International Conference on Fast Reactors
and Related Fuel Cycles: Safe Technologies
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ACHIEVEMENT AND NEW CHALLENGES FOR HIGH PERFORMANCE MATERIALS IN EUROPE

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Outline

- Motivation:
  - the European approach for nuclear energy sustainability
  - Requirements driving materials selection
- Materials Options: three examples
- European Initiatives

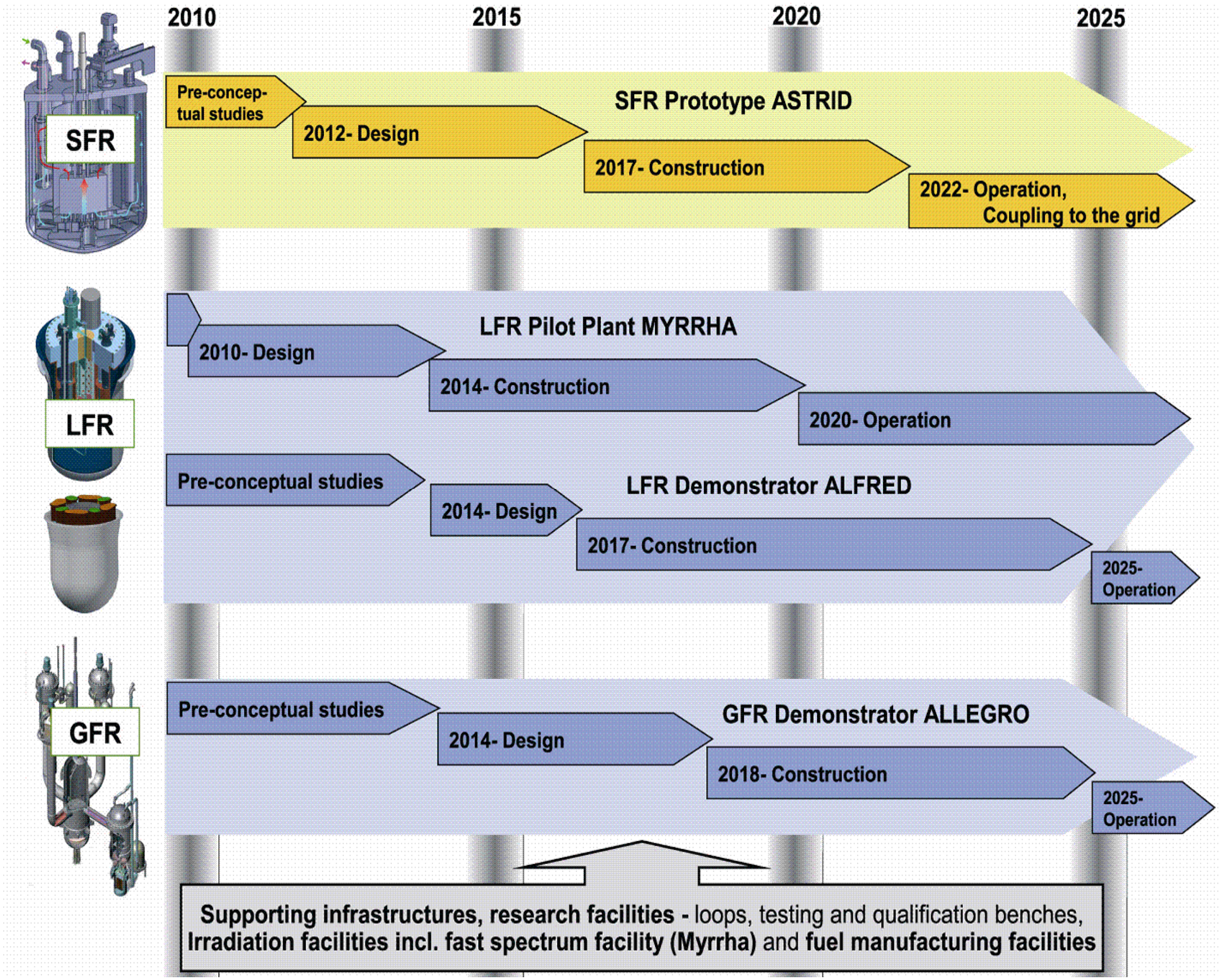
The European approach for nuclear energy sustainability: ESNII

Introduce in the nuclear technology development more sustainability aspects as e.g.

