THE PHEBUS FACILITY AND RELATED STUDIES

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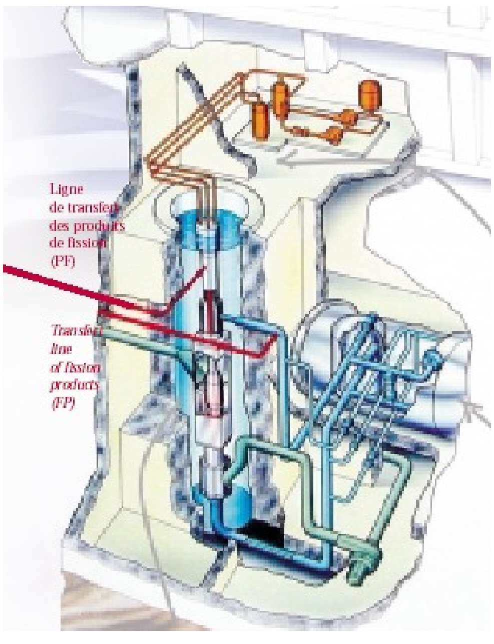
The experimental reactor PHEBUS is operated by CEA at the Cadarache Centre. The experiences performed since the 80's provide valuable information on the phenomena involved in severe accident. Since 93, the studies have been focused on the phenomena related to Fission Products (FP) releases in the framework of the PHEBUS FP international programme managed by the French Nuclear Safety and Radioprotection Institute (IRSN). The last test of this programme, called FPT3, was successfully performed in November 2004.

At the present status of investigations, an immediate need of complementary integral experiences in the field of severe accident studies does not appear clearly. A group of international experts is working in order to investigate the needs of global integral experiments in the field of severe accident studies. The conclusions of this working group are due to the end of 2006.
Nevertheless the potential of the PHEBUS facility offers a large field of capabilities and experimental studies open to other kind of experiments which can be explored. After a brief description of the PHEBUS facility and the FPT3 test performance, the potential uses of PHEBUS are discussed.

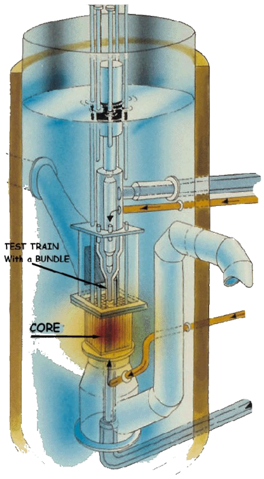
THE PHEBUS EXPERIMENTAL FACILITY

The Cadarache PHEBUS facility is a unique tool capable of carrying out global experiments. During the 70's et 80's, the PHEBUS reactor accomplished the LOCA(1974-1978) and CSD (1978-1989) programmes. Since 1991, an additional building (FP Lab) has been implemented in order to undertake the PHEBUS-FP programme. [1]

Basically, the facility is made up of :



- the experimental reactor : a pool type reactor with a maximum power of 38 MW_{TH}, which can operate for several days running at 20 MW. The driver core is made of 36 fuel elements (1816 rods with a 2.78% enrichment in ^{235}U). Core power is handled with 6 safety control rods. The experimental reactor has been designed to achieve specific experimentations linked with safety or global experiments. The reactor building is designed to withstand the highest possible earthquake on the Cadarache site (level 9 on the MSK scale),



- a leaktight experimental cell, located vertically at the reactor core centre, in which take place the degradation processes of the experimental fuel. This cell is linked with a primary circuit loop reproducing pressurized water reactor core thermal hydraulics conditions. **The in-core experimental section has a diameter of 124 mm**.
  This part of the test loop is intended to:
  - house the test device during experimental phases, allowing its positioning and its irradiation in the driver core,
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  - allow its withdrawal and installation while keeping the containment continuity of the high pressure circuits,
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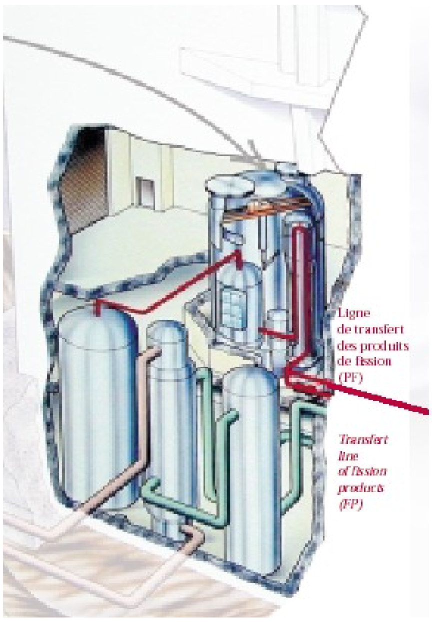
  - allow recovery of molten fuel in case of test assembly failure,
  - ensure the integrity of the driver core for all accidents foreseen.

