

Does M5TM balloon more than Zircaloy-4 under LOCA conditions ?

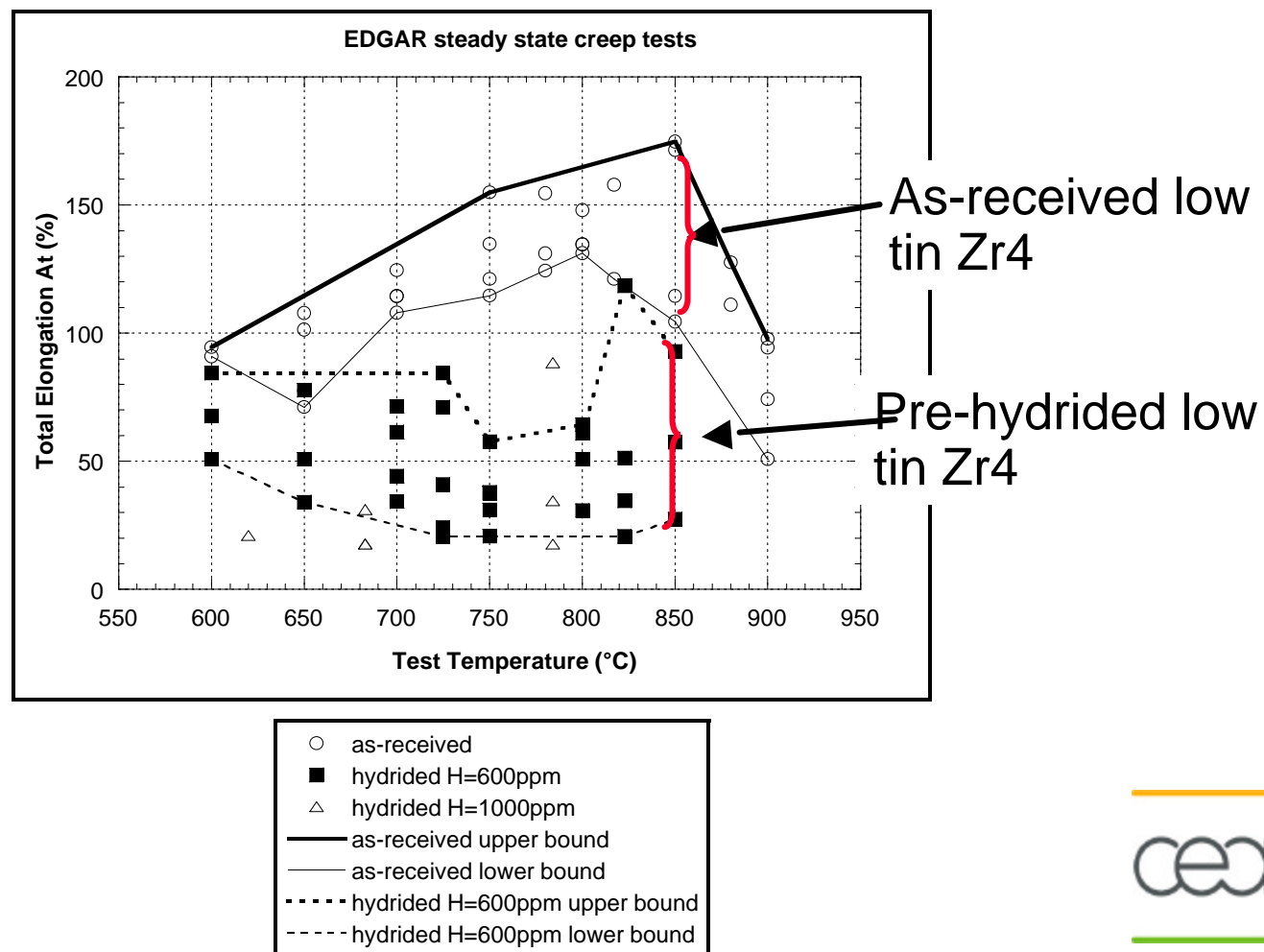
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BACKGROUND

- At the PHEBUS-STLOC meetings in Washington DC (Oct 2003) and Madrid (Nov 2003), IRSN asserted M5 cladding may exhibit bigger balloons than Zy4 under LOCA conditions
 - Higher risk of flow blockage for M5 ?
- IRSN's statement is based on isothermal **creep tests** performed on Nb based alloys (published by CEA, EDF and FRA-ANP in Toronto and Annecy ASTM Meetings)
 - At high fluence with a low hydrogen content (150 ppm) M5 exhibits higher ductility than Zy4, with a higher hydrogen content (600ppm)