- better use of resources;
- less waste;
- higher system efficiency;

All this while keeping very high safety standards

The European approach for nuclear energy sustainability: ESNII



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Requirements driving materials selection

- fast neutron spectrum
- higher fuel burn-up
- higher temperature and temperature differences
- other coolants than water
- thermal and mechanical, static and cyclic stresses
- long-term operation
- ….
- **Safety**: materials integrity during normal operation and transient conditions: defence-in-depth (multibarrier concept)

Physical Barriers

To prevent uncontrolled release of radioactive materials to the environment:

1) fuel matrix + 2) cladding

3) the reactor coolant pressure boundary (vessel and primary system)

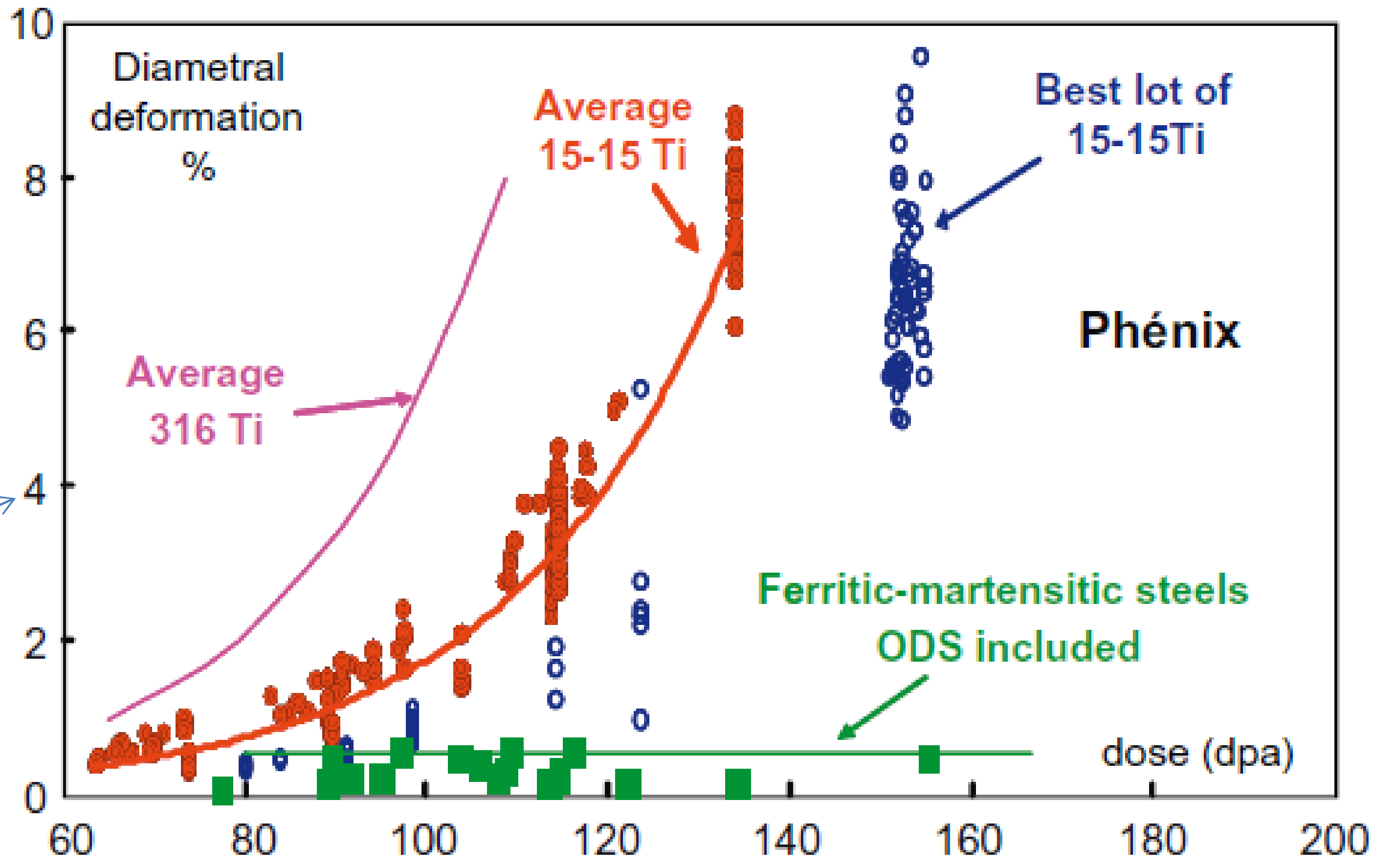
4) Steel liner + 5) containment

Material options: examples for three components

