PROGRESS REPORT OF THE FRENCH PROGRAM, AND BASIC DESIGN OF THE JULES HOROWITZ REACTOR.

A. Ballagny
CEA/CADARACHE BT.703
13108 SAINT-PAUL-LEZ-DURANCE CEDEX,
FRANCE

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Summary:
Since the SILOE reactor was shutdown on December 23, 1997, France has been entirely depending on the OSIRIS reactor to conduct the material and fuel irradiation programmes necessary to the evolution of its nuclear power plants (PV;R) and to prepare the future by analysing further reactor designs which might originate in other strategies, namely in the fuel cycle field. The Jules Horowitz reactor, which operation, scheduled to start in 2006, will last 50 years, must cover all irradiation needs including, as far as possible, those related to fast breeder reactor studies, more particularly since the SUPERPHENIX reactor shutdown was announced. RJH reactor studies therefore focus on the increase of flux levels and the search for the limit performance of U_3Si_2 based MTR fuels.

1 - FRENCH CONTEXT

France selected the long-term solution of nuclear power to meet most of its electrical power requirements. This option was substantiated by the latest report published by the Minist6re de l'Industrie (ministry of industrial affairs) (DIGEC) establishing a comparison of kWh costs. In most cases, nuclear power still remains the most competitive means of generating electricity, even if this advantage has somewhat diminished since the previous study released in 1993.

Consequently, for the CEA, R and D goals are quite clear:

- a relentless increase in competitivity, since the cost of the nuclear kWh is a challenge yet to be met in the competition between nuclear energy and fossil fuel energies, all the more since electricity market liberalisation is underway.
- an increase in the safe level of the reactors, through the incorporation of technological feedback and progress so that nuclear energy will be increasingly well accepted by the general public. To this end, the environmental impact of the nuclear industry should also be lowered by minimising the releases and the amount of wastes to be stored.
- long term planning, investigating other reactor systems than the PWR reactor system which might emerge from new strategies at the national level, in matters of back-end fuel cycle management or natural resources management (thorium…).

In the medium term, these goals will mostly concern pressurised water reactors. This research should lead to an increase in fuel performance, an extension of the nuclear powerplants' service life, and a qualification of the improvements of future reactors.

The implementation of such a programme requires the long term availability of test reactors, actual test benches for the qualification of material and fuel upgrading. However, since December 23, 1997, when the SILOE reactor was permanently shutdown, this task has been falling on the OSIRIS reactor alone. The Jules Horowitz reactor (RJH) project emerged in this context.

The announcement that the SUPERPHENIX reactor was to be abandoned and the PHENIX reactor scheduled for shutdown in 2004, was a challenge to the project team of designers: how could a NR irradiation programme be conducted in the RJH while conciliating the PWR and FBR reactor system flux requirements? This consideration broadens the scope of the feasibility study launched in 1996 to be completed by the end of 1998.

The Jules Horowitz reactor appears more than ever an absolute necessity for the development of the EDF nuclear powerplants and a "multi-reactor system" research tool for the future, all the more since the obsolescence of European research reactors will result in the RJH being one of the last, if not the last, material tests reactor available around 2010-2015.

It is therefore an ambitious project, covering the needs of our industrial partners, and of Europe as well, in matters of material and fuel irradiation throughout the first half of the 21st century.

2 - IRRADIATION NEEDS

2.1 - PWR experiments:

2. 1.1 - Fuels - Burnable poisons - Absorbers.

- Irradiations: loops, rod or specimen capsules, new or previously irradiated in EDF powerplants. 'Me programmes aim at lowering operating costs by increasing the fuel bum up fractions to 60,000 MWJ/t and at improving powerplant operational flexibility and safety. To this end, it will be possible to develop power transients and boundary irradiation tests liable to result in partial meltdown of fuel rods. Irradiation devices will be connected to a laboratory where on-line analysis of fission products released by the fuel will be performed within the scope of fission gas retention upgrading studies.
- Continuation of the qualification of fuels (UO_2 and MOX) through the definition of their operating limits, and of the operating limits of "microstructure" fuels and composites.
- Qualification of new cladding (Zr and ceramics alloys).
- Absorbers will also form the subject of specific programmes (urban - poisoned fuels... hafnium-cladded control rods...).

