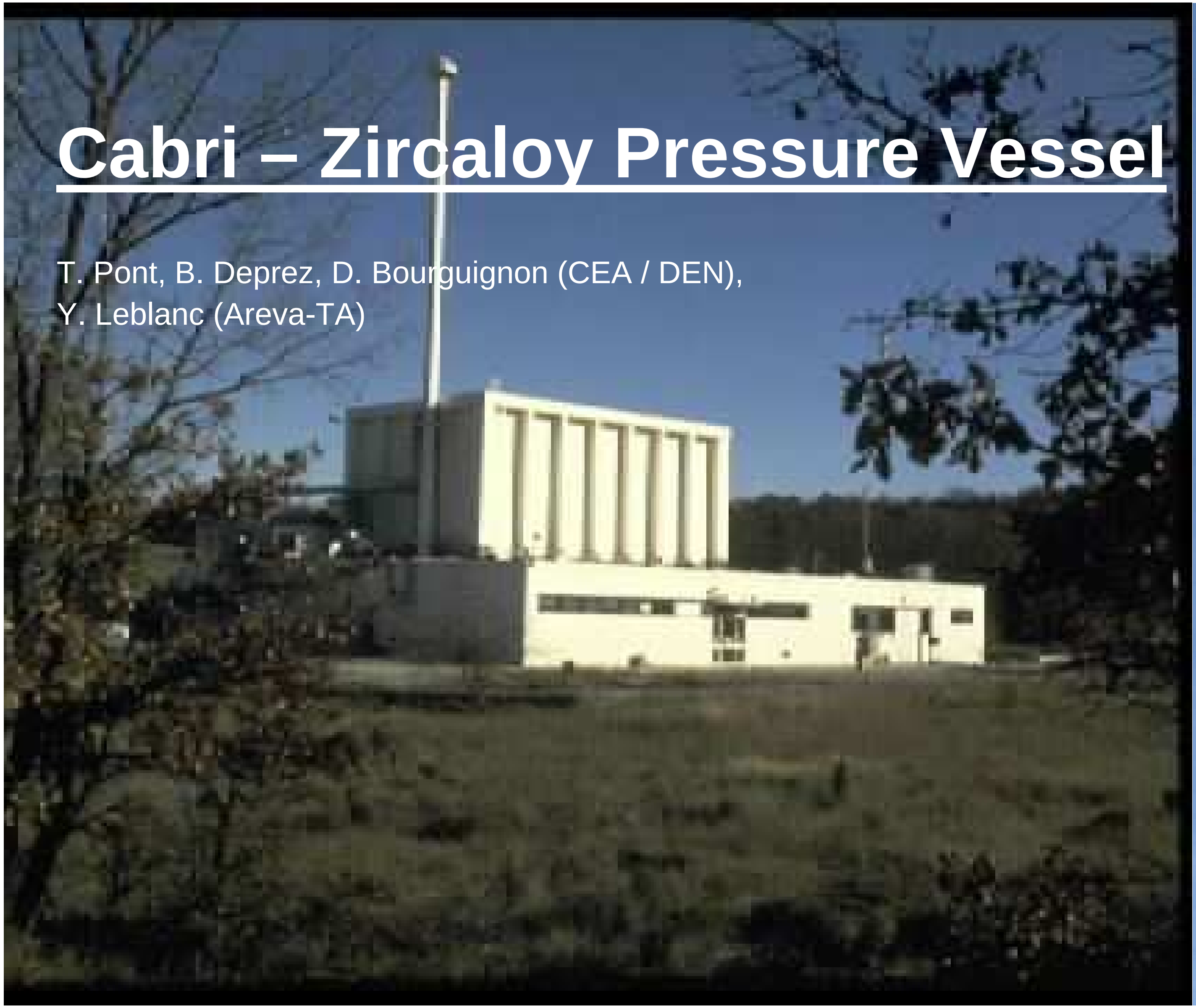
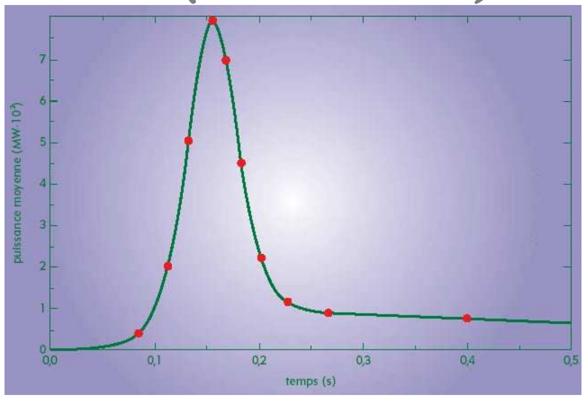
Cabri – Zircaloy Pressure Vessel