component	material	Innovation / innovative aspects
Fuel cladding	Reference: Austenitic steel (15Cr-15Ni-Ti stabilized)	Alternative to the reference is the development of: • Advanced Austenitic • ODS • F/M steel • $SiC_f SiC$ • MAX Phases
Reactor Vessel and primary system	Austenitic Steel F/M Steel	Estimation of long operational time Welding of thick components
Steam Generator	F/M Steels Ni alloys	Introduce relevant F/M Steels data in Design code (e.g. RCC-MRx) Assess optimal alloy composition to withstand high temperature requirements in GFR (and V/HTR)

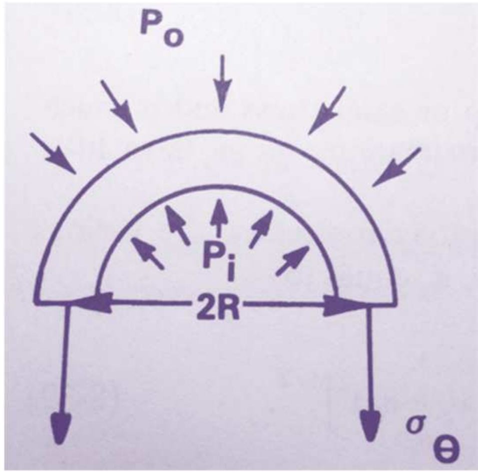
Fuel Cladding: limits of austenitic steel

For reference austenitic: Embrittlement limit



P. Dubuisson et al. / Journal of Nuclear Materials 428 (2012) 6–12

Fuel Cladding: Safety



Hoop Stress

$$\sigma_\theta = (P_i - P_0)\frac{R}{w}$$

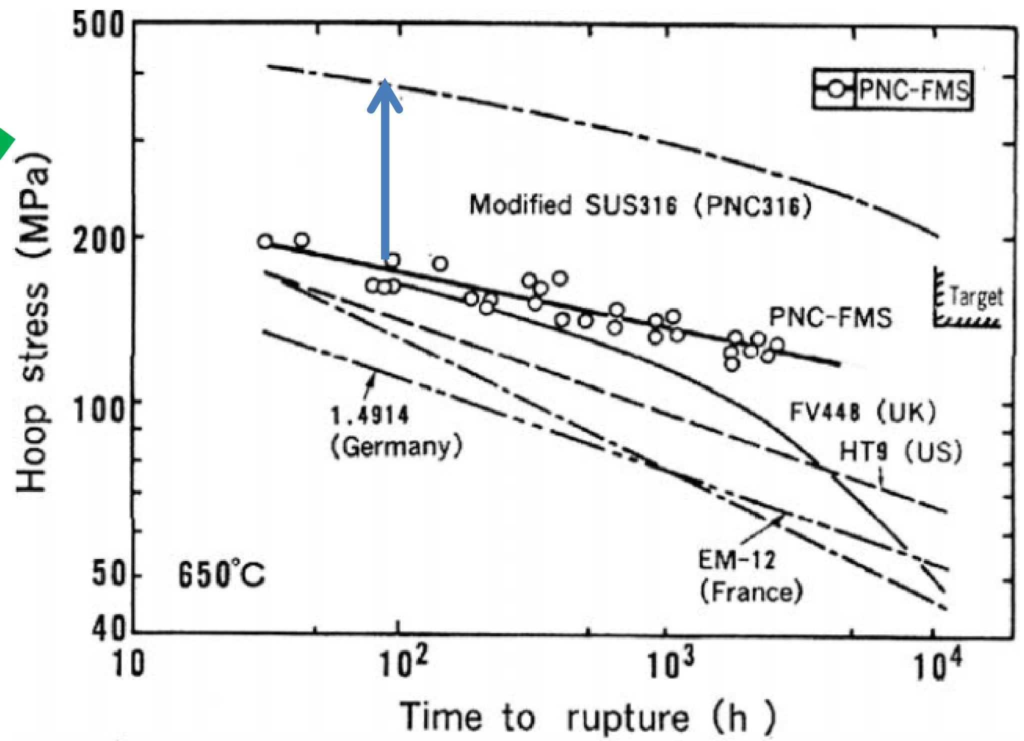
P_i = corresponding to fission gas plenum pressure

