the safety achieved with the EPR both in terms of "level" of safety and in terms of "quality" of safety.

Obviously, the process of certification for these systems has to fit with a context which, while remaining coherent with the current practices, will integrate new tools such as the simultaneous use of the determinist and probability techniques through, for example, a Risk Informed approach. This last one could become integral part of a design/evaluation approach which, generally speaking, will have to answer the following criteria: be in agreement with the current safety standards and those that can be foreseen for the future; prove a full agreement with the principles of the defence in depth ; allow, for the design/evaluation stages, to manage simultaneously deterministic and probabilistic criteria; address threats and hazards so as to guarantee the consideration of the internal initiating events within the framework of an homogeneous approach; improve the demonstration capabilities in the domains where gaps still exist in the of the current state of art ; demonstrate the reduction of the risk level with regard to the current systems.

Such an approach has to - in fine - allow optimizing the safety architecture in terms of performances, reliability and costs, notably by a better definition of the requirements, and the classification of the component of this architecture.

In conclusion, as regards the safety of the future French fleet systems, it is thus reasonable to expect a global improvement of the answer to the criteria identified by the INPRO methodology.

IV.C. Environment

The impact on the environment of the near future systems based on EPR technology and of later systems based on fast reactors are, by design, in an acceptable range for national, European and international standards.

Concerning the use of fissile materials, the replacement of current and Gen II PWRs by EPR will improve the natural uranium consumption by about 15 %. The main characteristics of the reactor to achieve this figure are:

- ✓ Better use of the fuel due to the larger core compared to current cores.

- ✓ Neutron leakage reduced by a heavy reflector at the periphery of the core.
- ✓ Improved mean unloading burn-up of 60 GW/tHM.

In the second phase of the scenario, fast reactors allow dramatic savings in natural resources during the century [5], as indicated in Table I.

IV.D. Waste management

In the waste management INPRO area, the first Basic Principle concerns the minimization of the waste production. For the long lived waste this is achievable with fast reactors due to their better efficiency compared to thermal reactors and the specific characteristics of the neutron spectrum.

By design, future fast reactors will minimize the generation of waste at all stages.

The second Waste management Basic Principle is related to the protection of human health and of the environment: Radioactive waste in an INS shall be managed in such a way as to secure an acceptable level of protection for human health and the environment, regardless of the time or place at which impacts may occur.

The third Waste Management Basic Principle deal with the burden on future generations. In the foreseen scenario this burden is minimized by recycling all actinides and then obtaining a reduction in waste masses to the final repository.

The last basic principle of the waste management area is related to the interactions and relationships among all waste generation and management steps and their optimization. This is accomplished by an adequate classification of the radioactive waste arising from the INS. This scheme permits unambiguous, practical segregation and measurement of waste arisings.

Intermediate steps between generation of the waste and the end state should be taken as early as reasonably practicable. The design of the steps should ensure that all-important technical issues (e.g., heat removal, criticality control, confinement of radioactive material) are addressed. The processes should not inhibit or complicate the achievement of the end state.

For present PWRs the overall waste management scheme was not fully addressed during the design stage.

Potential for optimization of effluents management are implemented for EPR.

All these issues are addressed by the present work done in the frame of the French 1991 Act.

Complete chain of processes from generation to final end state are sufficiently detailed to make evident the feasibility of all steps.

All fuel cycle steps are addressed by design in future INS.

IV.E. Proliferation resistance

The first Basic Principle on Proliferation resistance deals with features and measures implemented throughout the full life cycle for innovative nuclear energy systems to help ensure that INSs will continue to be an unattractive means to acquire fissile material for a nuclear weapons programme.

In this framework, the commitments, obligations and policies are regarded as acceptable by the international community.

The attractiveness for a nuclear weapons programme of nuclear material in this INS deployment scenario is considered as key criteria. On this respect the main characteristics of the fuels cycle must be underlined.

- ✓ Fast reactor cores considered have a breeding ratio equal to one. No radial blankets are used to produce plutonium.
- ✓ Closed cycle avoid "plutonium mines" in repositories.
- ✓ All actinides, uranium plutonium and minor actinides, are kept and recycled together so there is no separated pure Plutonium in any step of the fuel cycle.
- ✓ Present light water reactors are progressively replaced by fast reactors so there will be no need of enriched uranium and enrichment technologies and plants.

The use of fast reactors with on site treatment and fabrication with grouped actinide management makes the diversion of nuclear material reasonably difficult and detectable.

The second proliferation resistance Basic Principle states that both intrinsic features and extrinsic measures are essential, and neither shall be considered sufficient by itself.

Innovative nuclear energy systems should incorporate multiple proliferation resistance features and measures.

Each acquisition path must be covered by appropriate verification measures and covered by robust barriers.

The combination of intrinsic features and extrinsic measures, compatible with other design considerations, should be optimized (in the design/engineering phase) to provide cost-efficient proliferation resistance.

