# THE CABRI FACILITY: IMPLEMENTATION OF A PRESSURIZED WATER LOOP AND RELATED SAFETY REVIEW.

JC. CABRILLAT, M. MAEGEY, D. BOURGUIGNON, G. MIACHON, F. FORESTIER, JP. COULON,
CEA Cadarache 13108 Saint Paul lez Durance (France)

M. FAURY
IRSN Cadarache, 13108 Saint Paul Lez Durance (France)

**ABSTRACT**

The CABRI reactor operated by CEA at the CADARACHE Nuclear Center in France provided the condition for safety studies on nuclear fuel. Initially designed to support investigations on Fast Reactor fuel, large modifications are underway to provide representative conditions for studies on Light Water Fuel types. A general overview of these modifications, the related safety review and supporting studies are described in the paper.

## Introduction

The experimental CABRI reactor operated by CEA (France) at the Cadarache Nuclear Centre reproduces, mainly on a single fuel rod, fast Reactivity Initiated Accident (RIA) from a steady state along with Loss of Coolant Accident (LOCA). Initially designed for safety studies on fast reactor fuels, a sodium loop get through the water cooled driving core.
Nowadays a strong scientific interest, supported by OCDE, conducted a large international community to sponsor an international programme (The CABRI Water Loop Programme /1/ /4/) related to the experimental studies on advanced PWR fuel behaviour under fast power transients and eventually LOCA. This programme is headed by the Nuclear Safety and Radioprotection Institute (IRSN).
Despite valuable results were obtained for PWR fuel tests in the CABRI sodium loop (The REPNa programme /2/ /3/), most representative conditions are needed to fully valorise the experiments. This point, associated to the low short time needs for safety tests in LMFBR reactor, is at the basis of the decision to replace the sodium loop by a water loop able to produce PWR operating conditions for the future programme. In addition, the facility dating from the sixties is foreseen for an operating time of about 15 years or more: an important upgrade must go with the modification of the experimental tool, modifications resulting for an important part from the results of a safety analysis taking into account the recent evolution of the regulation and new analysis practices. All the aspects of the modification are submitted to a global safety review examination by the French Nuclear Safety Authority. The global facility modification, initiated and controlled by IRSN for the Water Loop Programme Steering Committee, is conducted by CEA.

## The CABRI facility : history and present modifications

### Some History

Built in 1962, the first tests performed in the CABRI facility during the pioneer period of Nuclear Energy Research concerned the determination of the operation field of metallic high enriched fuel used in the experimental reactors. At the beginning of the seventies the facility was adapted to fast reactor fuel investigations: additional buildings were constructed to host sodium circuits and two reactors sharing an experimental sodium loop were implemented in the reactor hall:

- The CABRI reactor able to submit one or three fuel pins to fast power transients obtained by a quick depressurisation of Helium3 absorber's gas filled tubes located inside the driving core.
- The SCARABEE reactor able to simulate sub-assemblies plugging. The driving core is composed of U-AL fuel with a high enrichment (95%).

**The Water loop implementation and related modifications**

The global project, named CABRI+ project, covers the following modifications and related operations resulting from the implementation of the water-loop and the upgrade of the facility:

- The end of the SCARABEE reactor operation involving the nuclear fuel evacuation to COGEMA LA HAGUE for reprocessing (done in 2002) and the dismantling of the core structure (2002), core cooling circuits and sodium loop (2003),
- The updating of the CABRI reactor by the dismantling the sodium circuits, the reinforcement of the core structure (2003), of the control rods mechanisms and of the reactor pool in relation with seismic behaviour (2004), the improvement of the reactivity injection system (Helium3 circuits), and the implementation of the water loop (2004 - 2005),
- The cleaning up of the facility concerning conditioning and evacuation of various active materials: past test assemblies, sodium purification traps, dismantled sodium circuits, organic liquid, tritium contaminated circuits,.. A specific building is being built (2003) for waste conditioning.
- The reinforcement of buildings and various mechanical components (among them the nuclear ventilation system) in relation with the behaviour under seism or with the evolution of the legislation concerning environment protection. (2004-2005)
- Revision of the fire mitigation concept, (2002 and 2004)
- Updating of different systems (control command, electric supply,…)

The planning of the global facility modification is rather tight, taking into account the schedule of experimental programmes (performance of the two last tests in the sodium loop in November 2002, and a time target for the first test in the new water loop at mid 2006). Moreover the administrative process including a public inquiry, and the review of the project by the French Nuclear Safety Authority in order to obtain an administrative decree to modify the CABRI facility have to be conducted in parallel.