ISOTHERMAL CREEP tests RESULTS

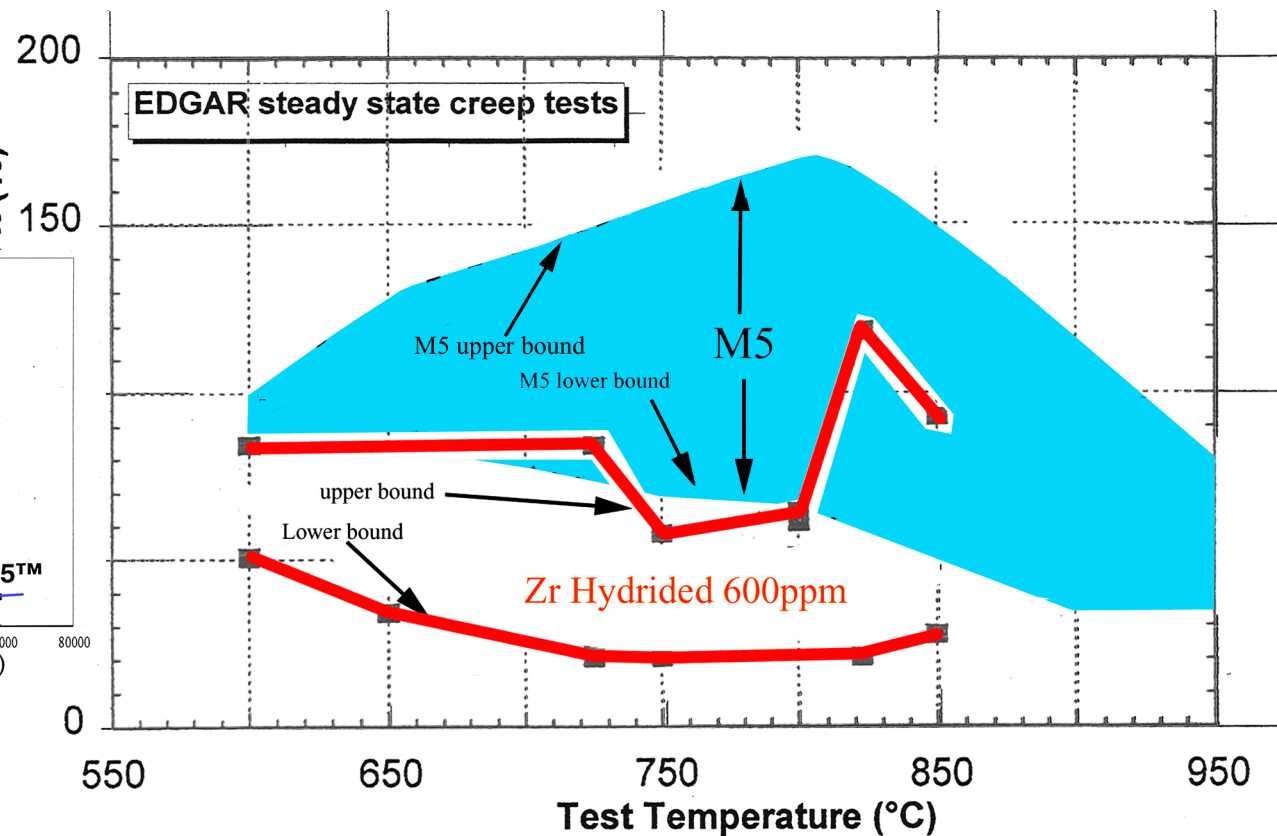
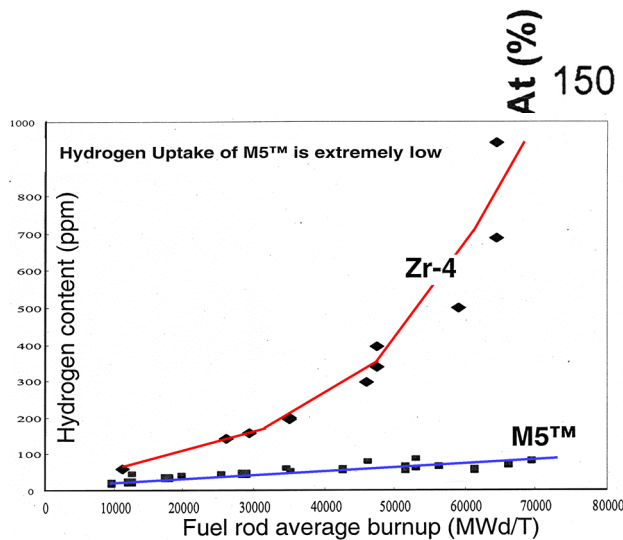




