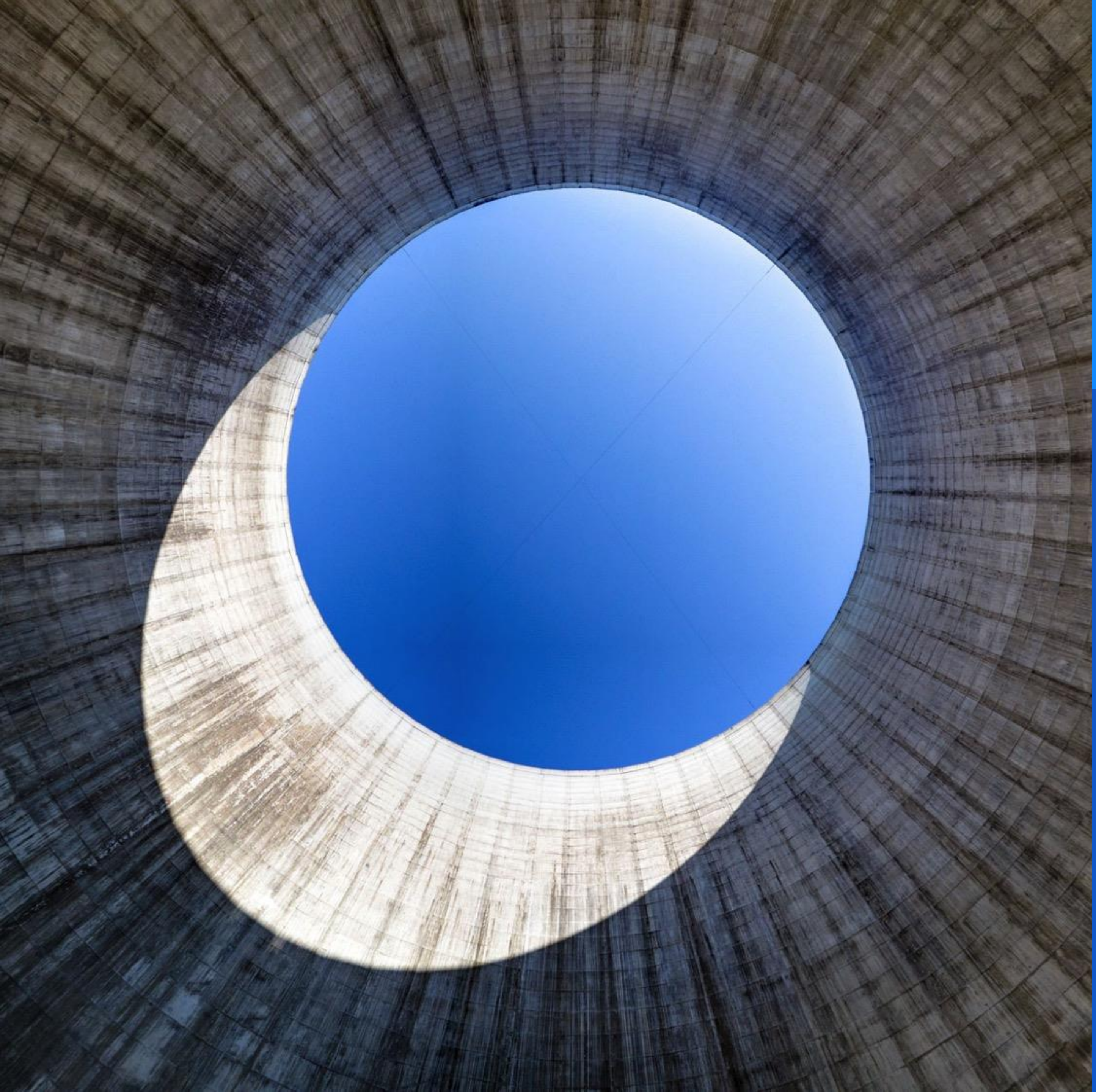


NeT Workshop

November 23rd 2022

Garching

# How you can implement the lessons learned from NeT round robins to day-to-day problems in nuclear industry


Vincent ROBIN (EDF DT)

Josselin DELMAS (EDF R&D)

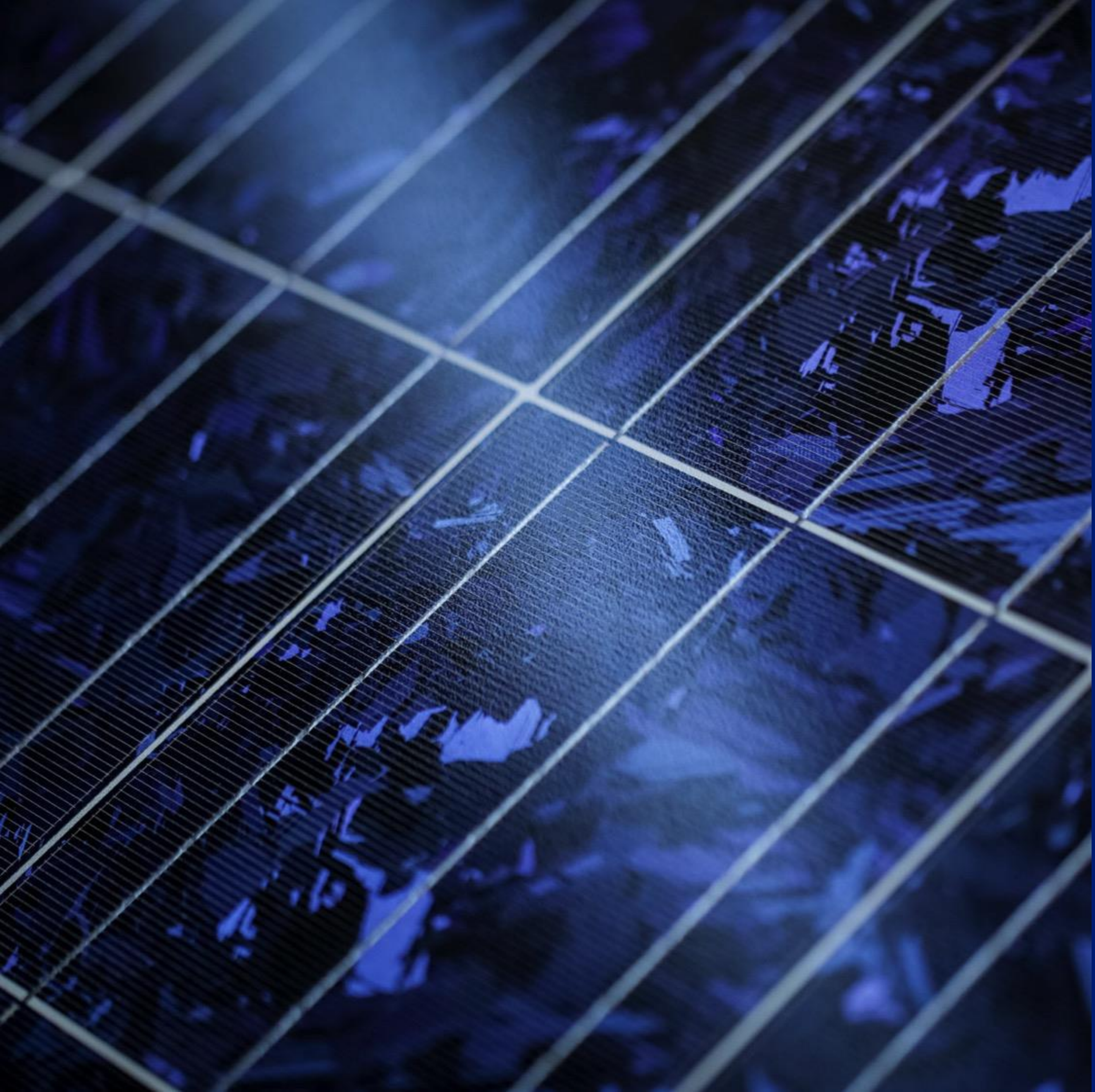
EDF Direction Technique and R&D

# Summary

1. Introduction
2. Computational Weld Mechanics
3. R&D activities
4. NeT activities
5. Fitness for service assessment
6. Conclusion

# Summary

1. Introduction (Welding residual stress assessment, regulations rules), *Vincent*
2. Computational Weld Mechanics (Principle of residual stress prediction based on simulation), *Vincent*
3. R&D activities (with a focus on Ni base alloy assemblies and weld repair), *Josselin*
4. NeT activities (focus on TG4, TG6 and TG8), *Vincent*
5. Fitness for service assessment (PWSCC) *Josselin*, (Fracture Mechanics) *Vincent*
6. Conclusion, guide of the safety authorities on the qualification of scientific calculation tools and its application to the implementation of engineering methods.



