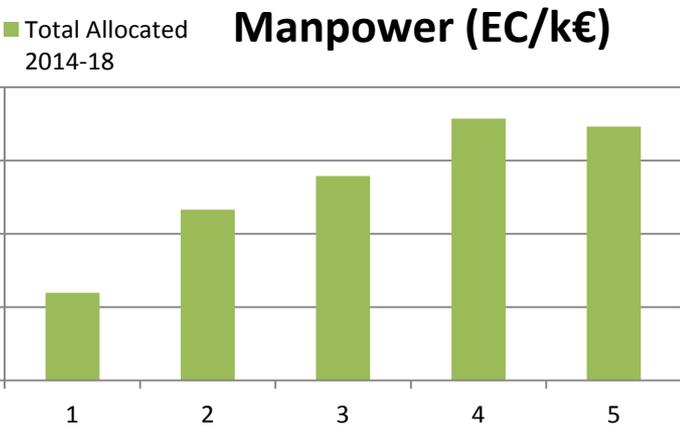
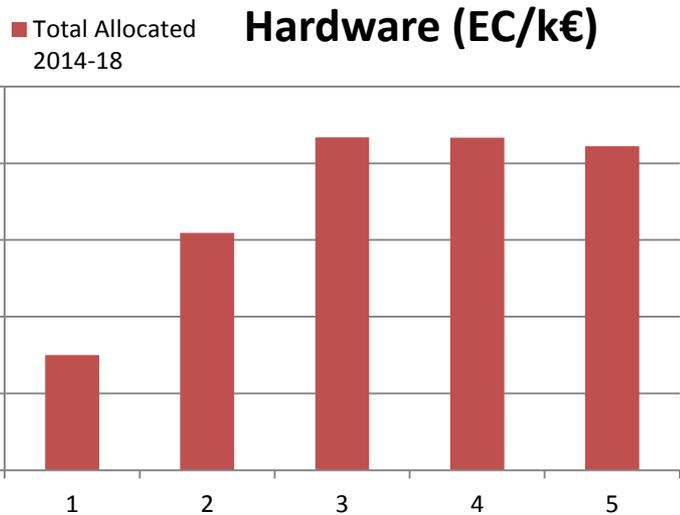
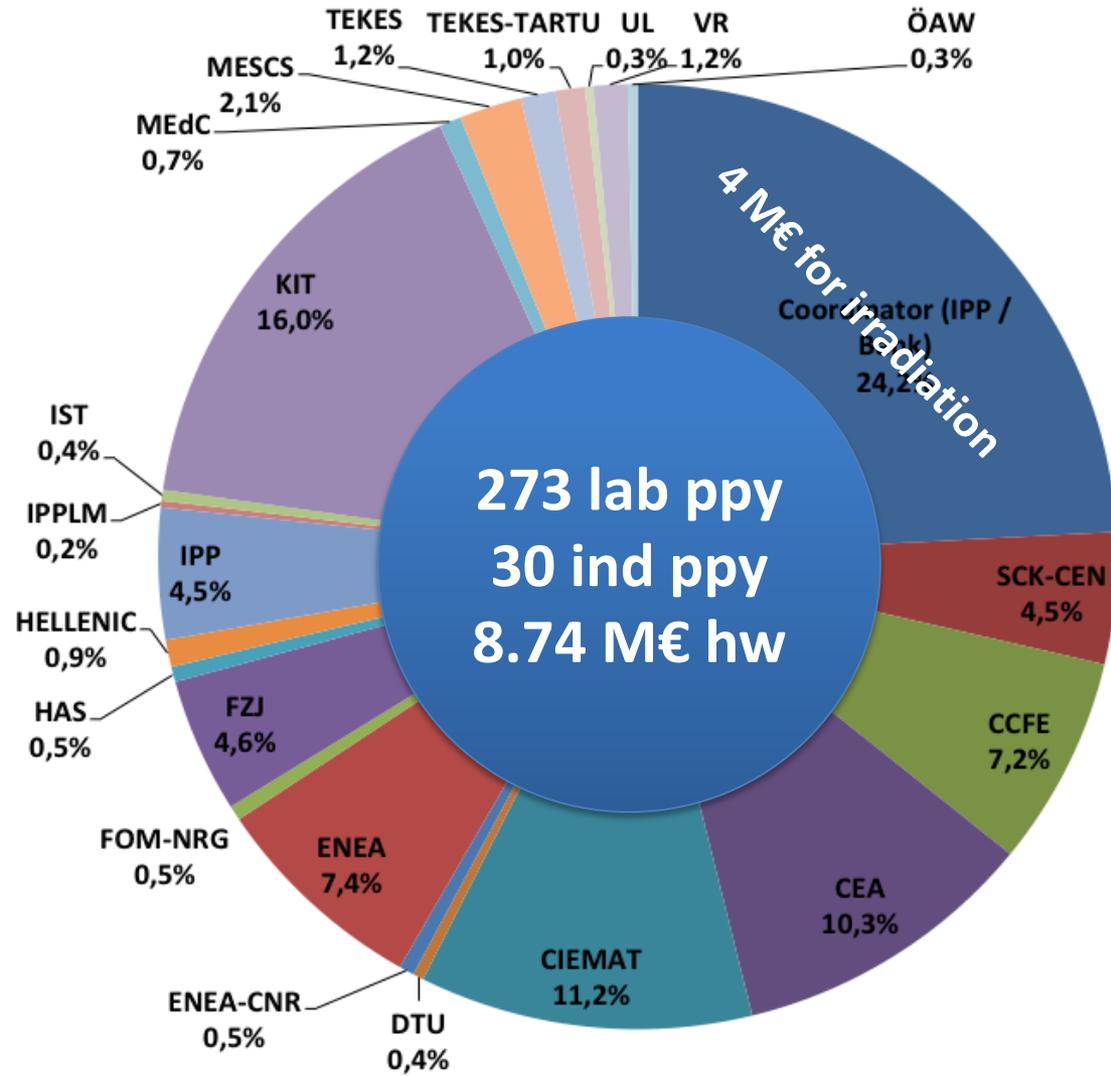


# *The EUROfusion program on 9CrWVTa steels*

M. Rieth, P. Fernandez, J. Henry, J. Hoffmann, L. Pilloni, A. Puype, N. de Wispelaere



## Total Allocated Resources by RU





- **Fill gaps in the database and develop design codes** for the baseline materials including irradiation data
- **Development of new materials** to mitigate requirements of advanced DEMO component designs
- **Demonstration of the production** of such materials in processes scalable to **industrial standards**
- **Characterization & Documentation** of the properties of such materials
- **Develop models for neutron radiation effects**, specifically microstructural evolution and embrittlement, in iron alloys, steels, tungsten, and degradation of functional materials



## ODS steel: Fabrication & Demonstration

- Production of a 100 kg 14%Cr ODS steel batch by mechanical alloying
  - Plates: thickness 2 mm, size 2 m<sup>2</sup>
  - Demonstration of applicability to first wall
- Alternatives to mechanical alloying (feasibility studies and industrial large-scale fabrication)

## Optimization of RAFM steels for possible water cooling

- Specific thermal treatments (for optimum DBTT)
- Change of chemical composition (for optimum DBTT)