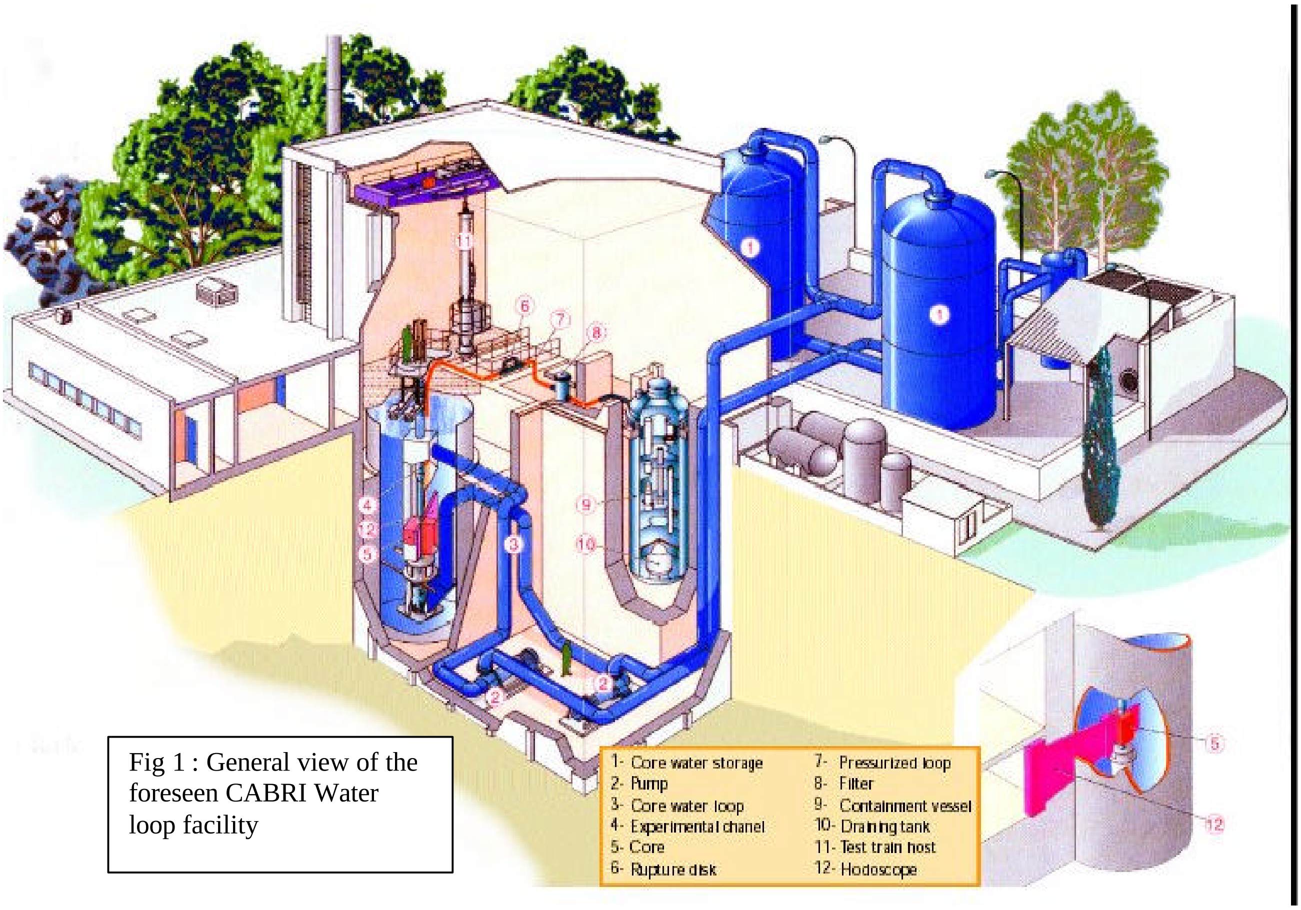


Fig 1 : General view of the foreseen CABRI Water loop facility

# The CABRI reactor and the water loop

After modification the CABRI reactor will be mainly composed of ( fig.1) :

- the present driving core located in its reinforced water pool, which produces 25MW in permanent operation. This core is cooled by a forced water flow (3000$M^3$/h) and its UO2 nuclear fuel is enriched at 6% U235 and cladded with steel. The design of the rods allows fast power excursion with limitation on fuel temperature (2200°C) and thermal flux through the clad to avoid boiling of the coolant. A vertical channel along the core axis receives the appropriate section of the water-loop, an horizontal one receives the collimating system of the hodoscope. This system is able to follow the displacement of the experimental fuel during the transient.
- the new water loop providing themohydraulical conditions representative of the nominal PWR'ones, and enables to simulate LOCA conditions.
- a revisited and upgraded helium3 reactivity insertion system.

