THE NEW CABRI WATER LOOP : DETAILLED DESCRIPTION OF THE NEW WATER LOOP AND OF THE SPECIFIC NEW ZIRCALOY IN CORE EXPERIMENTAL CELL

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ABSTRACT

The experimental CABRI reactor provides conditions for testing nuclear fuel under a fast Reactivity Initiated Accident (Simulation of a rod withdrawal for example). Mainly devoted to LMFBR up to now, the experimental CABRI reactor is being modified for testing LWR fuel in representative conditions. A new water loop able to produce the PWR operating conditions and a zircaloy experimental cell will be installed in the Cabri reactor.

Beginning with a detailed description of the new water loop (process, capabilities, design, safety analysis), the paper will end with a specific point on the new experimental zircaloy in core experimental cell and the related studies : zircaloy 4 characterization, applicability of conception Code to a pressure zircaloy experimental cell, zircaloy / stainless steel junction, development of a ultrasonic control machine for surveillance on site.

INTRODUCTION

The experimental CABRI reactor operated by CEA (France) at the Cadarache Nuclear Center 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 in a sodium loop, the facility is being modified in order to have a water loop able to provide thermohydraulical conditions representative of the nominal PWR's ones.

The implementation of this new loop lies within a broader scope including an upgrade of the main components of the facility and a safety review.

The global modification is conducted by a CEA project team. The design and control of work of the new water loop realization was entrusted to FRAMATOME ANP/Advanced Projects and Decommissionning Division plant sector (as prime contractor). The project is financed by IRSN in the framework of an international collaboration.

THE CABRI WATER LOOP

Description of the new loop.

After modifications, the CABRI reactor will be mainly composed of (see fig 1) :

- the driving core located in its reinforced water pool, which can produce 25MW in permanent operation. This core is cooled by a forced water flow (3000 m3/h). 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

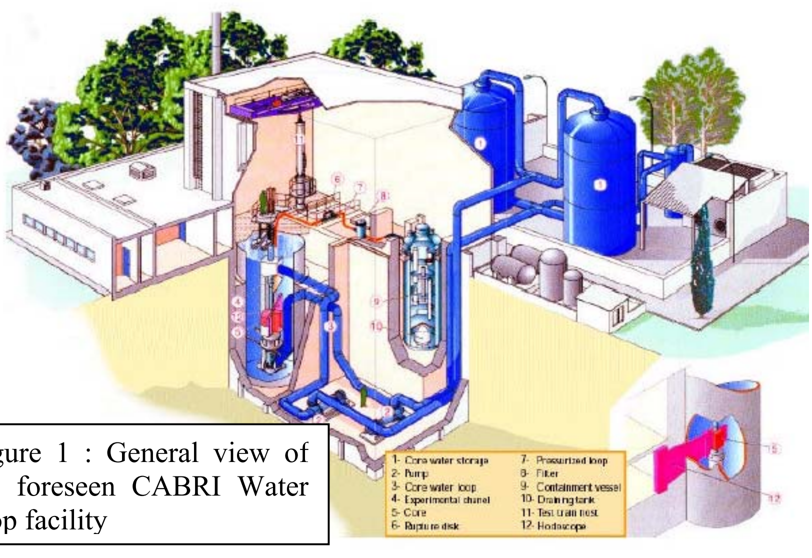


Figure 1 : General view of the foreseen CABRI Water loop facility

experimental fuel during the transient,

- the new water loop able to provide thermohydraulical conditions representative of the nominal PWR operating conditions.

The main components of the new water loop are (see figure 2) :

- the in core new experimental cell,
- a primary circuit composed of a primary pump, a primary heat exchanger and heater to regulate temperature of water, a pressurizer, control and isolation valves, two pressure relief valves,
- a secondary loop with a pump, expansion tank and heat exchanger able to transfer power from primary circuit to a cooling loop,
- a draining circuit with a draining tank of 3, 1 m^3 (see figure 6) able to confine liquid and gaseous wastes of the primary circuit,
- auxiliary circuits connected to the primary circuit : filling loop, nitrogen supply for the pressurizer, compressed air,…