2.1.2 - Materials

Increasing powerplant service life requires implementing an extensive high fluence material irradiation programme requiring damage accumulation rates over 10 dpa/year. The qualification of new materials will concern: the reduction of the doses to which the personnel is exposed, the reduction of waste volumes and the upgrading of safety margins.

2.2 - FBR experiments:

A very high fast flux is required to:
- validate the concept of actinids and long-lived fission products transmutation in fast breeder reactors,
- accumulate damages on structure and cladding materials. The purpose is to reach very high damage rates on steels or other materials under thermaldynamical and chemical conditions representative of future FBRs: gas, liquid metal, ...
- select FBR fuels: the objective is to obtain high fission rates so as to achieve high bum-up rates more quickly. Since pellet/cladding interaction is essential, the damages in the cladding must be representative. These experiments require a representative spectrum and an amplification of the global flux level. This phase must be followed by a more precise designation, under representative conditions, of the fuels selected,
- perform transients on future FBR fuels by subjecting them to a ramp change of power.

Today, such irradiations can be conducted in 3 types of reactors:
- technological irradiation reactors or the light water pool type (HFR and OSIRIS until 1997) where tests are conducted on a small number of pins at low bum up rates,
- fast irradiation reactors of small dimensions (PHENIX and BOR 60) where tests are conducted on a few pins at high bum up rates,
- the SUPERPHENIX reactor (shutdown), of industrial dimensions, where larger scale qualifications were performed (a few assemblies) and at a high bum up rate.

2.3- Other feasible programmes covered by the design of the RJH reactor

- Fusion programs requiring high fast fluxes for the qualification of materials.
- Various qualifications for other potential reactor systems: boiling water reactors, high temperature reactors...
- Activation analysis.
- Production of radionuclides for the medical field.
- Industrial activities: neutronradiography.

3 - CHARACTERISTICS OF THE JULES HOROWITZ REACTOR

The purpose of the RJH reactor is to perform irradiations under specific conditions representative of the various reactor systems from the basic research stage right up to the qualification of cladded fuels for all systems, including extreme operating conditions liable to result in partial meltdown of the fuel.

It will furthermore be possible to install, at the centre of the reactor core, a moveable loop, of the gas, pressurised water, or liquid metal type, etc... according to the type of programme. On the whole, the experiments will be very well- instrumented, associated to a fission product analysis laboratory, and therefore highly focused on R and D, thus ensuring complementarity with the under irradiation tests directly performed within EDF power reactors.

The RJH reactor will therefore require a wide range of neutronic fluxes to ensure a great variety of mostly unpredictable needs over a 50 year service-life.

The essential characteristic of the RJH will be a great potential for flexibility and evolution, i.e. an ability to adapt readily to program modifications. The initial design provided for thermal and fast flux levels twice as high as OSIRIS' should the programmes require it. The coverage of FBR programmes resulting from the shutdown of SUPERPHENIX demands that the components of the flux be at least 10 times that of OSIRIS.

3.1 - Characteristics of the initial version

The purpose of this version is to meet in priority the pressurised water reactors (PWR) needs while endeavouring to near the performance required to implement fast breeder reactor (FBR) programmes.

The study of an open core pool reactor design, of the OSIRIS reactor type, but with a performance close to the operating limits (specific power = 600 kW/1) showed that the PVVR needs could be satisfactorily answered as regards the thermal flux level or the fast flux level.