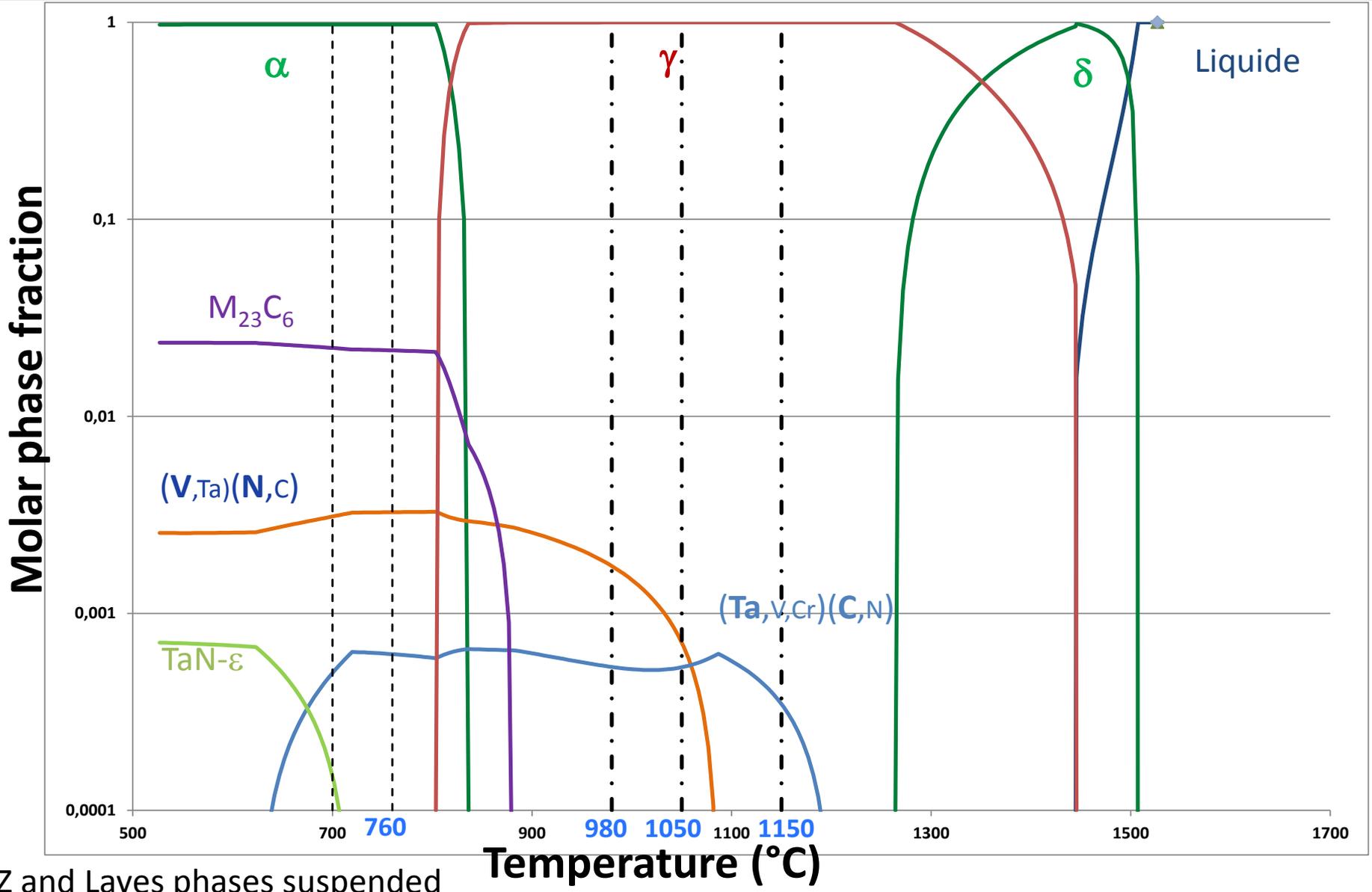
**focus of this presentation**

## Development of RAFM steels for high temperature applications

- Specific thermal treatments on EUROFER
- Special thermo-mechanical treatments (TMT)
- Fine tuning of the chemical composition

## RAFM: Reduced Activating Ferritic-Martensitic

# Effect of Extreme Heat Treatments: EUROFER



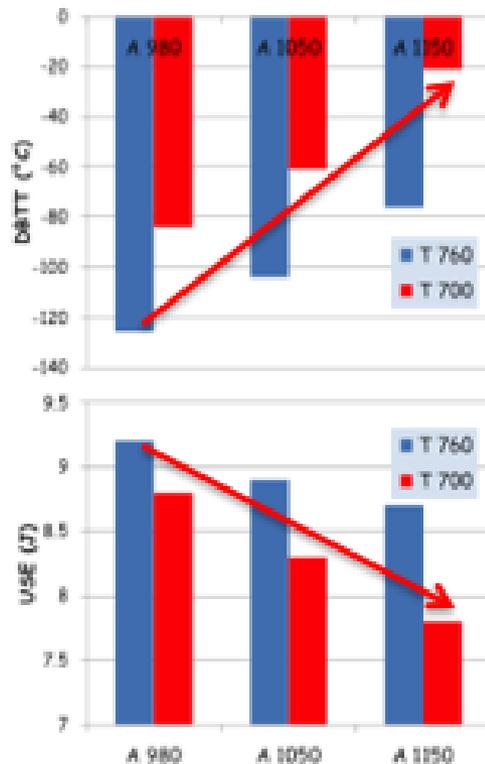
# Advanced Steels: High Temp. Applications



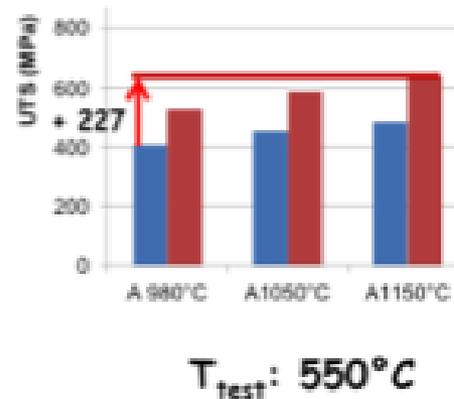
## Adjustment of EUROFER properties by varying heat treatment temperatures

- Austenitisation: 980 °C – 1150 °C
- Tempering: 700 °C – 760 °C

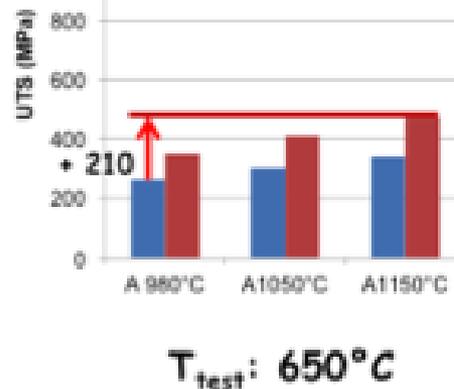
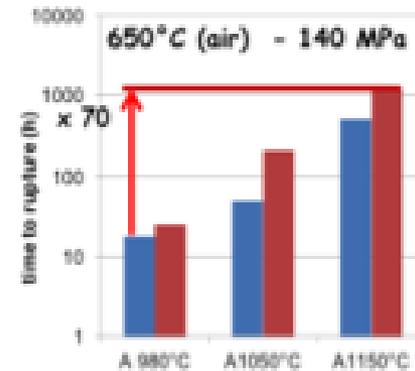
### Charpy Properties