Corrosion and hydrogen uptakes are lowered for modern clad alloys : ductility is better kept. Lower the corrosion, lower the associated H uptake, better the ductility, bigger the balloons

higher blockage ratio will be likely for modern alloys

■ See references 7 to 9



Creep tests not relevant to determine the balloon sizes

- **Isothermal creep tests** are relevant to determine the cladding creep laws NOT the cladding strains at failure under LOCA conditions
- The international community is using the **thermal ramp test** results to assess the cladding strains at failure under LOCA conditions

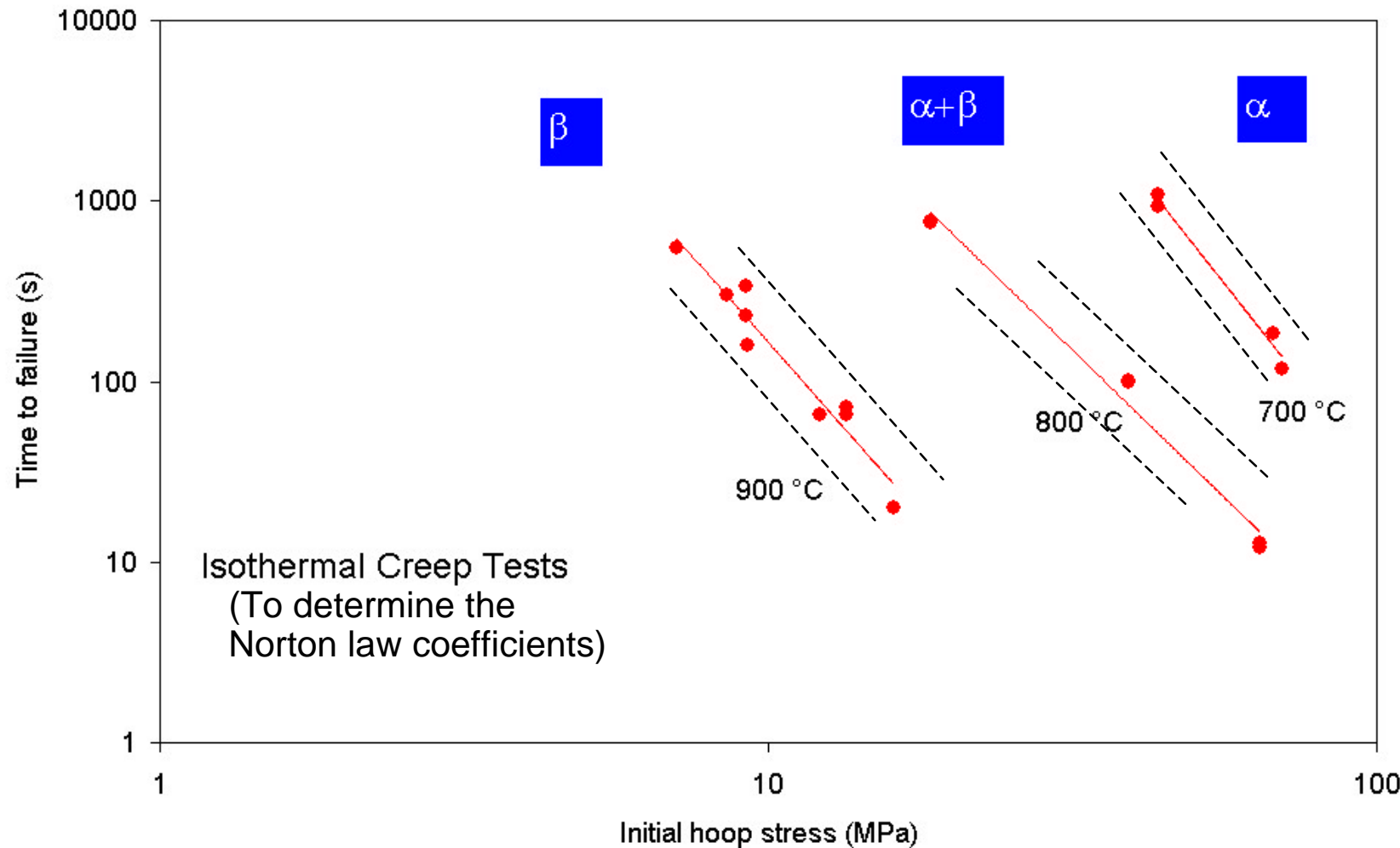
LOCA design approach

- To simulate and analyze the clad ballooning behavior during the blowdown phase of a LOCA transient one needs :
 - To know (at each time of the transient) the metallurgical state of the cladding (α and β phases distribution),
 - To identify the creep laws for the 3 temperature domains : α , $\alpha+\beta$ et β ,
 - To characterize the cladding strains at failure
- *The approach is global : the impact of one parameter has to be investigated throughout the entire process.*

