Cabri – Zircaloy Pressure Vessel

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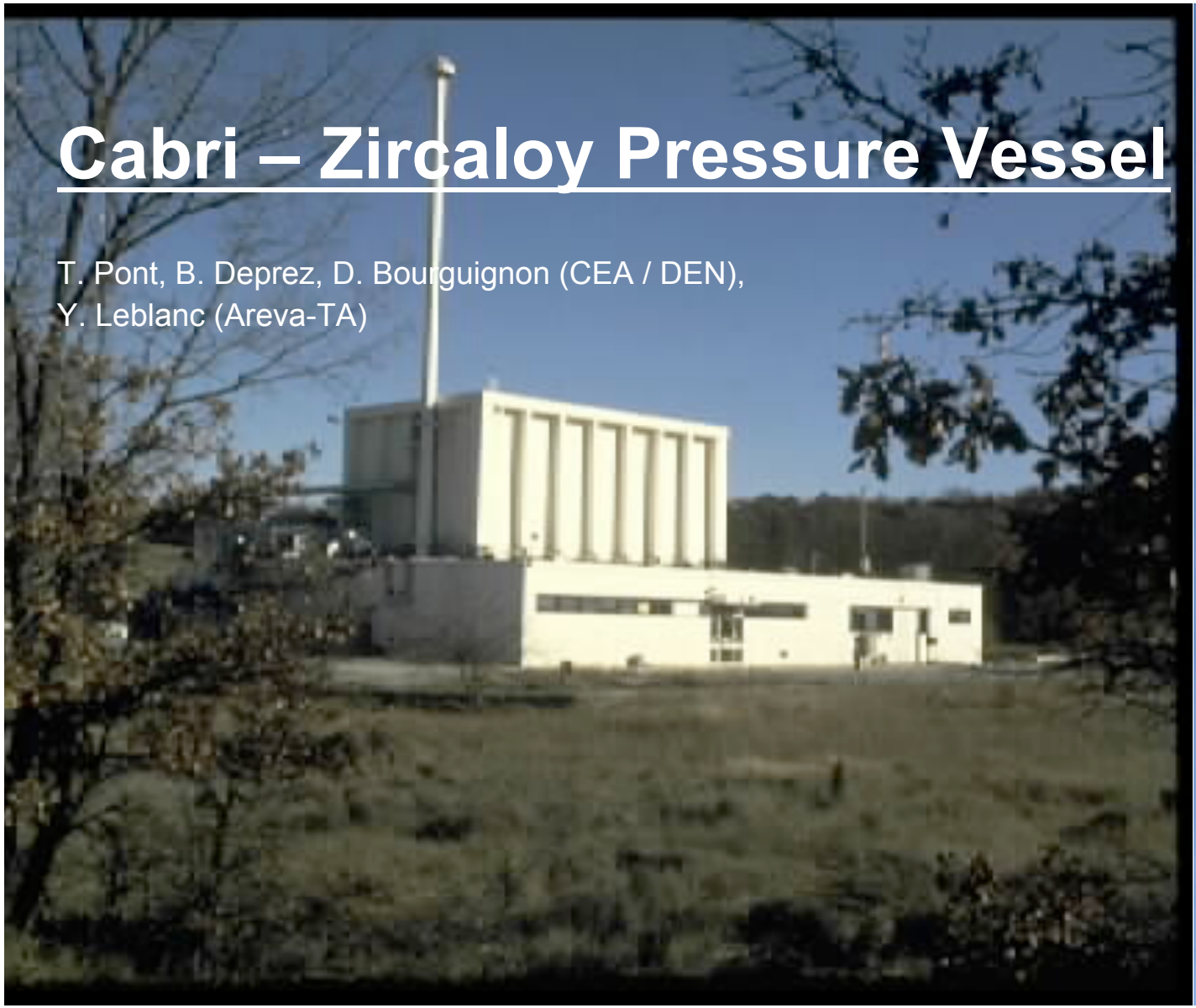
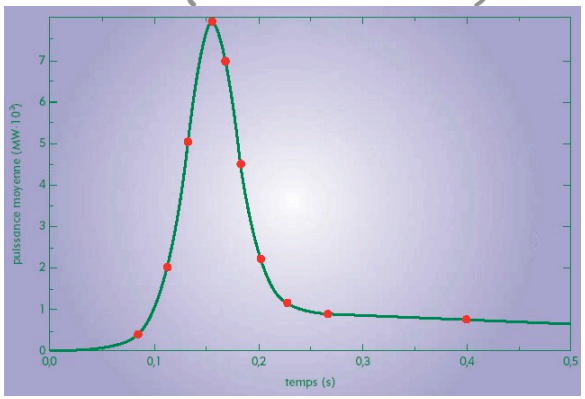
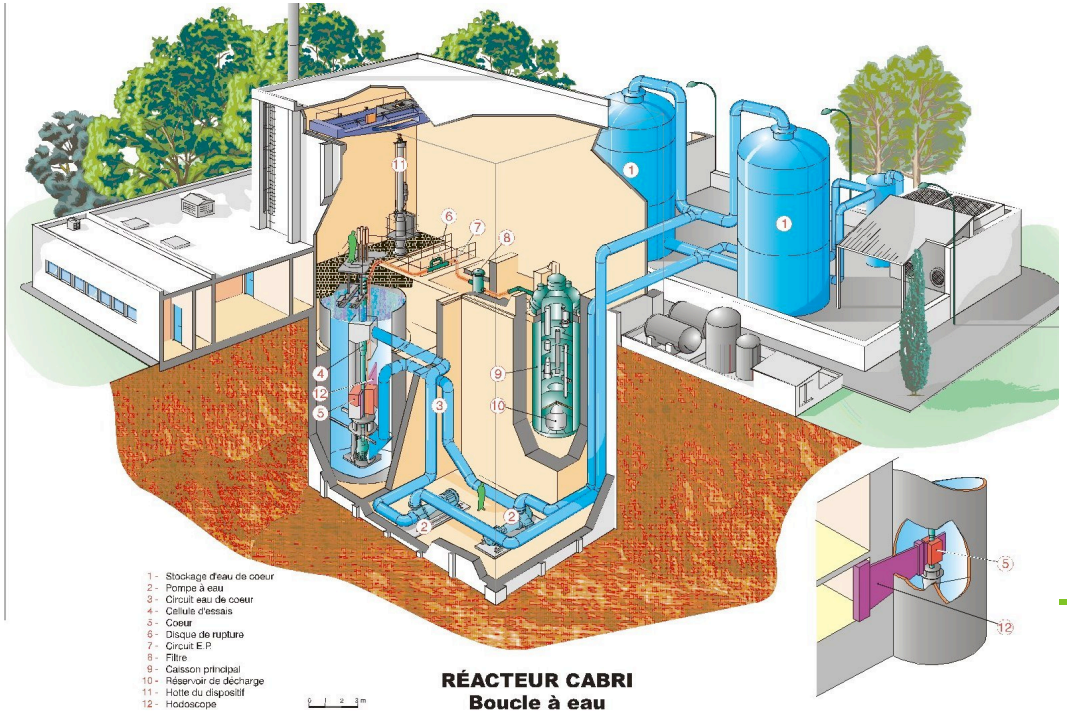