# 1. Introduction

# 1. Introduction (1/4)

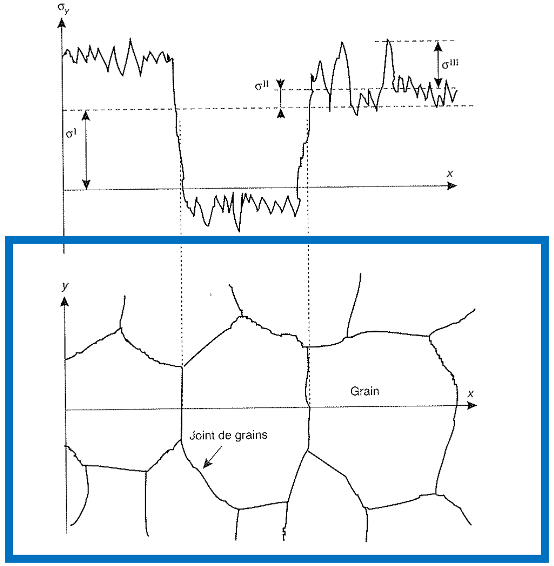
The scope of this presentation concerns modelling of metallic components at solid state considering **continuum mechanics** - *The level of stress we consider in engineering design assessment….*

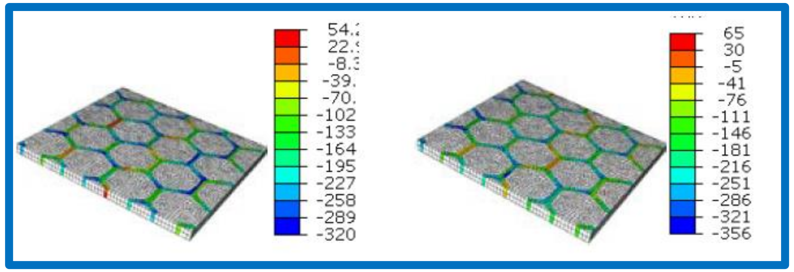
**Stresses in metals**

Order 3: heterogeneous micro-stresses (defects in the grains)

Order 2: homogeneous micro-stresses constant at the level of the grain (average of the stresses of order 3)

Order 1: macroscopic stresses which are constant on a large number of grains (average of the stresses of order 2)





*[1] C. Zhang, Y. Charles, M. Gaspérini, B. Bacroix, V. Robin et G. Perrin, **Simulation numérique par éléments finis d'agrégats polycristallins soumis à des chargements thermomécaniques issus du soudage**, CFM2013 Congrès Français de Mécanique, August 2013, Bordeaux, France.*

# 1. Introduction (2/4)

Historically, the French nuclear construction code considers that residual stresses are not an issue insofar as this aspect is covered by

- the **design margins** (safety coefficients on in service-loads),
- the **choice of materials**, some of which are intrinsically ductile or not sensitized to SCC,
- The **manufacturing process**, which prescribes stress-relieving heat treatments for materials likely to undergo incidental or accidental situations in the brittle domain (cold shocks in particular, linked to the emergency transitory).

# 1. Introduction (3/4)

Welding processes and related operations (levelling, grinding, stress relieving heat treatment…) are particularly looked at because welds are the place where a certain number of difficulties can be concentrated:

- design of assemblies and geometrical transitions,
- technological manufacturing defects,
- modification of the material leading to particular properties in the thermo-mechanically affected zone…

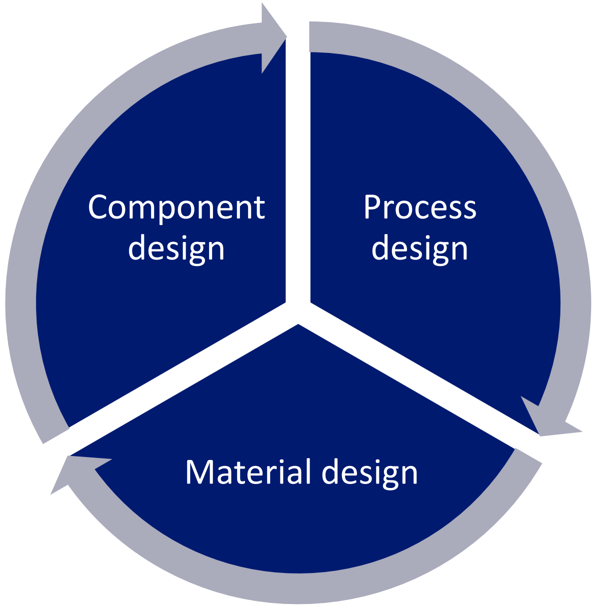
This is why this presentation focuses only on **welding residual stresses** and what justifies the work undertaken for many years by EDF to master this aspect and to quantify the margins on the consideration of residual stresses in the damage tolerance in service (PWSCC and brittle fracture in particular).

# 1. Introduction (4/4)

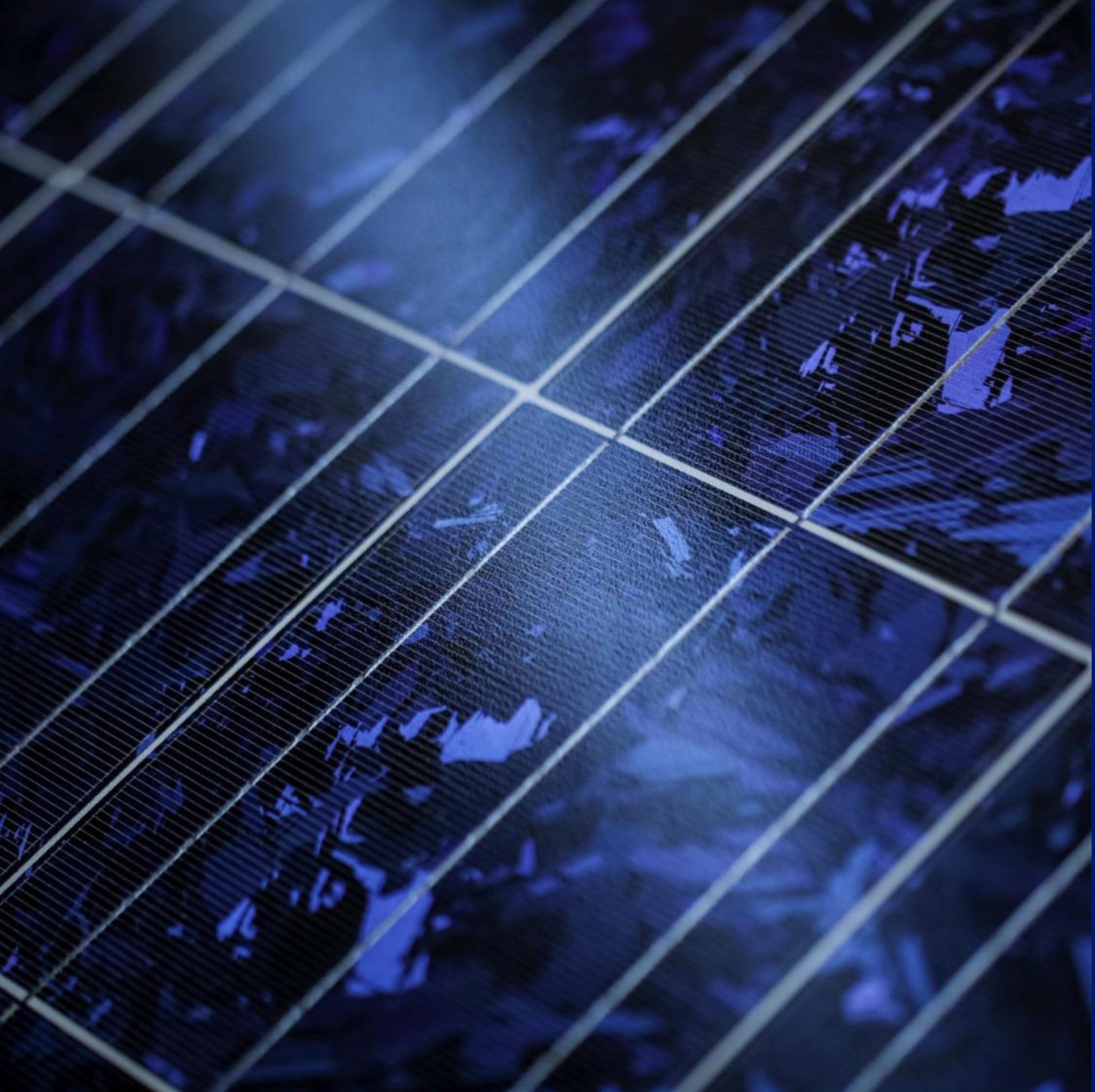
Sometimes, considering residual stresses proves to be essential to justify the commissioning of equipment or to maintain the nuclear power generation unit in service.

These cases will be used as a basis for the presentation which will show the interest for EDF to rely on the work of the NeT network for the determination of residual stresses:

- Residual stresses and PWSCC risk
- Residual stresses and brittle fracture risk (low tenacity)
- Residual stresses and impact of manufacturing
  - Deviation from manufacturing rules
  - Repair and mitigation processes




Addressing residual stresses requires a combination of design, manufacturing and material considerations



# 2. Computational Weld Mechanics

# 2. Computational Weld Mechanics (1/9)

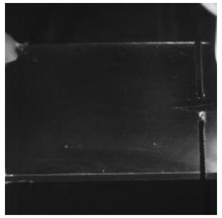
The determination of residual stresses is based on two approaches widely tested in the framework of NeT network:

- The experimental techniques (non-destructive and destructive measurements),
- The numerical methods coupling more or less strongly the physical phenomena

The presentation focuses on **physics-based computational tools** that require validation (ability to account for physical phenomena) by measurement or by benchmarking with other scientific computational tools equivalent in terms of functionality.

# 2. Computational Weld Mechanics (2/9)

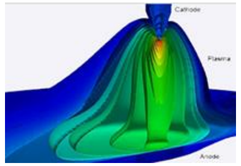
**The reality with the eye of the camera**

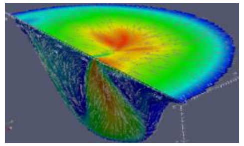


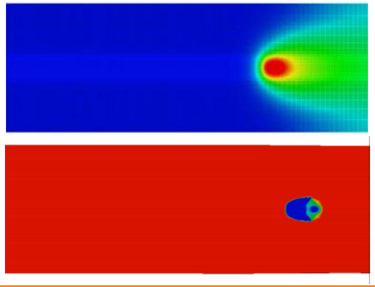
*Hot cracking susceptibility test*

Measurements of physical quantities

**The model with its parameters to describe some of the physics**







MP models (fluid dynamics)

TMM models (solide state)