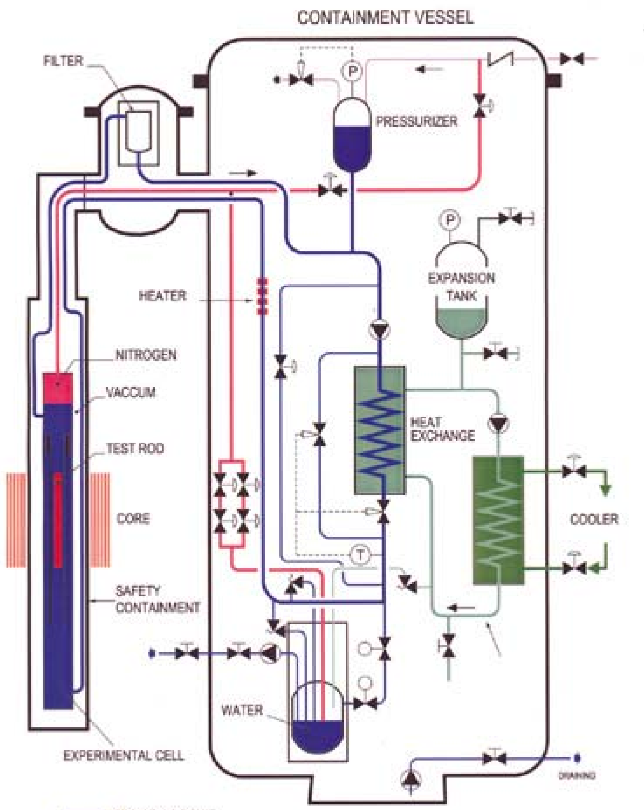


Figure 2 : Schematic diagram of the water loop

A main containment vessel (diameter : 2,6 m, high : 9 m, see figures 3, 4 and 5), located in the past SCARABEE block, contains the primary circuit, secondary circuit, draining circuit, auxiliary circuits and ensures the second barrier.

Between the in core experimental cell located in CABRI vessel and the main containment vessel, the water flow goes through one inch pipes that are under double containment. On the downstream pipe from the cell, a filter is able to catch the active products ejected in case of clad rupture. Another containment vessel contains this filter (housing and cartridge), and enables the change of the cartridge after test.

Figure 4 : Main containment vessel during layout in Cabri facility

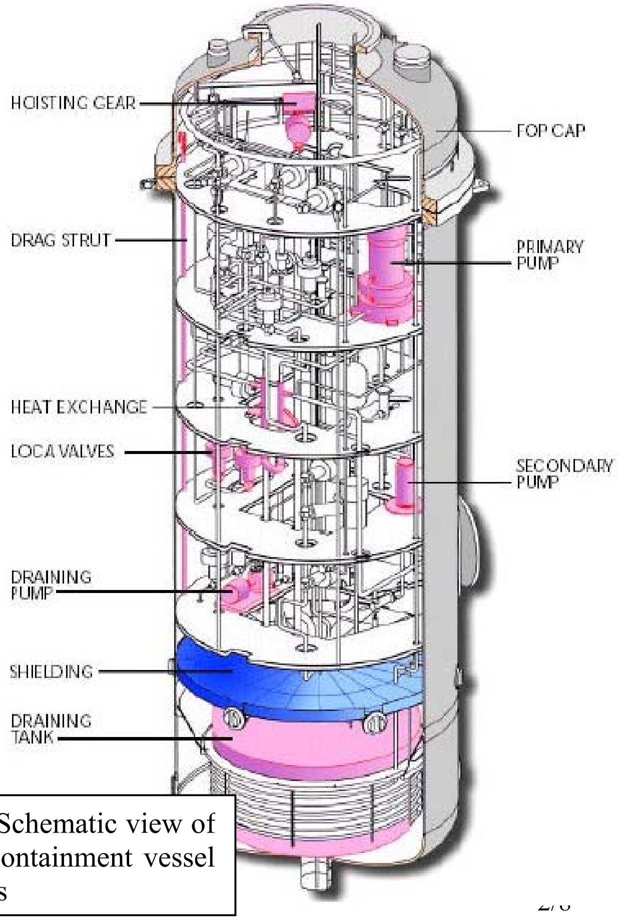


Figure 3 : Schematic view of the main containment vessel and circuits

Figure 5 : Main containment vessel during manufacturing

Figure 6 : Draining vessel during manufacturing

Process, variables

For the primary circuit, the nominal operating conditions in the experimental cell are :

- Flow rate : 1 to 6 m^3/h
- Pressure : 155 bars
- Temperature : 300 °C

The maximum power extracted by heat exchangers to the cooling loop is 75 kW.