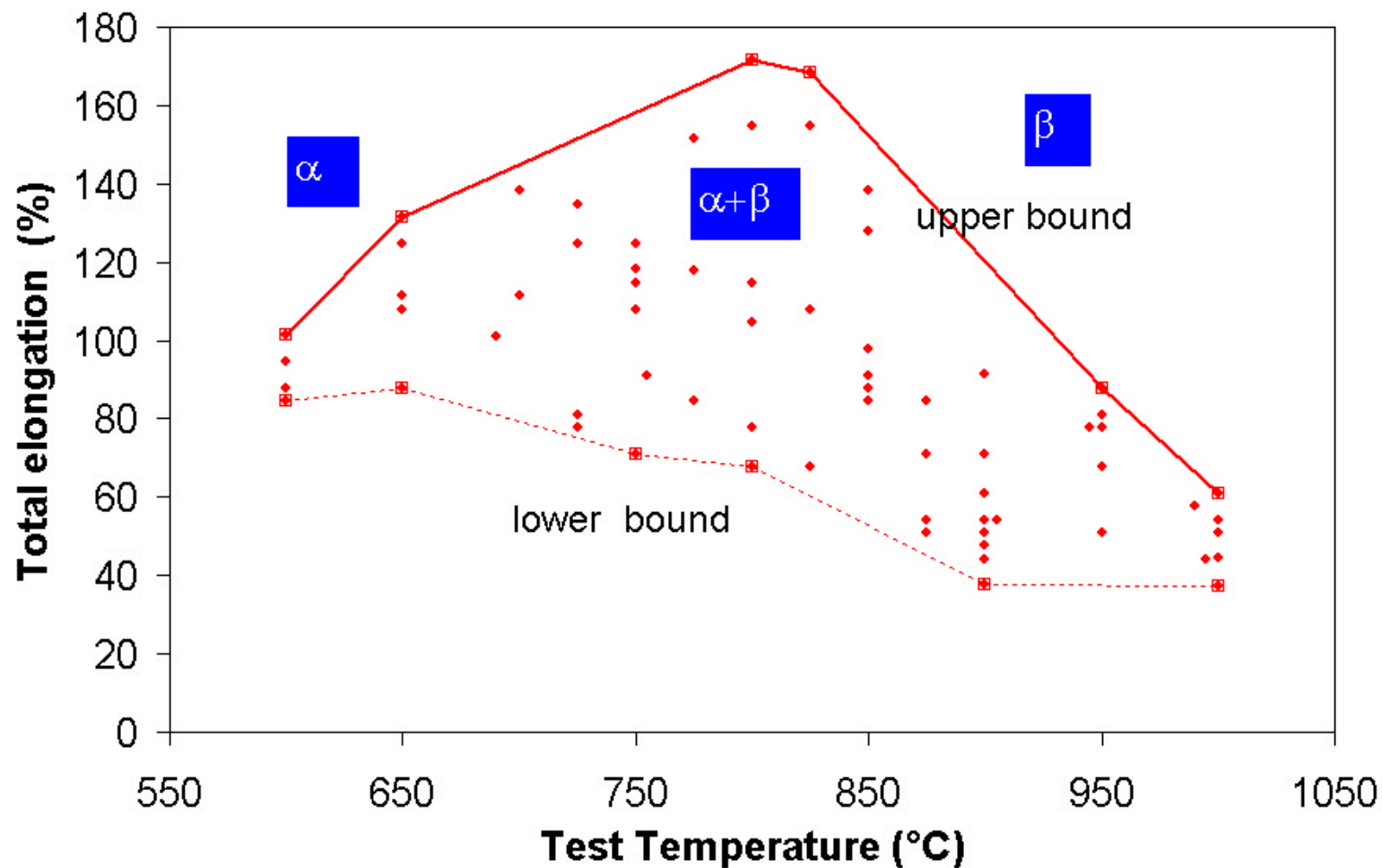
Separate effect tests

- Separate effect tests were performed on as received and pre-hydrated conditions to provide the requested data :
 - Metallurgical tests to determine the transition temperatures and the phase transformation kinetics
 - » At equilibrium and in heating and cooling conditions
 - Isothermal creep tests (rod internal pressure is maintained constant) to determine the mechanical laws
 - » Isothermal conditions
 - Thermal Ramp tests to determine the strains at failure
 - » Prototypical of a LOCA thermal transient