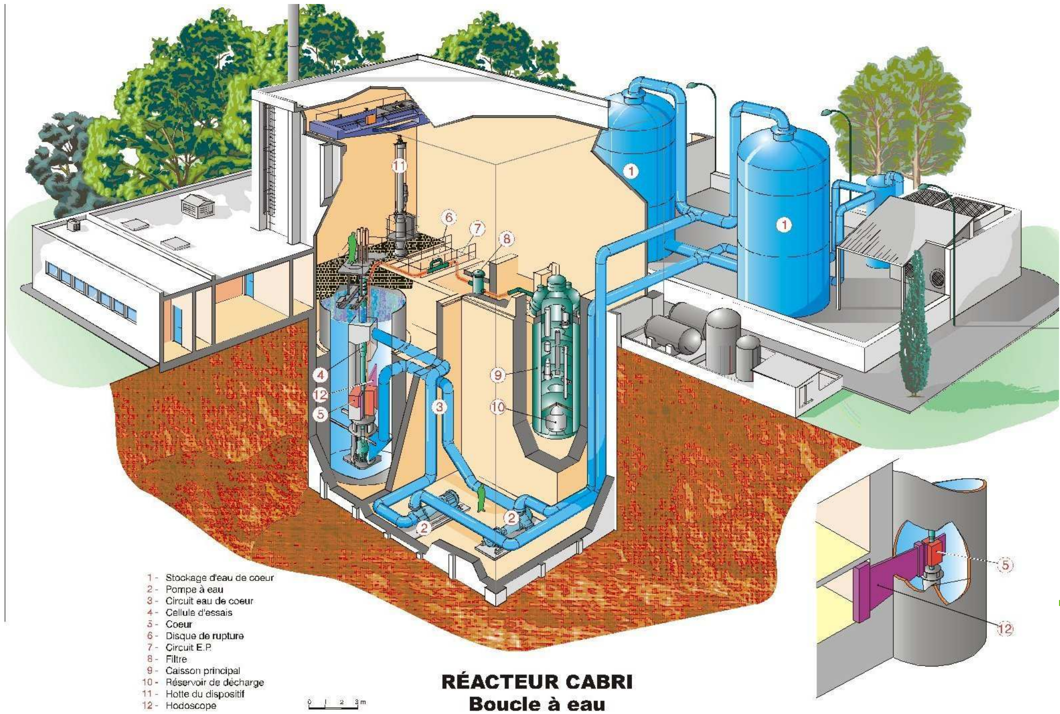
T. Pont, B. Deprez, D. Bourguignon (CEA / DEN),
Y. Leblanc (Areva-TA)



