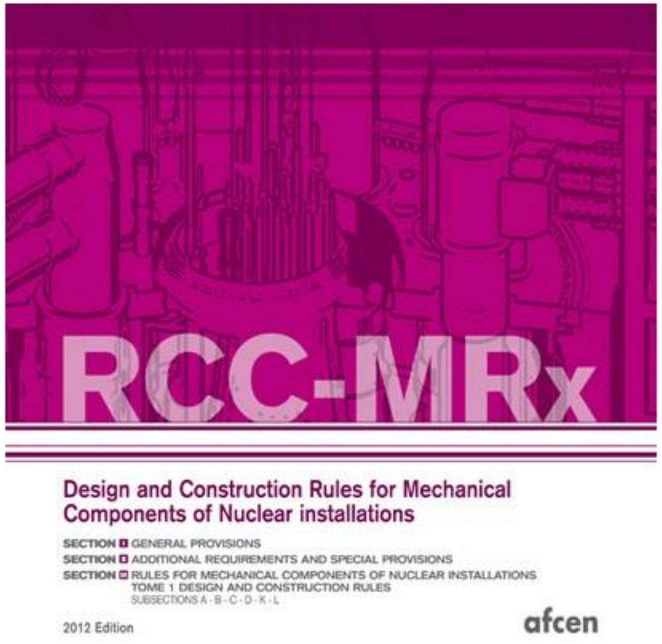
# ONGOING DEVELOPMENT ACTIVITIES FOR RCC-MRx AND ITS ENLARGEMENT TO DIFFERENT GEN IV SYSTEMS.

*K.-F. Nilsson, JRC; C. Pétesch CEA/AFCEN,*

*SNETP Forum, June 02, 2022*

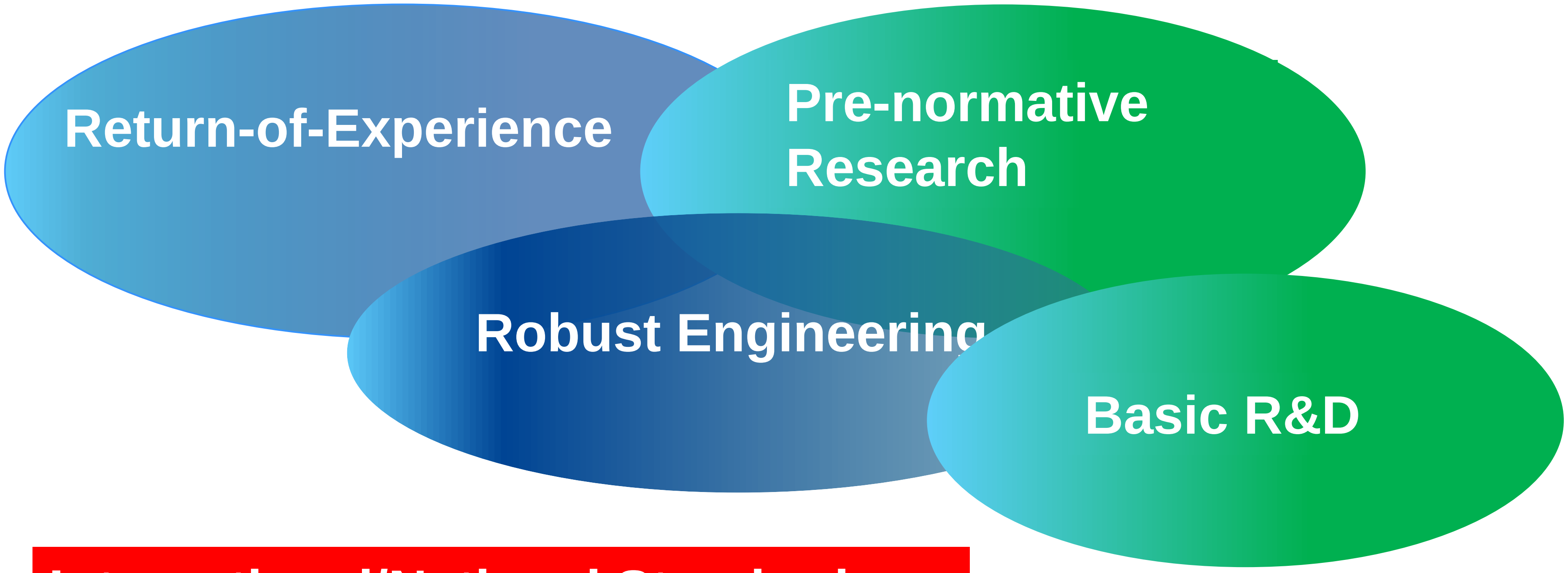
# Activities I will refer to:

- **CEN WORKSHOP 064 PHASE 3 “Design and construction codes for Gen II, III and IV nuclear facilities”, PG2 — Mechanics Gen IV and innovative reactors**
- **Pre-normative research projects: EERA JPNM and EURATOM**
- **GIF – Advanced Manufacturing & Materials Engineering Task Force**




I only refer to activities where I have been directly involved.
Thus, e.g.  not the AFCEN RCC-MRx committee internal work.

# Basis & Targets for Nuclear Design Codes




**International/National Standards**

IAEA Safety Standards Safety of Nuclear Power Plants: Design Specific Safety Requirements No. SSR-2/1