Main safety options and design

The water loop is designed in order to guarantee the containment of the radioactive materials. Several independent barriers are set up between radioactive products and the environnement, according to the in depth defense principle.

So the experimental loop is composed of two barriers, according to the fact that the tested fuel pins can undergo clad rupture during the experiment :

- the first barrier is composed of the primary circuit including connection towards the other circuits up to the blocking valves which are doubled. For the experimental in core cell, the first barrier stops at the joints level. The integrity of the primary circuit in the event of accidental overpressure is ensured by two pressure relief valves (discharging in the draining tank).
- the second containment limits the consequences of the first barrier failure. It is composed of the containment cell (call safety tube) for the in core part, the piping double containment and the main vessel which contains the circuit and components (see above).

A third barrier is composed of the reactor building and its associated ventilation.

The various components of the first two barriers, subject of this document, were displayed in safety classes based on the following general principles :

- Class 1 : Wrap under pressure of the primary fluid.
- Class 2 : Materials confining the fluids containing the radioactive products (except class 1) or ensuring containment between the second and the third barrier or whose failure can lead to the loss of a safety function of a level 1 material.
- Class 3 : Materials ensuring the second containment (except class 2) or which can involved the loss of a safety function of a class 2 material.

With each safety classes, was associated the equivalent level of the RCC-M code (see below) used for the design and the construction of the loop.

The principal design conditions are :

- For the primary circuit : design pressure : 190 bar and design temperature : 355 °C; maintain of tightness with Maximum Historically Probable Earthquake (MHPE) seismic condition and non rupture with Safe Shutdown Earthquake (SSE) seismic condition. The primary circuit is also designed for the eventual pressure wave related to fuel/water interaction in case of clad rupture and fuel ejection from the experimental pin.
- For the main containment vessel : design pressure : 8 bar and design temperature : 130 °C (both resulting from first barrier rupture) ; maintain the tightness with MHPE and SSE seismic conditions.
- For the safety tube, taking into account some aggressions like guillotine break of the primary cell and whipping of pipings. Such design allows the mitigation of the consequences of such aggressions particularly regarding the preservation of the driving core integrity .

NEW EXPERIMENTAL CELL

Description

The in core experimental cell is a cylinder with two concentric shells (outside and inside shells) in zircaloy which hosts the test device with the experimental fuel pin.

The dimensions of the inner shell (water pressure vessel, see figure 7) are : maximum internal diameter : 145 mm ; minimum internal diameter : 71 mm ; maximum thickness : 24 mm ; minimum thickness : 11,5 mm ; length : 9 m

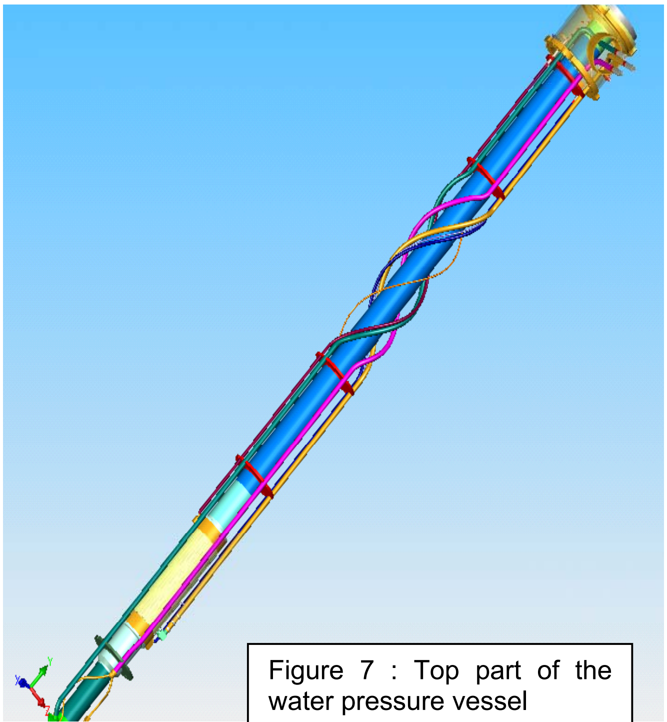


Figure 7 : Top part of the water pressure vessel

Primary water supply circuit is connected at the bottom head of the water pressure vessel and primary return circuit is connected in the middle of the water pressure vessel , after the experimental zone of the test device.