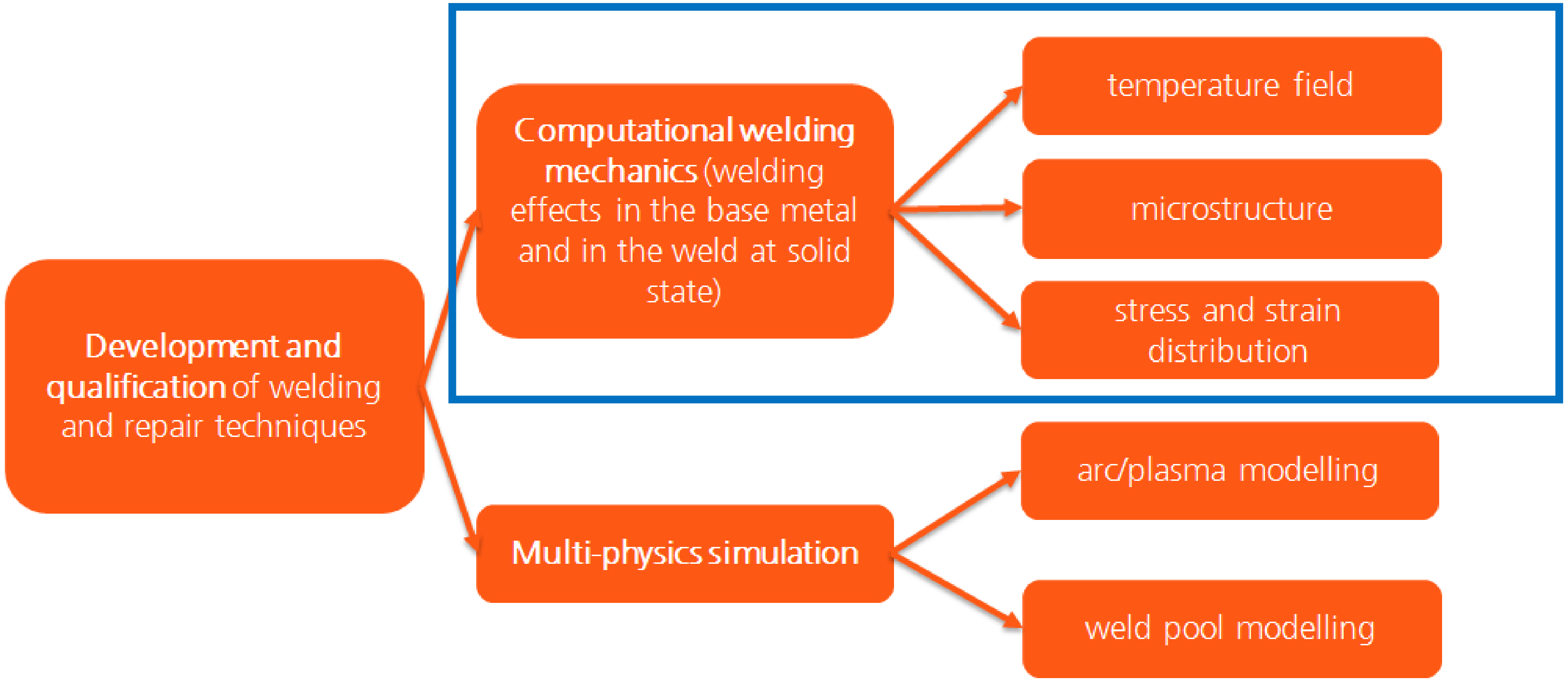
Uncertainties

Surrogate modelling

Calibration analytics

Simulation

# 2. Computational Weld Mechanics (3/9)

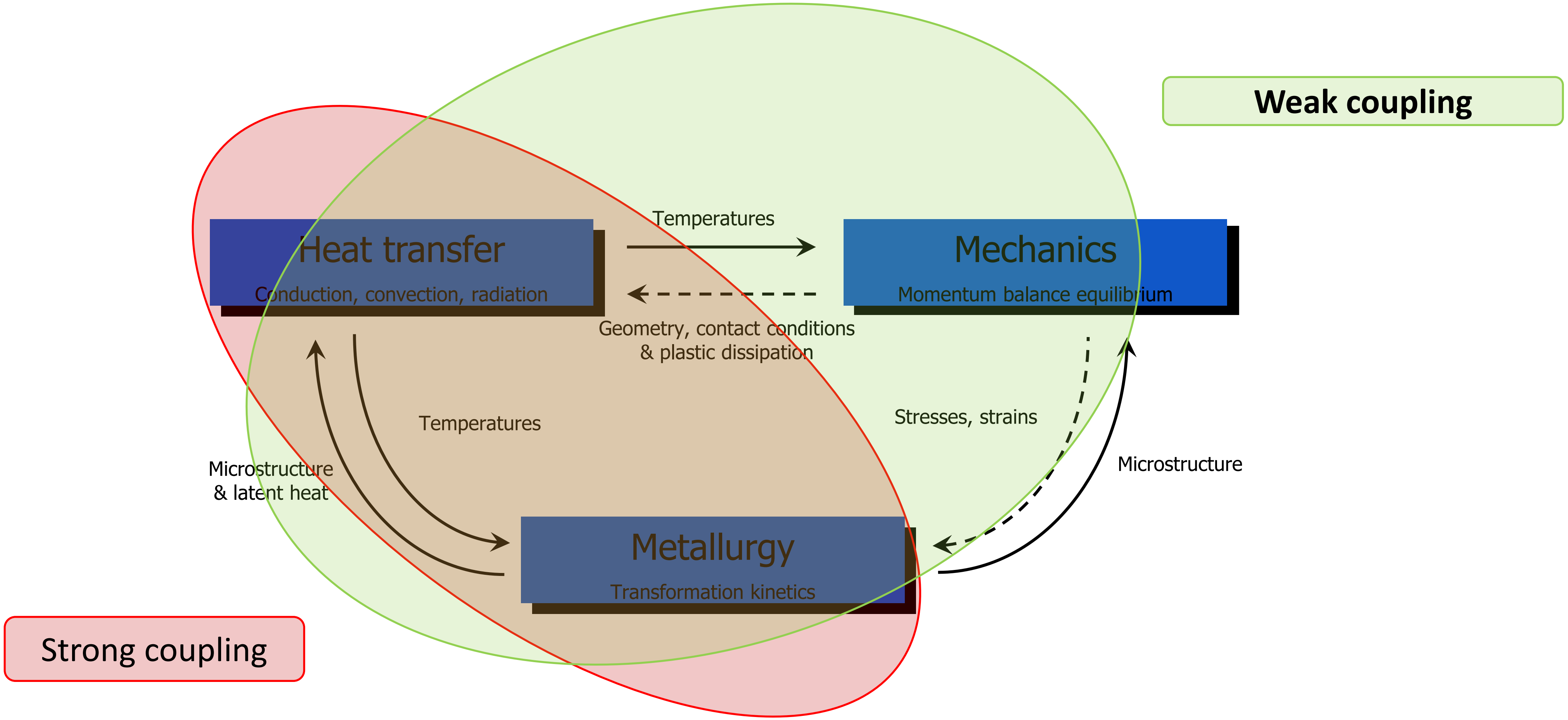



FEM couplings ***[1]*** :

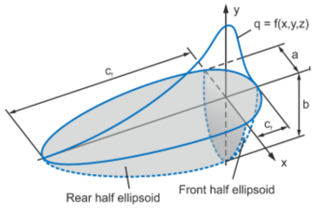
- Heat transfers
- Continuum mechanics
- Microstructure evolution that modify mechanical behaviour

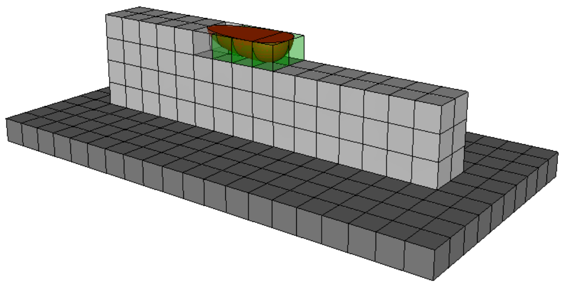
*[1] CEN ISO/TS 18166:2016,* ***Numerical welding simulation*** *— Execution and documentation, 2015.*

# 2. Computational Weld Mechanics (4/9)



# 2. Computational Weld Mechanics (5/9)



**Conventional Welding**

**Key parameters**

**1 - Heat source modeling**

2 - Mechanical behavior depending on temperature and microstructures

Determination of **thermal cycling** at any point of the assembly

Mapping of **phase volume fractions and hardness**

Homogeneity of the **microstructure**

Risk of **hot and cold cracking**

**Local deformation** of the welded joint

Permanent deformations and **residual stresses**

Residual states and **fitness for service assessment**

## Heat transfer

$$\rho \frac{\partial H}{\partial t} - div(\lambda.\mathbf{grad}\,\theta) - Q = 0 \quad \text{in domain } \Omega$$

## Boundary conditions

$$\lambda.\mathbf{grad}\,\theta.\mathbf{n} = q(\theta, t) \quad \text{on } \partial\Omega_q$$

$$\theta = \theta_d(t) \quad \text{on } \partial\Omega_\theta$$

$$\partial\Omega = \partial\Omega_q \cup \partial\Omega_\theta$$

## Initial conditions

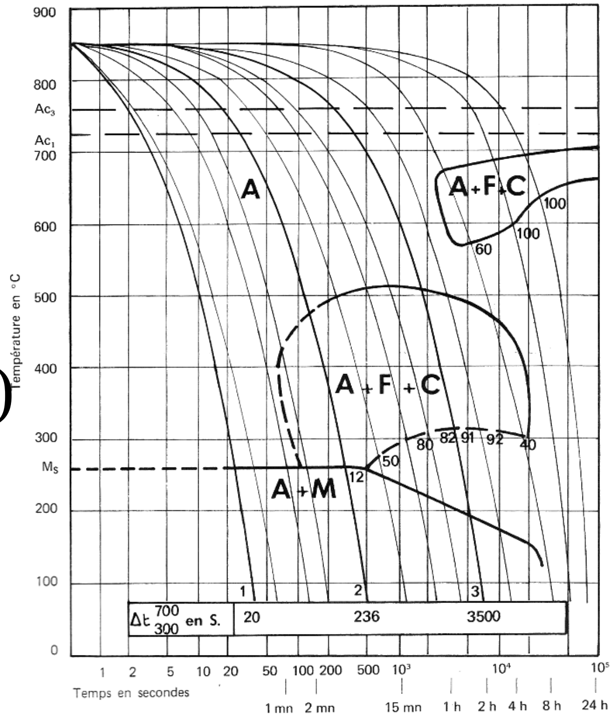
Robust FE code (Heat transfer and metallurgy)