Creep tests on as-received M5 : Time to failure (t_R) vs S_0

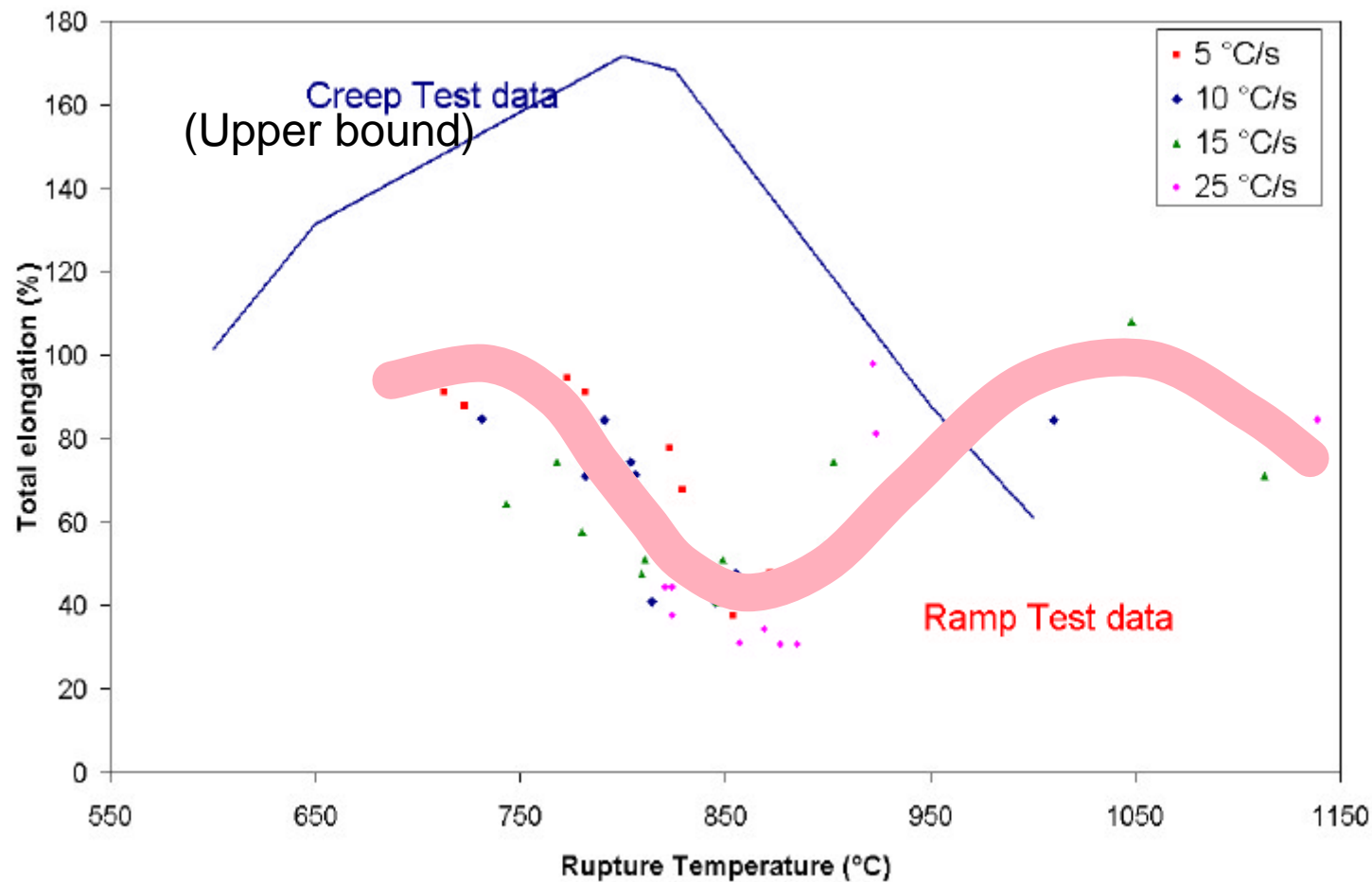