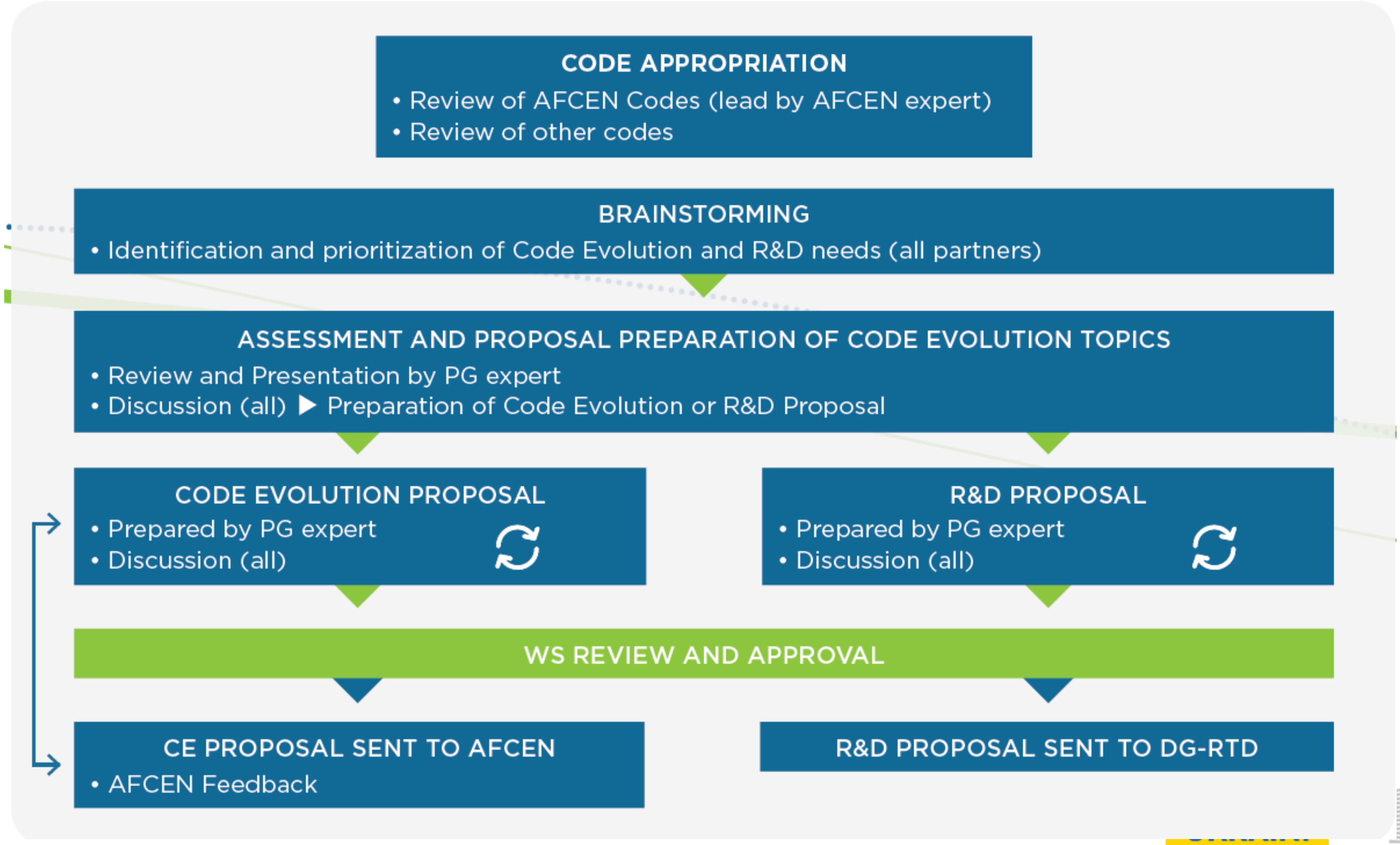
4.16. Where an unproven design or feature is introduced or where there is a departure from an established engineering practice, safety shall be demonstrated by means of appropriate supporting research programmes, performance tests with specific acceptance criteria or the examination of operating experience from other relevant applications.

SLAVA UKRAINI

European Commission

# CEN WS064 Objectives

- Identify Code Evolution needs for the Innovative nuclear reactors
- Propose: Code Evolution and/or pre-normative R&D proposals or other supporting documents



# CEN WS064 Output (Phase 2 & 3)

## R&D Proposals (7)

- HLM Compatibility
- 60 years design life
- Irradiated characteristics Adv. Reactors
- Weld design creep & creep-fatigue
- Design rules creep/relaxation/fatigue
- Protective coatings & surface Alloys for HLM
- Small Punch Test

## Code Evolution Proposal (14)

- HLM Compatibility
- Negligible creep
- Extension of Temperature ranges for mechanical properties
- Extension of creep data
- Multiaxial Tubeshet analysis
- Re-introduction 304LN
- Small Punch
- Creep-fatigue Design Rule cyclic softeining
- Weld data and processes (4)
- Compliance ASME NQA-1

SLAVA UKRAINI

European Commission

# Code Evolution & pre-normative research topics

Compatibility structural material & Pb-coolants

New materials solutions: Advanced Manufacturing or New Materials

60+ years Design Life Ageing + flexible operation

Safety beyond design conditions

Digitalization

Integrated Modelling/experiment

High Temperature (creep, creep-fatigue, ageing)

Liquid metal corrosion and embrittlement

(Irradiation damage)