Thermal flux: 6 to 9.10^{14} n cm^{-2} s^{-1} (specifications: 5.10^{14} $n.cm^{-2}s^{-1}$)
Damages due to fast flux: > 13 dpa per year (specifications: > 10 dpa per year)

The shutdown of the SUPERPHENIX breeder reactor (and the final shutdown of the Phenix reactor scheduled for 2004) announced in January 1997, lead the project team of designers to strive to increase the RJH reactor performance so as to keep implementing the irradiation programmes covered by both breeder reactors.

In France, the studies performed on these reactors will have to continue for 2 reasons:
- breeder reactors alone will permit eventual valorisation of the ^{238}U. Even though this valorisation process is currently postponed due to the abundance of natural uranium, resorting to breeder reactors will probably be unavoidable.
- only fast breeder reactors allow the burning of minor actinids and of long-lived fission products. Typically, a fast breeder reactor, at equilibrium state, could bum nearly all the waste it produces. In the future, this might be a decisive advantage over all other thermal reactor designs.

3.2 - Improvement of the RJH reactor flux performance:

Performance - average for fast flux on care	OSIRIS* - SILOE*	Open or pressurised RJH reactor * 100 MW –1661 (Reference)	Pressurised RJH reactor 100MW – 100 l 200 MW – 200 l	Pressurised RJH reactor 100 MW – 50 l 200 MW –100 1	PHENIX**	SPX**
Specific power (kW/l)	-300	600	1,000	2,000	400	280
ϕ_1 (E14 $cm^{-2}s^{-1}$) (>0.907 MeV)	1.7 to 2.1	3.4 to 3.9	5.5 to 6.5	11 to 13	6.6	5.5
ϕ_2 (E14 $cm^{-2}s^{-1}$) (5 keV to 0.907 MeV)	2.2 to 2.6	5.6 to 6.4	9 to 11	18 to 21	35.2	34
ϕ_{1-2} (E14 $cm^{-2}s^{-1}$) (> 5 keV)	3.9 to 4.7	9 to 10.3	14.5 to 17.5	31 to 34	41.8	39.5
ϕ_{total}(E14 $cm^{-2}s^{-1}$)	8	16	27	56	44.2	41.7
dpa/year	4 to 5	11 to 15	18 to 25	36 to 50	35 to 50	30 to 45

* average perturbated and corrected fluxes in devices in core
** average calculated fluxes (not perturbated, not corrected) in fuel

The above table shows that it is theoretically possible to achieve fast flux levels similar to those of the SPX and PX, while reaching specific powers around 1,500 MI.

To evacuate such power:
- flow velocity within the core must be increased (>20ni/s),
- inlet temperature must be as low as possible,
- the primary system must be pressurised to provide a margin for the potential boiling of water at the core exit.

Considering the RJH reactor design and operation (MTR), a maximum speed of 15m/s should not be exceeded to avoid interfering with the operation of the reactor and irradiation devices.
Furthermore, the core inlet temperature must not be less than 25 OC.

According to core calculations, for a specific power of 600 kW/l, clad temperature in the hot channel is not far from the maximum permissible temperature of 160 'C (at the hottest point). The fuel temperature, around 250 °C, is also deemed critical. To define these limits more accurately, two irradiations are scheduled in the BR2 reactor at MOL (Belgium) where the elements will have a geometry identical to that of BR2 standard elements, but with the RJH reactor fuel (U_3Si_2 at 5.8 gU/cm').

CONCLUSION:

Implementing the French nuclear energy policy requires ever effective research and development means.
The Jules Horowitz reactor project emerged in this context.
In 1998, the announced shutdown of SUPERPHENIX and the scheduled shutdown of Phenix in 2004, led the CEA to inquire into a potential continuation of fast breeder reactors R and D

programmes with the RJH. The increase in performance of the RJH reactor to cover this need is limited by the temperatures not to be exceeded on MTR fuels; (cladding and U_3Si_2 fuel).
A programme was launched to accurately determine these limits.
Anyway, it will not be possible to achieve the desired fast flux levels. Consequently, the programmes requiring significant damage rates will not be implemented in the RJH reactor.