The main components of the water-loop (fig.2 ) are :

- the in core experimental cell, a cylinder with two concentric shells in zircaloy, which hosts the test train with the experimental fuel. The inner shell (the first barrier) designed for the nominal operating conditions (155bar/300°C), is also able to confine the pressure wave related to fuel/water interaction in case of clad rupture and fuel ejection from the experimental pin. The outside shell (the second barrier) separated from the inner one by a voided gap, insulates the driving core from the water loop. The choice of Zircaloy material is emerging from the necessity to have the highest possible neutronic coupling between the driving core and the experimental fuel.. It is assessed on a past experience: the first in core cell of CABRI made of stainless steel was changed earlier (1978) after the start of the reactor for a cell in zircaloy . The coupling factor multiplied by a factor 1.5, satisfies afterwards the experimental needs.
- the components producing the various thermohydraulic conditions displayed in a containment vessel (Second barrier) located in the past SCARABEE block.
- the circuits (double pipes) connecting the in pile cell to the components of the caisson through a filter able to catch the active products ejected in the water. The junction between connecting pipes in steel and in pile cell in zircaloy are of diffused types. They are located outside the reactor pool in case of any examination needs.

**The Use of Zircaloy material for the in core experimental cell**

Connecting with the mentioned conception choice, the use of Zircaloy is a real challenge. The demonstration that this material meets the basic hypothesis of codes which suggests the use of materials with a low anisotropy, a sufficient ductility and tenacity to prevent fast fracture, a good experience of fabrication and operation in equivalent conditions needs to be done. Even the applicability of the validated conception codes such as ASME or RCC-M must be demonstrated.

By the way the demonstration of the Zircaloy fracture taughness is assessed on:

- a specific fabrication of a heat ingot of zircaloy in order to get high mechanical properties and an homogeneous material,
- a campaign of mechanical properties determination on zircaloy and welding sample, used particularly in fracture mechanics calculation, by the means of resilience, traction and tenacity tests at various temperature,
- fracture mechanics calculation,
- a thermo-hydraulic mock-up,
- the gathering of all experience and feedback on quite similar uses of the zircaloy.