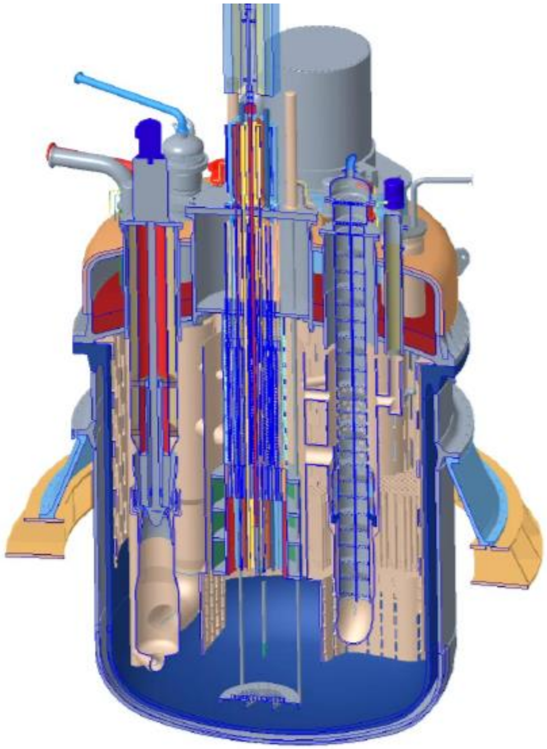
Weld integrity

Miniaturized tests Small Punch Test

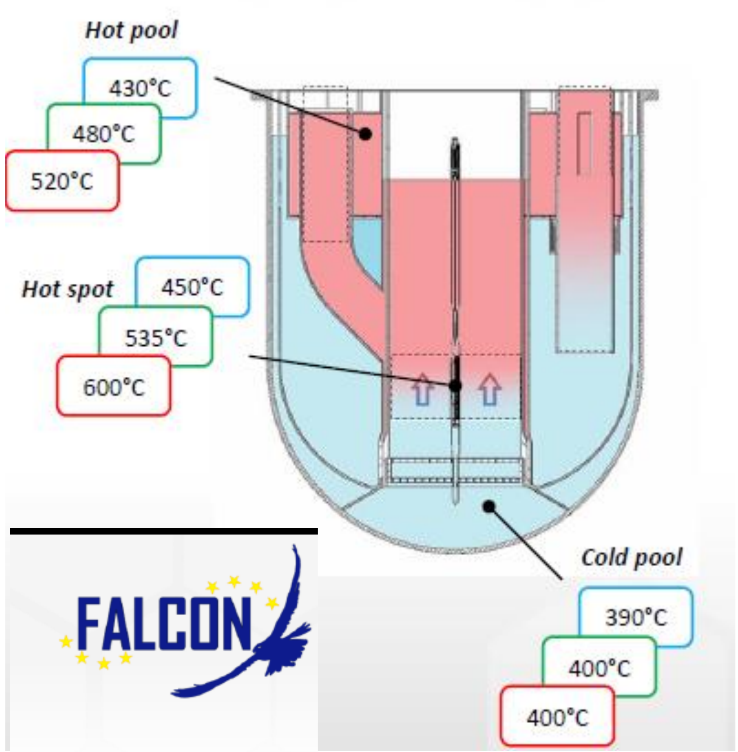
Accelerated tests

# Heavy Liquid Cooled Nuclear Systems
## European projects

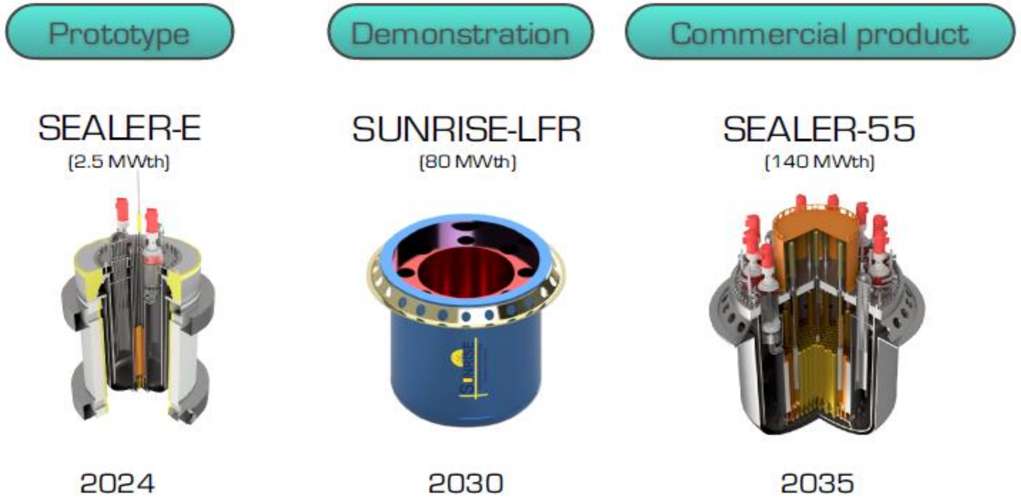
MYRRHA – Lead-Bismuth Accelerated Driven System SCK-CEN, Belgium



European LFR Reactor ALFRED Demonstrator → FOAK, FALCON (e.g. ENEA, ANSALDO)




SEALER: SMR LFR, Sweden





SLAVA UKRAINI

European Commission

# Needs to design & licence lead cooled reactors

- Liquid Lead is an aggressive environment.
- Key Degradation mechanisms:
  - Liquid Metal Embrittlement (tensile, fracture toughness, creep, fatigue);
  - Corrosion, erosion.
- To license the HLM reactors we need to demonstrate good compatibility between the HLM coolant and components/material.
- Or in other words demonstrate fit-for-purpose.

SLAVA UKRAINI

European Commission

# RCC-MRx AFCEN Design Code for Innovative Reactors 2018 Edition (CEN WS 064 Code Evolution Proposal Phase 3)

**RDG 2321 Use of the Code in innovative coolant environment**

The operator (Prime Contractor) should follow the recommendations hereafter in order to insure structural integrity under operating conditions (mainly coolant chemistry):

1) **The chosen material, in the chemistry controlled coolant, has the same behaviour as in air except for the depletion of the corrosion allowance,**
2) **All failure modes inside or outside of the design Code shall be identified and addressed, flaws, local corrosion and local thinning will be detected before defects become critical(*), assuming a limited corrosion speed,**
3) The requested coolant parameters (composition, pressure, temperature, circulation speed…) will be satisfied all over the systems,
4) Failure of the chemistry control system that could cause high speed corrosion is detected and the grace time is sufficient to take corrective action.
5) These are satisfied including accepted and probable variations of both structural material and coolant.

SLAVA UKRAINI

European Commission

# Test programme Liquid Metal Embrittlement

# MATTER 2010 -2015: Ferritic-Martensitic steel, Grade 91, Reference material

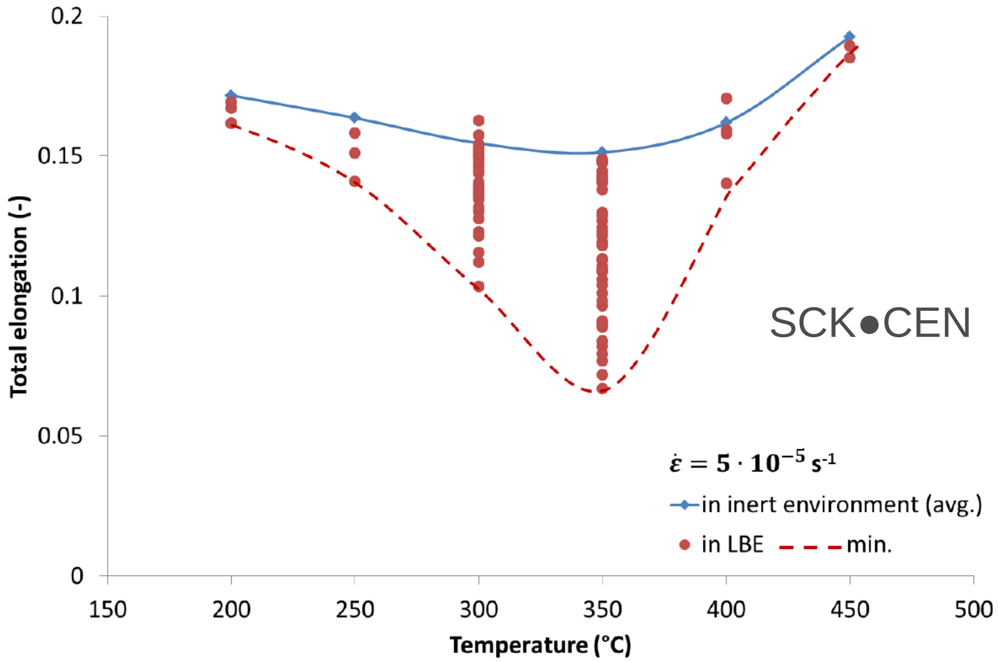
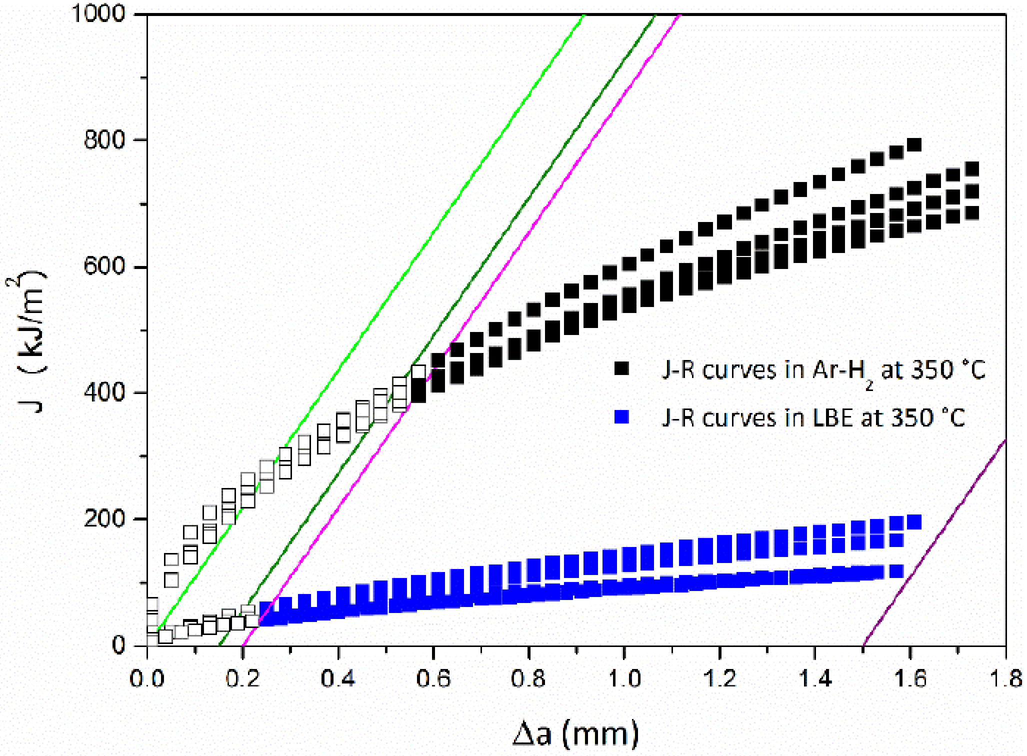