Cabri Reactor

- CABRI is a CEA Research Reactor (Cadarache center - France)
- Devoted to experiment on accidental situation (RIA- Reactivity Initiated Accident) on nuclear fuel (high burn-up)
- 1st international program CIP carried out for IRSN (French TSO)



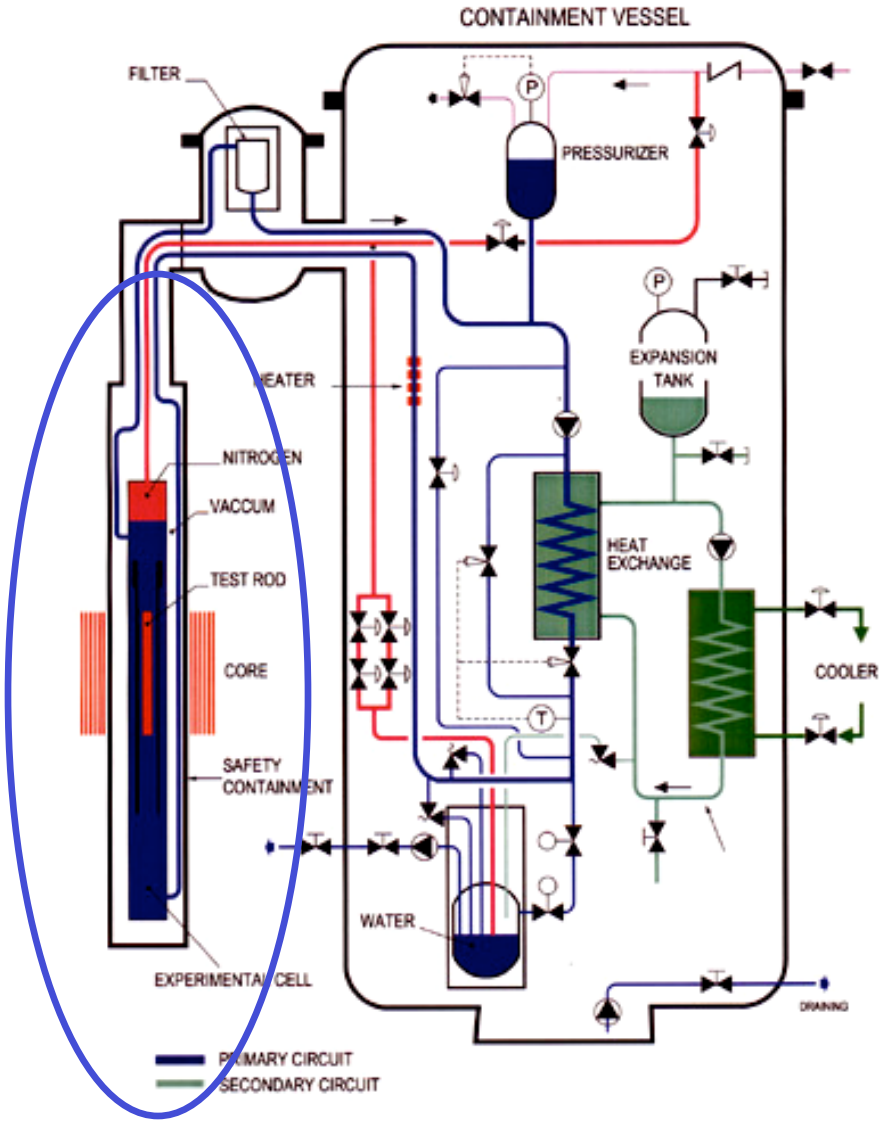


Cabri Update (beginning in 1999):