  The off-core part of the test loop is located in a sealed vessel, inside the reactor building. It includes all components necessary to set up experimental conditions in order to reproduce nominal and accidental operating conditions of nuclear power plants.



- A specific experimentation building, the FP lab, adjacent to the reactor. This lab includes a replica, on a $1/5000^{th}$ scale, of the main elements of a nuclear power plant reactor : the reactor coolant system including the steam generator; a tank simulating the containment of the reactor building. The entire assembly is contained within a 350 m3 leaktight housing. This vessel is linked to the reactor in core cell through a specific circuit that allows the FP transfer from the in core test device to specific FP samplings and instrumentation. This building, dedicated to FP programme, has been erected in the early 90's.

Those three main systems are fitted with a complex instrumentation including conventional detectors (thermocouples, flowmeters, pressure sensors), gamma spectrometry and sampling devices. These equipment allow the different physical parameters to be measured and the various fission product concentrations in the experimental circuits to be determined.

The PHEBUS facility also possesses equipment which, subsequent to the experiment, permits handling of the experimental device and the sampling instruments, their examination (tomography of the in pile test section, sample counting) and their conditioning for transfer toward laboratories specialized in destructive examinations and analyses. For the FP Programme, between experiments, the experimental circuits are entirely decontaminated. Parts of them are replaced. These operations last for a period of about 2 years.

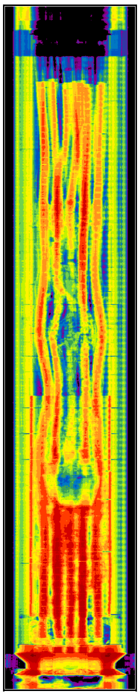
PHEBUS FP PROGRAMME

The international PHEBUS–FP programme has been the most important nuclear safety project in the world. This programme allows a core meltdown accident (severe accident) in a Pressurized Water Reactor to be reproduced in representative conditions on a reduced scale. Such an accident results from the failure of either normal or emergency cooling system in the reactor core : this occurred in 1979 in reactor Nr 2 of the Three Mile Island Plant.

The PHEBUS FP test matrix consisted in six tests designed in order to increase scientific knowledge regarding the sequence of events in the accident. They have provided the data required to develop necessary models for an improved assessment of :

- the core degradation, corium relocation, and corium pool formation;
- the hydrogen production by oxidation during core degradation;
- the nature and quantities of radioactive products released into the environment (the source term).

Knowledge acquired from the PHEBUS FP Programme has provided more accurate assessment and improvement of the models used in integral codes for plant applications.
In depth analyses have been performed in the frame of the project on different phenomena, including unforeseen results as iodine behaviour or fuel relocation temperature. An International Standard Problem (ISP) have been conducted in the frame of the OECD/CSNI on FPT1 results.



The fifth test, FPT3 was performed on November 18th, 2004. It principally aimed at determining the influence of boron carbide (B4C) control rod - material used both in newer Pressurized Water Reactors and in Boiling Water Reactors operating in Europe, and certain Russian reactors operating in eastern Europe - upon fuel degradation and fission product behaviour.

This test has been achieved successfully by CEA and IRSN experimental teams, allowing the relocation of about 10% of the fuel bundle and a significant fission product release.

In the reactor building, the main actions implemented after the test were the scanning of the test train - including tomographs and numerical radiographs – in a specific tool so called PEC (Examination and Control Equipment). For now, the test train is waiting for a specific conditioning -immobilizing matrix injection- that will allow its transfer, cutting and post irradiation examination in external facilities.
Concerning the FP lab, the samplings have been recovered and gamma counted. The present phase consists in decontaminating the experimental circuits in order to complete the mass balance in the circuit. The following dismantling of the experimental circuits is scheduled to be will be carried out in the PF Lab until 2008.