*Figure 23. Temperature dependence of total elongation of T91 measured in inert environment and in LBE at strain rate 5·10$^{-5}$ s$^{-1}$. The dashed red line depicts the minimum value in LBE.*




In the MATTER project 2011 – 2015, it was shown that Grade 91 suffers from Liquid Metal Embrittlement in contact with Lead-Bismuth Eutectic and therefore excluded as reference material also for lead

SLAVA UKRAINI

European Commission

# GEMMA Project (2017 – 2021)

- Austenitic steels, e.g. 316L, appear to be corrosion resistant and not susceptible to Liquid metal Embrittlement (LME)
- How about the welds as they may contain ferrite?
- Objective:
  - Assess the compatibility for liquid lead with austenitic welded plates by a Test Programme
  - → Basis for Engineering Data & Design Rules → first steps for RCC-MRx Design Code

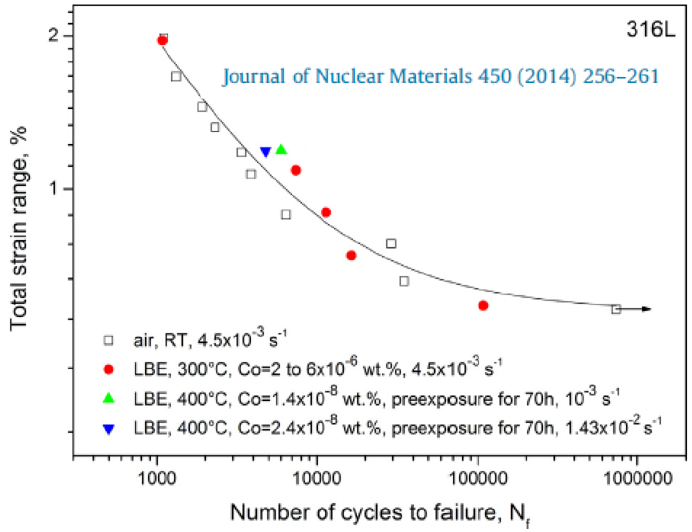



**Fig. 6.** Fatigue endurance of 316L tested in LBE at 300 and 400 °C, compared to air tests conducted at RT.

316L austenitic steels show very limited LME and good fatigue properties

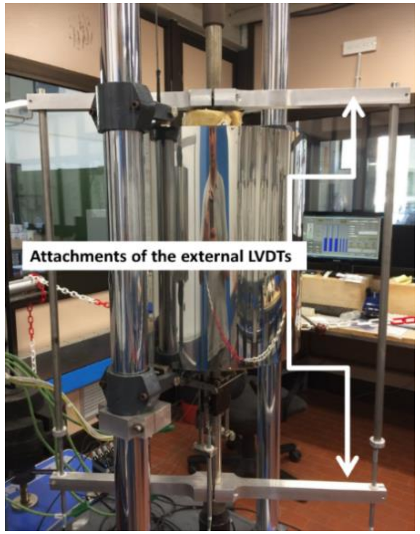
GEMMA

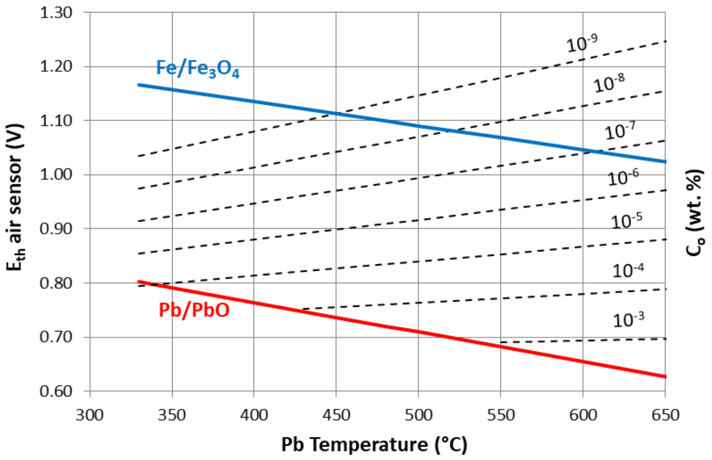
SLAVA UKRAINI

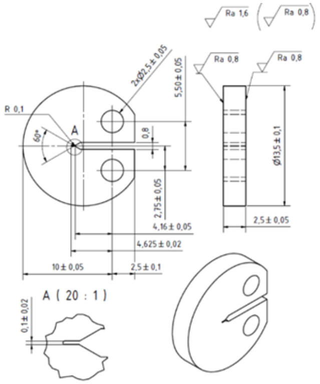
European Commission

# Experimental challenges testing in lead

- Indirect Measurement of specimen deformation (all);
- Use of sub-sized specimen (FT, creep) SSRT);
- Non-inspectability of specimen (FT);
- Controlling the lead conditions, e.g. oxygen content (all);
- Pre-exposure conditions (SSRT, FT)?