- Replacement of the Na loop by a water loop
- Safety analysis review
- Refurbishment of the facility
- Cabri Modification French Decree

Cabri – Water loop

- Create experimental conditions equivalent of PWR : 155 bars / 300°C
- Possible interaction between UO2/H2O => dynamic pressure wave
- Safety class : N1
- Afcen RCC-M Code : N1
- Nuclear Pressure Equipments
- Experimental vessel in Zirconium alloy ===>



Experimental pressure vessel main challenges

Context :

a) Need of neutron transparency for the experiment,

b) Geometry fixed by the existing core,

c) High pressure and temperature (high stresses),

a + b + c => Use of Zircaloy 4 in great thickness

d) Nuclear Pressure Equipment,

d => ***High quality (design, construction and control)***
+
French Nuclear Authority control

Experimental pressure vessel main challenges

energie atomique • energies alternatives

AREVA

Challenges:

- *Supplying Zy4 with adequate mechanical properties,*
- *Forming and welding Zy4 in great thickness,*
- *High quality.*

Context:

- *Poor recent industrial experience on Zy4,*
- *No nuclear code available for Zy vessel level 1.*

CEA choose to use RCC-M edition 2000 (code for construction of PWR) as reference with some specific rules to adapt to zirconium alloys :

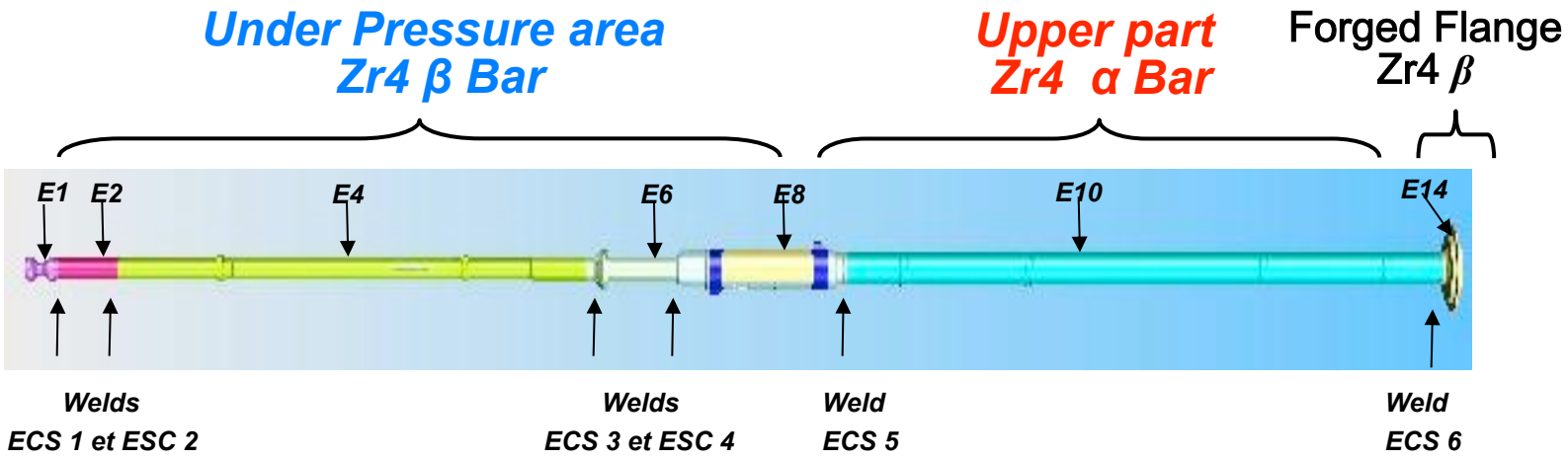
- *Procurement / Mechanical properties / Welding / Forming / Control*

Note: In parallel, development of RCC-MX (Design and Construction Code for Research Reactors) by CEA, AREVA-TA and AREVA-NP which includes rules for: Zirconium / Aluminum / Irradiated materials => Interaction between the project team and the RCC-MX Committee.

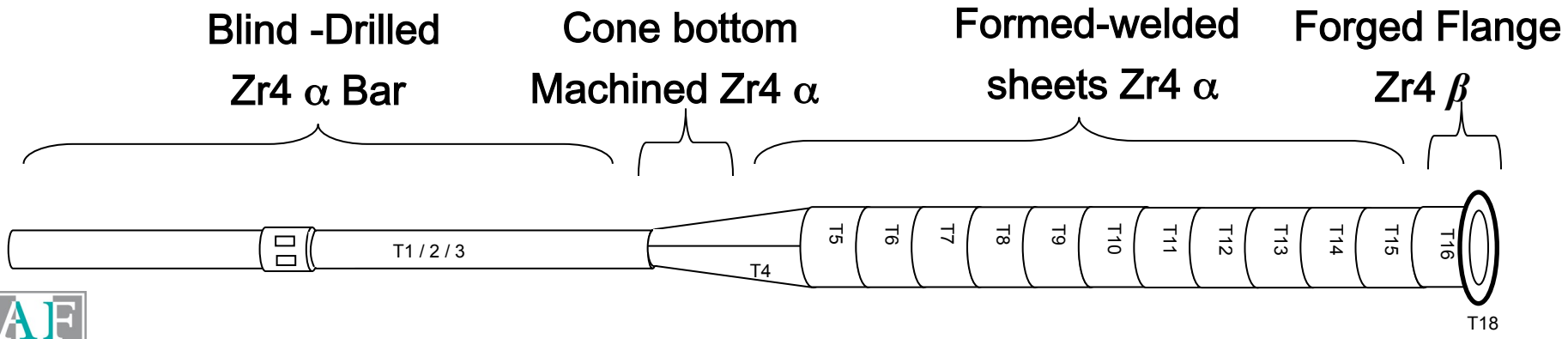
AFAQ ISO 9001 ISO 14001 OHSAS 18001

Zircaloy Materials

Experimental Vessel



Containment Vessel



Zircaloy α procurement

Specification for each type of products:

- *Chemical composition: ASTM Grade R60804 (Zy4)*
  - *Except for Oxygen content restricted to : 1000-1500 ppm*
- *Metallurgical state: recristallized (α)*
- *Mechanical properties: Requirements on:*
  - *Yield Strength, Tensile Strength and Elongation at room temperature*
  - *Yield Strength, Tensile Strength at operating temperature*
- *Non destructive examinations: dimensional and ultrasonic testing*
- *Destructive examinations: Chemical composition (complete on the ingot and H,O,N on products), Metallographic examination, Corrosion, Tensile Test, Hardness, Bending test for plates*

Zircaloy β procurement

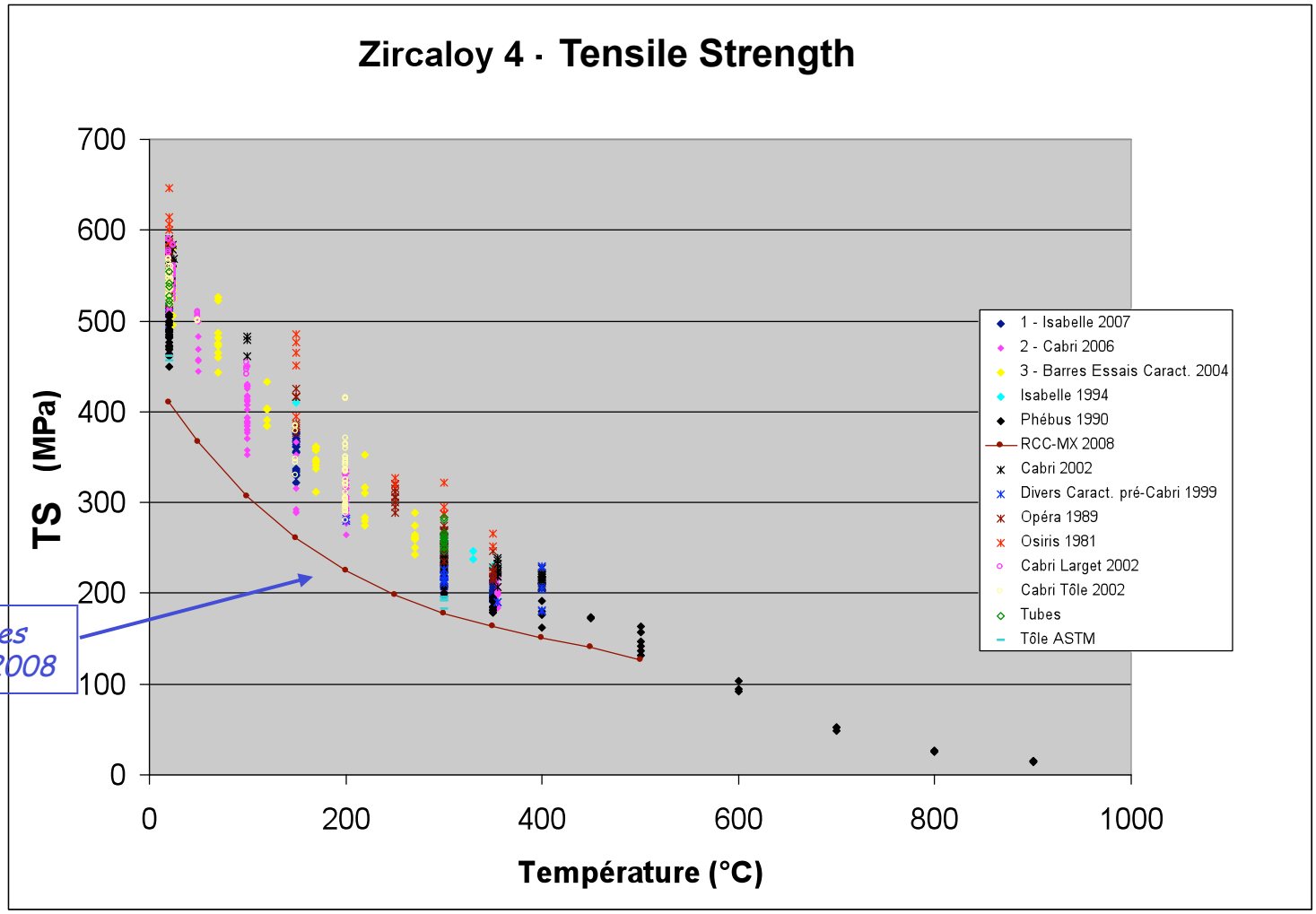
Particular specification (material under pressure and neutron flux):

- *Chemical composition: ASTM R60804 +*
  - *Target Tin content: 1.7 % (upper ASTM limit)*
  - *Target Oxygen content: 1.6 % (upper ASTM limit)*
  - *Sulfur content: 10 to 50 ppm*
- *Metallurgical state: quenched (β)*
  - *Better homogeneous tensile properties*
- *Non destructive examinations: dimensional and ultrasonic testing*
- *Destructive examinations: Chemical composition (complete on the ingot and H,O,N on products), Metallographic examination, Corrosion, Tensile Test, Hardness, Creep test in the range 200°C to 400°C*

Note: This particular specification (β quenched Zr4) is not covered by RCC-MX.