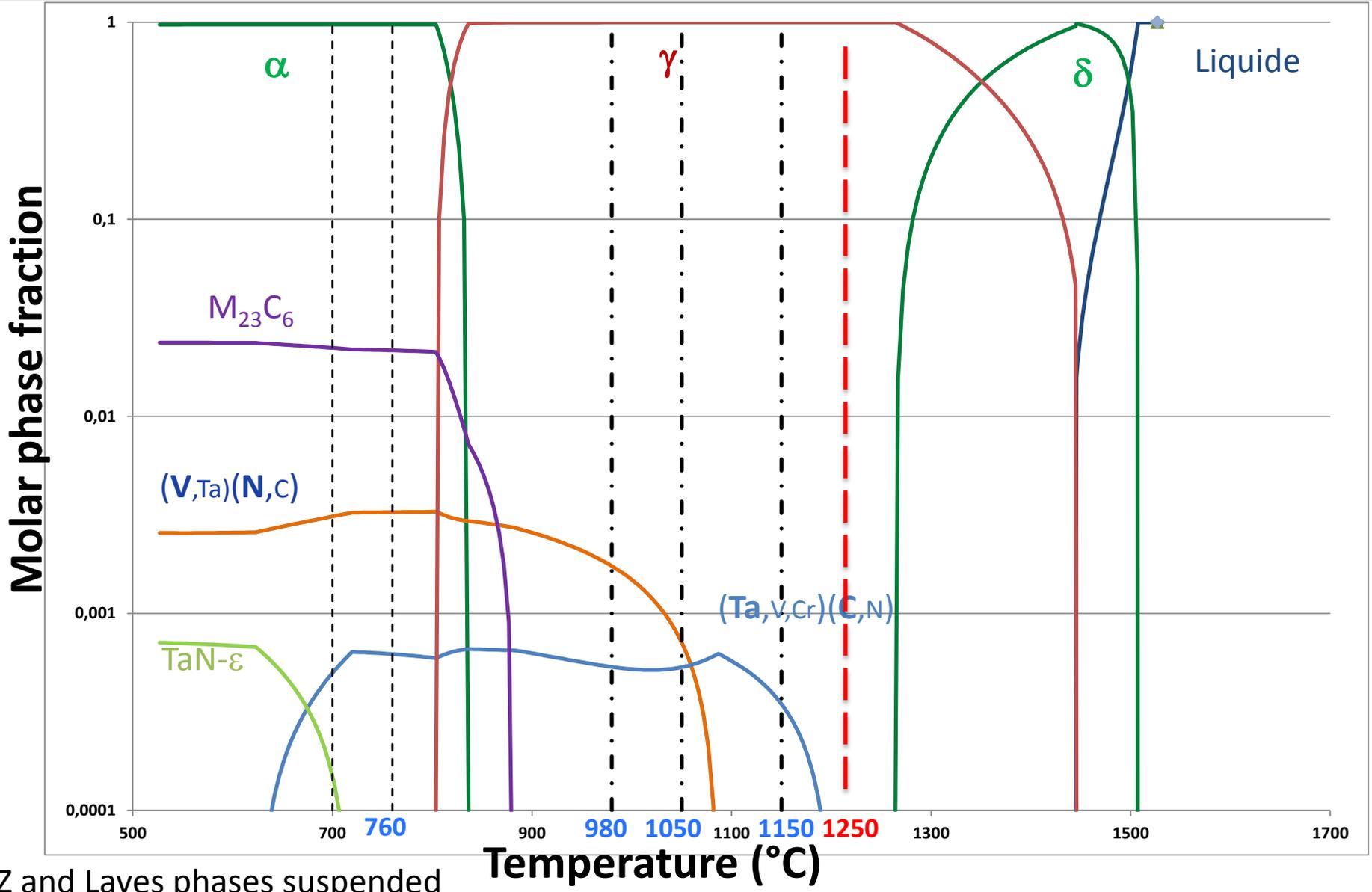
### Tensile Strength



### Creep Strength



# Effect of Extreme Thermo-Mechanical Treatments

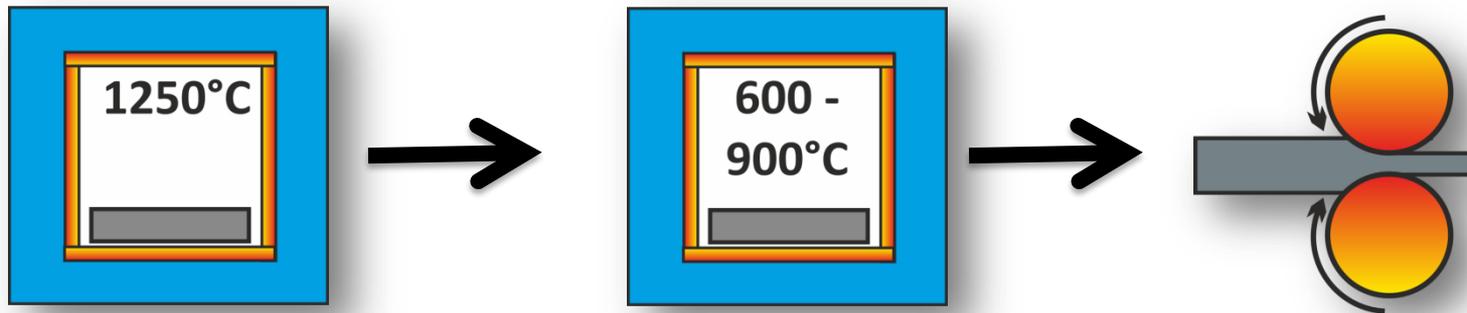


Z and Laves phases suspended



## Very high austenitization temperature for full dissolution of secondary phases

- Increase PAG size for improved creep strength (lower diffusion)
- Possible problem: Retain enough ductility at RT



Dissolution of all secondary phases (carbides, nitrides)

Cooling to rolling temperature in furnace (metastable austenite phase)

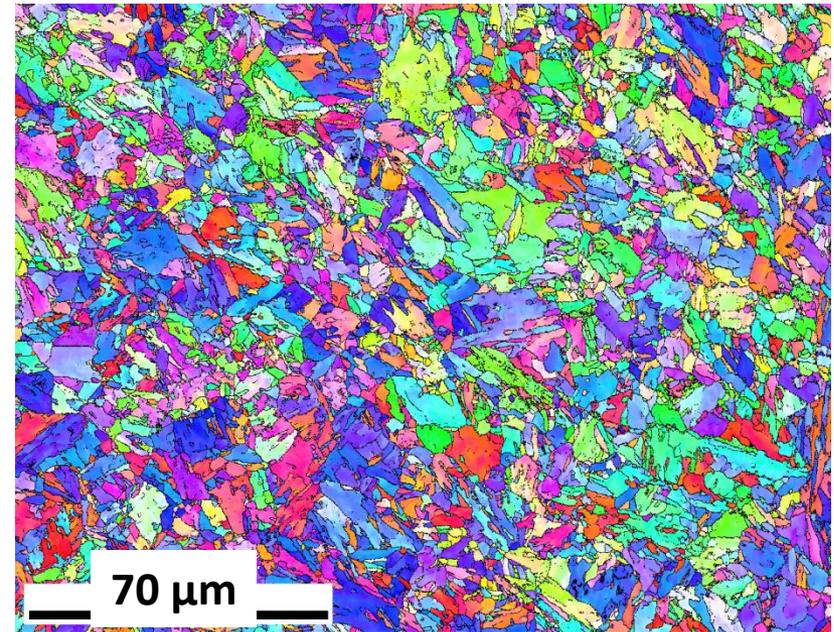
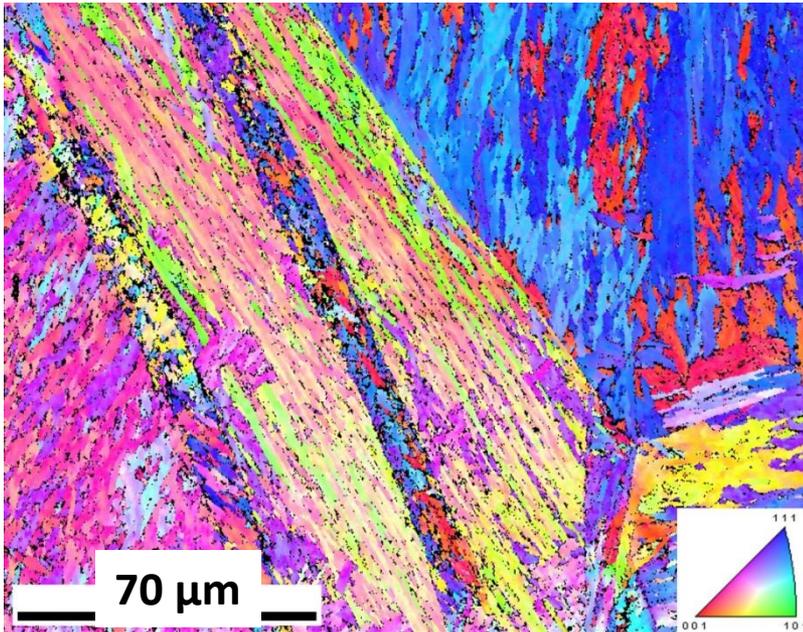
Rolling in the austenite phase



## EUROFER

Extreme TMT

Standard Heat Treatment



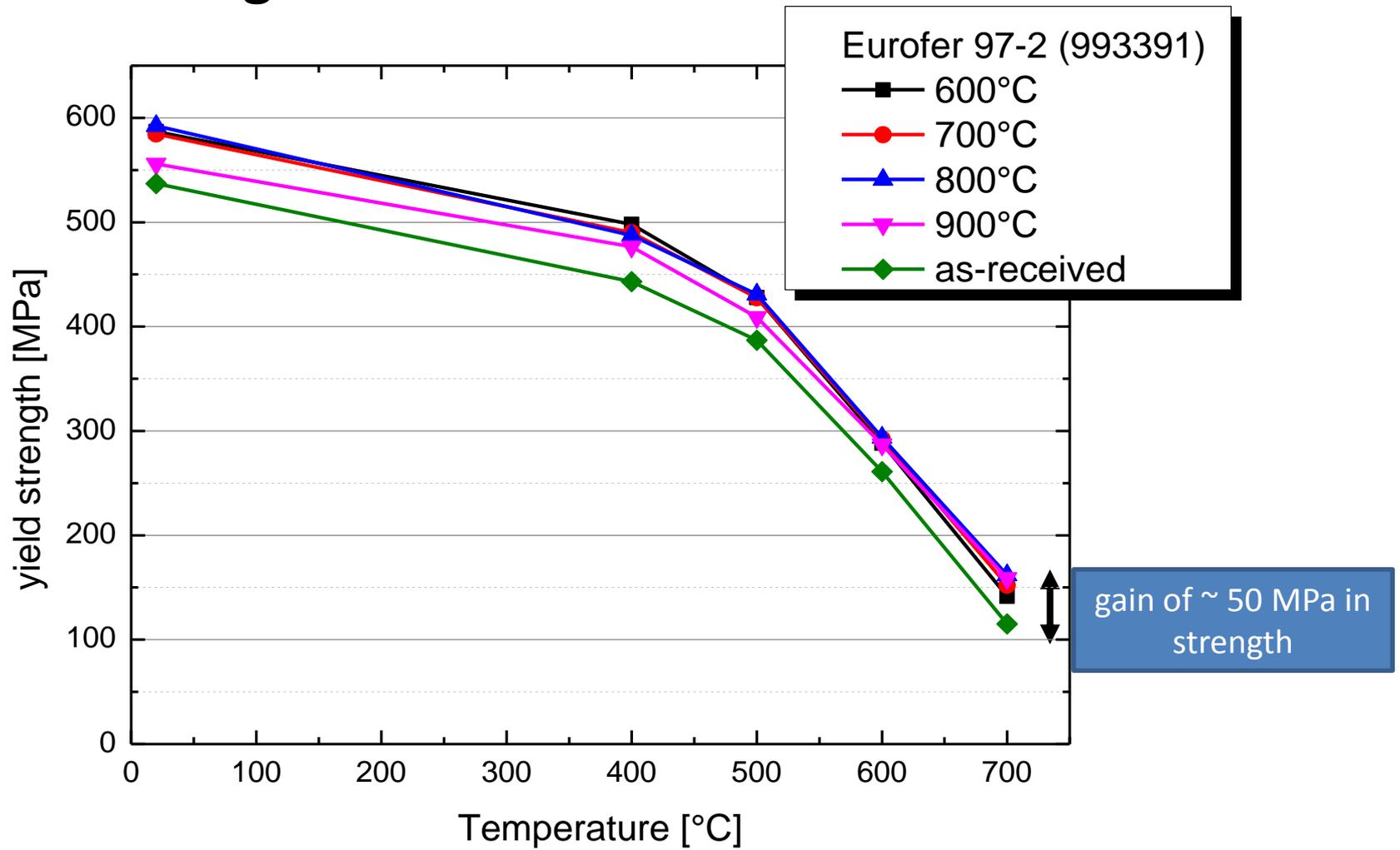
1250°C/30 min + TMT at 800°C + 750°C / 2h