Cabri Reactor

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



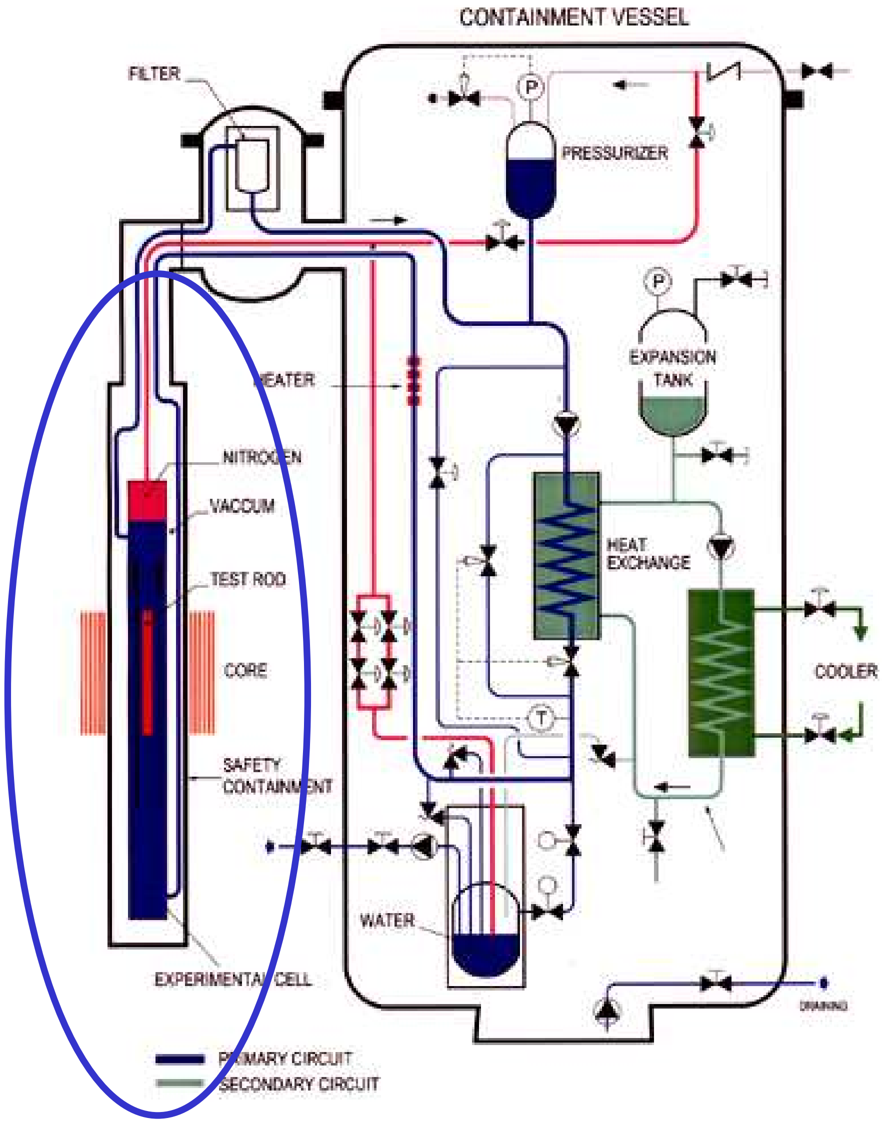


<u>Cabri Update (beginning in 1999):</u>

- *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

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.