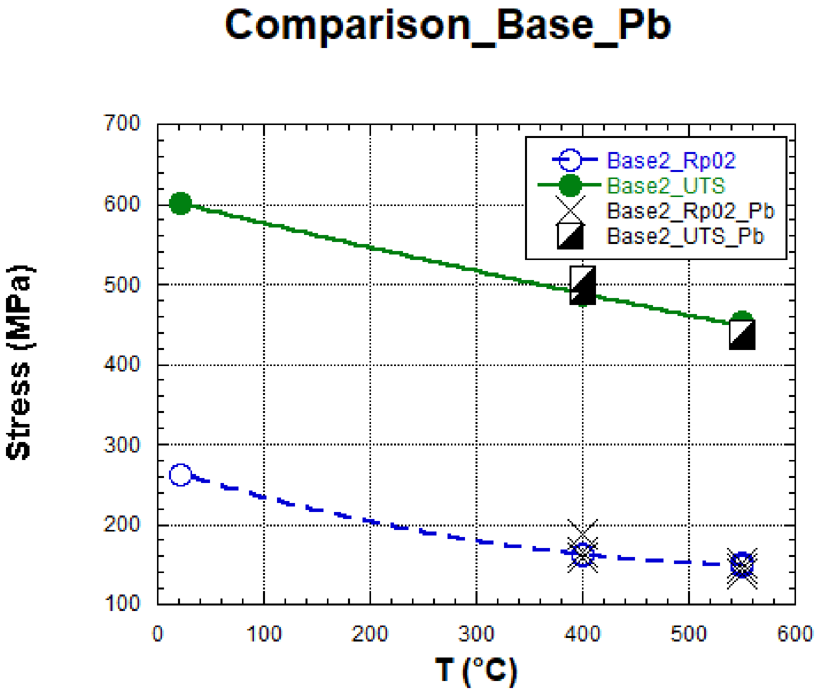



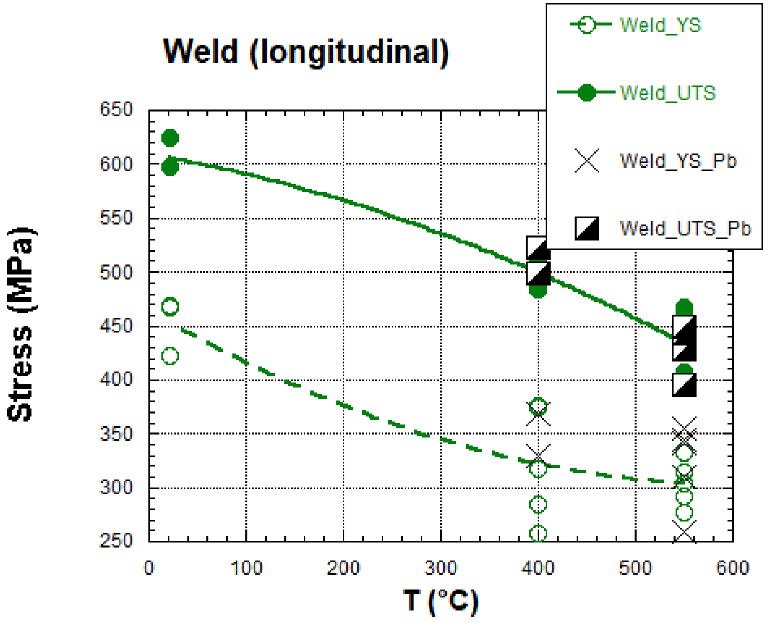



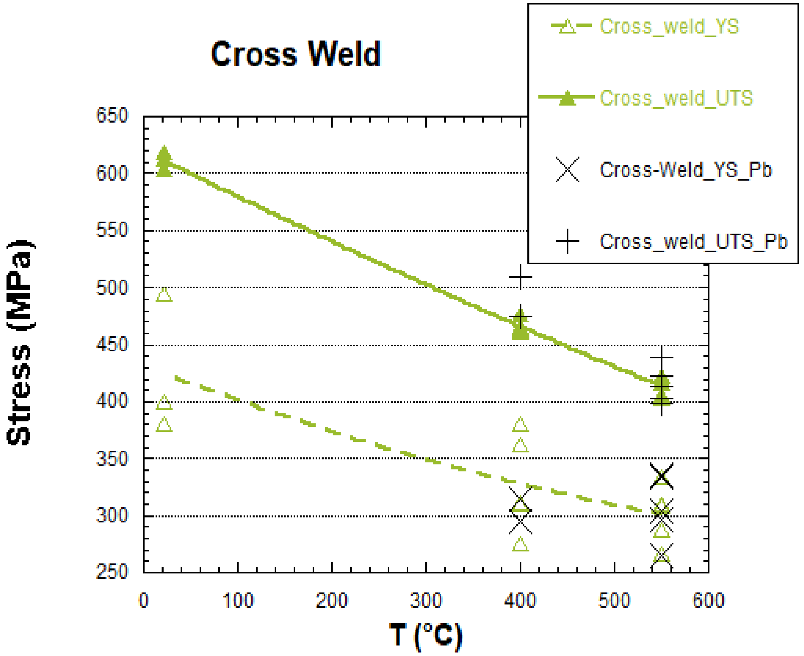

SLAVA UKRAINI

European Commission

# GEMMA: SSRT 316L-TIG (ENEA)



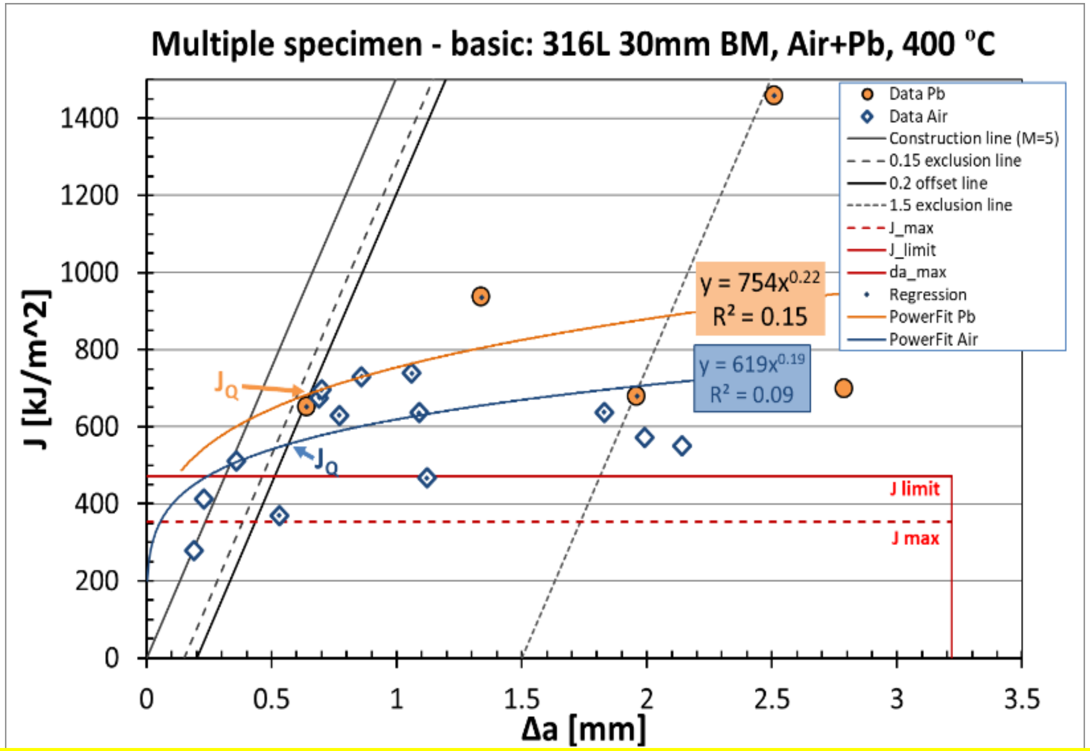

- No LME  on yield stress, ultimate strength or ductility
- Larger scatter for weld than for base material
- Over-matched weld ($R_{p02}$(weld) > $R_{p02}$(BM))