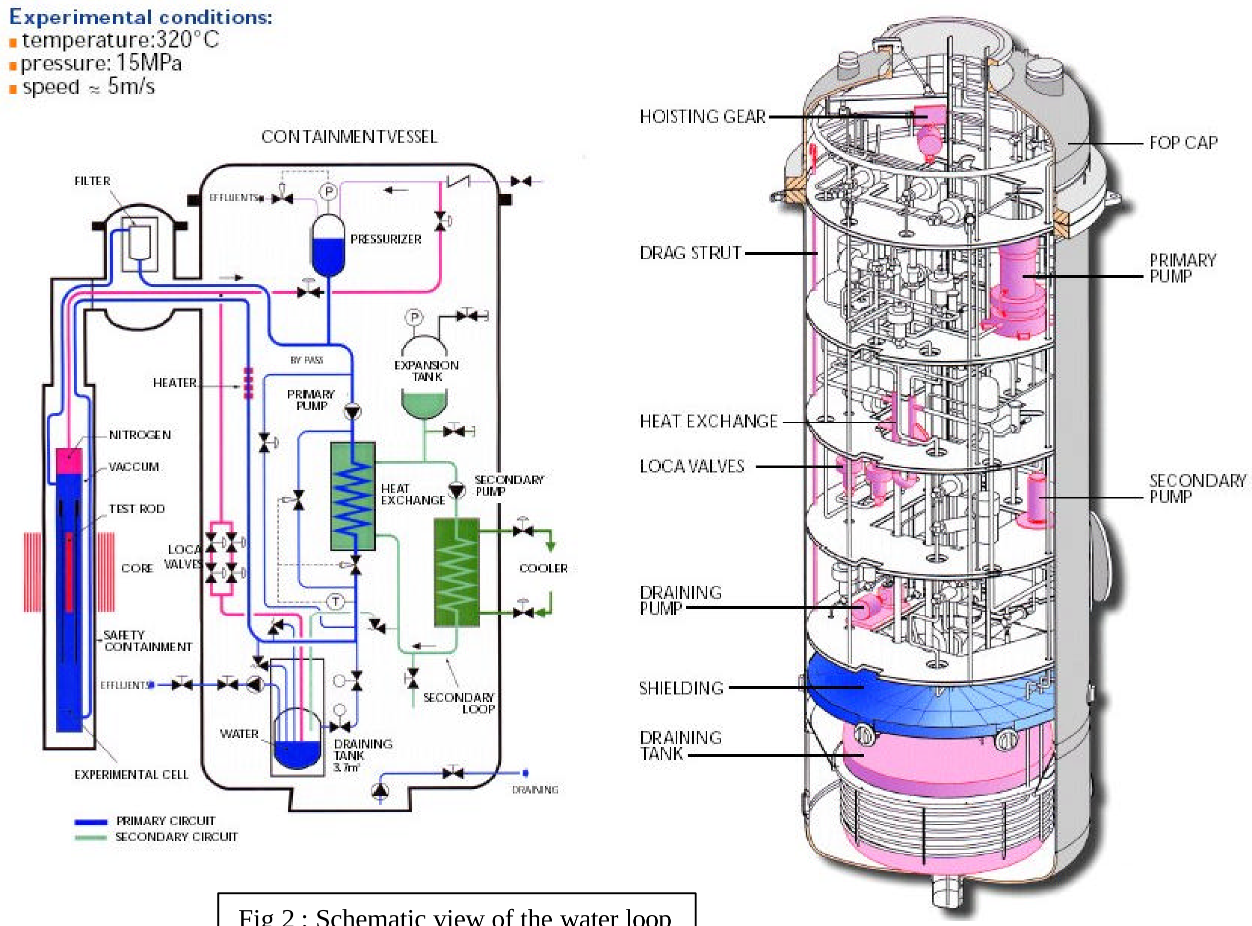


Fig 2 : Schematic view of the water loop and containmentt vessel

**The nuclear fuel of the driving core**

The maximum driving core energy released during the power transient from a steady state is limited by the maximum fuel temperature rise (2200°C) and thermal flux through the clad. Both parameters are determined, previously to the performance of each test, by calculation with the DULCINEE code. This code has been qualified in 1988/90 on specific experiments which consist to submit fuel pins introduced in the sodium loop to representative power pulses. From destructive examination the fuel pellet structure, gap dimension between pellets and clad along with gas composition were determined and physical models of the DULCINEE code adapted. Since these experiments a large number of transient have been performed; before continuing the programme a characterisation of the most solicited core fuel pins will be done: profilometry, analysis of the gas composition, examination of the fuel pellet structure and gap dimension. From these examinations the validity of the DULCINEE code will be confirmed or the code will be modified.

## The facility upgrade

Three main guidelines are sustaining the upgrade of the facility:

- The change of components which age creates problems of maintenance, reliability, and ergonomy: the neutronic control, electric supply, ventilation, supervisor, some water circuits are the main items concerned by a lifting.
- The increase of performances both from the experimental point of vue (The modification of the reactivity insertion system for example) or the facility operation .

- The recommendations deduced from the safety review which integrates the recent regulations related to hygiene and workers security, environment protection (particularly the French decree of 31/12/1999), fire mitigation, seismic behaviour, .....

Concerning the main mechanical components, the deduced following modifications can be noticed:

- A double skin and leakage detection system in between are being set up on two water pools hosting temporarily experimental test trains, the driving core, various radioactive items and on tanks hosting liquid wastes.
- The reinforcement of the core pool structure, and of the core supporting structure.
- The reinforcement of the crane supports.
- The improvement of mechanical components supporting system (pumps, motors,...).

For the buildings (Fig3) the main modifications originate in the seismic reinforcement. These modifications are presently under determinations including the results of recent cross hole investigation, expertise of the present status of concrete structures (conformity to initial plans, status of reinforcing steel). The modification will consist into reinforcement of the reactor hall (under and over structure reinforcement), of the core support,.... The under structure reinforcement, if envisaged, will induce delicate works under existing buildings placed side by side to the reactor building.

Ventilation system will be also completely renewed including an increase of the ratio of air extraction (from 3000 M3/h to 10000 M3/h), and new fire mitigation systems.