P_0 = corresponding to bulk coolant pressure at axial position

R = radius of cladding

w = cladding wall thickness

stress to rupture strength of clad
F/M vs. Austentic steels:
can pose safety related limits on F/M steel



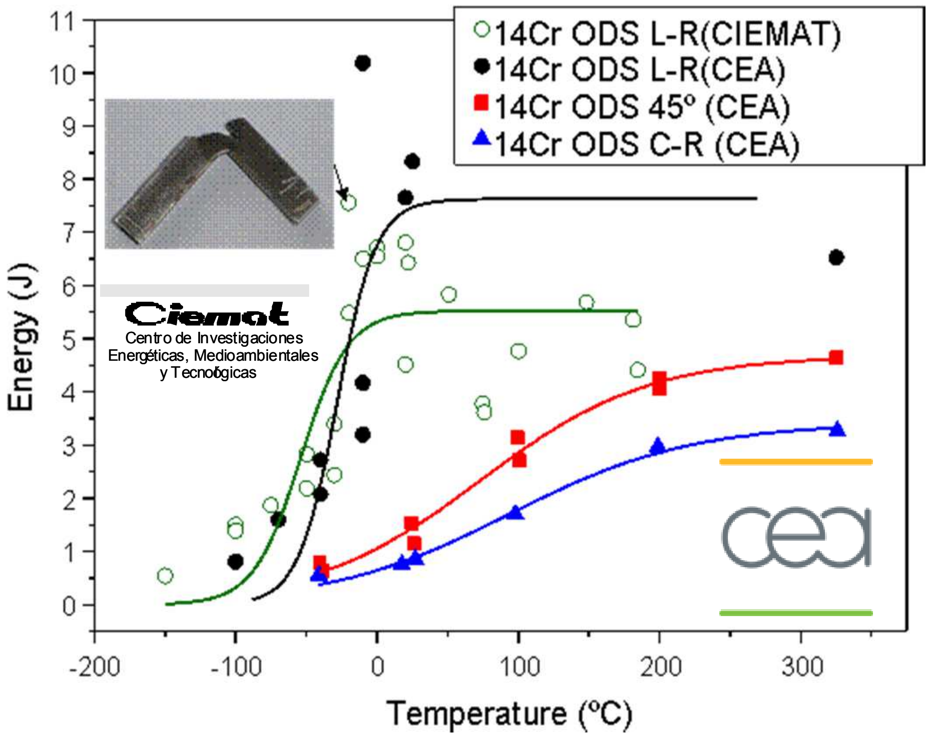
J.S. Cheon et al. / Journal of Nuclear Materials 392 (2009) 324–330

Fuel Cladding Innovation: ODS – example of issues

Anisotropy

Requirements
- Integrity and low deformation in service
- Good impact properties before and after irradiation
- Good internal and external corrosion resistance
- No insurmountable effect during the reprocessing of the fuel

ODS Issues
- definition of reference composition
- reproducibility
- Up-scale to industrial quantities
- Weldability
- Anisotropy
- Mechanical Performance under irradiation
- ….



Impact test results from CEA and CIEMAT on 14Cr ODS – Results from GETMAT project