SLAVA UKRAINI

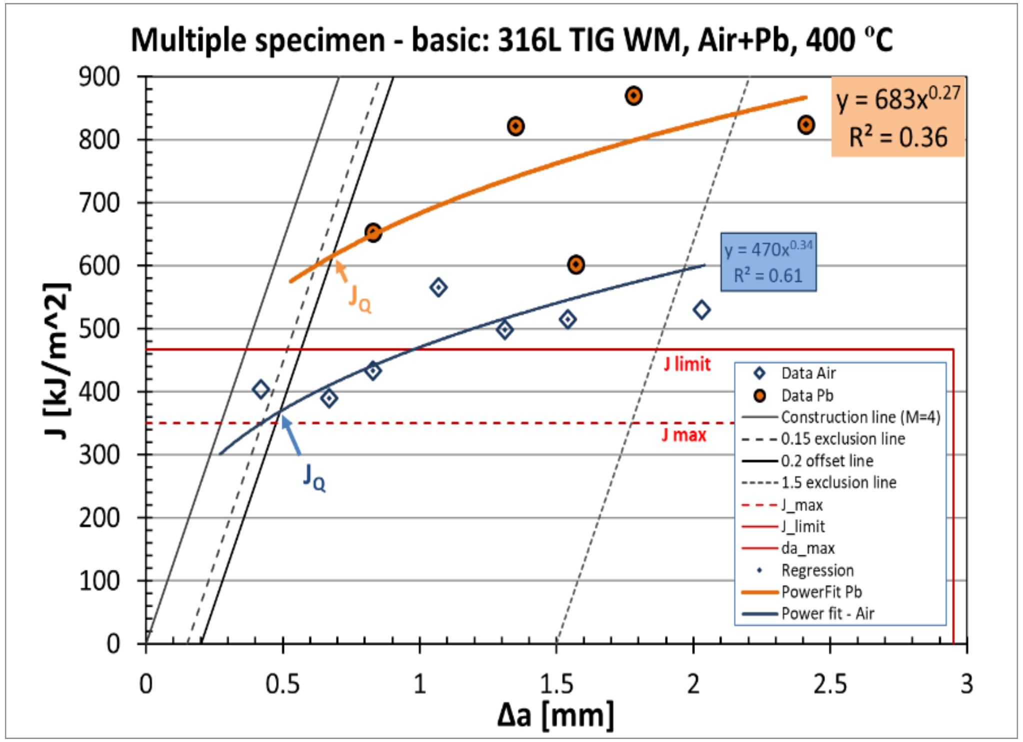
European Commission

# GEMMA: Fracture Toughness – 316L – TIG (CVR)

## Base material




## Weld material



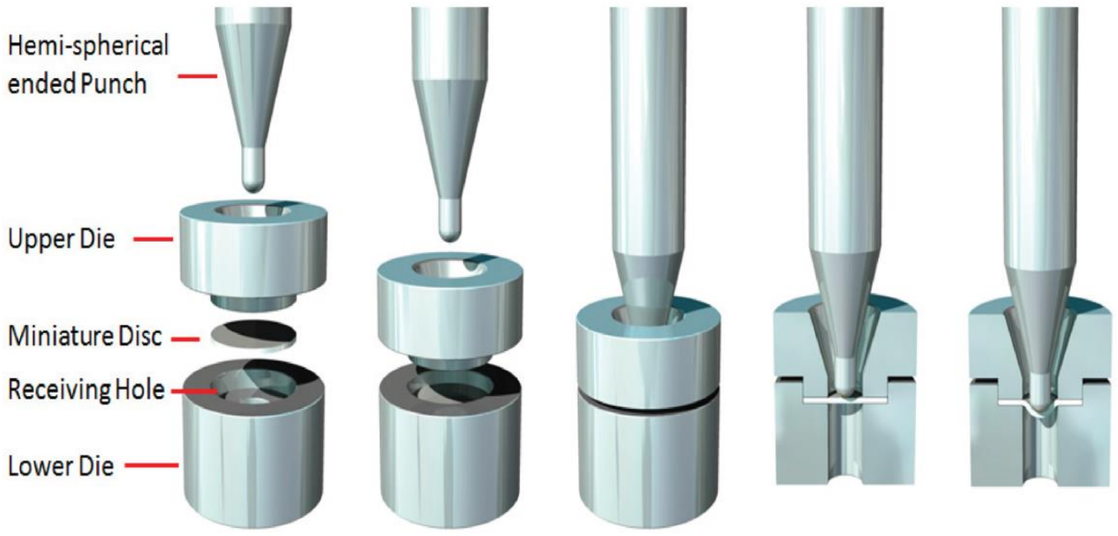

Fracture toughness 316L/15-15Ti BM/WM

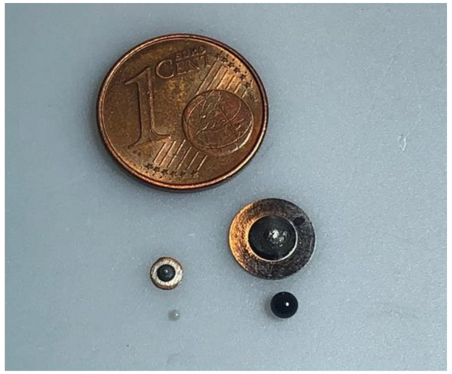
- Clear tendency for higher fracture toughness in Pb than air
- All crack growth resistance, and most initiation ($J_Q$), are non-valid due to
  - high fracture toughness
  - small specimen size and
  - high ductility
- Large scatter in multi-specimen evaluation due to deviation of initial crack shape but also loading and material inhomogeneity

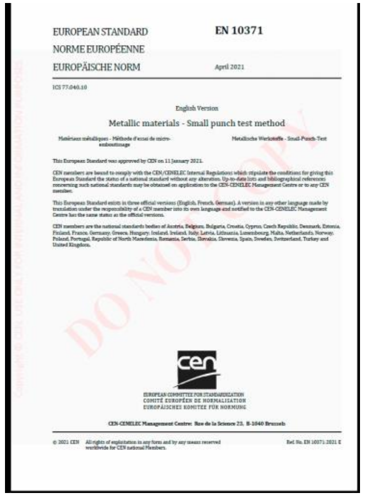
# Liquid Metal Embrittlement – RCC-MRx

- According to “RDG 2321 Use of Code in innovative coolant environment”
  - Liquid Metal Embrittlement (LME) LBE/ P91 F-M steel → Ruled out
  - No sign of LME for Pb for LBE/316L Tensile/fracture/fatigue → Needs some further verification to be conclusive