The water pressure vessel is designed for the same design conditions (pressure, temperature, seismic loads) than the primary circuit, and it also allows 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 (safety tube), separated from the water pressure vessel by a void gap, insulates the water pressure vessel from the driving core and water of the pool.

The dimensions of the safety tube are : maximum internal diameter : 348 mm ; minimum internal diameter : 154 mm ; maximum thickness : 11,5 mm ; minimum thickness : 7 mm ; length : 9 m

Applicability of conception code to the Cabri zircaloy vessel

Concerning the employment of zircaloy for Cabri water pressure vessel, with a thickness significantly stronger than usual applications of zircaloy, it has been necessary to analyse the applicability of the Design and Construction Rules for Mechanical Components of PWR (RRC-M code).

For the in core experimental cell, the applicability of the code and its criteria is mainly conditioned by the following points:

- For the supply of materials, the specification has to be adapted to the alloy and produced (bars or sheets) with representative criteria and in coherence with the technical manufacturing program,
- For the design, the choice of allowable stresses and minimum values of toughness has to be made as for ferritic steels,
- For welding operations, welding processes (electron beam or GTAW welding) need to be adapted and accepted by the way of associated qualifications.
- About creep consideration, more data on zircaloy at high temperatures has to be collected so as to justify the unimportant creep curve, the failure stress in creep and the limit of allowable stress in creep.

None of these points call into question the applicability of the code. Information on mechanical behavior is given in next chapter : Use of zircaloy and characterisation.

Use of zircaloy and characterization

In order to obtain the highest possible neutronic coupling between the driver core CABRI and the experimental fuel, the structures of the in core part of the loop are made of zircaloy.

At the beginning of the project, the available data (pressure and temperature) for sizing the water pressure vessel was 200 bars (resulting from water/fuel interaction on clad rupture) and 500°C (due to gamma radiation heating). These 2 parameters combined with the geometry fixed by the existing core of Cabri led to the need for a zircaloy with higher characteristics than usual standard. On this basis, it was decided to anticipate the provisioning of a specific casting for CABRI and launch its characterization..

Specificities of Cabri casting are mainly to retain for the percentages of oxygen and tin the ASTM specification high values as objective values. For the bar products (intended for the water pressure vessel manufacture) a hardening starting from the beta field after all the forging operations was carried out. The objective of the strong percentage of oxygen and tin is to increase both mechanical characteristics and creep resistance. The hardening in final stage is made on purpose to obtain a homogeneous material in term of longitudinal and transverse directions behavior.

The characterizations were carried out for each batch of products (constituted of bars of each diameter and sheets of same thickness) and including some fusion lines and welds. The main objectives were to :

