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Large Research Infrastrucures and Networking : Two Key Factors for Maintaining Nuclear Expertise in Europe

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ABSTRACT

Large research infrastructures are of key importance to improve the efficiency and the safety of nuclear energy production. To support present and coming power reactors and fuel cycle facilities and to develop future systems, it is necessary to optimise these infrastructures and their use by taking into account the networking of existing facilities, the access by the European researchers to conduct their own research projects and the creation of new installations when facing ageing issues.

Large infrastructures include material testing reactor, hot laboratories for material and fuel under irradiation studies, fuel cycle researches and facilities dedicated to severe accident studies. For example, the CEA severe accident study platform has been recently used by a Bulgarian team to conduct its own research project with a grant provided by the European Commission.

Furthermore, because present European material testing reactors are ageing, renewing the irradiation capability is an important and structuring stake for the fission research in Europe in order to continue safe and optimised operations of existing reactors, to support Generation 4 RTD and to keep alive competences. Considering that, CEA has decided to launch the project Jules Horowitz aiming at building a new research reactor.

The access to the CEA facilities, including the Jules Horowitz reactor, combined with equivalent possibilities of access to other European facilities through a specific platform would help to develop a long-term vision, to create a coherent and dynamic strategy, to contribute to the stimulation of a large cooperation on nuclear fission, to enable a common approach of safety issues, to gather competencies, to promote the attractiveness of nuclear research to young scientists and to maintain European nuclear expertise at the highest level.

This paper intends to provide a view of the existing and needed infrastructures, discuss the ways of access and finally open the discussion on the interest of networking.

1 INTRODUCTION

In March 2000, the Lisbon European Council has set to the European Union a new strategic goal for the next decade: “to become the most competitive and dynamic knowledge-based economy in the world capable of sustainable economic growth”.

Establishing a European Area of Research and Innovation is considered as a key element to reach such an ambitious objective, and some strong efforts are being made throughout the 6th Framework Programme to identify and support the research activities the most suited to both increasing the competitiveness of the European Union and promoting a sustainable development. Quite naturally, energy technologies have been given special care: energy systems (fuel cells, hydrogen, new and advanced concepts in renewable energy technologies …), fusion and fission technologies have been identified as thematic priorities of the new EC and EURATOM Framework Programmes. The technologies to develop are especially expected to address the reduction of greenhouse gases and pollutant emissions, the EU security of energy supply and the increase of the competitiveness of European industry.

As regards nuclear fission, which is certainly one of the technologies which can meet these requirements, existing technologies are mature and proved:

- Second generation nuclear power plants, essentially standard Light Water Reactors, have reached a high level of safety, reliability and cost-effectiveness demonstrated over thousands of years of cumulated operation.
- Mature industrial solutions are available for all stages of nuclear fuel cycle, including spent fuel treatment, conditioning of MLW, vitrification of HLW, and various interim storage solutions.
- Geological disposal will be unavoidable for high level, long-lived nuclear waste. Progress is being made in some member countries to develop practical solutions for geological disposal aiming at industrial implementation in early 2020íes.

Nevertheless, in order to establish itself as a credible option for long-term energy production, accepted by public opinion, nuclear fission energy generation should go further towards meeting criteria for sustainable development:

- High-level safety and security;
- Protection of workers, population and environment, against radiological hazards;
- Minimised long-lived, high level radiotoxic waste;
- Safe disposal of remaining waste products;
- Optimised use of natural resources.

Existing, second generation reactors already allow making steps towards these criteria through fuel performance improvement (higher burn-up, less radiotoxic waste) and safe waste disposal.

Third generation reactors are expected to allow further improvement as regards safety (lower risk of accident, zero-impact outside the reactor site), waste (reduction of volume, thermal load and toxicity) and a lower natural uranium consumption per kWh (factor 2 gain).

New progress is expected from ***fourth generation*** innovative concepts regarding, in particular waste, uranium consumption and process connected to the application (H2 production).

That means a real challenge is to be met step by step. For such a challenge, large research infrastructures are of key importance. However, such infrastructures are of high costs; so, it is certainly necessary to optimise them and their use by taking into account the networking of existing facilities, the access by the European researchers to conduct their own research projects and the creation of new installations when facing ageing issues.

2 CEA EXPERIENCE

For a long time, CEA conducts R&D programmes in support of nuclear fission energy production. These research programmes generally consist of theoretical developments and experimental qualifications among which tests in large facilities are the ultimate verification. More and more, these programmes are conducted through international co-operations.