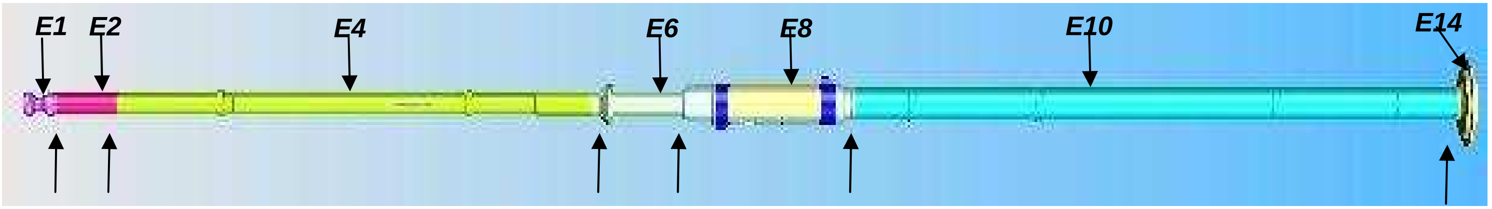
Zircaloy Materials

Experimental Vessel

Under Pressure area
Zr4 β Bar

Upper part
Zr4 α Bar

Forged Flange
Zr4 β



Welds
ECS 1 et ESC 2

Welds
ECS 3 et ESC 4

Weld
ECS 5

Weld
ECS 6

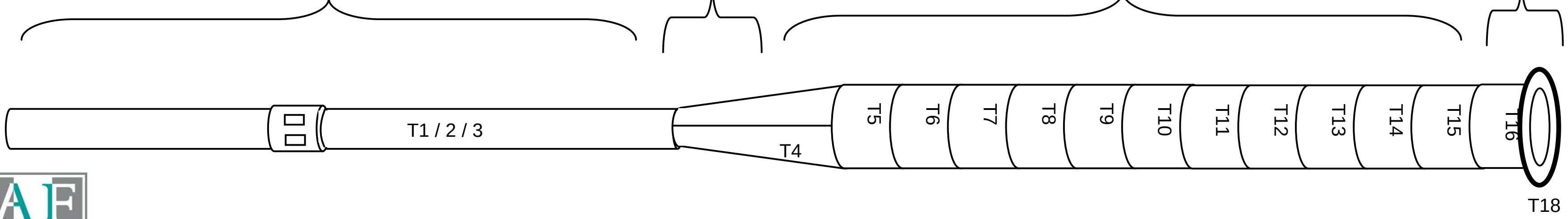
Containment Vessel

Blind -Drilled
Zr4 α Bar

Cone bottom
Machined Zr4 α

Formed-welded
sheets Zr4 α

Forged Flange
Zr4 β



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

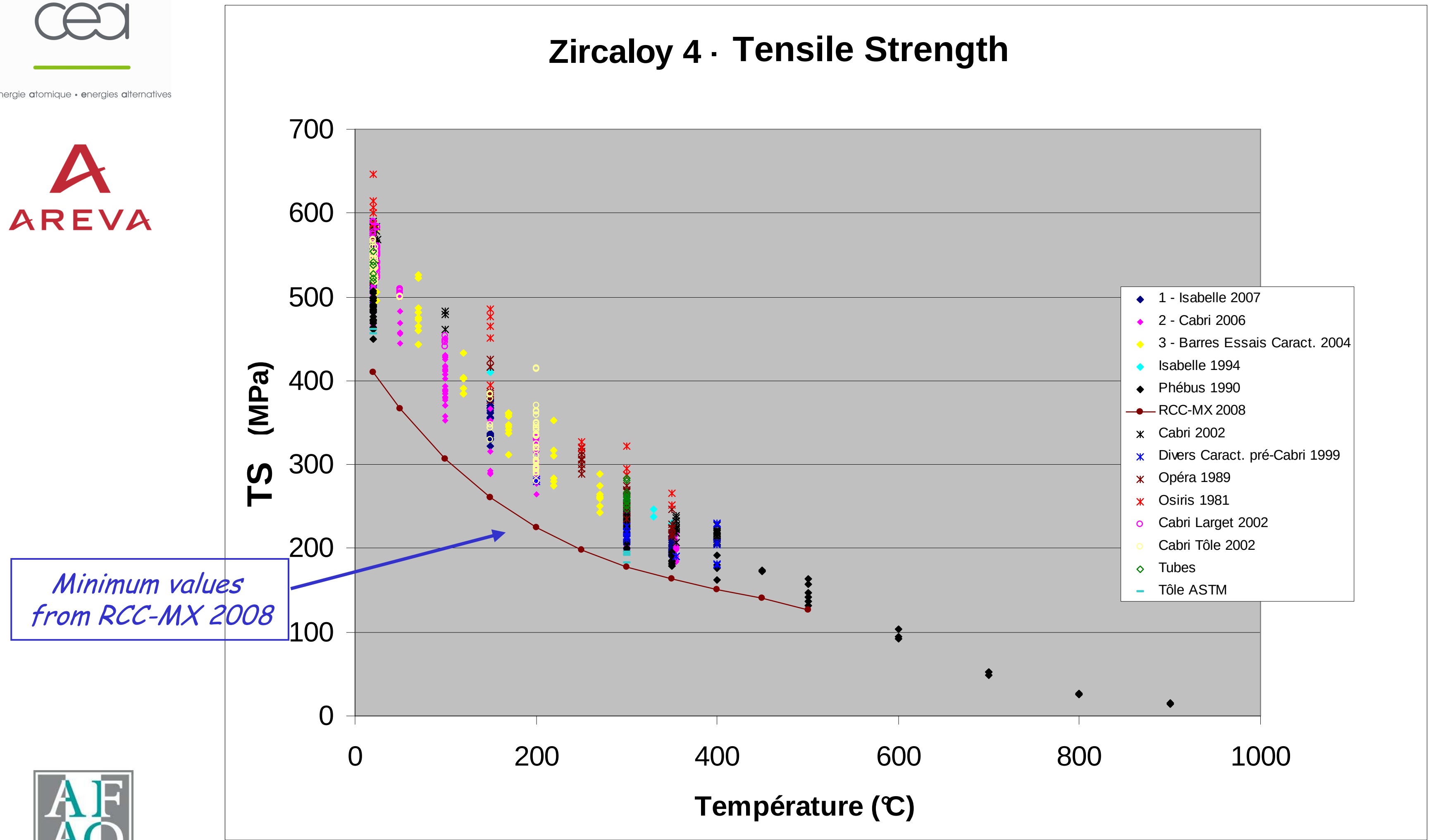
Particular specification (material under pressure and neutron flux):