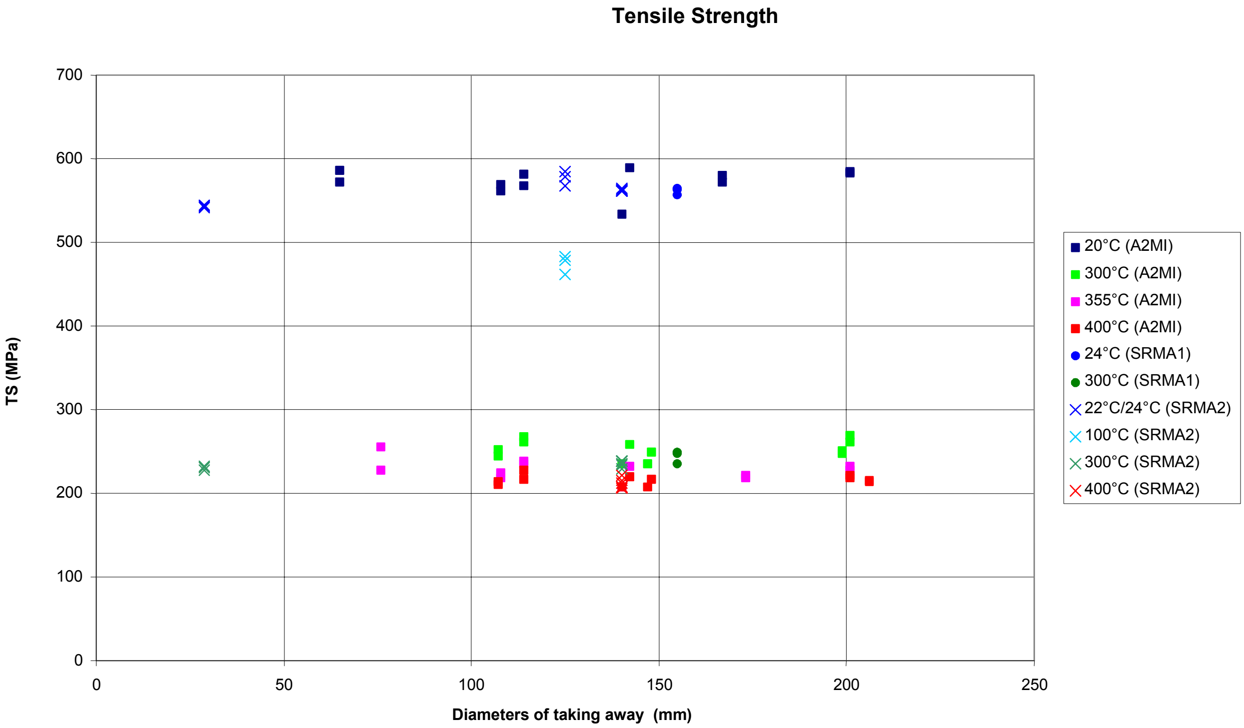
- determine the allowable stresses values to use in calculations,
- validate the toughness values used in fracture mechanic calculations,
- show the good homogeneity of the various products,
- justify the unimportant creep curve ,
- supplement the data on creep at 400°C (the only temperature regarded as significant in the case of CABRI operation).

Some main results are given afterwards.

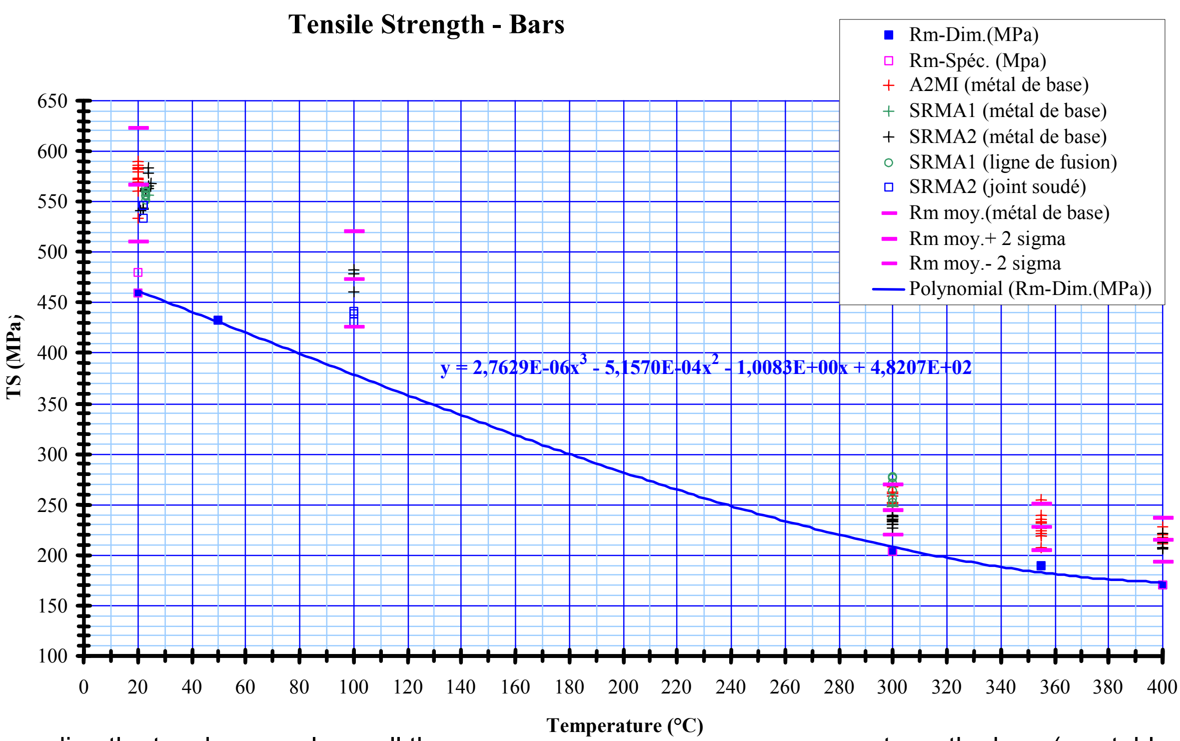
For the beta treated bars, all the results (0.2% Yield Strength, Tensile Strength, Elongation) show a good homogeneity and a good isotropy of the matter :