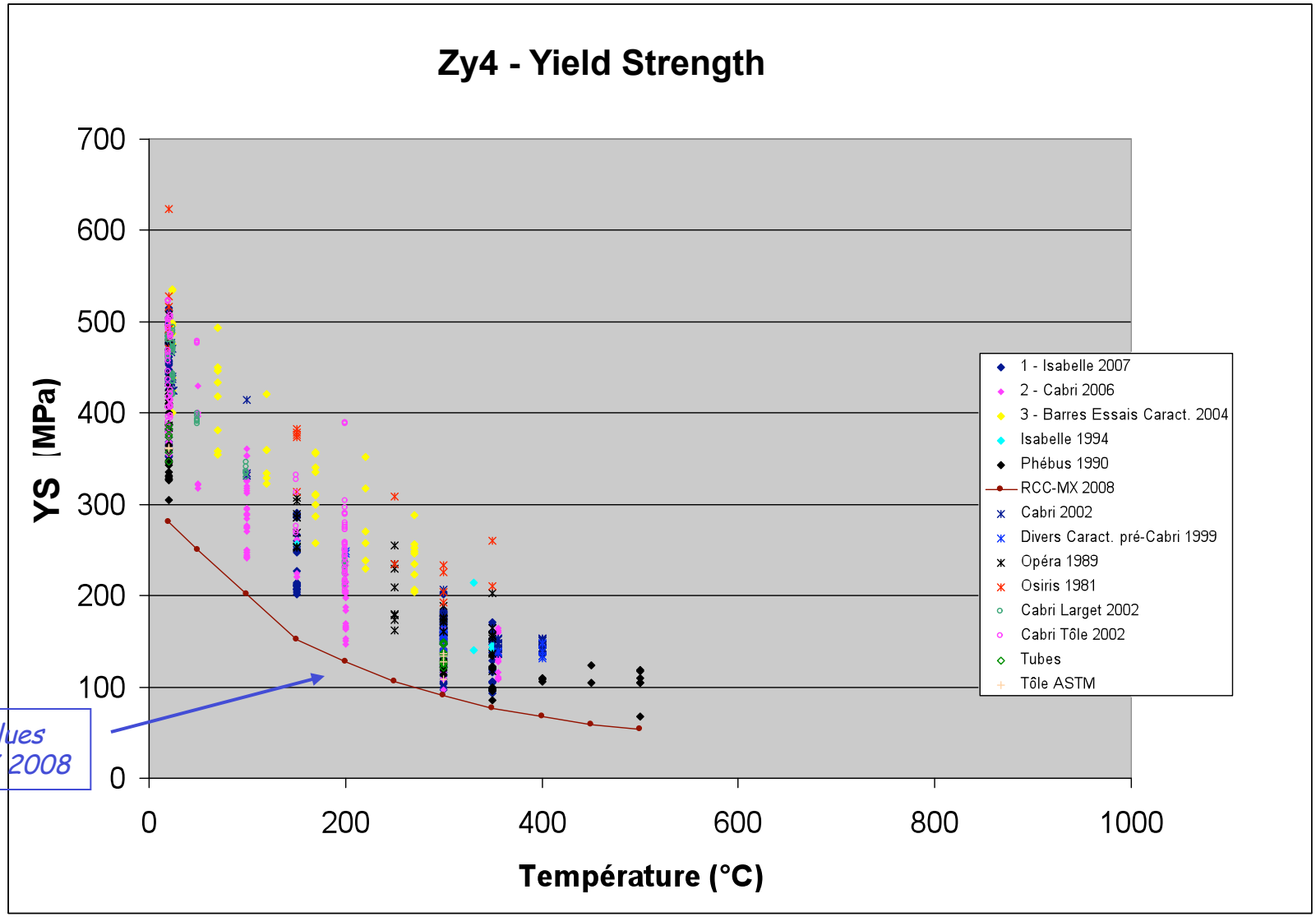
Zircaloy mechanical characterizations

Tensile properties: Recording of 700 tensile tests on 15 different castings (half of them on Cabri products).