1050°C / 30min + 750°C / 2h

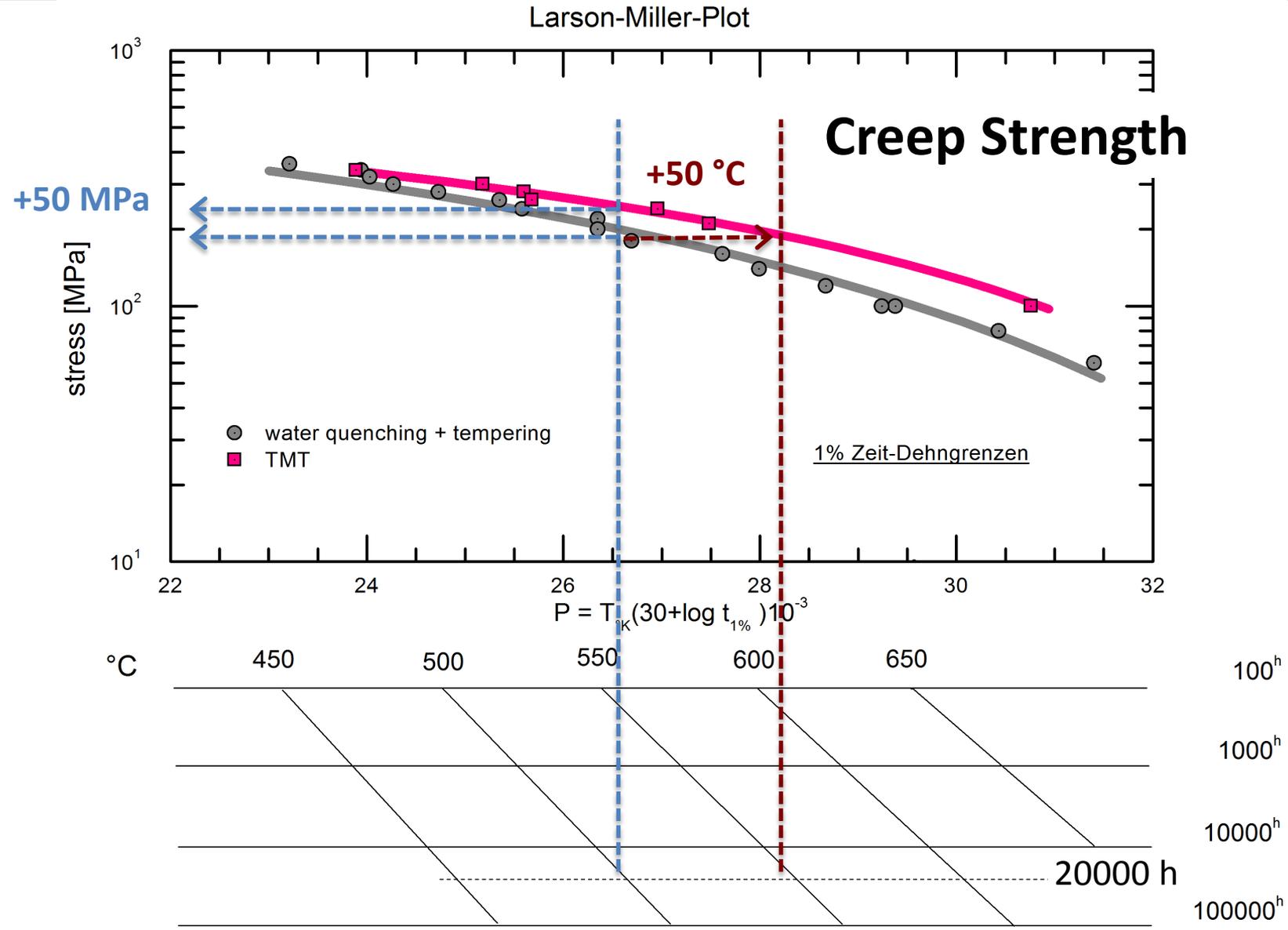
- Very large prior austenite grains (0.5-1 mm)
- But fine martensite laths



## Tensile Strength

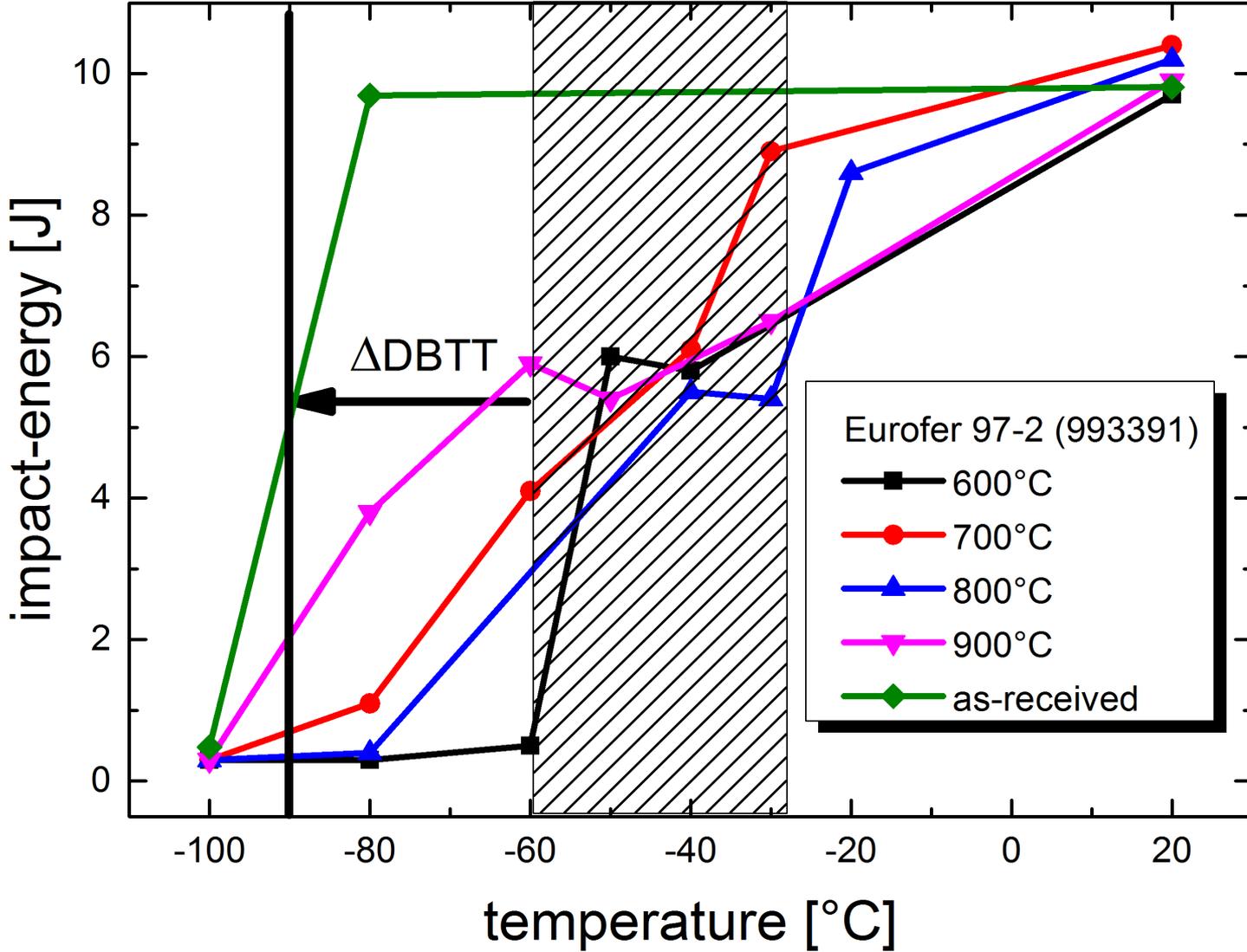


# Effect of Extreme Thermo-Mechanical Treatments





## DBTT Shift (Charpy)





## Objective(s):

1. Selection a of chemical compositions of 9%Cr RAFM steels with the aim of improving high temperature properties (creep and creep fatigue properties in particular) as compared to standard Eurofer.
2. Determination of the hot rolling temperature range by using the obtained phase diagrams.