2.1 Large Research Infrastructures

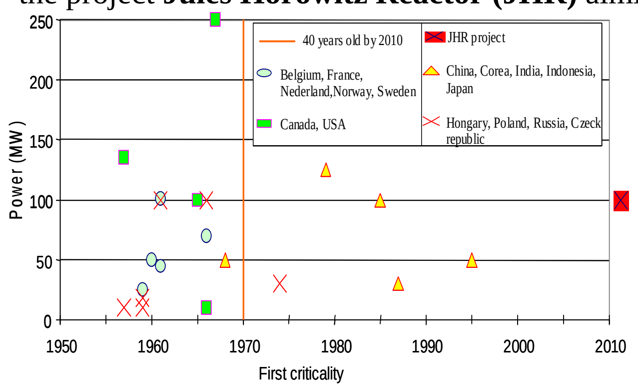
2.1.1 Infrastructures for the studies of materials and fuels under irradiation

Structure material and fuels behaviour under irradiation is of paramount importance to sustain nuclear energy generation in the coming decades; the issues at stake are:

- Plant life time management support (material ageing) for second & third generations;
- Generation-3 long term technological evolution (performance improvement, evolution consistent with fuel cycle plants, …);
- Fuel performance, safety and economy improvement for the third generation;
- Fuel behaviour validation in incidental and accidental situation;
- Fuel optimisation for HTR;
- Performance optimisation of selected material and fuels for Generation-4.

They justify the need for a consistent set of reliable infrastructures composed of an irradiation reactor and hot laboratories to perform post test analyses. At present, CEA operates the **OSIRIS** reactor in Saclay, the **LECI** hot laboratory in Saclay for structure materials and the hot laboratories **LEFCA** and **LECA/STAR** in Cadarache for fuels.

Nevertheless, considering the age of OSIRIS and of other irradiation reactors (see Fig. 1 & 2), the various experimental conditions corresponding to the third generation reactors and fourth generation innovative concepts, the increasing need of instrumentation and the result of the analysis conducted within the FP-5 project FEUNMARR [1], CEA has decided to launch the project **Jules Horowitz Reactor (JHR)** aiming at building a new research reactor.



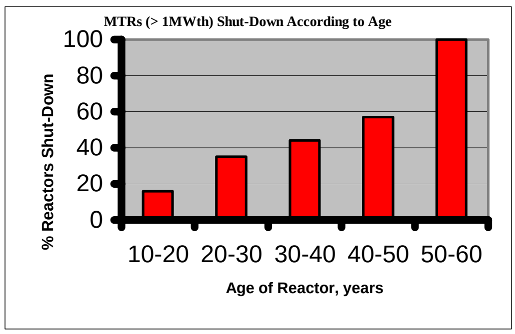


Figure 1: Age of current irradiation reactors Figure2: Increasing risk of shut-down

The JHR-Project is part of a long-term project proposing adequate experimental and testing strategy relevant for the main part of the XXIst century.