- *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℃ to 400℃*

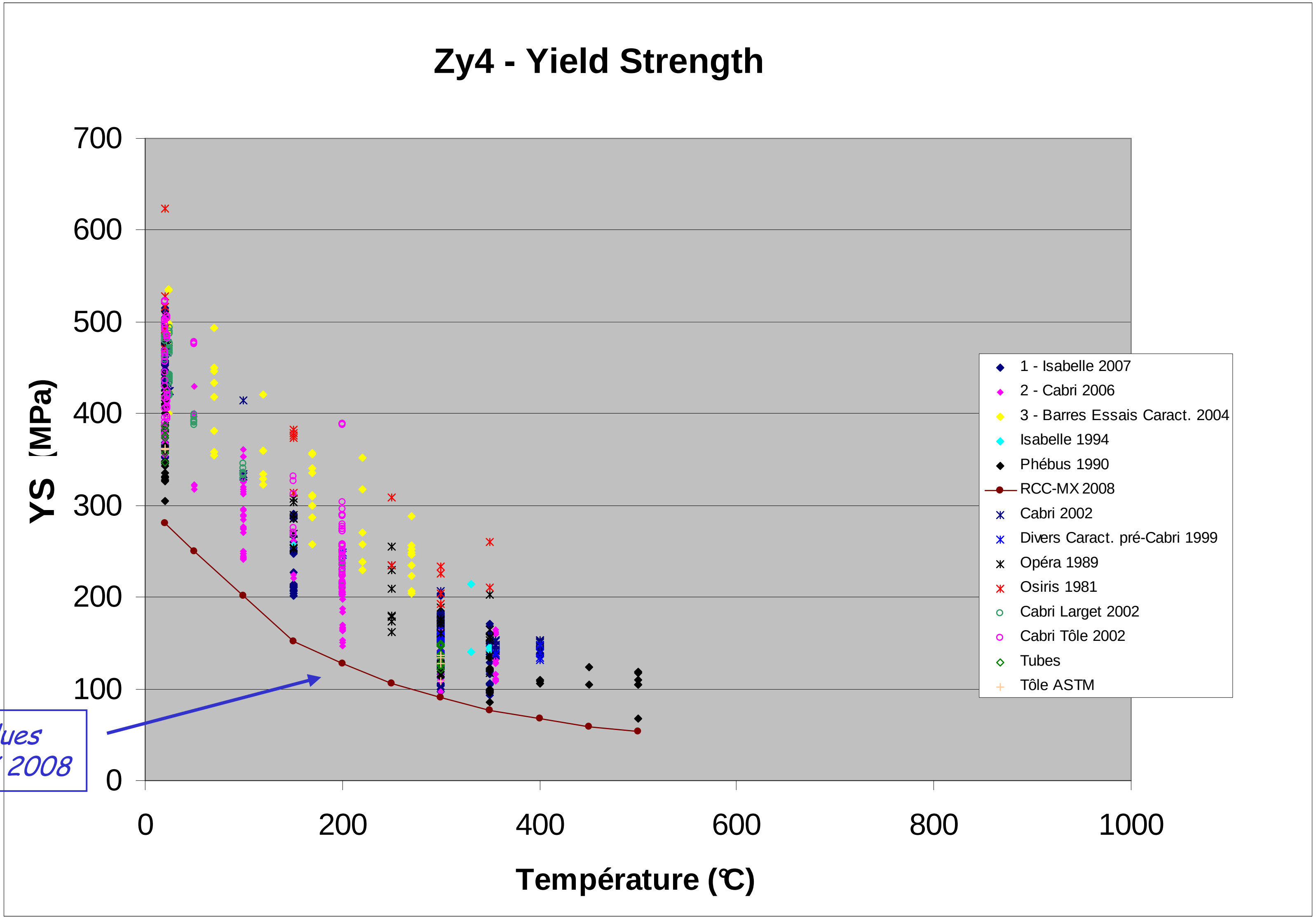
Note: This particular specification (β quenched Zr4) is not covered by RCC-MX.