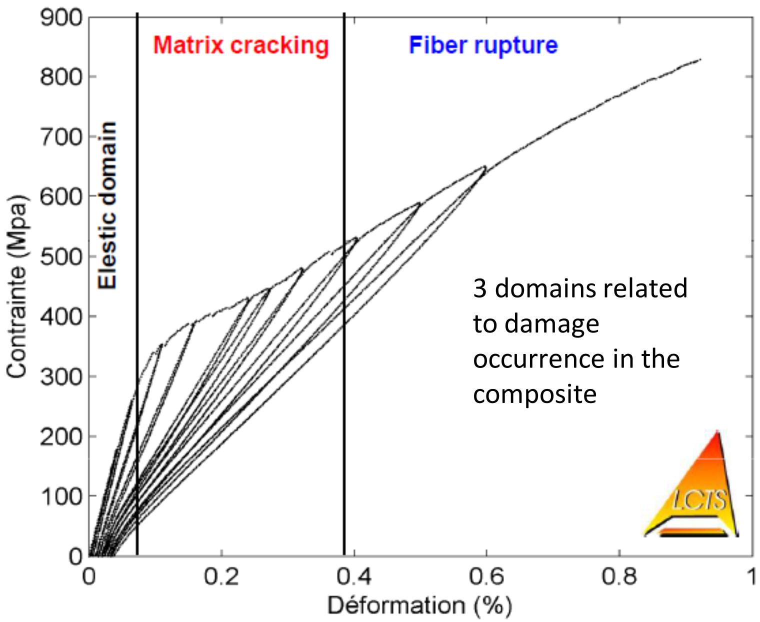
Courtesy M. Serrano, CIEMAT 2012

Fuel Cladding Innovation: SiC_fSiC – examples of issues

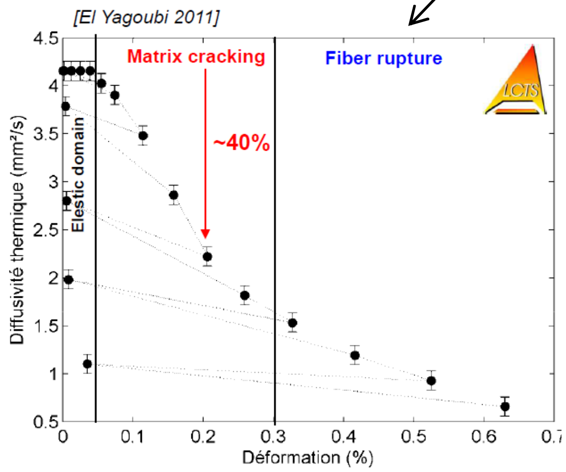
Non linear response to Th-mechanical stresses depends from SiC_fSiC architecture, constituents, ….

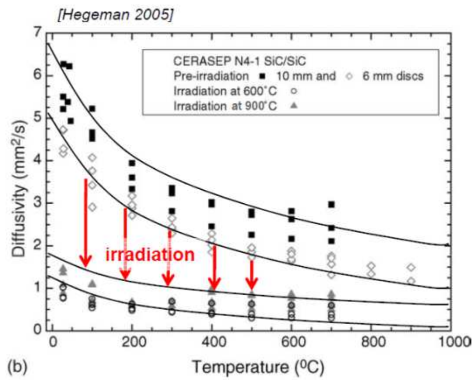
SiC_fSiC shows Matrix cracking in the elastic domain

Thermal conductivity drops with Matrix cracking and irradiation

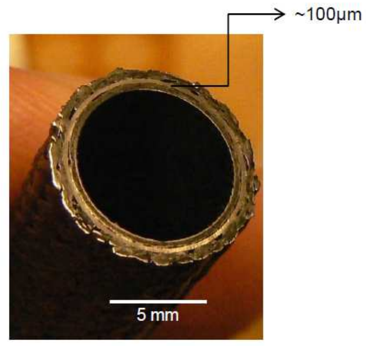


Tensile Test on a minicomposite
[El Yagoubi 2011]





Leak tightness is lost with Matrix cracking: can be addressed through the sandwich concept (CEA)