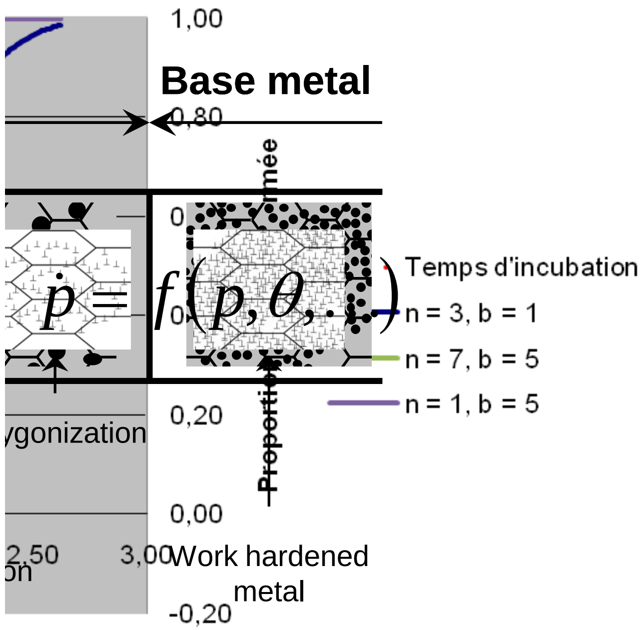
# 2. Computational Weld Mechanics (6/9)

**High temperature processes**
**Metallurgical consequences**

Molten

$$p_f = p_a(1-e^{-bt^n})$$




$$\dot{p} = f(p, \theta, \ldots)$$

Microstructure modifications can be modelled by germination/growth kinetics or phenomenological models

- Phase transformations
- Tempering phenomena
- Recrystallization phenomena

Well characterized and validated industrial models

# 2. Computational Weld Mechanics (7/9)

Conventional Welding

**Key parameters**

1 - Heat source modeling

**2 - Mechanical behavior depending on temperature and microstructures**

Determination of **thermal cycling** at any point of the assembly

Mapping of **phase volume fractions and hardness**

Homogeneity of the **microstructure**

Risk of **hot and cold cracking**

**Local deformation** of the welded joint

Permanent deformations and **residual stresses**

Residual states and **fitness for service assessment**

## Global mechanical equilibrium

$$\mathbf{div}(\boldsymbol{\sigma}) + \cancel{f_v} = 0$$

## Stress-strain relationships

$$\dot{\varepsilon} = \dot{\varepsilon}^{\mathbf{e}} + \dot{\varepsilon}^{\mathbf{p}} + \dot{\varepsilon}^{\mathbf{th}}$$

Relation with $\boldsymbol{\sigma}$ following Hooke's law

Classical plasticity or viscoplasticity and **transformation induced plasticity** is included

$$\dot{\varepsilon}^{\mathbf{p}} = \dot{\varepsilon}^{\mathbf{pc}} + \dot{\varepsilon}^{\mathbf{pt}}$$

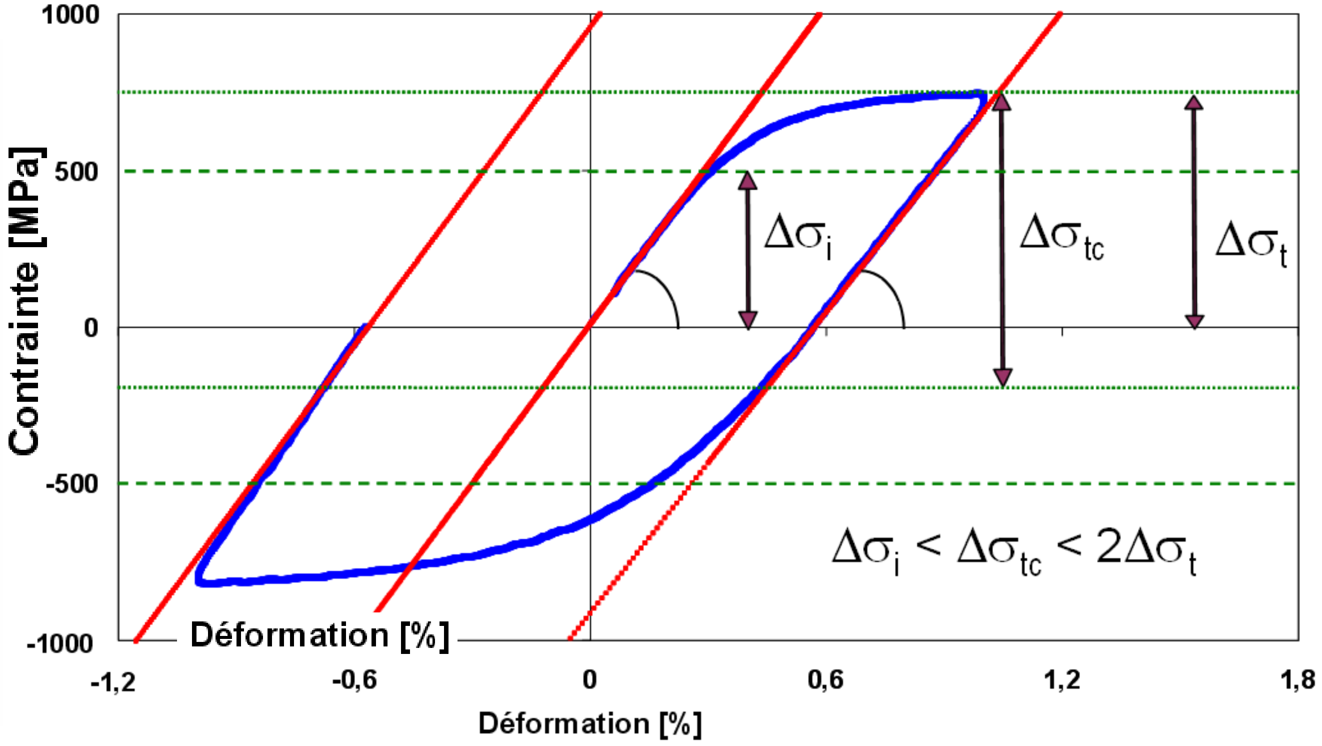
**Volume change during transformations** is included

$$\varepsilon^{th}(T) = \sum_{\text{Phases}} p_k . \varepsilon_k^{th}(T)$$

Robust FE code (Mechanics with inputs from heat transfers and metallurgy)

# 2. Computational Weld Mechanics (8/9)

**High temperature processes**
**Mechanical consequences**




***Prescribed deformation tests (several speeds)***

***Holding stages (a few seconds) equivalent to relaxation tests***

Consequences on deformations and residual stresses

- Volume changes and transformation induced plasticity
- Behavior laws depending on temperature and microstructure
- Mixed strain hardening (isotropic + kinematic) under cyclic loading
- Viscous effects at high temperatures

Well characterized and validated industrial models

# 2. Computational Weld Mechanics (9/9)

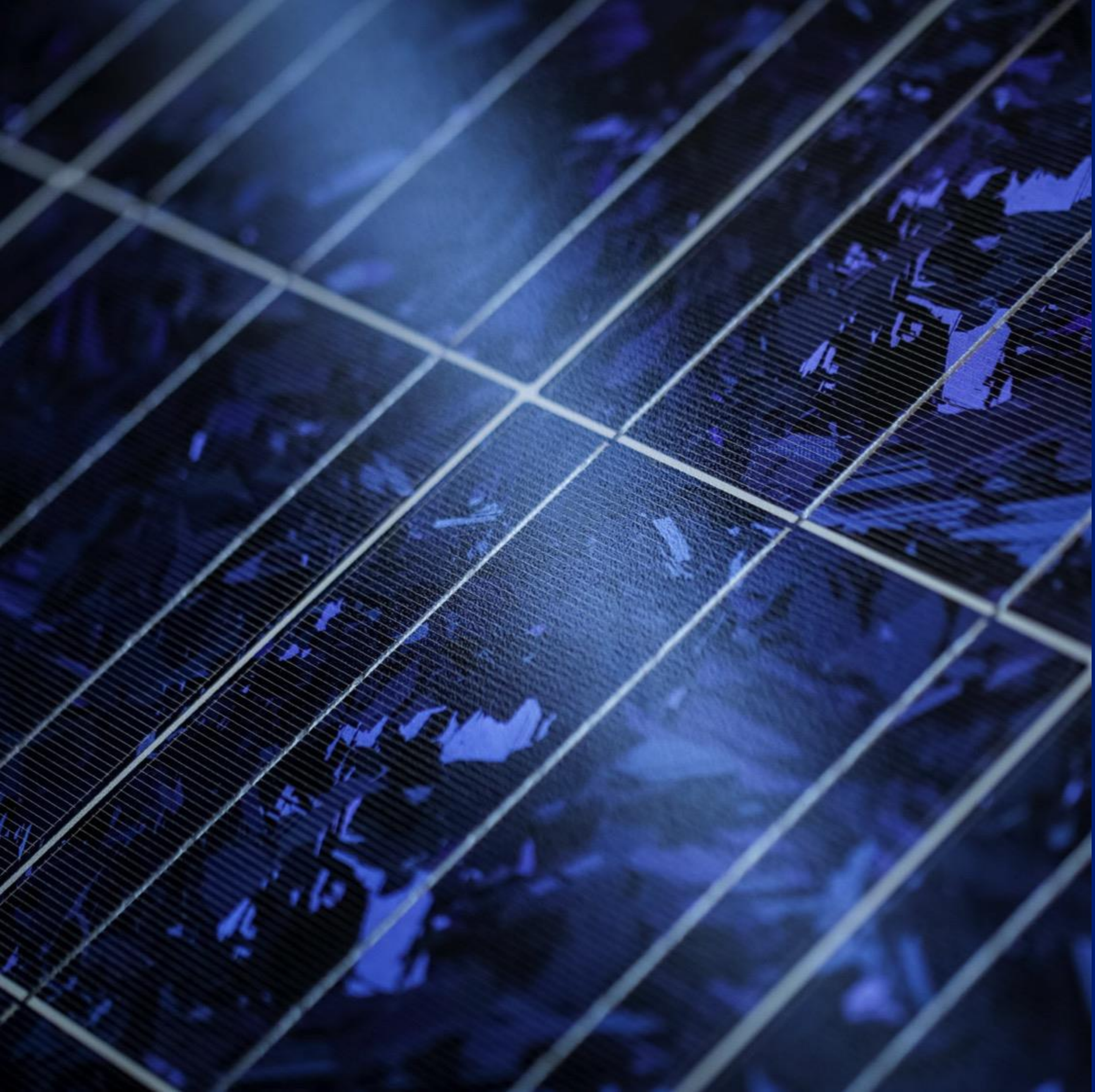
Such a scientific calculation tool is useful to answer all the questions about the confidence in the determination of the residual stresses regarding :

- Variability of process parameters
- Variability of welding sequence
- Managing PWHT
- Presence of welding defect (hot and crock cracking, technological defects)

**R&D project**
- Modelling
- Welding monitoring
- Welding metallurgy…

Finally, **having these elements allows us to argue with the regulator about the uncertainties related to the determination of the residual stresses**. The measurements and the prediction models are based on different assumptions. These are thus more easily accepted if there is good agreement between the two approaches.