Intrinsic features for proliferation resistance are included at the design stage of INS (and associated fuel cycle facilities) alleviating the non proliferation costs. An important feature of this concept is the drastic reduction of transportations of nuclear material between several sites.

The verification approach with a level of extrinsic measures agreed to between the verification authority (e.g. IAEA, Regional safeguards organizations, etc.) and national requirements.

IV.F. Infrastructure

The first Infrastructure Basic Principle states that regional and international arrangements shall provide options that enable any country that so wishes to adopt INS for the supply of energy and related products without making an excessive investment in national infrastructure.

In our case, a national legal framework is already established covering the issues of nuclear liability, safety and radiation protection, control of operation and security, and proliferation resistance by the Basic law of 1963 plus basic safety rules.

Safety and radiation protection arrangements are also established in the European framework and their standards apply to the French nuclear system.

Concerning the industrial and economic infrastructure of the country, it is supposed to be adequate to support the project during construction and operation.

The size of installations to be deployed matches the local needs and support infrastructures are internally available.

In the field of socio-political infrastructures, adequate measures are taken to achieve public acceptance of the planned INS installation.

The information to public is coordinated by the CSSIN (High Council for Nuclear Safety Public Information), and the participation of public in decision-making process (to foster public acceptance) is implemented by the CLI (Local Information Commission) and the CPDP (Particular Commission for the Public debate).

Long term commitment. is considered as sufficient and established by the. French national act on energy supply and the Atomic Energy Committee.

Finally, public acceptance of nuclear power is sufficient to ensure there is negligible political or policy risk to the investment. Instruments are implemented to check continuously the public acceptance. e.g. in France a periodic standardized poll is implemented under the responsibility of safety authorities.

In addition, the necessary human resources are available to enable the operating organization to maintain a safety culture to achieve safe operation of the INS installation. The present operating organization, Electricité de France (EDF), has enough knowledge of the present plants to be an intelligent customer and should keep a stable framework of trained staff.

To maintain high standards in safety culture, periodic safety review mechanisms are implemented, covering technical infrastructure and management areas. This includes a peer review from IAEA and periodic inspections and audits by

the safety authority plus a periodic (10 years) in depth revision for licensing renewal.

IV. CONCLUSIONS

The INPRO methodology was used to assess a French reference scenario, on the transition from present LWRs to EPRs in a first phase and to 4th generation fast reactors in a second phase during the 21st century.

Improvements were pointed out on the six areas considered: economics, safety, environment, waste management, proliferation resistance and infrastructure.

The cost of the electricity produced by the EPR is around 10 to 20 % less than the one for the GCC. The cost for the EPR does consider the externalities not taken into account for the GCC.

Comparisons focused on the capital cost between a nuclear system and a fossil conventional system is systematically unfavourable to the nuclear.

Lower building delays will increase attractiveness of future nuclear systems compared with other ones.

For the GFR/SFR the objective is to achieve a design the cost of which has to be comparable or less than the one of the innovative LWR (EPR).

Safety features of EPR design were underlined eg. measures to prevent severe accidents and to minimize their consequences. Future fast reactors will be designed taking into account the experience gained from the past and present designs and taking advantage from the design and operation of the current reactors.

The main characteristics of fuel cycles envisaged are coherent with the requirements for improved proliferation resistance.

In the Waste management area the transition from current PWRs to Gen IV fast reactors allows significant gains in waste production and management.

The whole infrastructure needed for the deployment of future nuclear systems is well established in the French context.

NOMENCLATURE

EPR : European Pressurized Reactor
GCC : Gas Combined Cycle
GFR : Gas Fast Reactor
INPRO : International Project on Innovative Nuclear Reactors and Fuel Cycles.
INS: Innovative Nuclear System.
SWU: Separation Work Units.
TRU: Transuranic Elements

REFERENCES

1. "Guidance for the Evaluation of Innovative Nuclear Reactors and Fuel Cycles"
IAEA report TECDOC 1362.
2. "Methodology for the assessment of innovative nuclear reactors and fuel cycles."
IAEA report TECDOC 1434.
3. M. DELPECH et al., "Global actinides management scenarios : transition from Gen II / Gen III to Gen IV systems – Case of the french fleet" Proc of int. of ICAPP 2005, Seoul, Corea, may 15-19 2005.
4. L. BOUCHER et al., "COSI : a simulating software for a pool of reactors and fuel cycle plants" Proc. of 13th Int. Conf. on Nuclear engineering, Beijing, China, May 16-20, 2005 (ICONE 13-50253).
5. C. GARZENNE et al, "Assessing Environmental And Health Impact Of The Nuclear Fuel Cycle: Methodology And Application To Prospective Actinides Recycling Options" Proceedings of GLOBAL 2005. Tsukuba, Japan, Oct 9-13, 2005.