# Small Punch Test – EN 10371:2021




EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 10371

April 2021

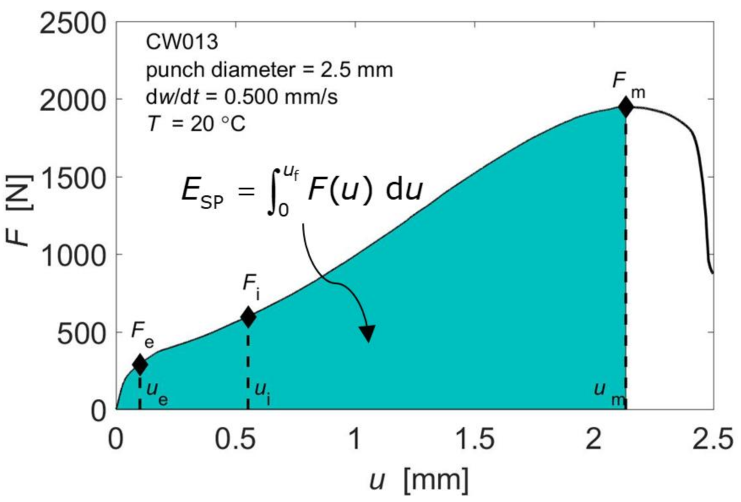
English Version

Metallic materials - Small punch test method

Tensile

$$R_m = \beta_{Rm} \frac{F_m}{h_0 u_m}$$

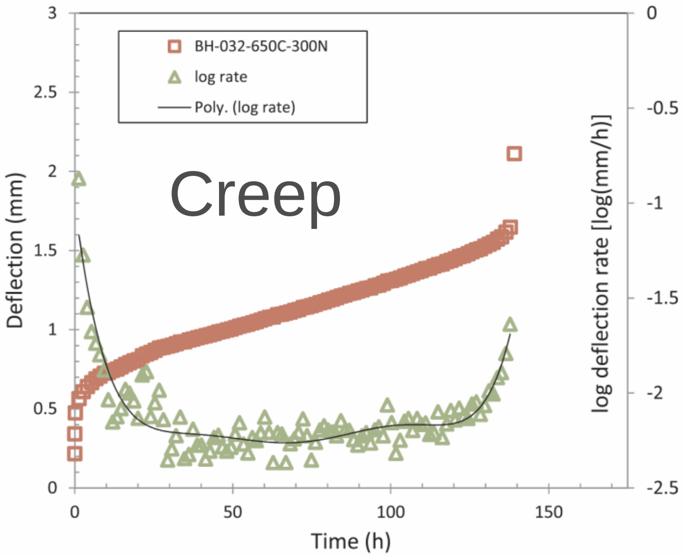
$$R_{p0,2} = \beta_{Rp0,2} \frac{F_e}{h_0^2}$$




Materials Science & Engineering A 731 (2018) 161–172

$$\sigma_{std} = \frac{F}{1.916 u_{min}^{0.6579}}$$

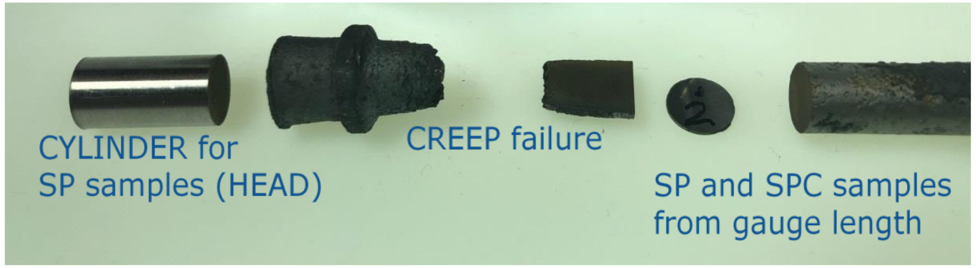
$$\dot{\varepsilon}_{std}^{min} = 0.3922 \dot{u}_{min}^{1.191} \quad (1/h)$$