Zircaloy mechanical characterizations

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



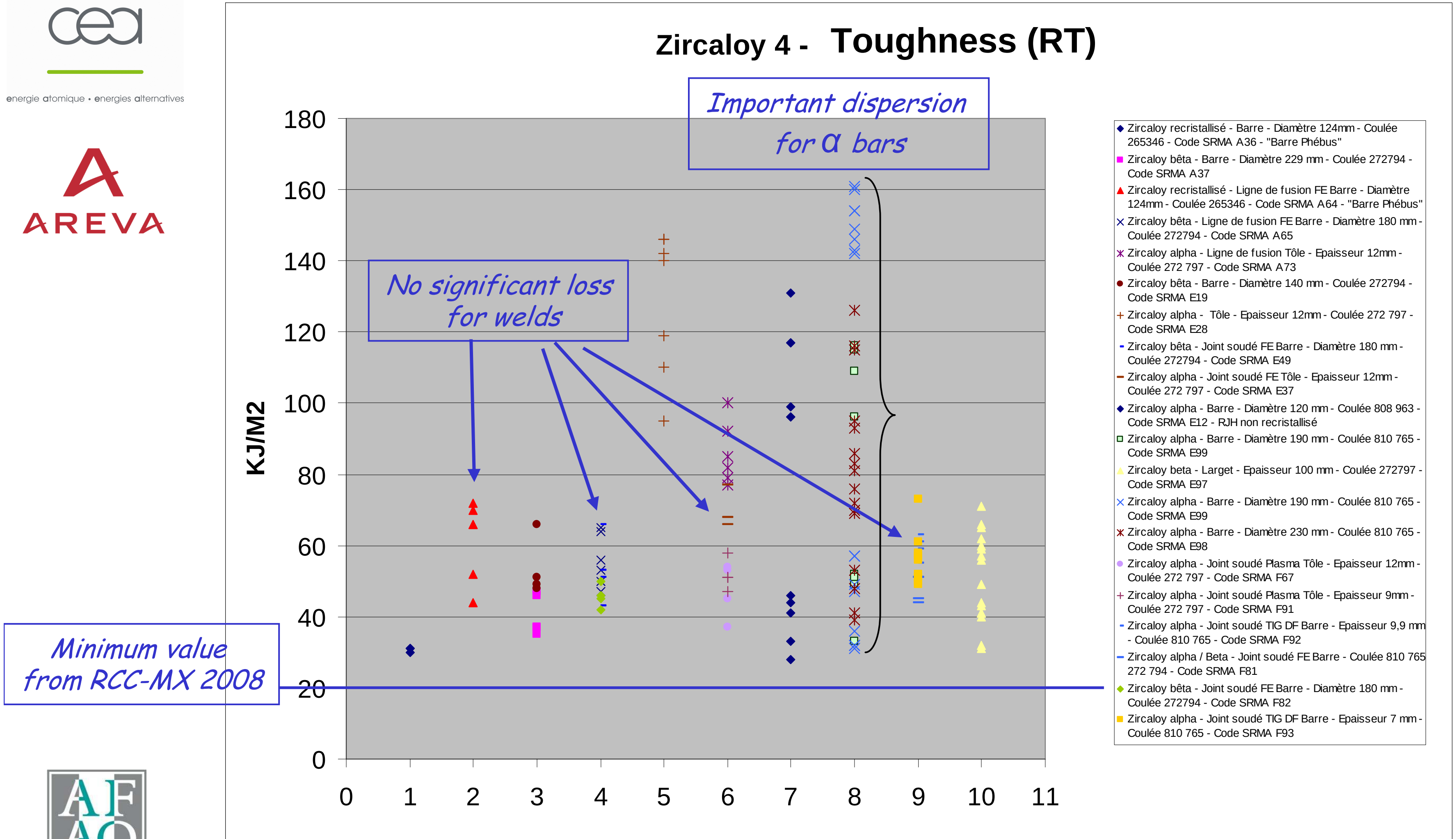
Zircaloy mechanical characterizations



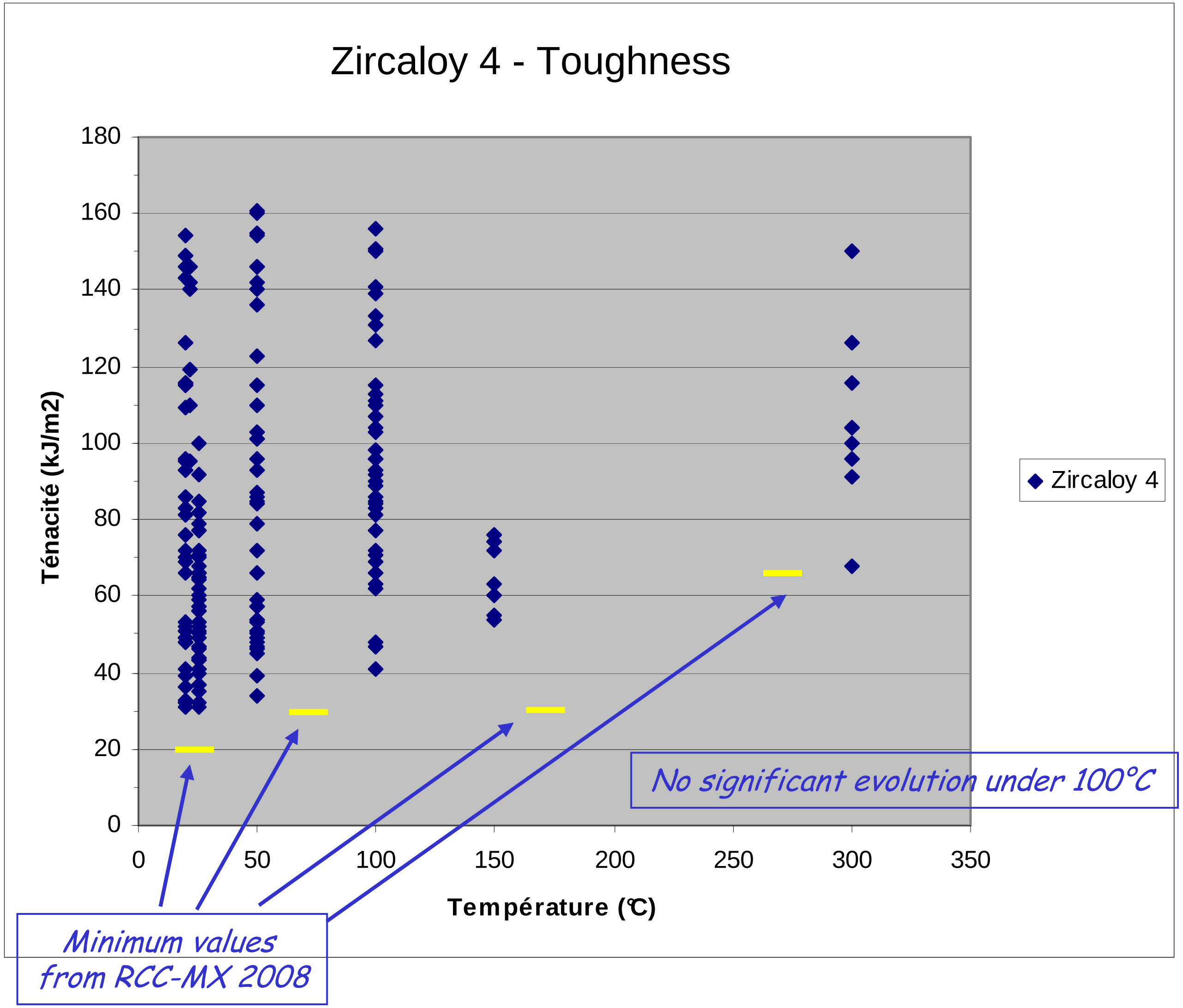
Minimum values from RCC-MX 2008

Zircaloy mechanical characterizations

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

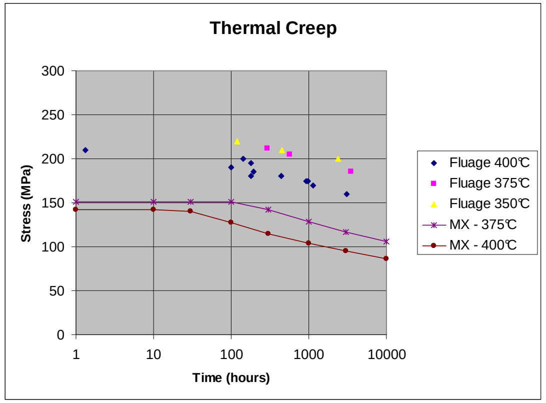


Zircaloy mechanical characterizations

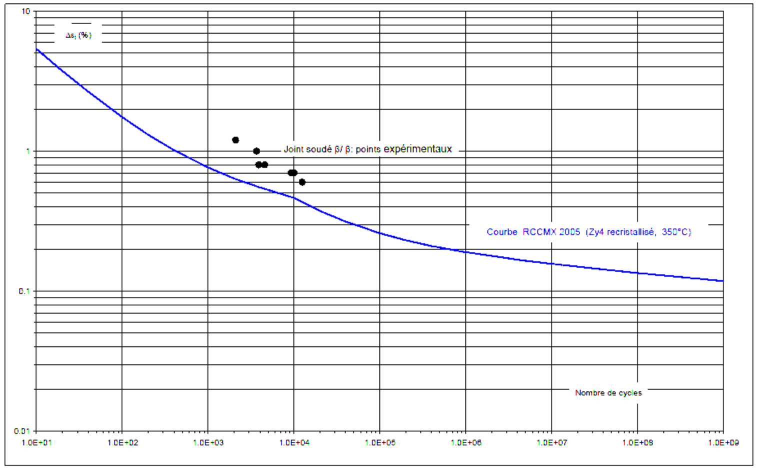