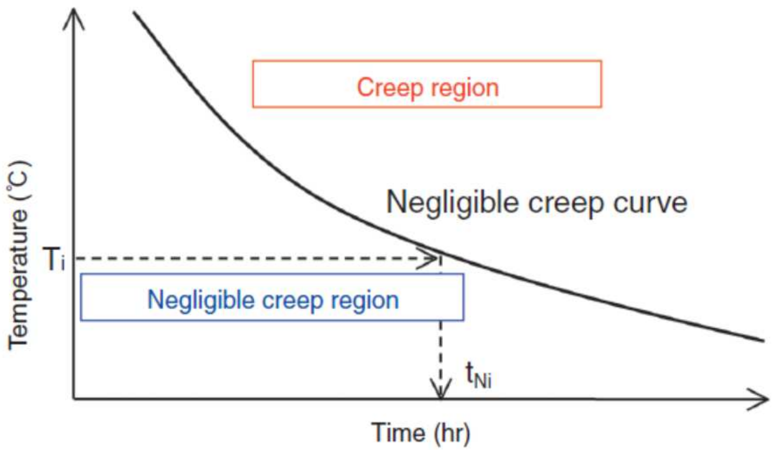


Examples of sandwich cladding prototype
SiC/SiC + metallic liner + SiC/SiC

Source: M. Le Flem, CEA 2012

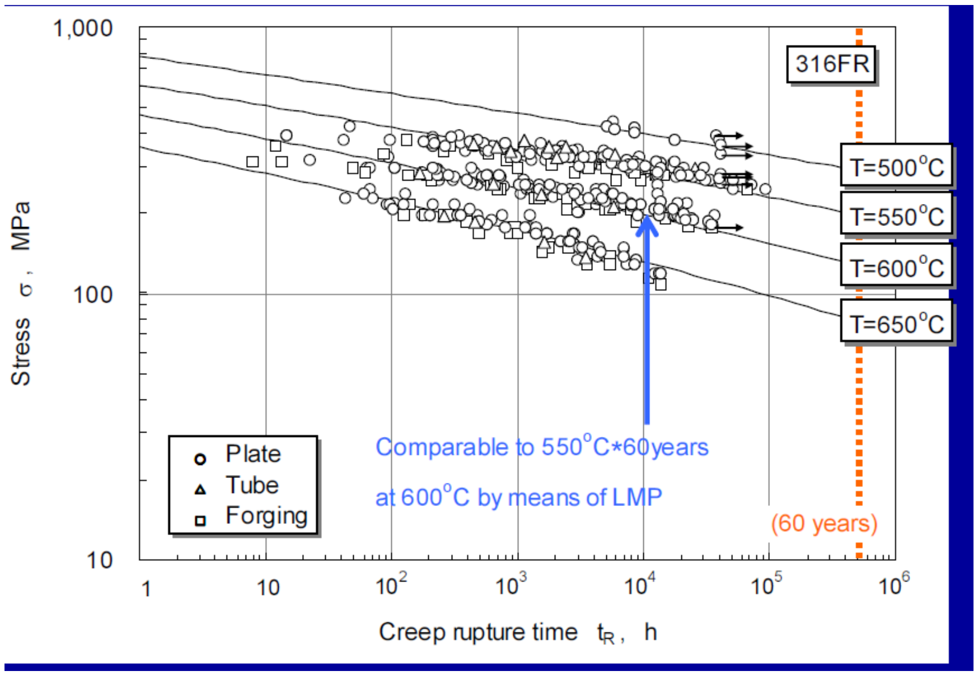
Reactor Vessel: AISI 316 LN (reference for LMFR)

Reactor vessel has to be operate in a negligible creep regime at the temperature considered



M. Serrano CIEMAT, 2011

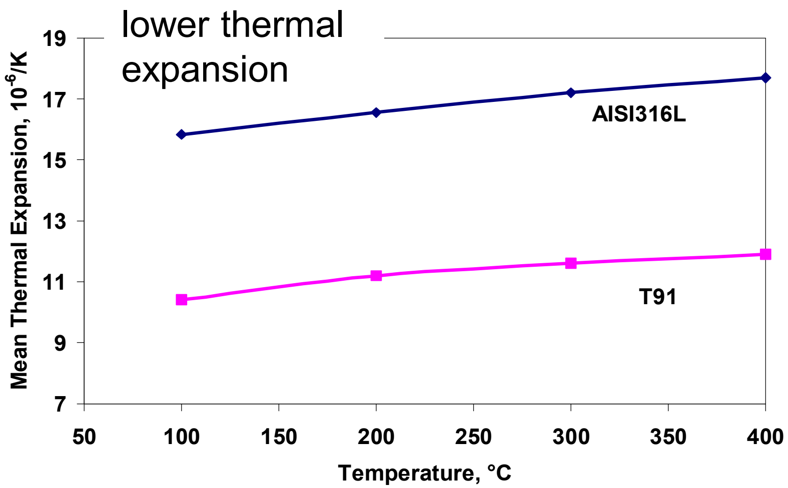
60-year design at high temperature (up to 550 °C)
Acquisition of material data:
- Long-term creep,
- long-term creep-fatigue,
- environmental effects (aging, corrosion, irradiation)