- between the various rounds,
- in the thickness of the rounds
- in the length of the rounds.

As an example, the figure below shows the tensile strength values for various rounds, at various temperatures and for various diameters of taking away samples. The relative standard deviation (standard deviation/average value) varies between 2 and 5 % following the temperatures.



Concerning tensile test behaviour of the fusion lines and weld seams, all the results highlight that there are no deterioration of the mechanical properties compared to the parent metal. In some configurations, one can even note a tendency to improvement. The figure below shows the tensile strength values for the bars compared to the base metal bars receipt values and with the curve selected to determine the allowable stresses values.



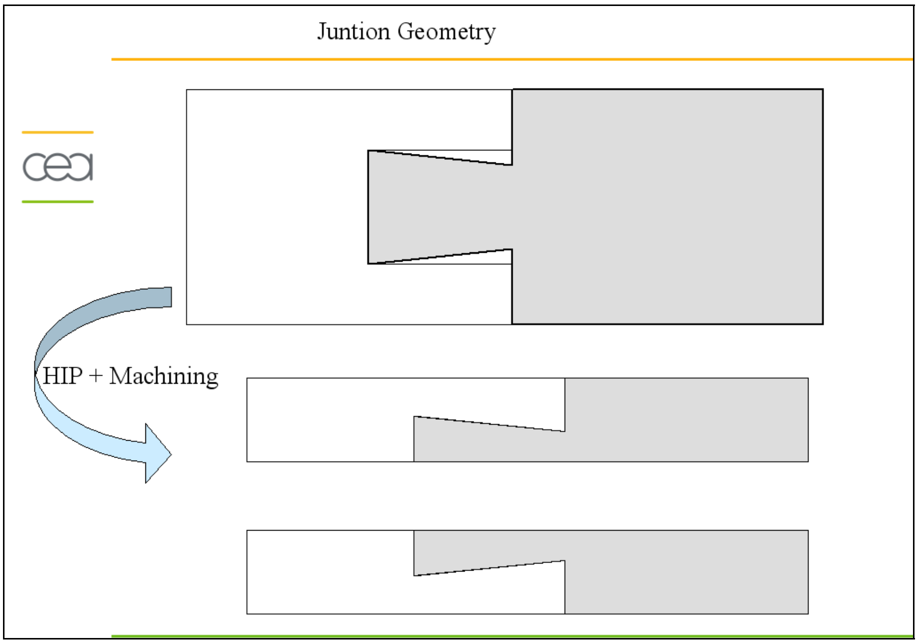
Regarding the toughness values, all the measurements on the bars (see table below) and sheets are over 50 MPa.m$^{1/2}$ (minimal value reserve for the elastic fracture mechanic calculations) and over the 35 kJ/m^2 (minimal value reserve for elastoplastic fracture mechanic calculations).