## Method(s):

The modified chemical compositions will be obtained on the basis of thermodynamic calculations of  $M_x-(C,N)_y$  phases in 9Cr(1-2W)VTa steels. Contents in C, N, Ta, V will be varied and the influence of W and Ti will be assessed.

→ **JMatPro & ThermoCalc Software**

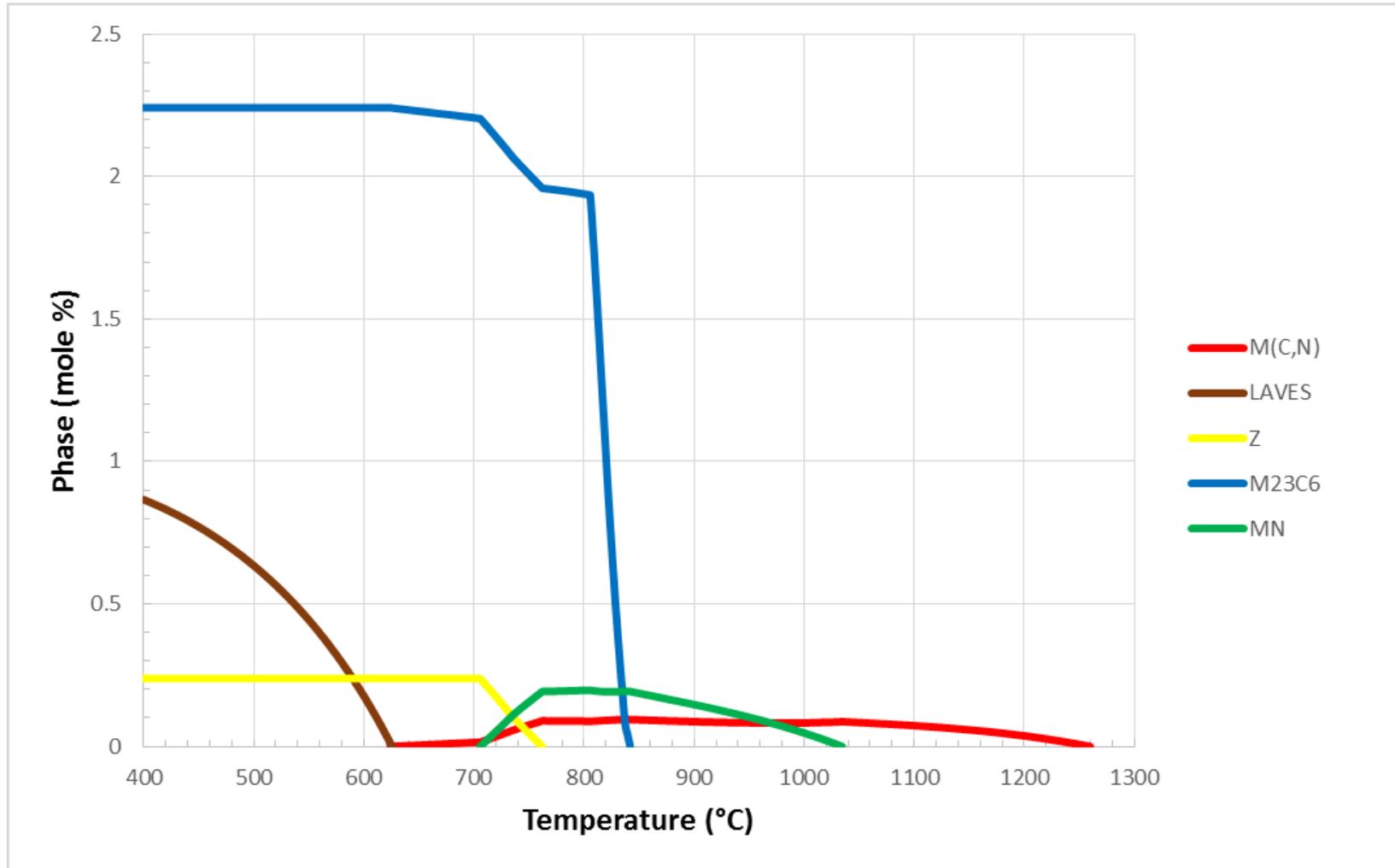
# Fine-tuning of Chemical Composition



EUROFER97

89Fe-9Cr-1.1W-0.5Mn-0.2V-0.14Ta-0.1C-0.02N

$\text{Fe}_{88.7}\text{-Cr}_{9.64}\text{-W}_{0.33}\text{-Mn}_{0.51}\text{-V}_{0.22}\text{-Ta}_{0.04}\text{-C}_{0.46}\text{-N}_{0.08}$



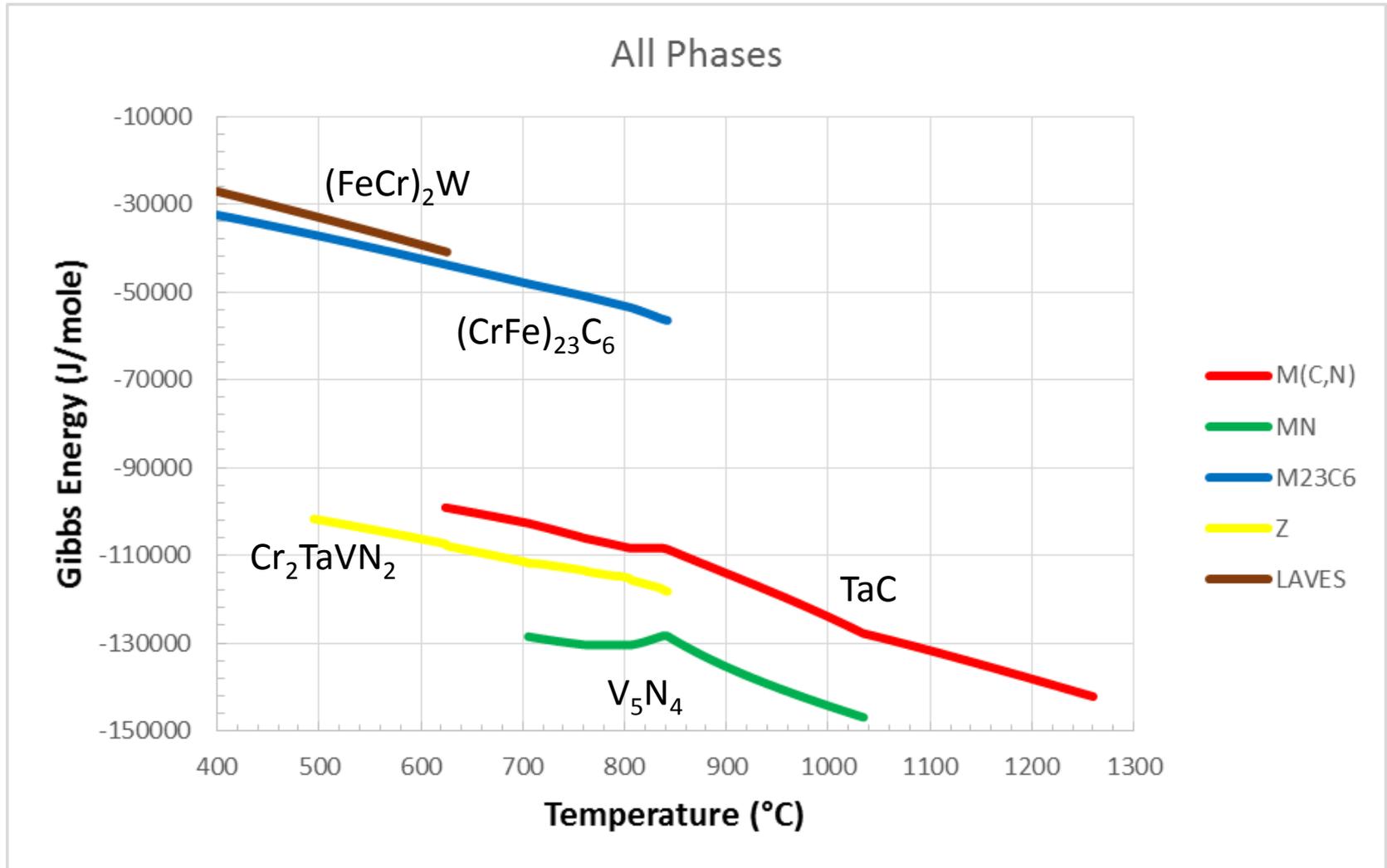
# Fine-tuning of Chemical Composition



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## Comparison and correction: Simulation - Reality