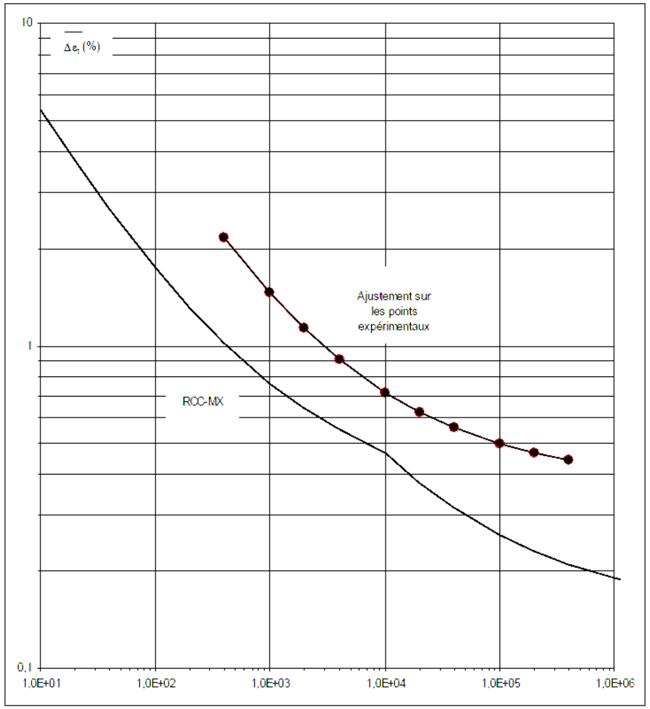
Zircaloy mechanical characterizations

Others characterizations:



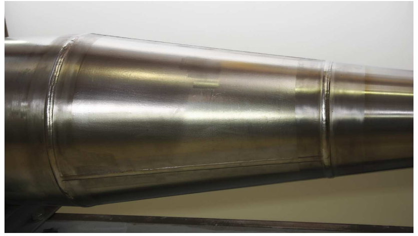
- *Thermal Creep (300℃, 350℃, 375℃ and 400℃)*
- *Fatigue:*
  - *Fatigue curve at 400℃*
  - *Paris law at 300℃*
  - *A few check for fatigue weld properties*

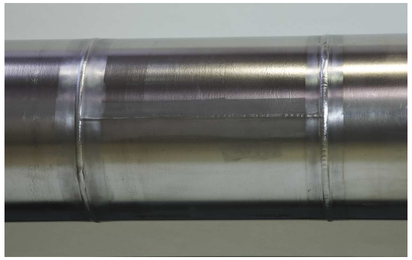




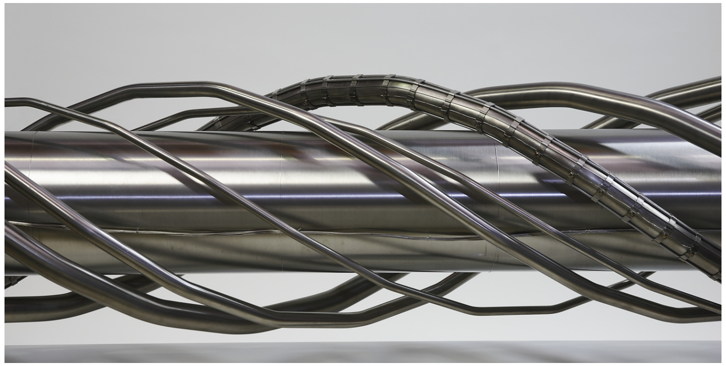
Construction - Forming

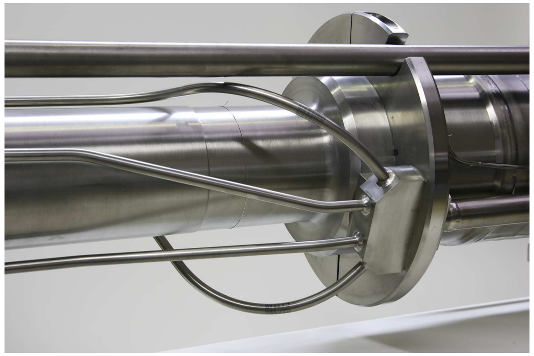
- *Upper part of the containment vessel made of formed-welded sheets*





- *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:

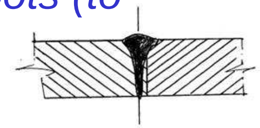
- *Specification (based on International and European standards with add-ons to meet RCC-M requirements)*
- *Vacuum chamber for EB welding (over 9 meters long)*
- *Avoid gas pollution for arc welding (inert gas protection chamber with oxygen concentration control)*
- *Mechanical properties equivalent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