Creep tests on as-received M5: ductility



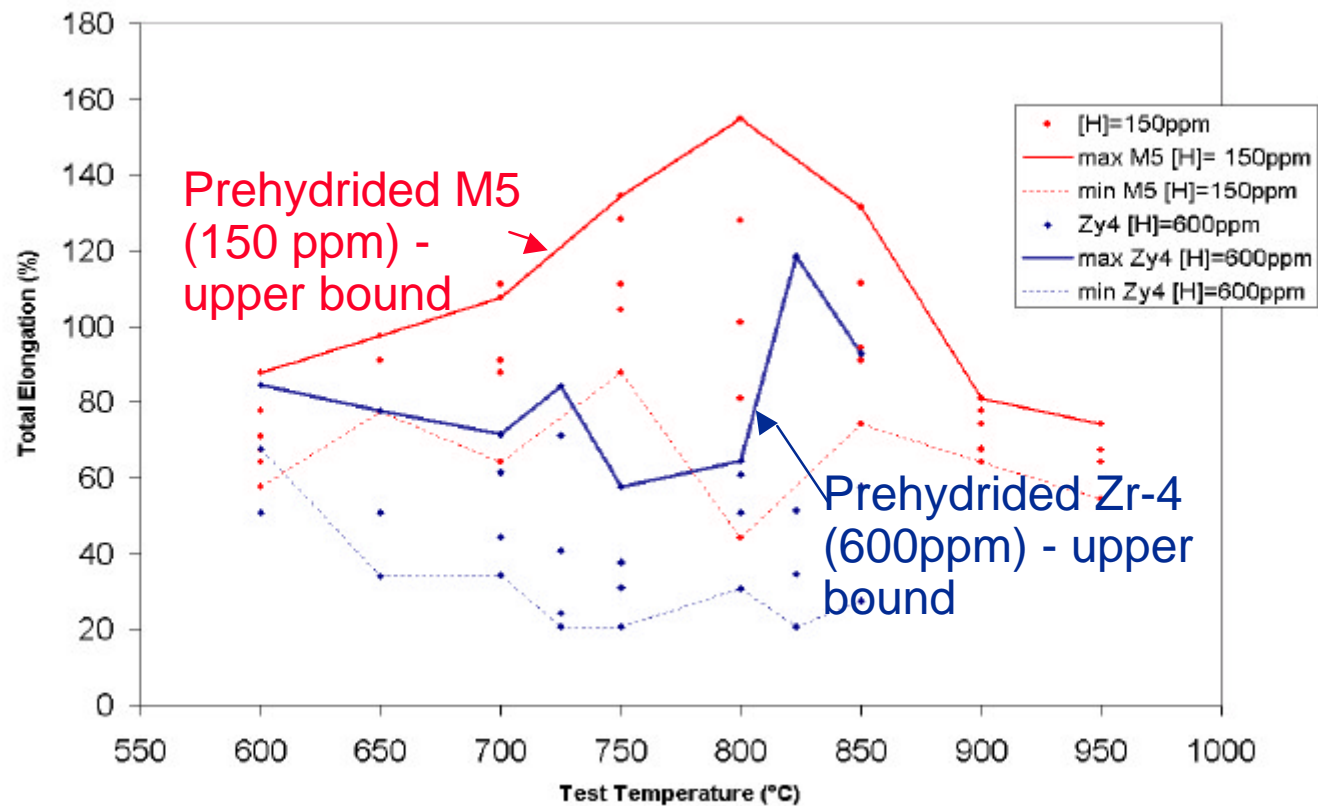
Temperature ramps on as- received M5 : ductility