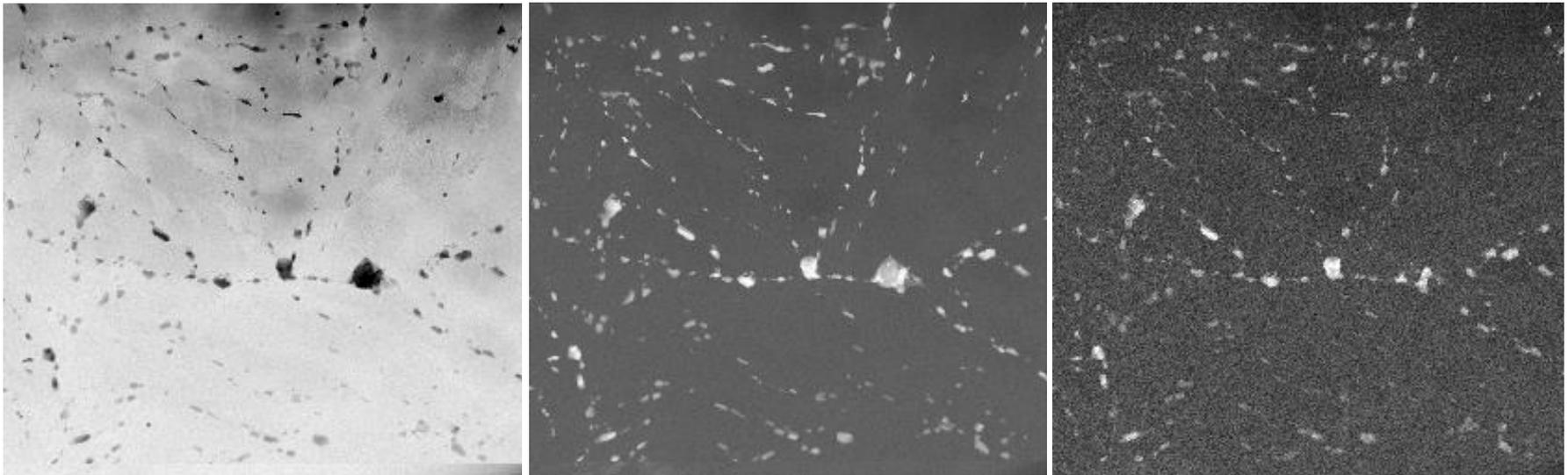
TEM studies on aged Eurofer samples

→ 30000 h, 550-600 °C: **no Laves phase  $\text{Fe}_{52}\text{Cr}_{15}\text{W}_{33}$**

Fe

Cr

W



11  $\mu\text{m}$

# Fine-tuning of Chemical Composition

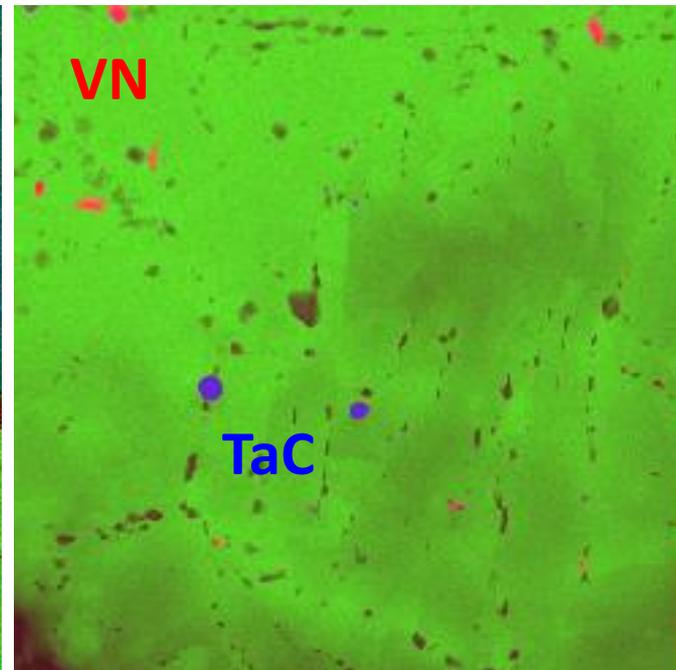
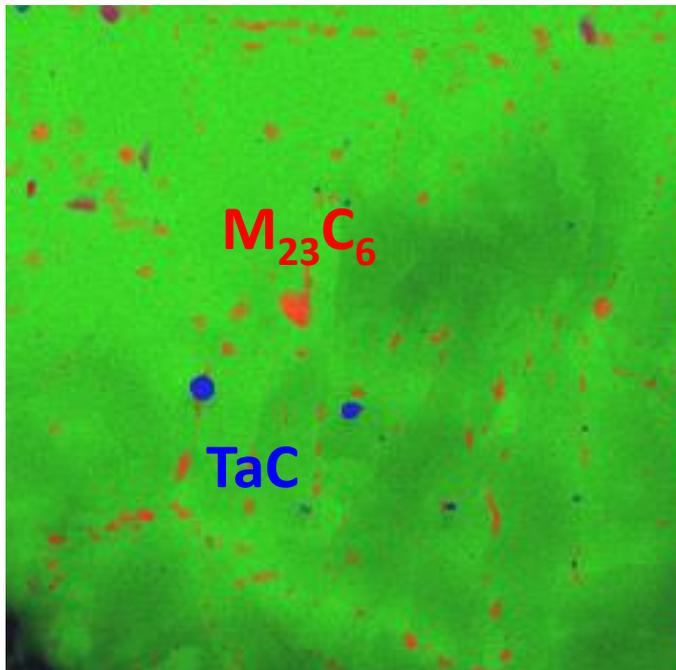