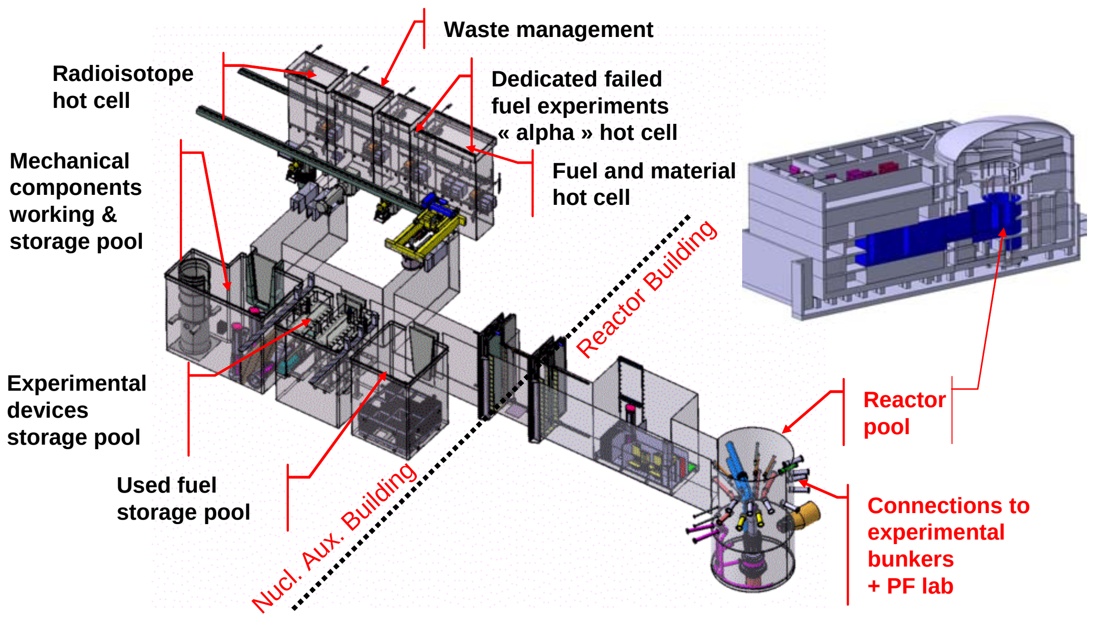


Figure 3: JHR, a 100MW tank pool reactor

Its design (Fig. 3) relies on the present scientific state of art and on the requirement of multi-scale simulation capability, allowing separate effect experiments such as:

- Investigation of metallic material behaviour under high irradiation doses, a challenging issue
  - For neutronics to create a local flux boost while controlling the gamma flux;
  - For thermo-hydraulics to control the mean temperature as well the thermal gradient;
  - For material science to couple high quality experimental data and simulation.
- Investigation of fuel behaviour under fast temperature transients by taking advantage of the recent knowledge in the fission gas dynamics at the microscopic level.

The "Jules Horowitz Reactor" should be operated as an international user-facility. Its first criticality is scheduled in 2013.

2.1.2 Infrastructures for safety research

In close cooperation with IRSN, CEA operates the **PHEBUS and CABRI** experimental reactors in which global safety tests are conducted within international frameworks.

Also in Cadarache, the **PLINIUS** platform ("Platform for Improvements in Nuclear Industry and Utility Safety") is an experimental infrastructure devoted to corium behaviour study. ***Corium*** is the mixture that would be produced by a hypothetical core melt-down in case of a severe accident in a nuclear power plant. Its main constituents are uranium dioxide (molten fuel), partly or totally oxidised cladding (zirconium alloy) and steel. In case of reactor vessel melt-through, it will interact and mix with substrate materials (usually concrete).

Due to material effects, prototypic materials (i.e. mixtures with the same chemical composition as a given corium, but with different isotopic composition) must be used to study corium phenomenology and to validate codes and models. The tests, performed in PLINIUS, are generally complementary of simulant materials tests and computer code analyses.

The PLINIUS platform, which is currently unique in the EU, is composed of 4 corium facilities [2]:

- VULCANO, capacity of about 50 kg of corium,which has been extensively used for the qualification of spreading core-catcher concept;
- COLIMA dedicated to materials and aerosols studies with a few kilograms of molten corium in a controlled atmosphere enclosure;
- KROTOS for corium-water interactions with a few kilograms of corium;
- VITI dedicated to physical property measurements with a few grams of corium.

2.1.3 Infrastructures for the study of fuel cycle and waste management

In a context of environmental protection through rational liquid and solid waste management, **ATALANTE** (French acronym for "Alpha facilities and analysis laboratories, transuranics and reprocessing research") supports fundamental and applied research activities ranging from laboratory studies (on very small quantities of radioactive materials) to demonstration experiments (on large quantities of spent fuel samples). This flexibility is exceptional in the world of nuclear research and makes it a key building block for research.

The ATALANTE project was initiated by CEA in the early 1980s to consolidate on a single site all its research facilities devoted to the back end of the nuclear power cycle: spent nuclear fuel, recycling, ultimate waste management and more recently the investigation of new concepts for future nuclear systems.

The research activities, conducted within the framework of the radioactive waste management act passed by the French parliament on December 30th 1991, address the following issues:

- Developing processes for separating long-lived radioactive elements (mainly minor actinides) to obtain ultimate waste packages in which, after a few hundred years, the radiotoxic inventory will be comparable to that of the initial uranium ore.
- Preparing and characterizing “targets” from previously separated actinides, to investigate transmutation of waste radionuclides.
- Specifying, fabricating and characterizing containment matrices (glass, ceramics and glass-ceramics) for actinides and fission products.
- Studying the long-term behaviour of possible containment matrices for deep geological disposal or for long-term interim storage.