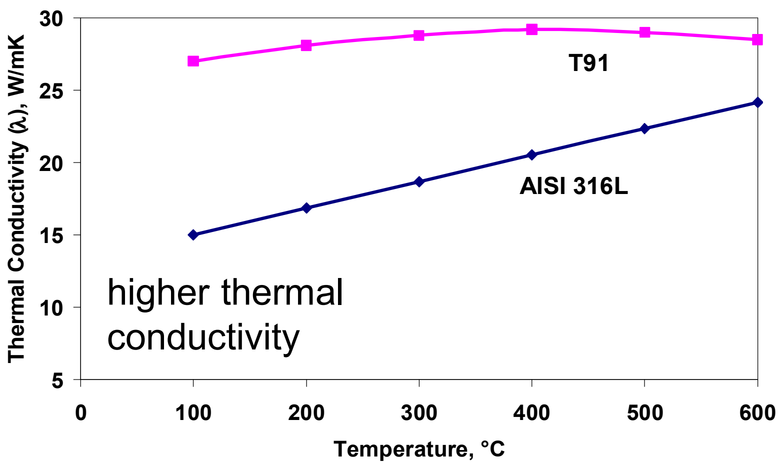


T. Asayama JAEA, 2009

SG: proposed material 9Cr F/M steel

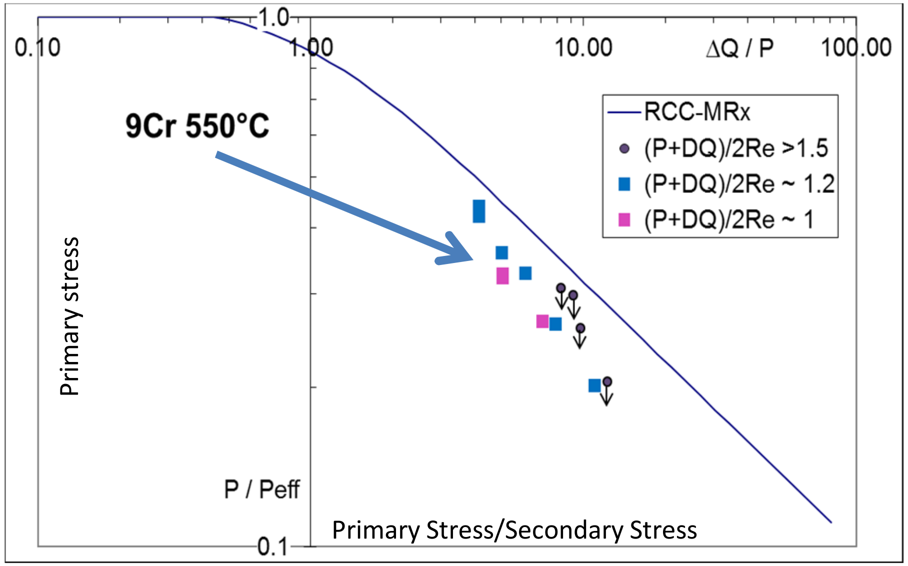
Advantage: good thermal properties





Issues to be solved:
cyclic softening, ratcheting, creep-fatigue, ...

The efficiency diagram as in RCC-MRx (for other steel) is not applicable to T91



tension - torsion tests

O. Ancelet, T. Lebarbé, CEA
MATTER Project, 2013

EU Initiatives: JP on Nuclear Materials

Joint Program on Nuclear Materials (JPNM) - Concetta Fazio, KIT

SP1	• Support to the European Sustainable Nuclear Industrial Initiative (ESNII) - **Karl Fredrik Nilsson, JRC IET**
SP2	• Oxide Dispersed Strengthened (ODS) Steels **Yann de Carlan, CEA**
SP3	• Refractory materials: ceramic composites and metal-based alloys - **Marie-Francoise Maday, ENEA**
SP4	• Modelling: Correlation, Simulation and Experimental Validation - **Lorenzo Malerba, SCK-CEN**
SP5	• Manufacturing, irradiation and qualification of advanced fuels - **J. Somers, JRC ITU**
SP6	• Modelling and separate effect experiments on fuels **M. Bertolus, CEA**

EU Initiatives: JPNM links

- **SNETP**: Participation to the definition of the European Strategic Research and Innovation Agenda

- **SET-Plan**: Being part of the European Energy Research Alliance (EERA) and contribution to the Materials for Energy road-map

- **Euratom**:
    - GETMAT Project on ODS and modelling of Fe-Cr alloys (almost finished)
    - MATTER Project (Coordinator P. Agostini, ENEA) on ESNII releavant structural materials

    NEW*NEW*NEW: MatISSE (Coordinator C. Cabet, CEA) on clad material ODS and SiCSiC tubes as well fuel /clad interaction relevant for ESNII

Thank you
for your
attention