TEM studies on aged Eurofer samples

→ 30000 h, 550-600 °C: **Is there Z phase  $\text{Cr}_2\text{TaVN}_2$  ?**

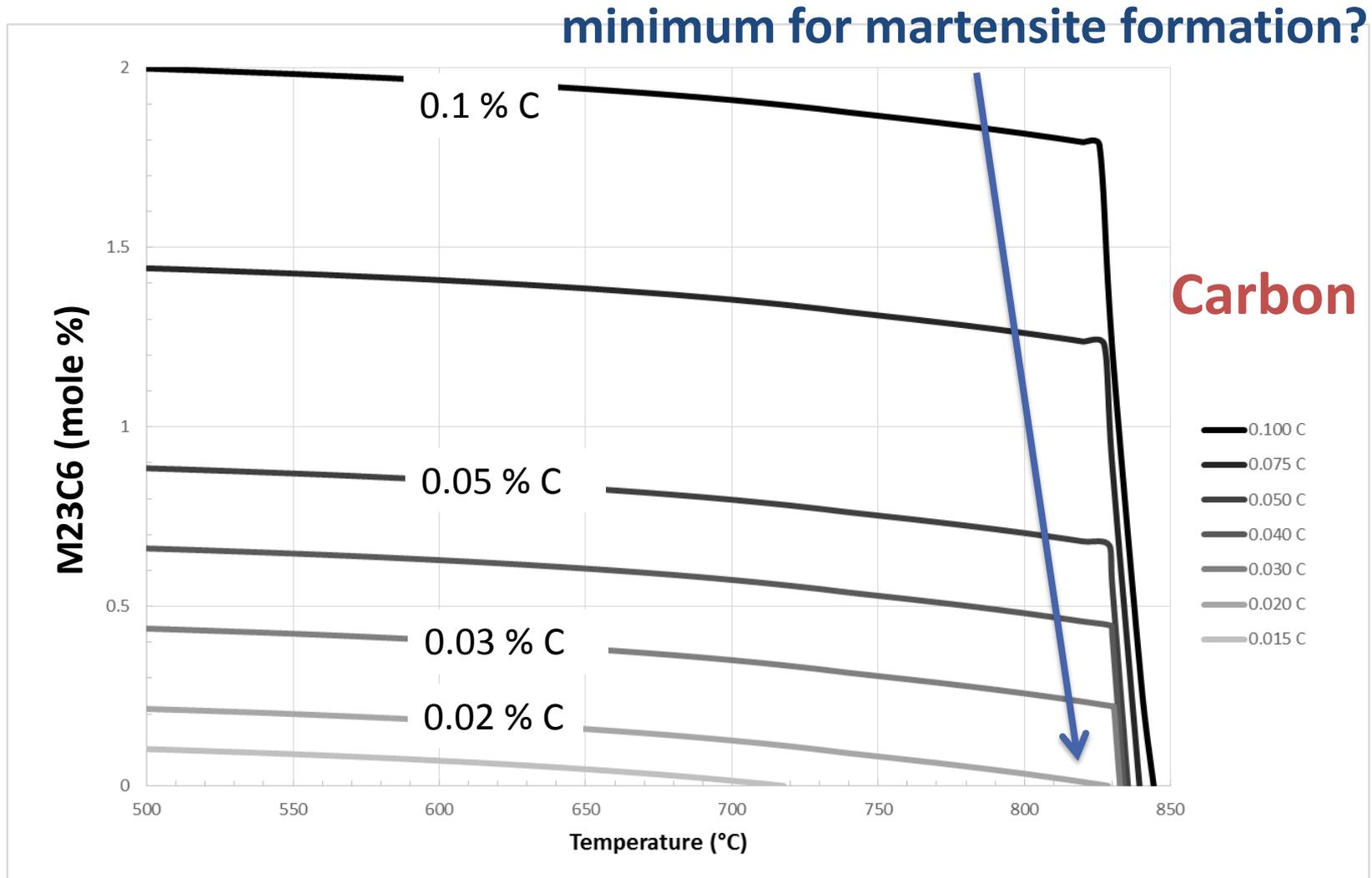
**Cr Ta Fe**

**V Ta Fe**



- Precipitation map under development
- Provides correction parameters for simulation