Summary of the results of the toughness tests on the beta treated bars (base metal, fusion line, welded joint) - Average of measurements						
Temperature (°C)	**Toughness base metal**		**Toughness fusion line**		**Toughness welded joint**	
	J (kJ/m²)	**K_{JC}(MPa.m$^{1/2}$)**	**J (kJ/m²)**	**K_{JC}(MPa.m$^{1/2}$)**	**J (kJ/m²)**	**K_{JC}(MPa.m$^{1/2}$)**
20	46	72	56	79	In readiness	
100	78	90	—	—	‘’	
150	61	80	70	86	‘’	
300	85	90	114	105	‘’	

Zircaloy / stainless steel junction

Resulting from the choice of the zircaloy as material constitutive of the water pressure vessel, it was necessary to develop heterogeneous junctions (zircaloy/austenitic steel)

Taking into account the operating conditions of the loop (pressure and temperature) a specific type of junction was developed at CEA (DRT/DTEN/S3ME). The guiding principles are to cumulate a mechanical fixing by an assembly of cones and a connection by welding-diffusion (assembly in solid phase).



The diffusion between zircaloy and austenitic steel is made by High Isostastic Pressing (HIP), temperature just under 1000°C and pressure just over 1000 bars. The duration of a cycle (gone up, to mitigate, descent) is about ten hours.

One of the main difficulties encountered by the assembly of zircaloy and austenitic steel is the creation in the diffusion zone of weakening intermetallic precipitates. To avoid these precipitates, very fine metal inserts (< 100 microns) are placed between the two surfaces before the assembly. The choice of materials constitutive of the layers was performed on the basis of similar study carried out within the framework of the Cabri experimental device realization.

The first results of tensile tests show a satisfactory behavior. The tensile strengh values in temperature (345°C) are only slightly lower than those of zircaloy. In addition, the sample ruptures occur in the zircaloy and not in the diffused zone, which demonstrates a good connection between the 2 materials.

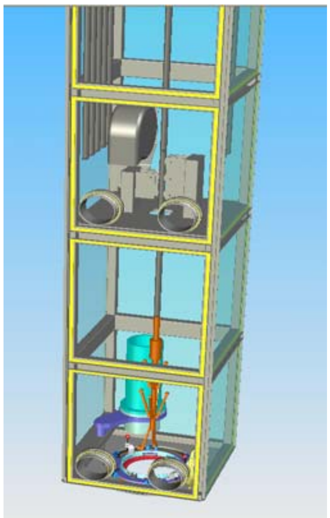
Ultrasonic control machine

On site, the water pressure vessel will be completely inaccessible (completely surrounded by the safety tube). Very exiguous space between the two structures on one hand and the plates centering the water pressure vessel in the safety tube on the other hand do not make possible to reach the external face of the vessel. In order to be able to carry out reglementary controls, a specific control equipment is being developped. In a similar way to what was carried out on the Phebus Reactor (CEA – Cadarache), this control equipment has to be able to run an inside televisual inspection, a dimensional check as well as a consistency control.

The specification requires :

- an accuracy of 0.1 mm to the measures of diameters and thickness,
- a detection, characterization and positioning of minimal defect in internal or external skin of : length = 5mm, width = 0.3mm and 0.5 mm depth,
- the possibility of inspecting all the weldings of the cell and the globality of the part being in regard of Cabri core reactor.

Two methods of ultrasonic inspections were adopted. Diameters and thicknesses measurements will be carried out by the traditional method of Pulsates Echo. And in order to be able to characterize and follow in service, if necessary, new defects, method TOFD "Time-of-flight diffraction" was adopted for the research of these ones. This technical ultrasonic method uses the diffraction of ultrasonic energies from ' corners' and ' ends' of internal structures (or defects) and allows to establish the characterization of them.



The head of control (equipped with the US probes or a camera) will be suspended to a carrying arm placed into a gloves box on top of the cell. This head of control will be motorized and will be able to rotate on itself. This rotation will constitute the first degree of freedom.

The gloves box, allowing maintenance operations on components without loss of the tightness, will contain the motorization necessary to the vertical adjustment (second degree of freedom), the gauges block and the different connectors allowing to recover the US probes signals.

The main technical challenge lies in the need to control seven different diameters (from 145mm to 71mm), displayed on nine meters height and without any risk of wedging when crossing the transition parts between two different diameters.

CONCLUSION

For a few years, facility upgrade and new loop implementation have been going on on Cabri site. Most of the challenges have been faced by now, but some specific points still need to be treated. FRAMATOME / ANP and the CEA project team are working on them.

Cabri facility, after a break of few years, should be available very soon. This “almost” brand new facility will be available for testing high burn-up fuel as it was designed for.