Fig 3: The CABRI Facility

## The Safety Review

The main principles for the Safety Analysis of the facility are a deterministic process for the design of systems and equipments (or check of the design for existing components) taking into account the different operating conditions.

The methodology is based on :

- a classification of equipment regarding their importance for safety,
- an identification of operating conditions (4 categories) with a classification issued from the principles applied to power reactor (PWR) and associated safety goals,
- conception rules issued from standard conceptions codes or particular specification (Zircaloy),
- a verification of the good level of the safety standards of the overall facility and more particularly of the new water loop. It is assessed on the basis of the study of accidents for the 3rd and 4th operating conditions along with situations out of design,
- the verification of the good level of safety by nevertheless the examination of the consequences of out of design accident ( For example the overpower of the core due to the maximal theoretical ramp of reactivity insertion of 100$/s must be checked).

Studies are conducted for envelope conditions by considering experimental fuel such as UO2 type fuel at 100MWj/T and MOX fuel at 90MWj/T.

**The operating conditions and safety targets**

The conditions taken into account in the design of components are those with a probability of occurrence higher than $10^{-6}$ per year. They are classified in four categories depending of the probability of occurrence (Normal operating conditions, events occurring with a probability higher than $10^{-2}$ for the second category, $10^{-2}$ to $10^{-4}$ and $10^{-4}$ to $10^{-6}$ for the third and fourth categories). A lack of primary pressure regulation, a small leak of on the primary circuit, a complete and fast rupture of a primary pipe are examples of events classified respectively in the second, third and fourth categories.
To those categories are associated targets in term of radiological impact along with rules concerning the number of events to be considered in the design of components (Table 1).

| Categories of operating condition | Maximal dose tolerated for Workers (total body) | Maximal dose tolerated for the public (total body) | Number of events to be considered |
|---|---|---|---|
| Normal operating condition | 2,5mSv/year | 1? Sv/year | |
| 2nd category | 2,5mSv/event | 10? Sv/event | Occurence*time of corresponding operation |
| 3rd and 4th category | 30mSv/accident | 1mSv/accident | 1 |

Table 1

A specificity of the CABRI reactor is its short operation duration time which limits the presence of potential risks related to control rods withdrawn, to power, to pressurised water, to experimental fuel in the cell, to presence of Helium3 in the core and naturally to pressure of interaction water/fuel during the test (a few ms). For example the time with rods up is evaluated at 16 hours a year. Applied to the seismic risk for example, only the cumulating of a seism of MHPE type (Maximal Historically Probable Earthquake) with all the phase of operation is considered. The simultaneity of a seism of SSE type ( Safe Shutdown Earthquake ) and reactor operation is set out of design.

## Conclusions

The transformation and upgrade of the CABRI facility are now on going, after the last two tests performed in the sodium loop in November 2002, in an intensive phase of activity where on site modifications, outside fabrications, administrative process and supporting studies are conducted in parallel.
Assessment of the use of zircaloy for the in core experimental cell, determination of seismic reinforcement of components and buildings, Helium3 reactivity injection system upgrade, public inquiry and safety review are the main challenges of the year 2003.

## References

/1/ Definition and status of the CABRI international program for high burn-up studies
Joëlle PAPIN, Jean-Claude MELIS, Catherine LECOMTE
28$^{th}$ WRSM du 23 au 25 Octobre 2000, Bethesda,USA

/2/ High burn –up effects on fuel behaviour under accidents conditions : the tests CABRI REP-Na.
Journal of Nuclear Materials 270 (1999) 55-64
Frantz SCHMITZ – Joëlle PAPIN
IPSN Département de Recherche en Sécurité – Centre d'Etudes de Cadarache 13108 Saint Paul lez Durance

/3/ The MOX fuel tests in the CABRI REP-Na Programme : Analysis and main outcomes.
LWR Fuel Performance – Park City 10 –13 April 2000
Bernard CAZALIS – Joëlle PAPIN – Francette LEMOINE
IPSN Département de Recherche en Sécurité – Centre d'Etudes de Cadarache 13108 Saint Paul lez Durance

/4/ Testing for extended UO2 and MOX fuel burnup.
Nuclear Europe Worldscan 5-6/2000
Joseph LEWI – Jean-Claude MELIS
IPSN Département de Recherche en Sécurité – Centre d'Etudes de Cadarache 13108 Saint Paul lez Durance