Minimum values from RCC-MX 2008

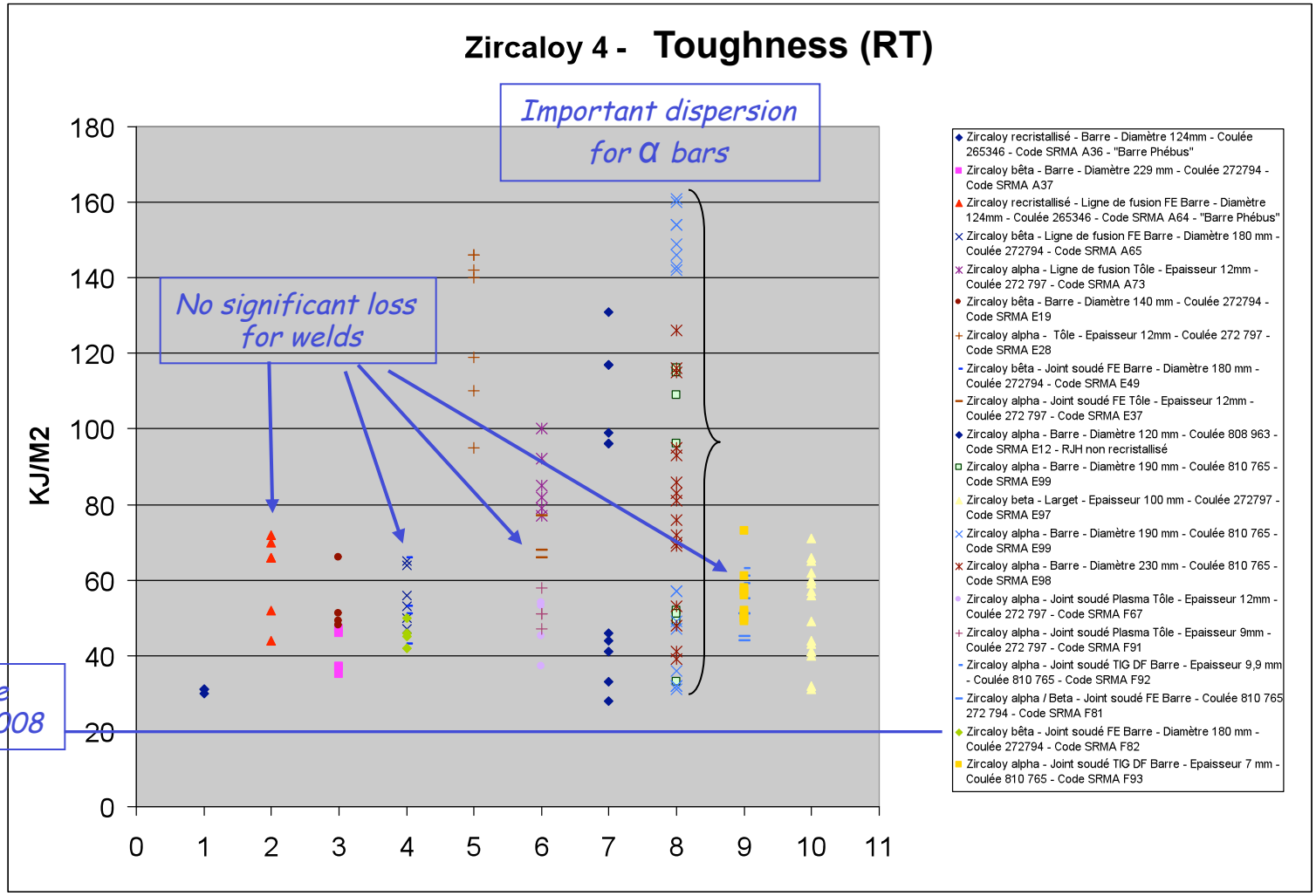
Zircaloy mechanical characterizations



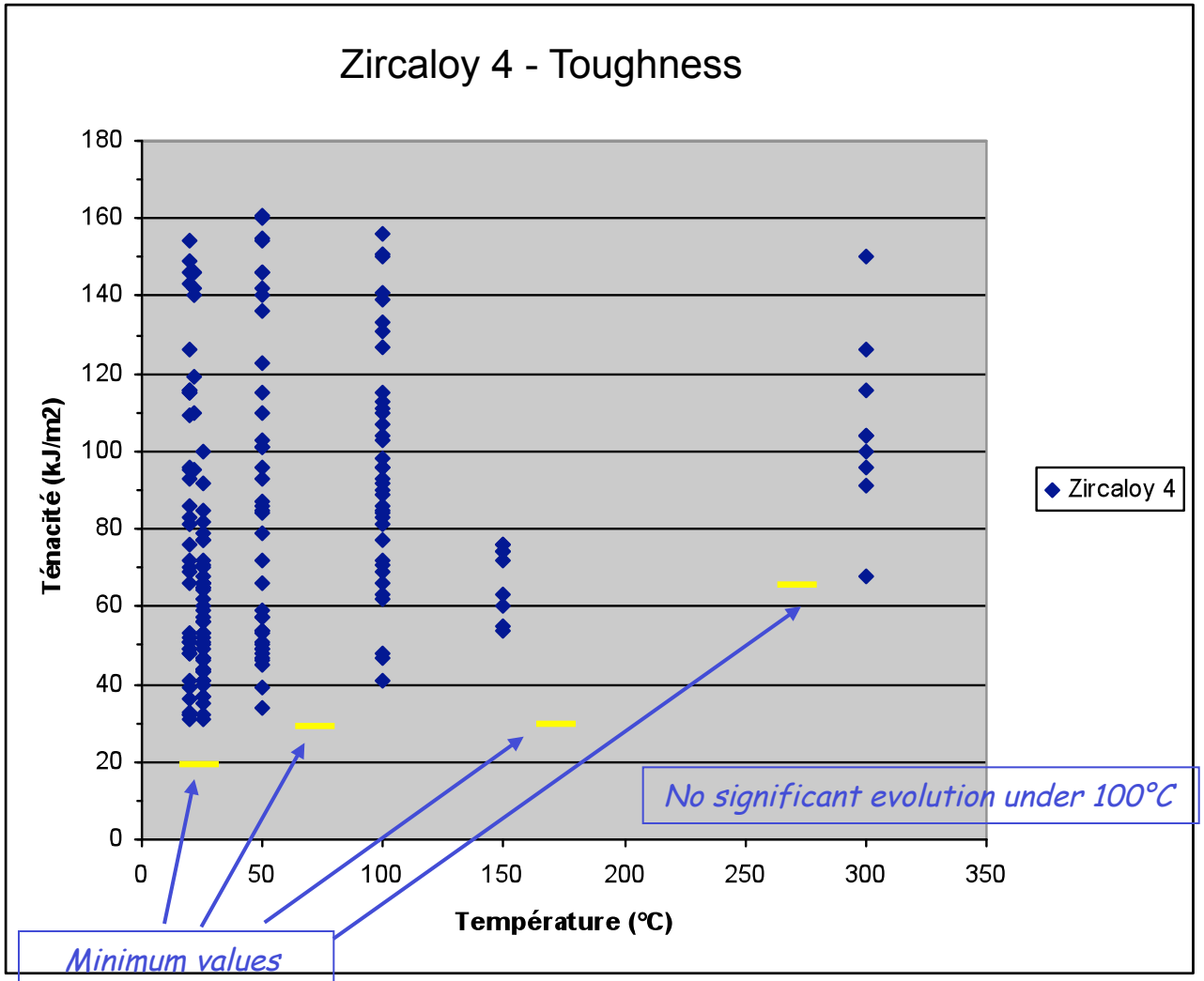
Minimum values from RCC-MX 2008

Zircaloy mechanical characterizations

Toughness: Recording of 200 tests on various castings