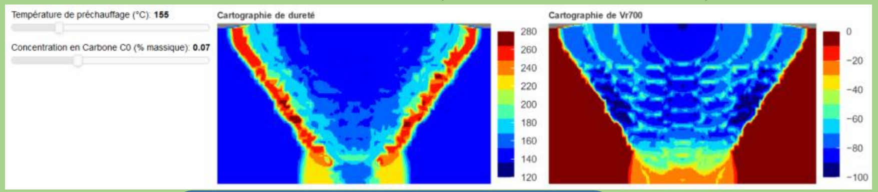
Well-characterized simulation models and mock-ups, such as the NeT network benchmarks, are a good medium for demonstrating the reliability of residual stress assessment. In the tool validation strategy, we talk about a transposition model between a simple test and a more difficult to model or characterize industrial equipment.



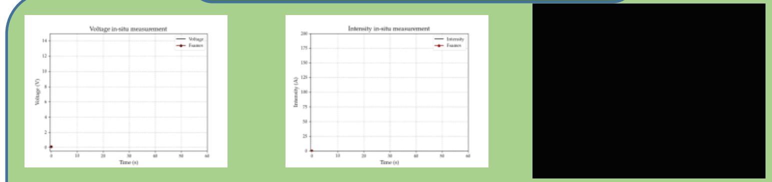
# 3. R&D activities

# 3. The skills in our lab

Numerical abacuses (hardness and Vr700)

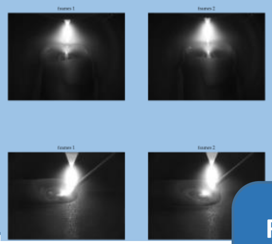



**Numerical abacuses - Real-time drift detection platform**




Real-time drift detection demonstrator

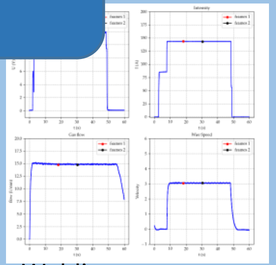
Welding pool monitoring



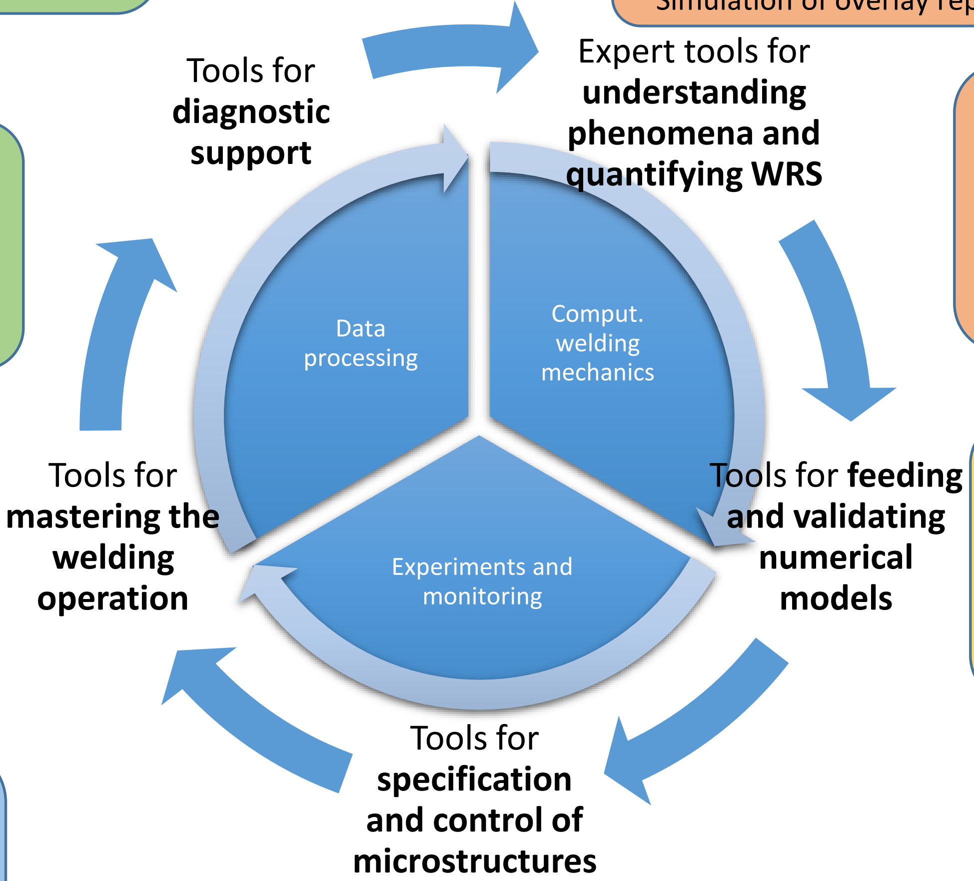
Experimental setup

**Real-time monitoring of the welding operation**

*France Relance* project

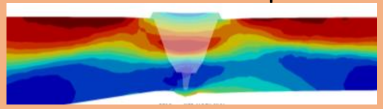


Welding parameters

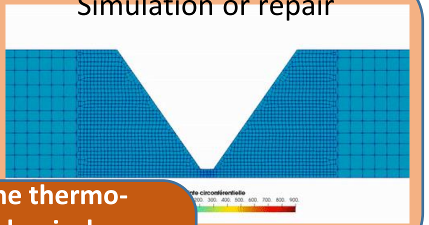


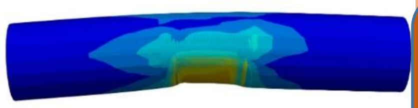

**Metallurgical expertise, mechanical characterisation and specific tests** (Satoh, Gleeble)

Simulation or repair



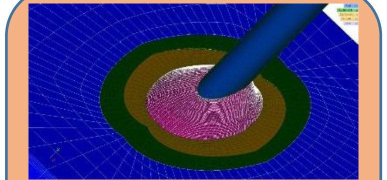
Simulation or repair





Simulation of overlay repair

**Prediction of the thermo-metallo-mechanical consequences of welding**: residual stresses, residual strains, hardnesses, metallurgical phases

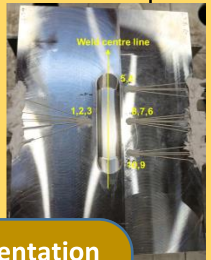


Simulation of a BMIN repair

Joint research centre

Instrumented mock-up

Instrumented mock-up




**Welding scene instrumentation** (thermocouples)
**Residual stress measurement**
**Strain measurement** (stereo-correlation, 3D scan)

H2020 project

European network

# 3. SAFER R&D project and organization

**Simulation du soudage en Appui à la Fabrication Et à la Réparation**
**Welding simulation in Support of Manufacturing and Repair**

**NEEDS**

**Improve the quality of welds and their control:**
- Reliability of the existing
- Innovative solutions

**Numerical Simulation / experimental Data analysis**

**WP 5: Expertise support and hotline**

**WP 1: Simplified numerical tools**
Numerical abacus

**WP 2: Welding residual stress**
Measurments & simulation

**WP 3: Support on Temper Bead codification at reduce temperature**
Defining operation process from Tekken tests

**WP 4: Real-time monitoring & control**
Numerical simulation, experimental and proof of concept

**WP 6: Weldability and metallurgy**
Effects on micro-structure of welding parameters and chemical composition

Applications

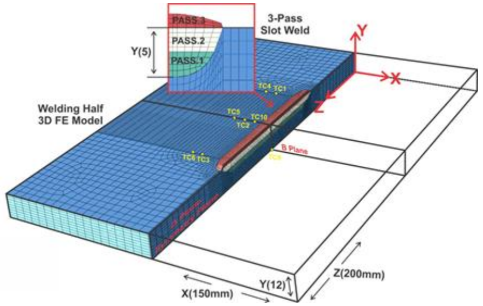
- Manufacturing of pipe lines
- Repair of BMIN(*)
  SCC cracking risk
  PWHT and finishing

***(*) Bottom Mounted Instrumentation Nozzle***

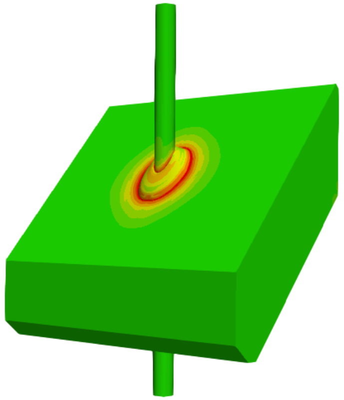
- **Repair on Vessel**
- **Laboratory mock-up & EPR2**
- Improve kwnoledge & optimize chemical composition for secondary loop for **FA3** & **EPR2**