The PHEBUS FP Programme has ended with the FPT3 test. A new programme (called ST-LOC), has been defined by IRSN [2] and should have been carried out in the facility between 2007 and 2012. This programme was postponed, taking into account the lake of international financial support and for the LOCA part of the programme, the global will to wait until the completion of single rod tests before any decision on a Phebus test.

The following lines deal with the facility capabilities, in order to open its operating field to experimentations - not specifically linked with severe accident-, that might be carried out in PHEBUS in order to answer to research or industrial needs.

PHEBUS FACILITY MAIN ASPECTS

PHEBUS facility **is operational**. Heavy maintenance operations have been realized during the three last years, bringing the facility to a high safety and performance level proven by the FPT3 success. This reactor is nevertheless not designed for long period irradiation.

A unique characteristic of the PHEBUS reactor design is **the in-core experimental cell dimensions** that allow representative experiences on a bundle of fuel rods (for instance). The available space in the test section and the pressure tube design allow to consider processing all types of experimental fuel in the testing device :

- irradiated or fresh fuel,
- MOX or UOX fuel rods,
- Fuel pins or fuel plates such as U_3Si_2, UMo,…

In addition to the traditional instrumentation i.e. flow, pressure and temperature sensors, the test loop owns a device providing on-line delayed neutrons measurements (DND), as well as a sampling device of gases contained in the depressurisation tank.
The in-pile test device can also carry lots of measurement instruments. Temperature, flow and pressure sensors can thus be located close to the experimental fuel in order to improve the accuracy of measurements (a test device can hold more than one hundred sensors). Other types of sensors such as neutron flux detectors, self-powered neutron detectors, melting detectors, vacuum detectors, strain gauges, position detectors, clad failure detectors can fit.
In fact, the available space allows accommodating much larger sensors than generally used in other nuclear research reactor test devices.
The central experimental loop also allows a homogeneous neutronic flux on the test train section which is particularly interesting for statistic effects.

Concerning the FP Lab, which can be looked at as a large hot cell, other **measurements are also available in the "Fission Products loop".** According to the type of test carried out, it is still possible to transport the products released during the test by the experimental fuel towards a set of equipments embedded in a 350 m^3 containment vessel. This tank is equipped with remote arm manipulators, windows and video cameras, allowing handling as in a hot cell. The equipment used up to now was especially dedicated to the analysis of fission products released during a fuel bundle degradation (physicochemical composition analysis, particle size analysis, concentration…). But it is also possible to add new devices in this hot cell in order to carry out non destructive examinations at the end of each experimental sequence.

The **safety design** implemented for FP programme also appears to be particularly interesting for other programmes. The facility equipment and specifications are indeed designed to authorize an experience potentially involving a maximum of 6 kg of molten irradiated fuel. Each new experience requires a specific analysis, and Safety authorities agreement. The safety background of the FP Programme is by the way large enough to open a great field of research tests.

Concerning the cost, although a test in PHEBUS will never be a small and cheap experience, it has to be kept in mind that, as described before, the PHEBUS Facility gathers two main tools, the reactor and the FP lab. Such a structure has been operated simultaneously for the FP Programme tests. The FP Programme cost global increase has been especially linked with the hardening of access conditions in the 350 m3 vessel of the PF lab, due to recurrent contaminations during experimental circuits dismantling. If technically interesting, an experience carried out mainly in the PHEBUS reactor, might be cost effective due to the testing of many fuel rods at the same time.

POTENTIALLY FEASIBLE TESTS IN THE PHEBUS FACILITY

At the present time, a group of international experts is working in order to investigate the needs of complementary integral experiments in the field of severe accident studies. The conclusions of this working group are due to the end of 2006.
The STLOC programme, managed by IRSN, includes two experiences dealing with source term issue (High Burn Up, Mox and Quench) and two LOCA tests on irradiated fuel (Mox and High Burn Up). As said before, this programme is postponed.
Large descriptions of the contents of this programme are provided by IRSN.

Some specific experiences (not included in the ST LOC Programme) have already been identified.