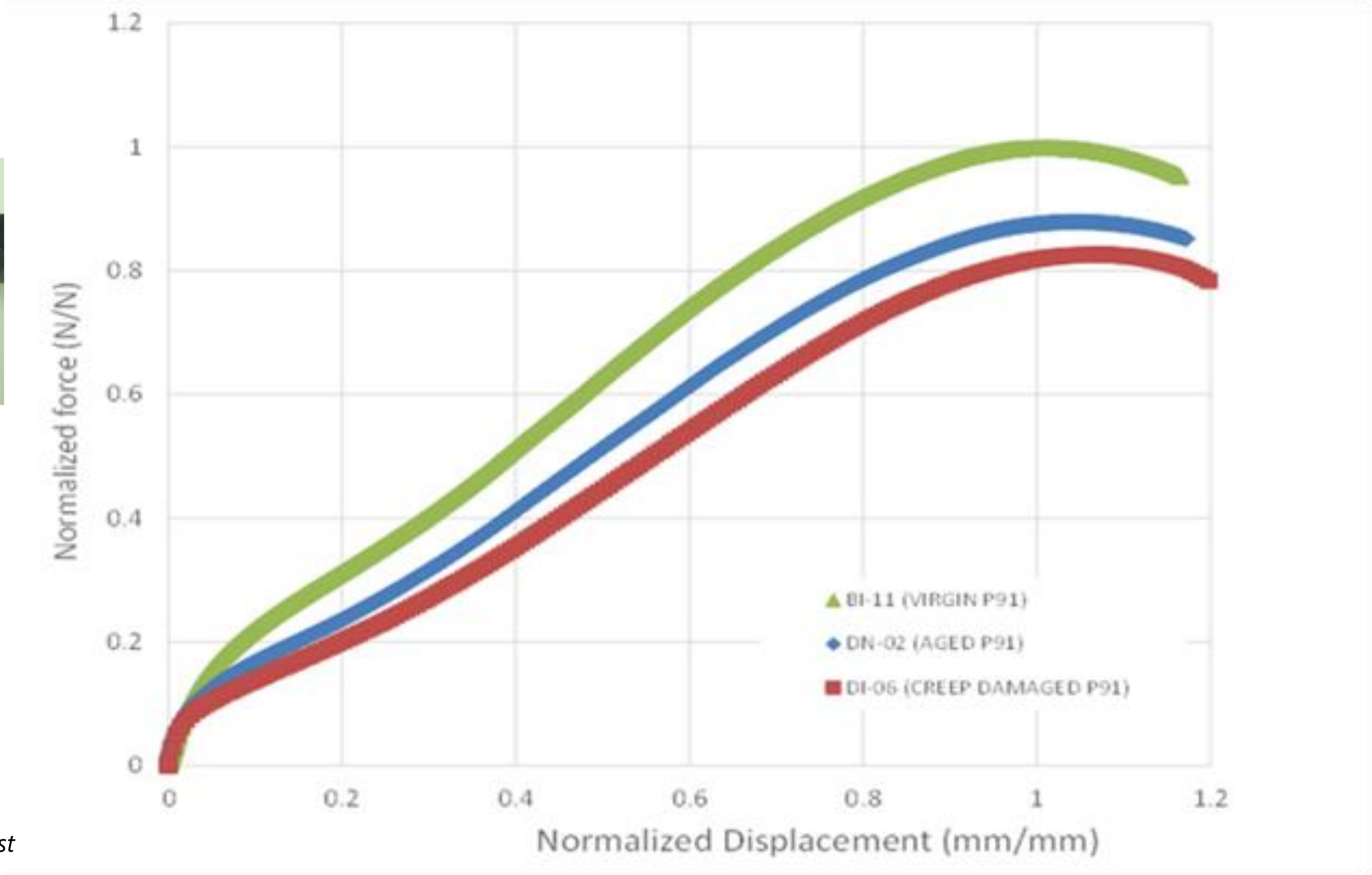




UKRAINI

European Commission

# Application: 316L – Rating: virgin/Aged/creep damaged



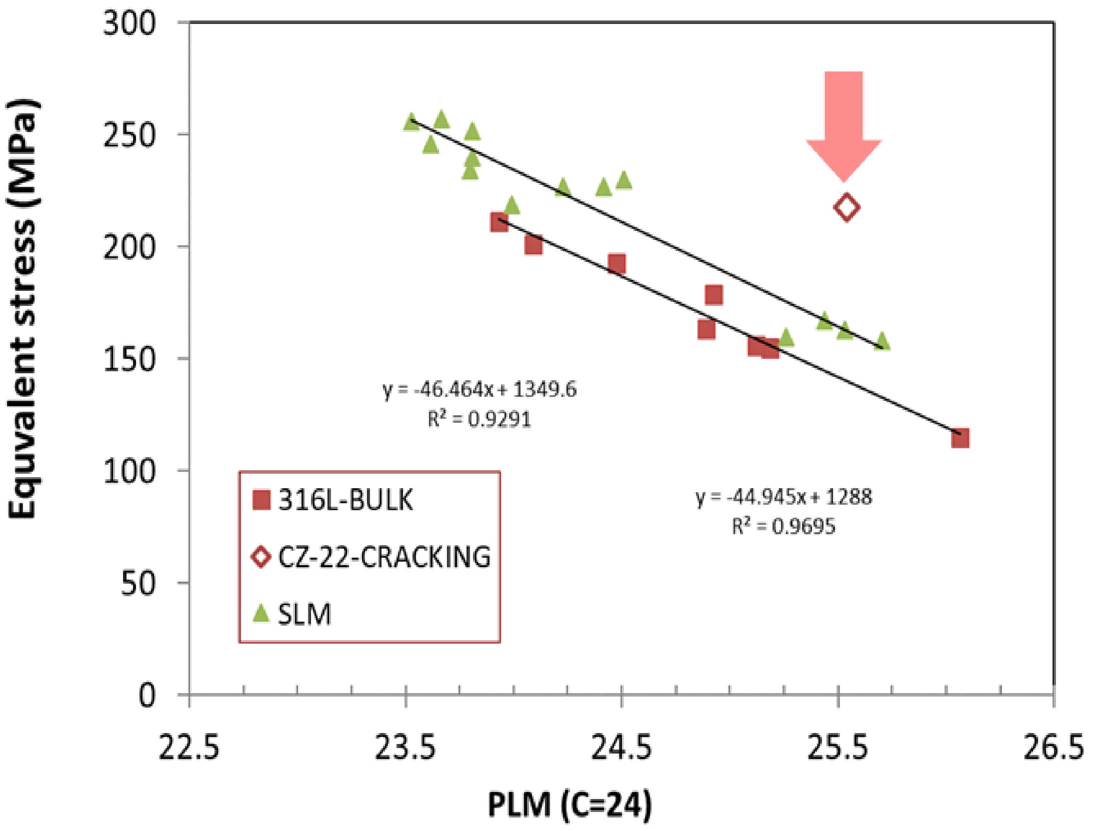




*Estimation of uniaxial and creep properties by small punch testing in support of ECCC test programmes*, S. Holmström et al. 2021 - ECCC - 5th International ECCC Creep & Fracture VIRTUAL Conference

SLAVA UKRAINI

European Commission

# Application: Creep Life – 316L Add. Manuf. vs traditional




316L (standard fabrication)

316L SLM (Additive manufactured)

*Estimation of uniaxial and creep properties by small punch testing in support of ECCC test programmes*, S. Holmström et al. 2021 - ECCC - 5th International ECCC Creep & Fracture VIRTUAL Conference

SLAVA UKRAINI

European Commission

# RCC-MRx Code Evolution - Small Punch Test

**afcen**

1, place Jean Millier

92400 Courbevoie, FRANCE

**REQUEST FOR MODIFICATION**

**Name of the Code**

**RCC-MRx**

**Registration**

*Reserved for AFCEN use*

**N°: DMRx 20-070**

Date: 26/11/2020

**TEXT INVOLVED**

**Edition:** 2018 **Chapter / Paragraph:** Appendix A20

**REQUESTING PARTY IDENTIFICATION**

| | |
|---|---|
| **Company:** SCK CEN | **Date of the request:** 19/11/2020 |
| **First name:** Stefan | **Name:** HOLMSTROM |
| **Phone:** | **E-mail:** stefan.holmstrom@sckcen.be |

Send this template and all necessary attachments to the relevant sub-committee: rcc-mrx@afcen.com

**Section III – Tome 1 – Subsection Z - Appendix A20: Constructive requirements linked to in-service inspections**

**afcen**

1, place Jean Millier

92400 Courbevoie, FRANCE

**DEMANDE DE MODIFICATION**

**Nom du Code**

**RCC-MRx**

**Enregistrement**

*Réservé à l'AFCEN*

N° : **DMRx 21-046**

Date : 12/05/2021

**TEXTE CONCERNE**

**Edition :** 2018 **Chapitre / Paragraphe :** RB 2500

**RB 2530 MATERIALS COMPARISONS BASED ON SCREENING TESTS**

In order to select a material, screening tests can be conducted for relevant mechanical properties of materials.
Although standards specimen tests are preferable, miniature testing techniques can also be used, for instance standardized small punch test techniques according to *EN 10371* can be used for comparing certain material property estimates (tensile strength, proof stress or creep strength).
In that case, sufficient sampling and representativeness of the procurement have to be demonstrated. The selection process and results have to be documented.
Note that screening tests are not considered as procurement or qualification tests.

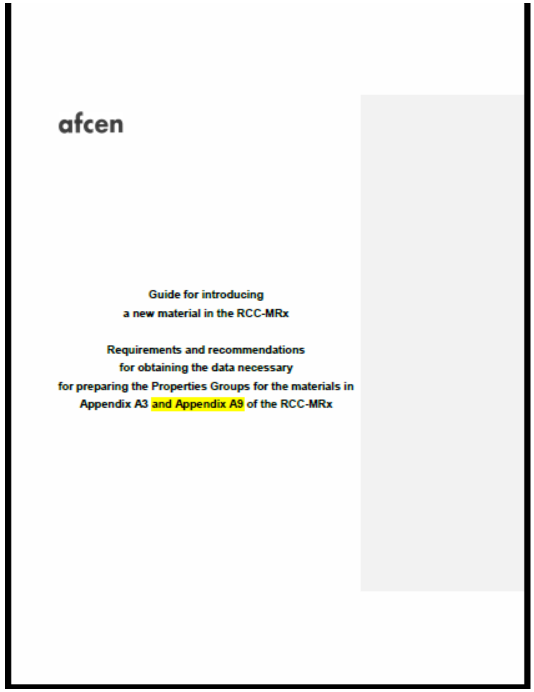
- R&D Proposal for further applications – e.g. can we use SP to determine specific material properties? + other applications

SLAVA UKRAINI

European Commission

# New Materials Solutions

- CEN WS 064: Guide for Introducing a New Material in the RCC-MRx Code — Extension of the Requirements & Recommendations for materials data RCC-MRx (Appendix 3 base material) to also include welds (Appendix 9)
- Discussions on Additive Manufacturing → waiting for outcome of NUCOBAM project (next presentation)
- Discussion Inclusion of Aluminum Forming Steels (AFA) austenitic steels for LFR/SMR reactors in RCC-MRx (Swedish Sealer)


afcen

Guide for introducing
a new material in the RCC-MRx

Requirements and recommendations
for obtaining the data necessary
for preparing the Properties Groups for the materials in
Appendix A3 and Appendix A9 of the RCC-MRx

The main challenge is to reduce the time from development to deployment

→ Accelerate the qualification of nuclear reactor material and components;

→ paradigm shift: Digitalization & AI, sensors, integrated modelling & experiments, accelerated & miniature testing, new design criteria…?

SLAVA UKRAINI

European Commission

# Keep in touch

EU Science Hub: ec.europa.eu/jrc

@EU_ScienceHub

EU Science Hub – Joint Research Centre

EU Science, Research and Innovation

EU Science Hub

# Thank you



European Commission