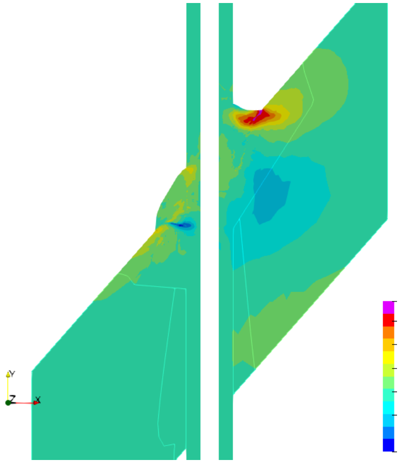
# 3. Focus on BMIN manufacturing simulation

Determine the residual stresses in alloy 600 and 82/182 weld metal as this material may be sensitive to PWSCC (link with TG6)




Material dataset and modelling hypothesis based on TG6 simulation benchmark (validation of the transposition from mock-up to component)

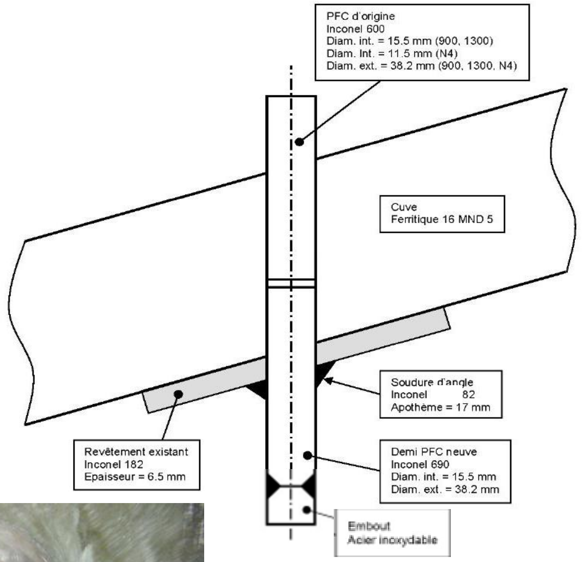




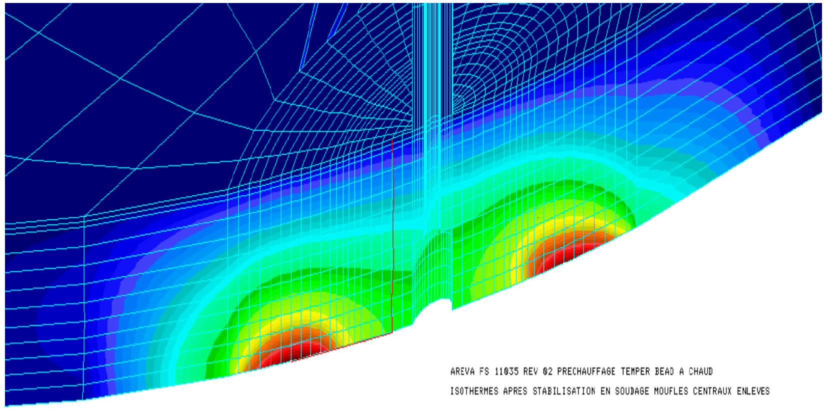
# 3. Focus on BMIN repair : temper-bead process

**« half nozzle repair » process** : New half nozzle welded on a Inconel patch,

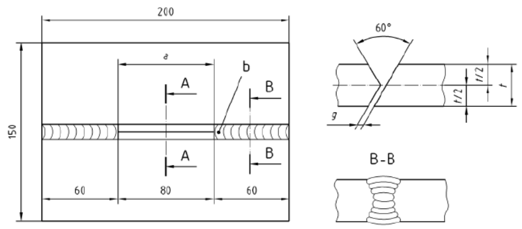
The patch have to be flawless, if not, the patch have to be repaired: need of **temperbead process** at low temperature (no PWHT possible)




**Determine the residual stresses in the ferritic steel as no PWHT is possible (link with TG8)**




Dimensions en millimètres




a) Essai sur chanfrein en Y

**Légende**

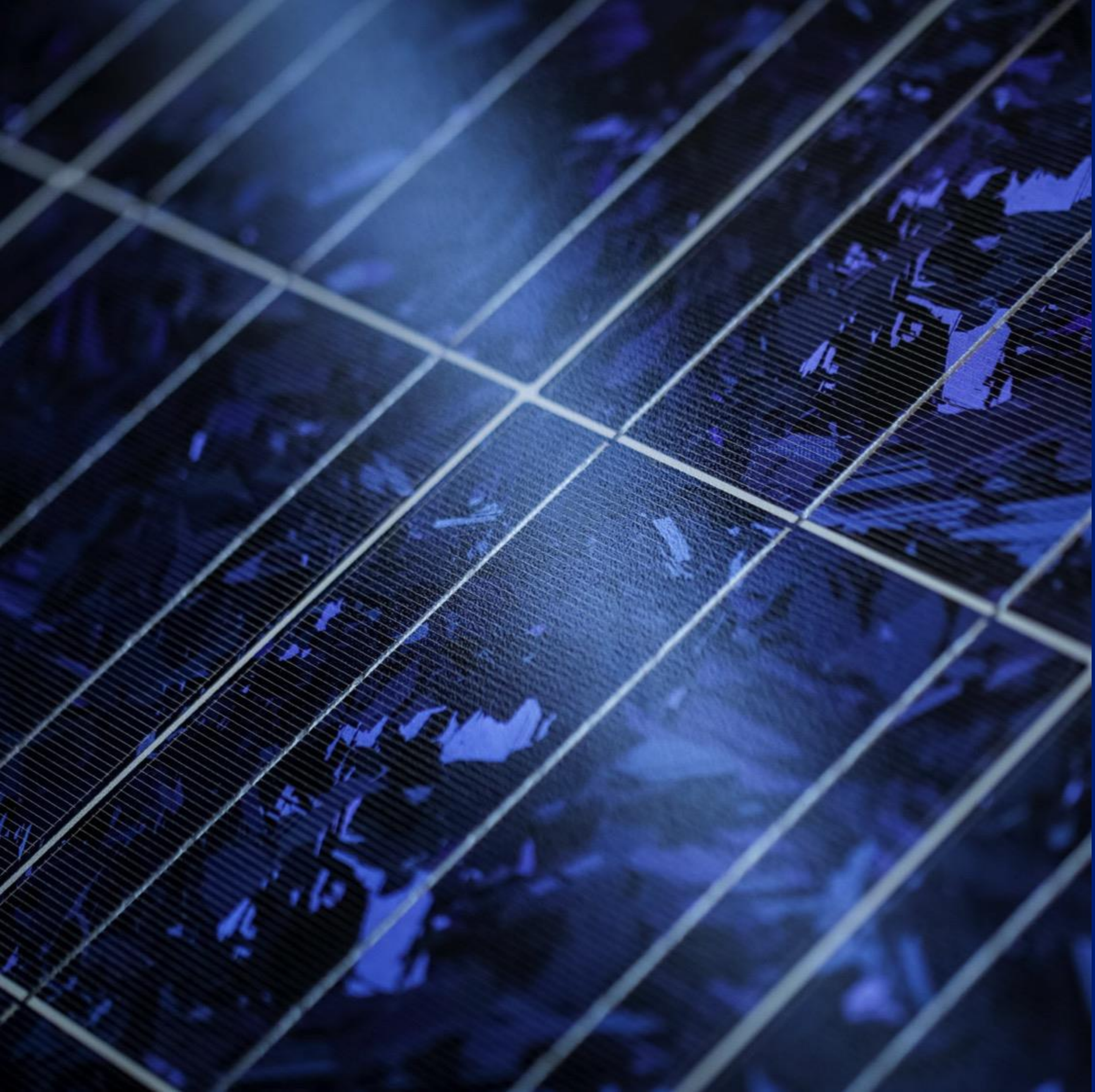
a Soudure d'essai (chanfrein en Y ou chanfrein en U)

b Soudure d'ancrage

*t* Épaisseur de la plaque d'essai

*g* Écartement à la racine 2,0 mm ± 0,2 mm

*W* Diamètre du trou percé (fonction de l'épaisseur) et largeur du chanfrein



# 4. NeT activities

# 4. NeT activities (1/5)

The mission of the European Network on Neutron Techniques Standardization for Structural Integrity (NeT *[1]*) is to develop experimental and numerical techniques and standards for the reliable characterisation of residual stresses in welds.

NeT was first established in 2002, and involves over 30 organisations from Europe and beyond. It operates on a “contribution in kind” basis from industrial, academic, and research facility partners.

Each problem examined by the network is tackled by creating a dedicated Task Group (TG), which undertakes measurement and modelling studies and the interpretation of the results. NeT achieves this by conducting parallel measurement and prediction round robins on closely controlled and well characterized benchmark weldments.

***[1]*** Visit the website www.net-network.eu

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# 4. NeT activities (2/5)

## Development of standards for stress modelling and measurements techniques

**Network title & mission**
The mission of the European Network on Neutron Techniques Standardization for Structural Integrity (NeT) is to develop experimental and numerical techniques and standards for the reliable characterization of residual stresses in structural welds.

**Partnership & resources**
NeT was established in 2002 and it has been operating since then on a "contribution in kind" basis from industrial, academic and research facility partners.

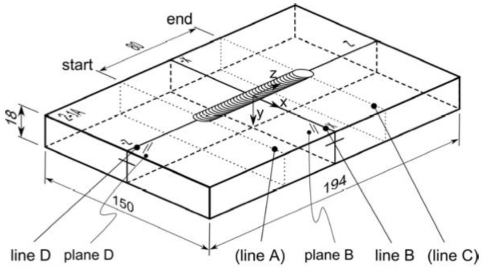
**Work programme organization**
Each problem examined by the network is tackled by creating a dedicated Task Group (TG), which undertakes measurement and modelling round robin studies and the interpretation of their results.