Ductility decreases in the ramp test



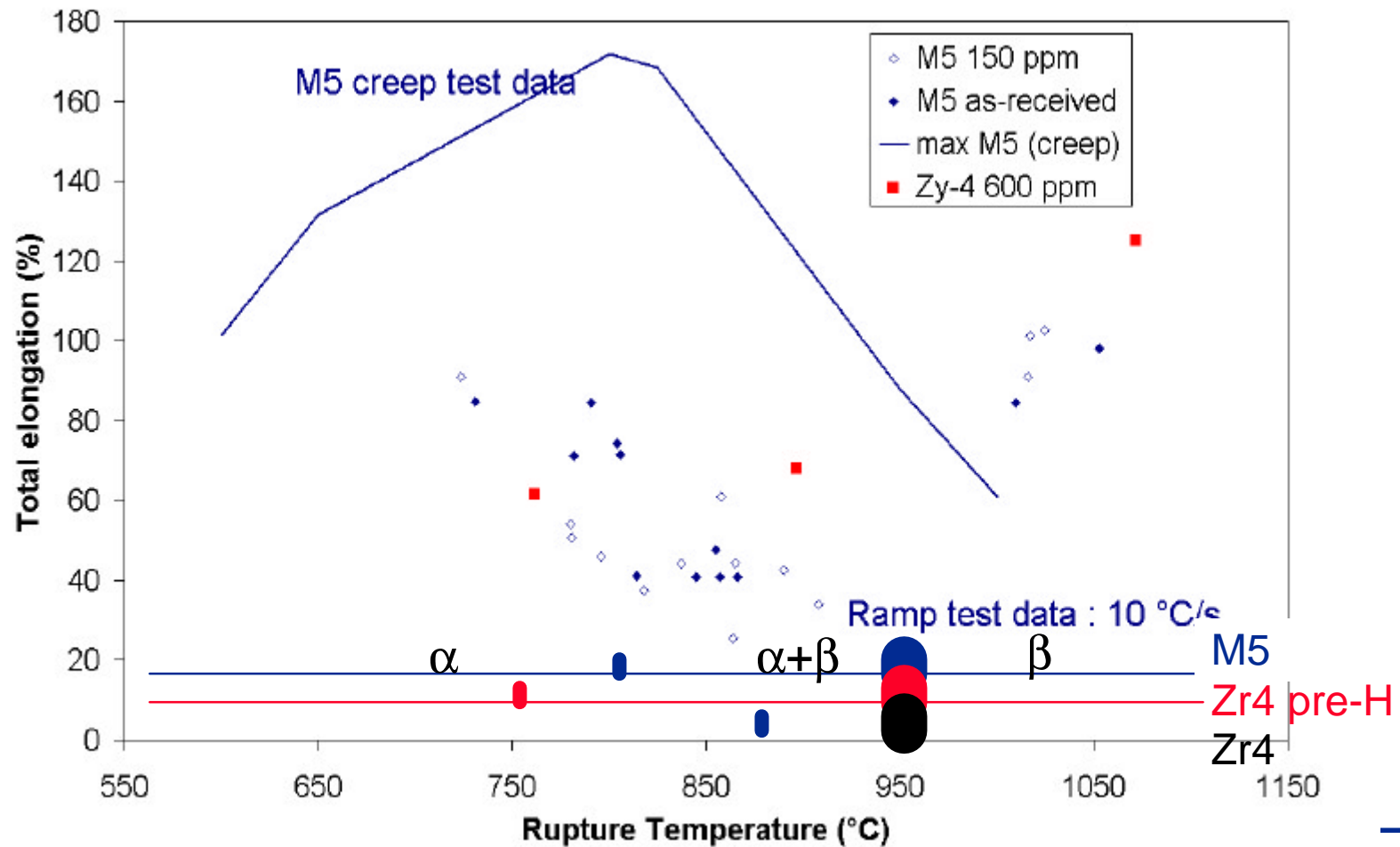
M5 (150 ppm) versus Zy-4 (600 ppm)

- Although Zy-4 600 ppm exhibits a lower ductility than M5 150 ppm in the **creep** tests.....



M5 150 ppm versus Zy-4 600 ppm

.....both alloys exhibit similar ductility in the **ramp tests**



Conclusion

- Creep tests are not relevant to conclude on ballooning under LOCA conditions
- **As-received and pre-hydrided** M5 and prehydrided Zy4 exhibit similar behavior in term of strains at failure (according to the available data : the data base has to be completed)
 - Similar maximum strains at failure for M5 and Zy4
 - α and β humps slightly shifted for M5 : same transient may give different strains for M5 and Zy4, so that no significant change is expected in the design analysis conclusions