and different welds (Electron Beam, TIG, Plasma)



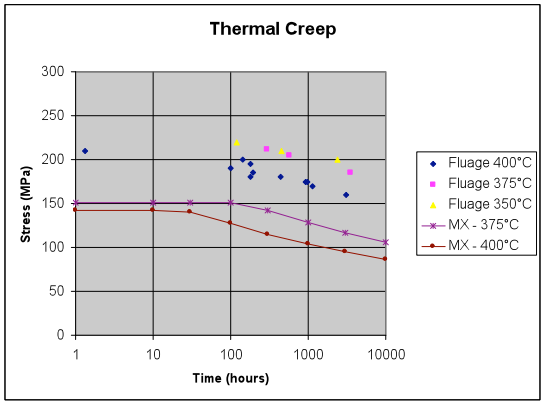
Zircaloy mechanical characterizations

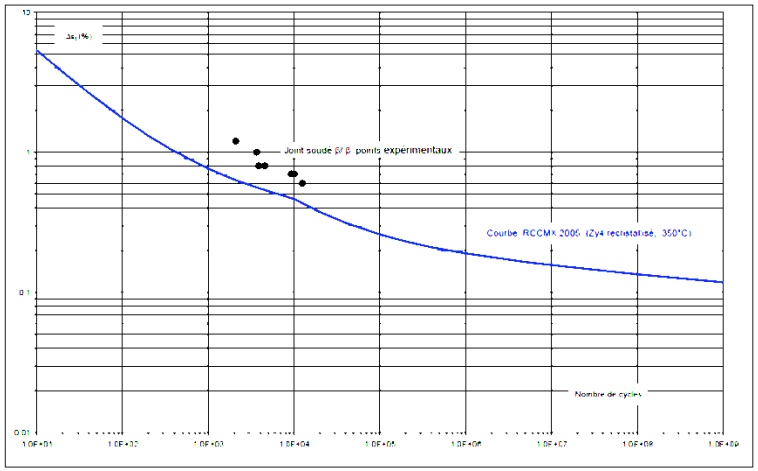


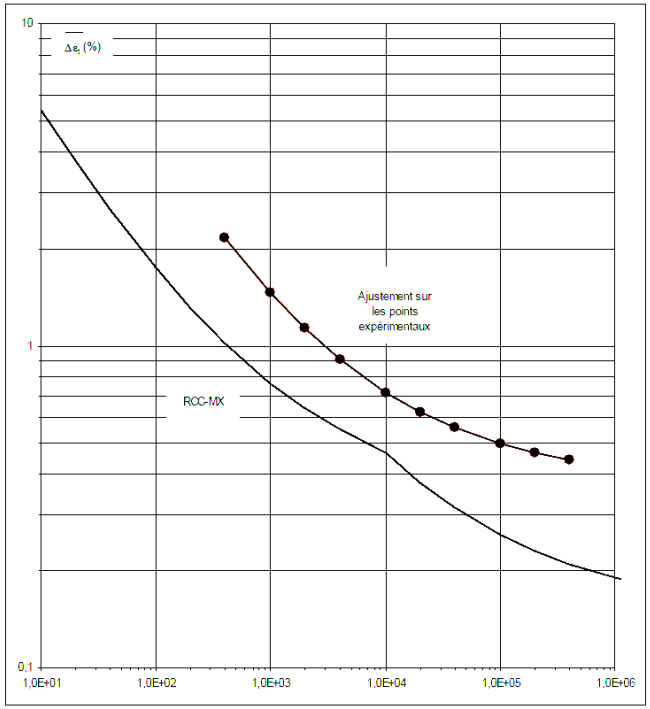
Zircaloy mechanical characterizations

Others characterizations:

- *Thermal Creep (300°C, 350°C, 375°C and 400°C)*
- *Fatigue:*
  - *Fatigue curve at 400°C*
  - *Paris law at 300°C*
  - *A few check for fatigue weld properties*

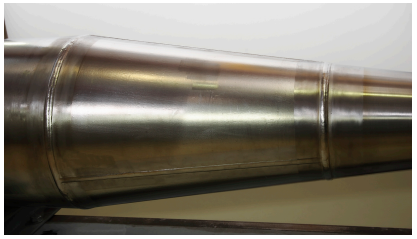


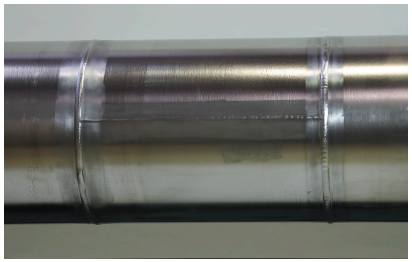




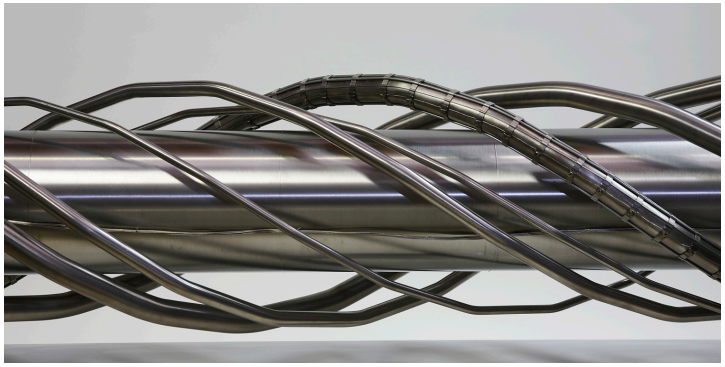
Construction - Forming

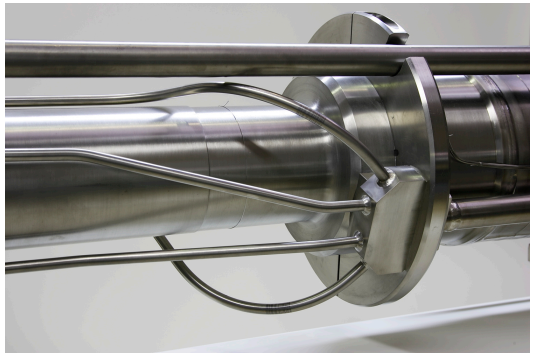
- *Upper part of the containment vessel made of formed-welded sheets*





- *Expansion loops and various elbows on pipes*





=> Qualification for each process
=> Need to adapt the forming mandrel diameter to the deformation capacity of Zy

Construction - Welding

Three process:

- *Electron Beam welding for the pressure vessel*
- *TIG welding for the pipes*
- *Plasma welding for the shell of the containment vessel*

Main challenges:

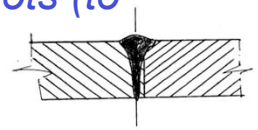
- *Specification (based on International and European standards with add-ons to meet RCC-M requirements)*
- *Vacuum chamber for EB welding (over 9 meters long)*
- *Avoid gas pollution for arc welding (inert gas protection chamber with oxygen concentration control)*
- *Mechanical properties equivalent to parent metal*

Construction - Weld control

Non destructive examinations:

- *Pre-welding :*
  - *Visual examination, liquid penetrant examination on bevels (replaced by thorough visual inspection (magnification X5) for EB-welded bevels),*
  - *Geometric examination of fit-up.*
- *Post-welding :*
  - *Visual examination, liquid penetrant examination (on both faces when possible),*
  - *Radiographic examination (x-ray),*

  + televisual (X 24) and ultrasonic inspections of the EB weld roots (to prevent any notch effect linked to an incomplete fusion).



Destructive tests (qualification and production weld test coupon):

- *Tensile test (room and operating temperatures),*
- *Bending test (face, root and side bends),*
- *Metallographic examination (with hardness profile survey cross the weld),*
- *Impact strength test,*

+ chemical analysis and corrosion test for arc welding.

Nuclear Pressure Equipment - Initial Visit

Objective: Reference point for in-service inspection

Three controls (by an automatic control equipment):

- Video inspection,
- Thickness measurement (US Pulse Echo, accuracy = 0.1mm),
- Defect research (interior and exterior walls, longitudinal and circumferential, calibration on 10 mm long and 1 mm deep notch, US TOFD method),
- Perform through a gloves box.

Conclusion

- *Successful hydraulic pressure test (285 bars) in July 2009 (under supervision of a Notified Body and the French Nuclear Authority).*

- *High technical challenges were overcome (in the difficult context of all projects with calendar and financial obligations).*

- *The project documentation capitalizes the industrial feedback.*

- *Integration of this feedback in the RCC-MX 2008 Code (see note).*

Special thanks to all IRSN, AREVA, CEA and manufacturers people highly involved in this challenging project.

Note: The RCC-MX and RCC-MR (Sodium Fast Reactors and High Temperature Reactors Code) merge into Afcen RCC-MRx Code (English and French editions of private draft in 2010). A public RCC-MRx edition is to be published by Afcen by the end of 2011 or 2012 => See "Future of French Design and Construction Code for Research Reactors" presentation by C. Pascal - Areva-TA.