2.2 Networking Activities

2.2.1 ACTINET

During the past decades, the actinide sciences have stagnated and become less attractive for young scientists, particularly in European countries. Due to the increase of safety requirements for maintaining up-to-date experimental capacities for handling alpha-emitting compounds, very few laboratories in Europe still possess expertise and tools at the scale required by the today technical challenges, and none of them alone covers the full spectrum required. Moreover, there are only a few labs in Europe that have the appropriate research facilities to support education in actinide sciences with the appropriate research experience.

Because of its strategic importance, the research in actinide sciences must therefore be revitalized, and become attractive again to students; a Europe-wide networking seems the only way of success.

The Network of Excellence **ACTINET-6** established in the framework of EU-FP6 and co-ordinated by CEA, aims at launching a sustainable network gathering a number of institutions, ranging from large National Laboratories to University Departments, within the broad area of actinide sciences, with the following objectives:

- Significantly improve the accessibility of the major actinide facilities to the European scientific community, and form a set of pooled facilities that will evolve to a multi-site user facility, as the corner-stone of a progressive integration process;
- Improve mobility between the member organisations, in particular between Academic Institutions and National Laboratories holding the pooled facilities;
- Merge part of the research programs conducted by the member institutions, and optimise the research programs and infrastructure policy via joint management procedures;
- Strengthen European excellence through a selection process of joint proposals, and reduce fragmentation by putting critical mass of resources on shared challenges.

2.2.2 SARNET

Safety of current nuclear reactors existing in Europe respects the principles of defence in depth. In particular, they incorporate a strong containment and engineering systems to protect public against radioactivity release for a series of postulated accidents. However, in some low probability circumstances, some severe accident sequences may result in core melting and plant damage leading to dispersal of radioactive material into the environment and thus constituting a health hazard to public well beyond the borders of the State where the damaged plant is located.

In spite of the accomplishments reached in severe accident research, thanks notably to the EU projects carried out within FP-4 & 5, a limited number of specific items (for example: core quenching, iodine chemistry, ex-vessel melt coolability, timing of base-mat failure,…) remain for which research activities are still needed to reduce unacceptable uncertainties for nuclear reactor safety and to consolidate severe accident management plans.

Up to now, research programmes in Severe Accident were usually decided first at national levels, though co-operation agreements are then often concluded around these national programmes, but on a case by case basis. Facing the inevitable reduction of the national budgets in this field, it is now necessary to better coordinate national efforts to optimise the use of available expertise and experimental facilities in order to resolve the remaining issues. Therefore, a number of European organizations, including technical supports of safety authorities, industry, utilities and universities, have decided to network in **SARNET** (Severe Accident Research and management NETwork) their capacities of research in the severe accident area in a durable way. This network, coordinated by IRSN, aims at:

- Tackling the existing fragmentation, notably in defining common research programmes and developing/qualifying computer tools;
- Harmonizing the methodologies applied for risk assessment and PSA-2;
- Diffusing the knowledge to new EU countries and associating them to the definition and the conduct of research programmes more closely;
- Bringing together top scientists in severe accident to form a world leader group in advanced computer tools for severe accident risk assessment.

2.3 The PLINIUS EU-Project: An example of Trans-national access

Through its Trans-national Access Program to Large Infrastructure, the European Commission finances (travel and subsistence of users + all experimental operations costs) the performance of experiments by European visiting scientists (except from the facility home country – here, France) on the PLINIUS platform. After the first call for proposals, a Bulgarian team was selected for a project in COLIMA, the objective of which was to study the fission product aerosol releases from a corium pool in a VVER-440, in the hypothetical scenario of a severe accident.

A test was performed in May 2003. The post-mortem analysis of the corium pool, of the deposits on the thermal gradient tube and of the filter and impactor samples, which are not yet totally completed, will provide insight to the vaporization of low volatiles and bounds for the Kozloduy NPP Environment Impact Assessment.

This visit of the Bulgarian team in the French infrastructure showed the potential of this type of programme to provide, as a by-product, a hands-on training. The users, which included, according to a recommendation of the selection panel, a young scientist, had their first direct contact with corium and have had the possibility to follow all the steps of a real material experiment. This gives interesting insight for code users on the actual experimental process and the origin of the data they use for calculation. For one of the visiting scientists, a power plant engineer, this experience was also an opportunity to get a better feeling of what are corium and the associated risk.