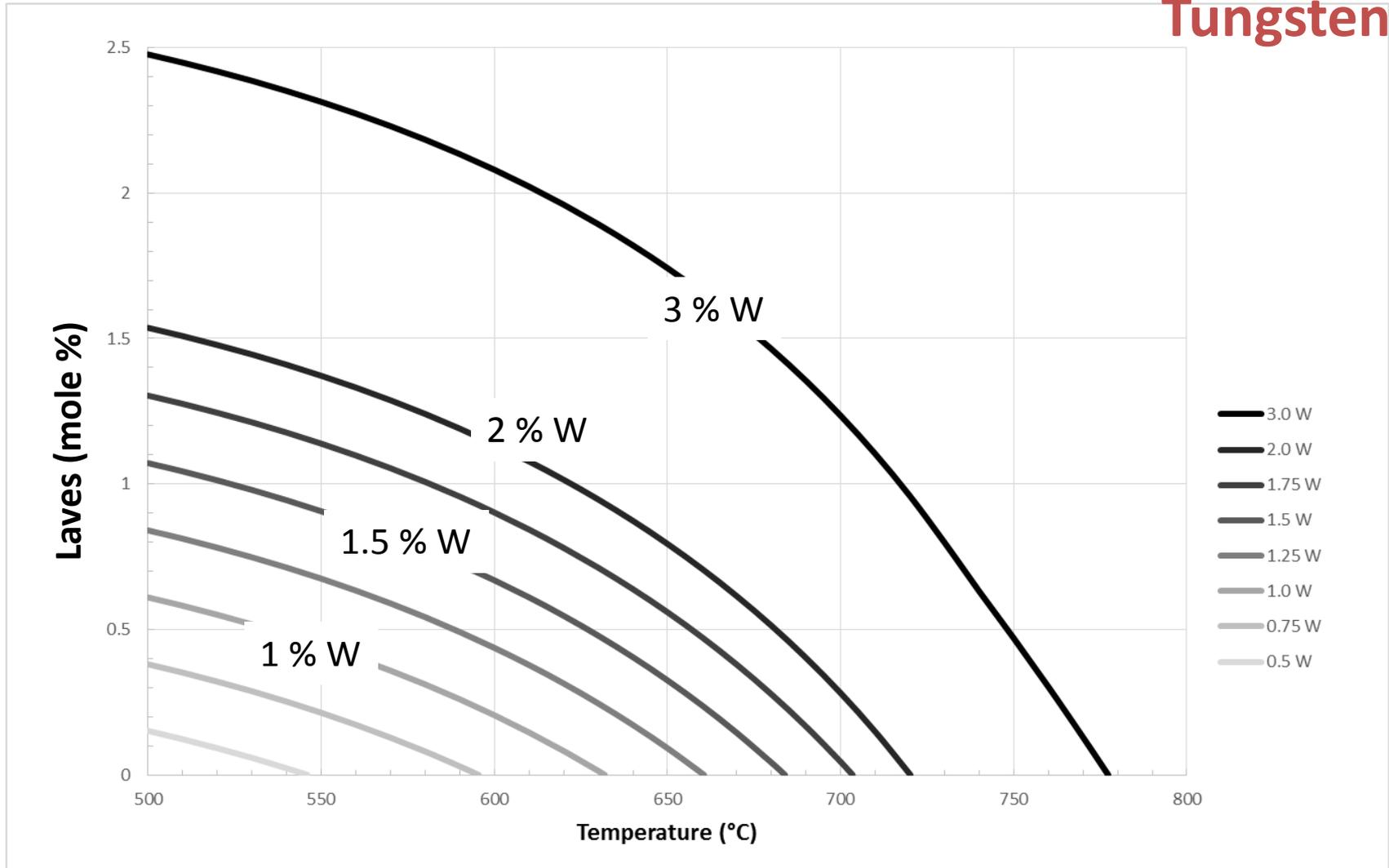
# Fine-tuning of Chemical Composition



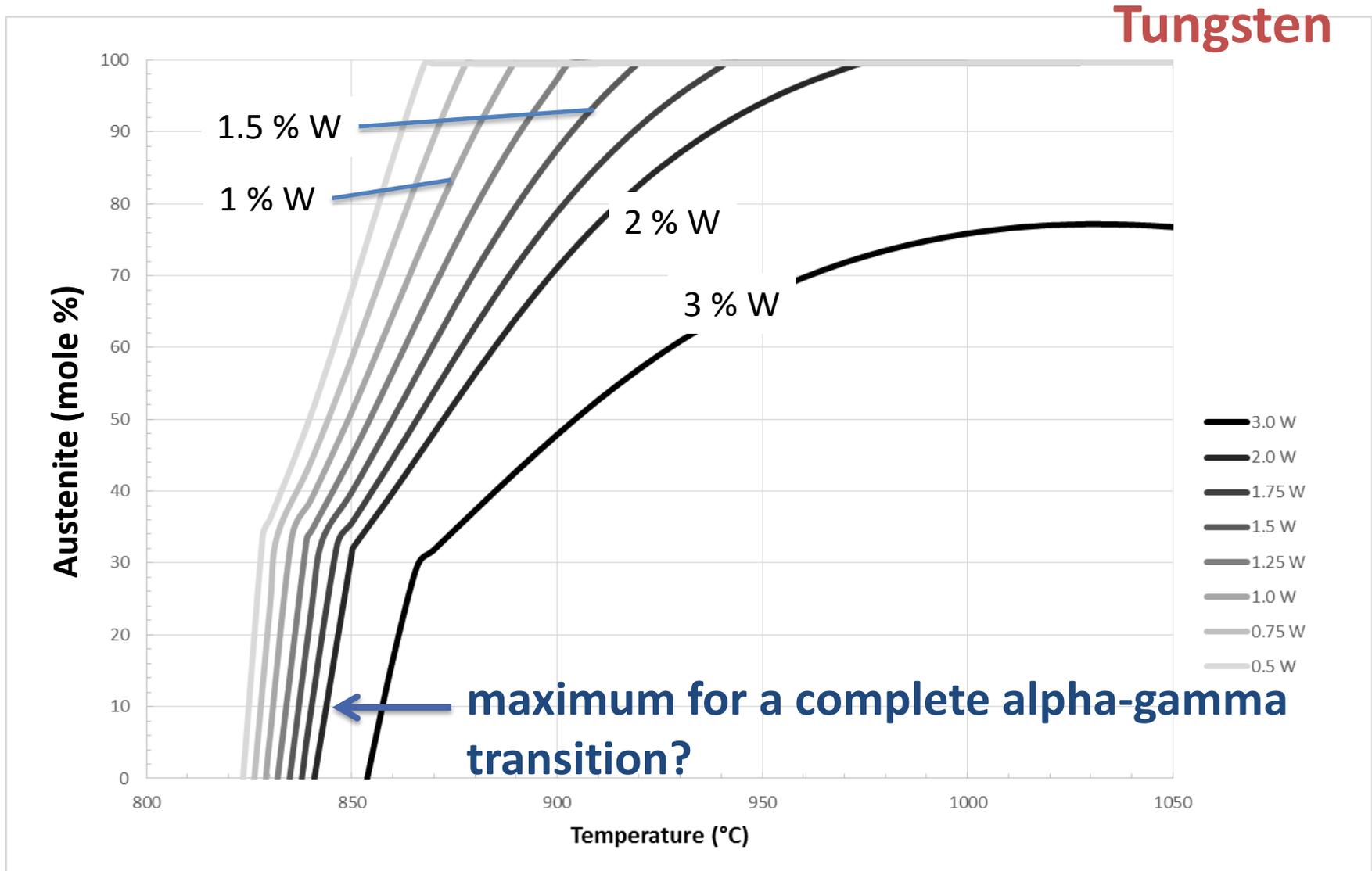
# Fine-tuning of Chemical Composition



**Tungsten**



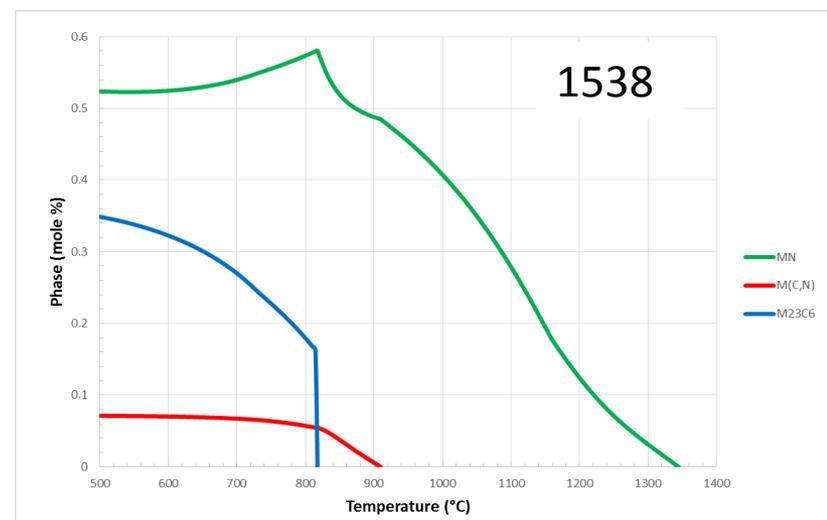
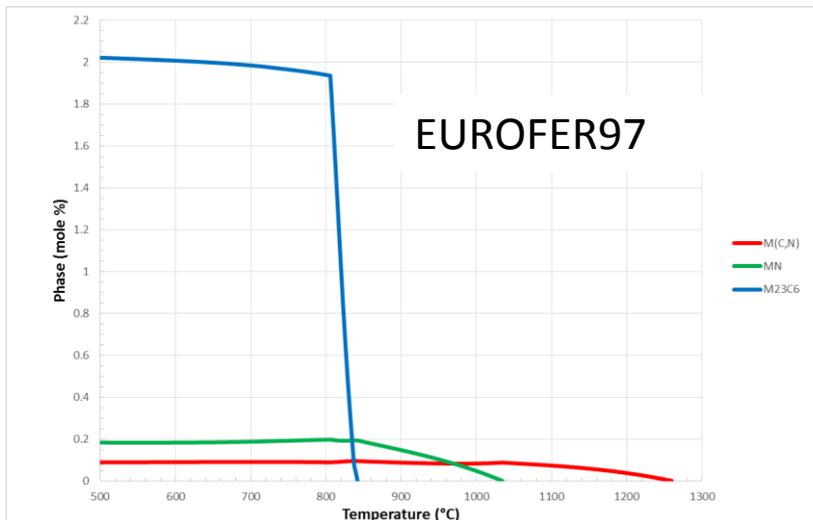
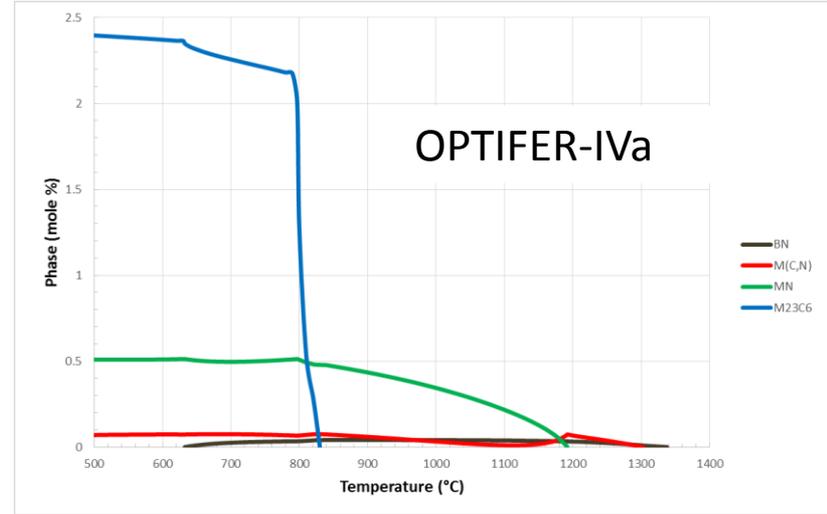
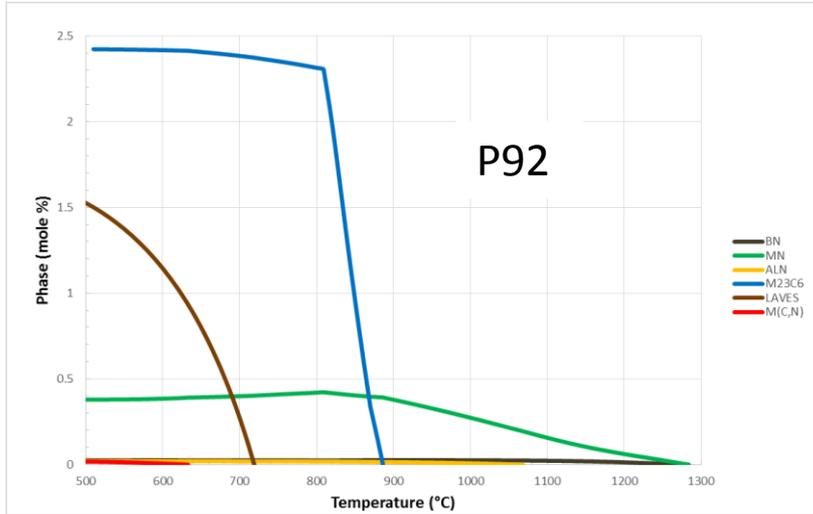
# Fine-tuning of Chemical Composition



# Fine-tuning of Chemical Composition



## Comparison/Correlation of known properties/alloys





## Strategies for optimization: some examples

- Reduction of **M23C6**
  - decrease of C content
  - but ensure Martensite formation
  - targets: 0.03 – 0.06 %
- **VN**: adjustment of amount and onset
  - target: 0.4 – 0.6 %
  - start of formation: about 1250 °C (solution annealing)
  - by variation of V and N
- **TaC**: “adjustment” of onset
  - target: below 0.2 %
  - start of formation: below VN
  - by variation of Ta
- **Isolate/identify effects of single elements**
  - Mn, Si – “further purification” by removal
  - W possible increase of strength by addition
- ...

# Summary and present status



- More than **30 heats** produced by industry (80 kg each)
- Development of a computational model for the selection of 9%Cr RAFM steels optimized for high temperature application (**Genetic Algorithm**)
- Mechanical properties & microstructural investigations under way → **irradiation in 2016/17**





- CCFE
- CEA
- CIEMAT (+ CEIT, URJC, UPM, ...)
- DTU
- ENEA-Frascati
- ENEA-CNR
- FZJ
- Wigner RCP (HAS)
- NCSR (HELLENIC)
- MPG (IPP)
- IPPLM
- IST
- KIT
- ISSP-UL (LATVIA)
- IAP (MEdC)
- JSI (MESCS)
- FOM-DIFFER (NRG)
- OEAW
- RBI
- LPP-ERM-KMS (SCK.CEN)
- UT (TARTU)
- VTT (TEKES)
- VR



Slovenska Fuzijska Asociacija  
Slovenian Fusion Association