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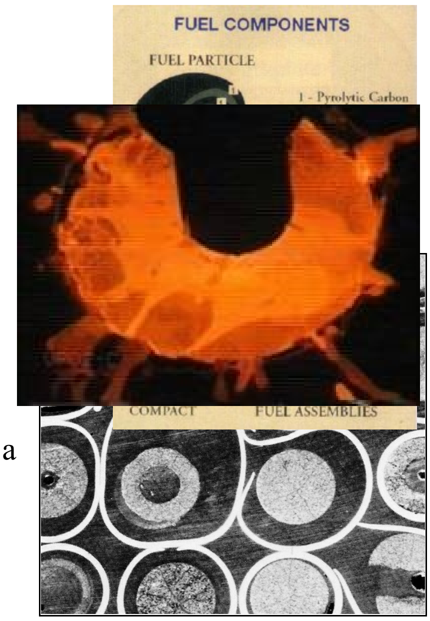
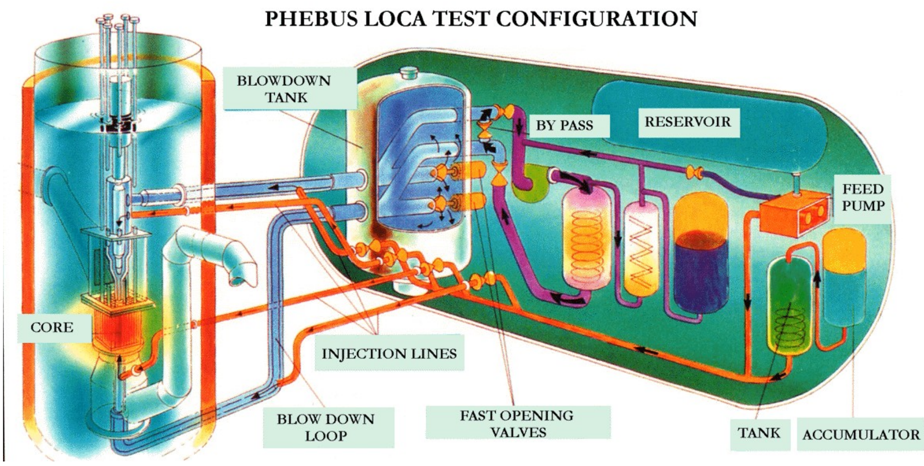
- **LOCA**

This test might consist in checking the state of a MOX fuel bundle with M5 cladding after a large breach LOCA transient. The goal might be to reach a clad temperature in excess of 1204 °C.





Due to the flexibility involved by the technical characteristics of the facility described here above, PHEBUS can be also seen as an available key research reactor open to a large field of experiences. It indeed can deal with Reactor safety studies and life management, specific material research, or also training and knowledge management in the Nuclear field. Potential others uses including GEN IV future needs might also be looked at.

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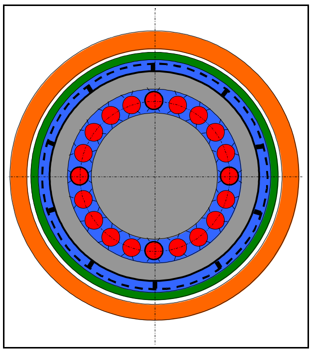

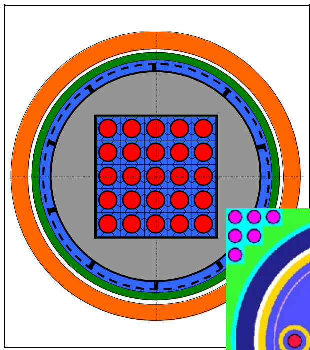

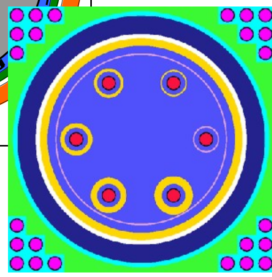

CONCLUSION

The PHEBUS FP experiments have proven the capability of the Programme to improve the understanding of the Source Term issue, but also the issue of the physics of core degradation and core melt progression. Today, the Cadarache PHEBUS facility is at a turning point of its operating phase. After a long period dedicated to severe accident studies, other types of experiment have to be carried out in order to take benefit of such a tool -that might be useful in a few years-. The modern equipment and performing human potential of this facility are key points for the satisfaction of different needs, either for research or industrial challenges.

References

[1] : P. Von der Hardt, A.V. Jones, C. LECOMTE, A. TATTEGRAIN – Nuclear Safety Research. The PHEBUS FP Severe Accident Experimental Programme, Nuclear Safety 35 (2), July – December 1994.

[2] : OECD - Nuclear Energy Agency – NEA/CSNI/R(2004)1 – JT00156633 : Summary record of the experts meeting on the proposed OECD – IRSN STLOC Project – Madrid, Spain? 18-19 November 2003.