*TG1: Single Bead-on-Plate Weldment (Stainless Steel)*
*TG2: Letter Box Repair Welds (Ferritic Steel)*
***TG4: 3-Pass Slot Weld (Stainless Steel)*** MANCHESTER 1824
*TG5: Edge Welded Beam (Ferritic Steel)*
***TG6: 3-Pass Slot Weld (Ni alloy)*** EDF MANCHESTER 1824
*TG7: Electron beam weld on high strength Al alloy*
***TG8: 5-Pass Slot Dissimilar Weld (Ni alloy) on Ferritic Steel*** EDF MANCHESTER 1824
***TG9: Wire Arc Additive Manufacturing (Stainless Steel)*** LMGC LABORATOIRE de MÉCANIQUE et GÉNIE CIVIL

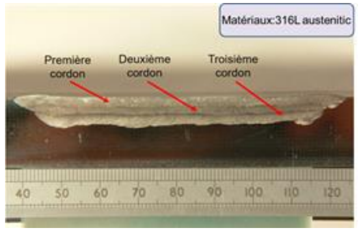
**Transposition mock-up to validate modelling and measurement techniques when applied on real components**

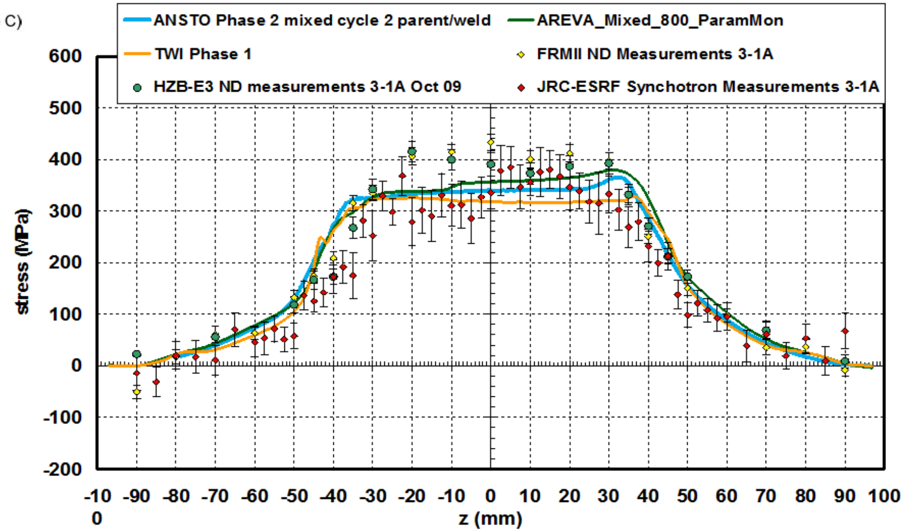
# 4. NeT activities (3/5)

## Development of standards for stress modelling and measurement techniques




**TG4 : Longitudinal stresses along line D9**




European network for the characterization of residual welding stresses allowing the industrialization of measurement and simulation methods (standardization, codification, etc.)

NeT TG4 *[1]*

- 16 simulations
- 14 measurements

NeT TG4 largely succeeded in its objectives, the project is probably the most detailed and extensive study on weld residual stress simulation and measurement yet carried out. It is currently being documented in a special issue of the International Journal of Pressure Vessels and Piping *[1]*. It deals with very well characterized **316L austenitic stainless steel for filler metal and substrate**.

**[1]** *Mike C Smith, Ann C Smith, Carsten Ohms, Robert C.Wimpory, The NeT Task Group 4 residual stress measurement and analysis round robin on a three-pass slot-welded plate specimen*, **International Journal of Pressure Vessels and Piping**, Volume 164, July 2018, pp. 3-21.

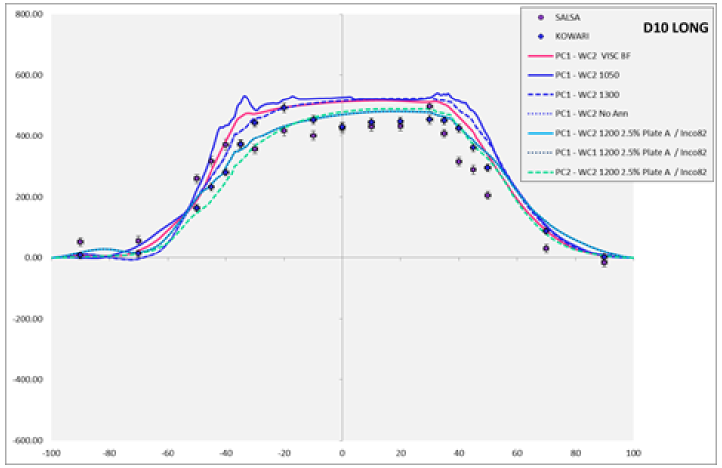
# 4. NeT activities (4/5)

## Development of standards for stress modelling and measurement techniques

### NeT TG6 *[1]*

- On going simulations and measurements

**TG6 : Longitudinal stresses along line D10**




European network for the characterization of residual welding stresses allowing the industrialization of measurement and simulation methods (standardization, codification, etc.)

The NeT TG6 project was started in early 2012. It examines the behaviour of Tungsten Inert Gas (TIG) welds made using nickel-based **Alloy 82 filler on an Alloy 600 substrate**, using a three pass slot weld geometry similar to the TG4 specimen. Residual stresses in welds made using Alloy 82 or Alloy 182 filler are of considerable interest because these alloys are susceptible to PWSCC *[1]*.

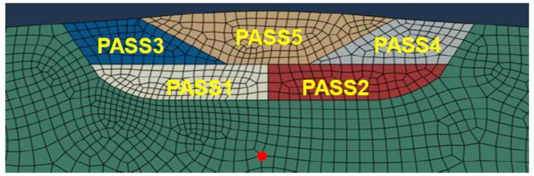
*__[1]__ Vasileios Akrivos, Mike C Smith, Ondrej Muransky, Carsten Ohms, Anastasios Youtsos, A residual stress measurement and numerical analysis round robin on a three-pass slot nickel-base repair weld – TG6, Procedia Manufacturing ,Volume 51, pp. 779-786, January 2020.*

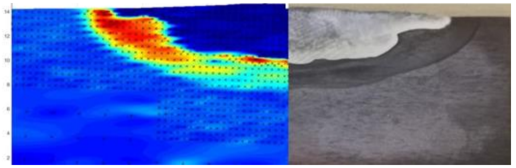
# 4. NeT activities (5/5)

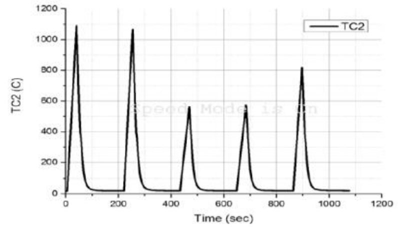
Development of standards for stress modelling and measurement techniques

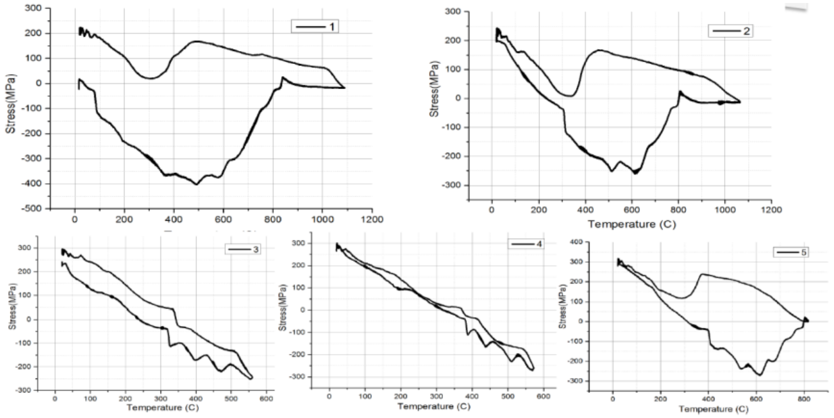
## TG8 : 5 pass bead on plate (Alloy 52 / 18MND5) *w/wo PWHT*

The NeT TG8 *[1]* round robin specimen is closely based upon the TG4 designs, except the thickness that is increased up to 30 mm for more self-clamping conditions and to reduce distortions. The use of nickel-based alloys for filler metal adds considerable residual stress measurement challenges, while this configuration undergoes a **complex mismatch behaviour with the base metal where phase transformations and tempering effects occur in the HAZ**.