3 A NUCLEAR FISSION TECHNOLOGY PLATFORM ?

Nowadays, the European Commission, together with some major European energy sector stakeholders, is thinking about the best way to build some Technological Platforms in view of promoting “bottom-up collaborative research activities”. A European Technology Platform is defined as a major, pan-European, mission-oriented initiative aiming at strengthening Europe's capacity to organize and deliver innovation. The mission of such a Platform is to bring together relevant stakeholders to identify the innovation challenge, develop the necessary research program, and implement the results. In his speech of March 11, 2004, in Brussels, Mr. Philippe Busquin, the previous European Commissioner for Research, has highlighted the Hydrogen Technological Platform, which has recently been launched by the European Commission, and which has already established a research agenda and a hydrogen deployment strategy based on a partnership between public and private organizations, with the cooperation of the European Investment Bank.

It appears that nuclear fission energy shares many common features with the envisaged hydrogen economy, making it apparently suitable for being organized in a European Nuclear Fission technology Platform. Indeed,

- There is a large potential global market for European manufacturers, mainly in Europe and Asia. European industry is well-structured, in good position on this market and should keep its competitiveness.
- A European R&D strategy would strengthen the position of European players in international cooperation.
- A broad European approach is needed for the development of design requirements and standards.
- Research infrastructures for nuclear fission are heavy and costly. A number of existing facilities are now ageing and should be replaced in the short or mid-term. Future large research infrastructures should be designed and operated as European facilities, while existing ones should be pooled as much as possible.

The creation in Europe of a Nuclear Fission Technology Platform (NFTP – Ref. 3) could be a way to bring together all interested stakeholders:

- To develop a strategic research agenda addressing the challenge of nuclear fission energy generation meeting sustainable development criteria ;
- To steer the implementation of an action plan, made of coherent, structured actions at different time scales ;
- To produce advice and recommendations on strengthening the European science base, integrating research teams and RTD tools, optimising the use of existing research infrastructures and creating new infrastructures when needed ;
- To create enabling mechanisms to support trans-European synergy, in particular through developing a sound training and educational system to maintain nuclear competence in Europe.

The content of such a platform would address the RTD topics which are of special importance to move towards the criteria for sustainable development and which are likely to receive priority in the upcoming decades. These topics include:

- Fuels and Materials: development of advanced fuel and materials resisting to high temperature and/or fast neutron fluence.
- Fuel Cycle: advanced spent fuel treatment, recycling processes for actinides and geological waste disposal technology.
- Reactor Design: innovative (power and/or heat generation) and advanced safety concepts.
- Radiation Protection: refined assessment of the impact of radiation and radioactive materials on man and the environment.

To reach the objectives, it is of paramount importance to mobilise all interested stakeholders in the definition and operation of this platform. Therefore, participants should include:

- Research community, both public and private;
- Utilities, as the end-users of Nuclear Power Plants;
- Nuclear industry, embracing reactor construction, fuel cycle and waste disposal.

- Public authorities, both in their roles of regulators and policy makers and as promoters of technology development.
- Society at large, to ensure that public awareness and understanding of the technologies and challenges do not lag behind developments.

The Nuclear Fission Technology Platform should also beneficiate of existing infrastructures.

4 CONCLUSIONS

Although, existing nuclear technologies are mature and proved, nuclear fission energy generation must still to be improved to meet all the criteria for sustainable development and consequently be accepted by public opinion as a credible option for long-term energy production.

To support the corresponding RTD programmes, large research infrastructures are of key importance. If some of them have been recently renewed, some others, in particular large material testing reactors, are ageing and some renewal is necessary. However, the costs of such infrastructures exceed national capabilities; they can only be created through international cooperation.

Thanks to the EU RTD Framework Programme, in particular FP5 with Trans-national Access and FP6 with the new tools: Networks of Excellence, Integrated Projects and Integrated Initiative for Infrastructures, a first level of horizontal multi-organizational integration is in progress The efficiency of these new tools in fostering integration at the European level will be learnt from experience. Nevertheless, this is certainly one of the best ways of promoting scientific cooperation and maintaining nuclear expertise in Europe.

Furthermore, it is announced [4] that "The overall objective of the proposed Research Infrastructures activity, as a pillar of FP7, is to stimulate international cooperation and to promote the further development of a fabric of research infrastructures of the highest quality and performance in Europe, as well as their optimum use on a European scale". A "top-down" scheme is introduced to support the development of new large research infrastructures, of strategic European interest.

Therefore, the European level seems the adequate level to launch a Nuclear Fission Technology Platform which would help to develop a long-term vision, create a coherent and dynamic strategy, contribute to the stimulation of a large cooperation on nuclear fission, enable a common approach of safety issues, gather competencies, promote the attractiveness of nuclear research to young scientists and maintain European nuclear expertise at the highest level.

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