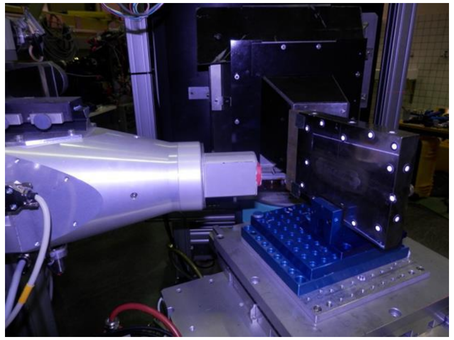


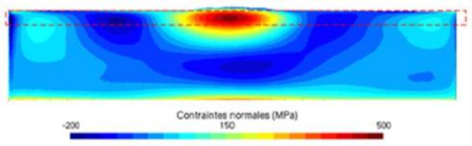


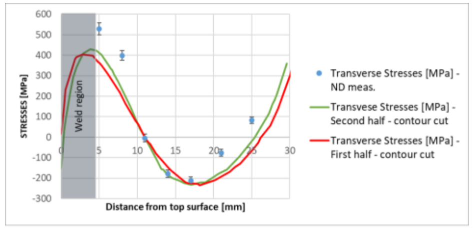

### Neutron diffraction

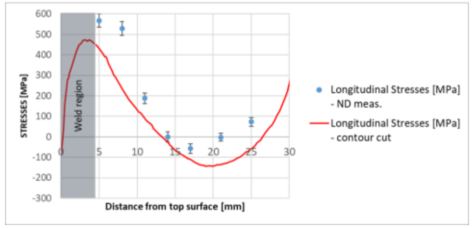


### Contour method




### Deep hole drilling

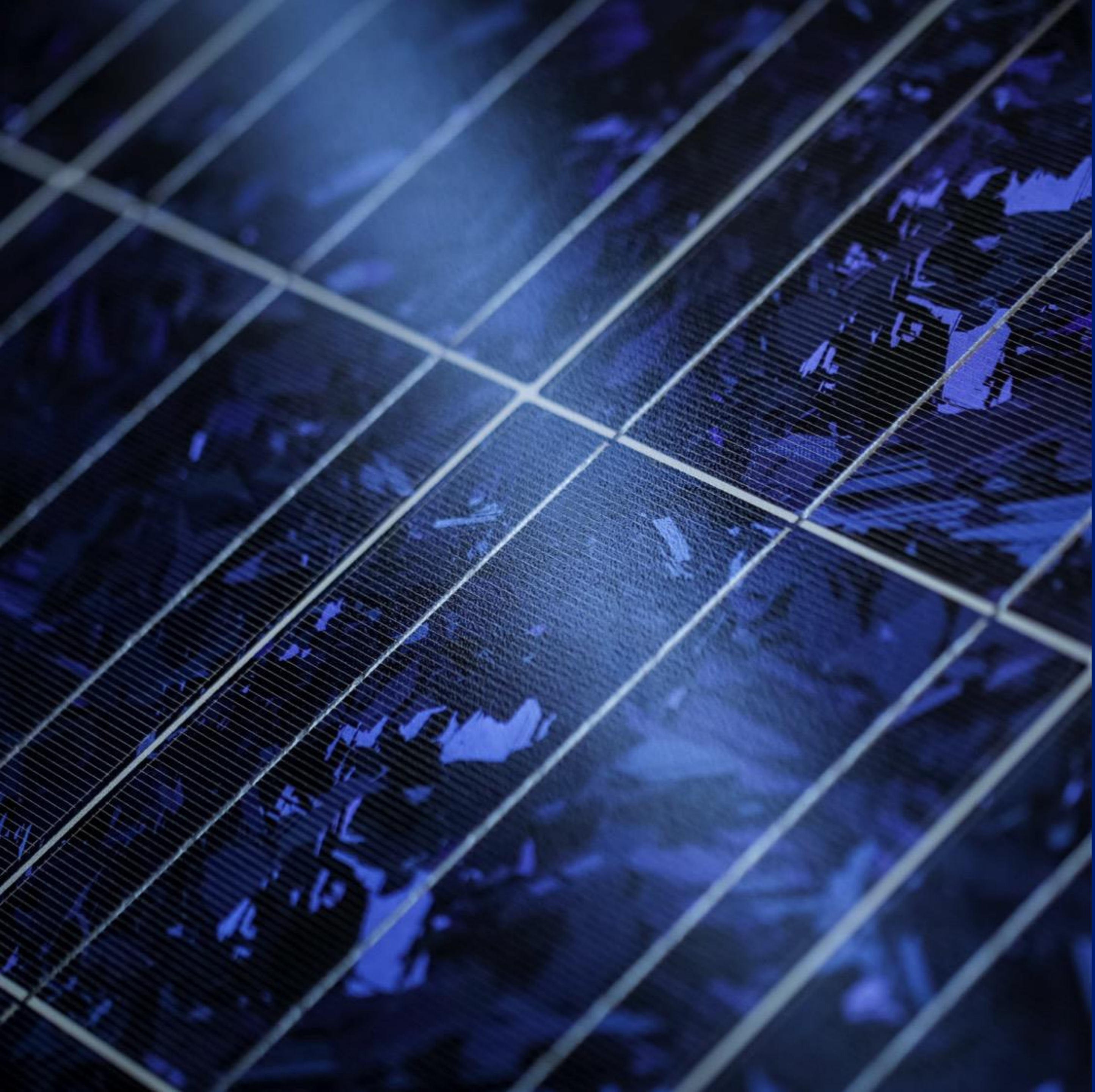



*CONTOUR METHOD AND NEUTRON DIFFRACTION RESULTS, BD LINE (R.C. WIMPORY (HZB), G. TRESPEUCH (SONATS)).*

**→ Transposition model : only the geometric complexity of a real configuration is not present but the impact is easily quantifiable by a simulation validated with TG8 round robin**

***[1]*** *V. Robin, S. Hendili, J. Delmas, J. Draup, Q. Xiong, M.C. Smith, A. Paget, NeT Project Task Group 8, an international benchmark on residual stress assessment for welding repair, PVP2022 85083, Proceedings of the ASME 2022 Pressure Vessels and Piping Conference PVP2022, July 17-22, 2022, Las Vegas, Nevada, USA.*



# 5. Fitness for service assessment

# 5. Chronology of CWM activities in support of the SCC issue

- One year ago, surprisingly PWSCC found on auxiliaries on primary loop near weldments made with stainless steel (316L)
- EDF engineering is mobilised in a task-force to understand and mitigate this phenomenon in an industrial context where it is complicated to leave the plant shut down for a long time
- The CWM team is involved in this task-force to:

  - ➢ Provide input data for code_coriolis (SCC crack initiation and propagation simulation)
    - Observation: Taking into account a fixed residual welding stress state in code_coriolis leads to unrealistic and penalizing crack propagation
    - Major result: Taking into account a residual state from validated CWM is crucial for a consistent estimation of propagation kinetics
  - ➢ Provide elements of understanding of the phenomena to support the defense of the file with the French Nuclear Authority
    - Observation: CWM allows to obtain a realistic residual welding state (in agreement with the experimental observation)
    - Major result: Axial compression stresses in the area where SCC defects were observed (consistent with literature and confirmed on several welds) allows to stop crack propagation
  - ➢ Characterize the risk related to welding on all the welds of the fleet
    - Observation: CWM allows to characterize the effect of manufacturing conditions on the risk of SCC
    - Major result: EDF R&D has developed an innovative decision support tools for prioritizing maintenance operations and prescribing remanufacturing

# 5. Applied approach (SCC)

- Finite element modeling and simulation of the thermomechanical behavior of a structure during welding with code-aster EDF software (Scientific computational tool meeting the requirements of Guide 28*)

- Methodology from the I3P Good Practice Guide for Numerical Welding Simulation (CEA/EDF/FRA) based on the principles of the ISO/TS18166 recommendation standard: Numerical Welding Simulation

- Heat and material input identified on macrographs made on the welds to be simulated in addition to the DMOS for each process studied (TIG auto/manual, coated electrodes)

- Material data from the INZAT program** (characterization dedicated to the numerical simulation of welding for 316L) and consolidated by the activity of the TG4 working group of the NeT network***

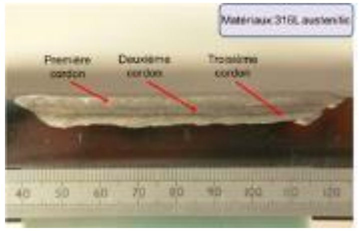
- 2D axisymmetric modeling assumption for multi-pass butt joints

- **Feedback** on similar assemblies (big components, "austenitic" and "ferritic" materials, conventional electric arc welding)

* Guide de l'ASN n°28 : Qualification of scientific computing tools used in the nuclear safety case – 1st barrier
** Research program, called INZAT (1996-2006), operated at the LAMCOS laboratory of the INSA of Lyon and in which EDF, ex. BCCN (DEP), CEA and FRAMATOME participated, had for objective to demonstrate the industrial interest of the numerical simulation of welding for the understanding of the consequences of the couple process/materials on the residual state of the assemblies
*** https://www.net-network.eu/

# 5. Lessons for the choice of the behaviour law - NeT network

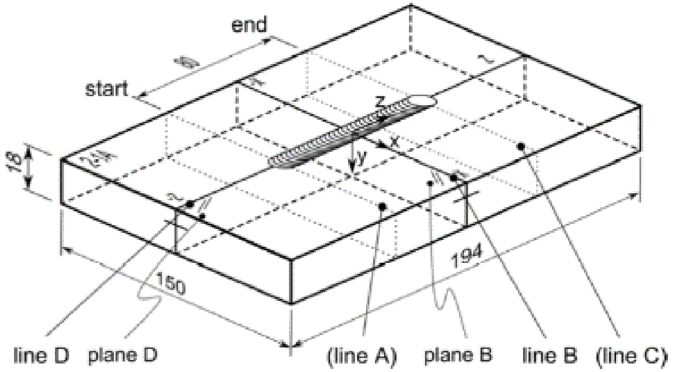
## NeT TG4 *[1] :* 16 simulations, 14 measurements

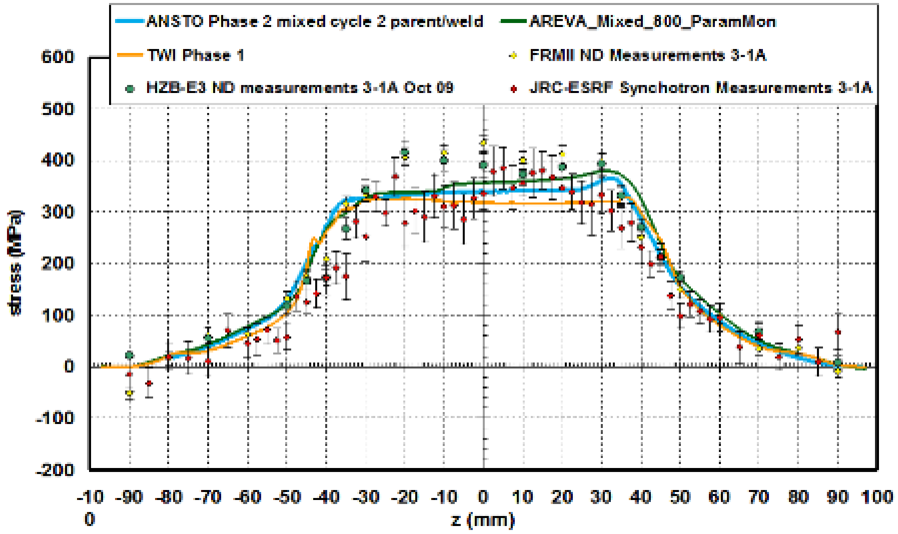


**TG4 : Longitudinal stresses along line D9**

3 elements are important with regard to material behaviour and the consideration of residual stresses *[2]*:

1. hardening recovery for strain hardening in the fusion zone and in the HAZ (regarding material corrosion susceptibility) *[3]*,
2. Mix iso-kin hardening for stress distribution (regarding crack propagation),
3. viscous effects.

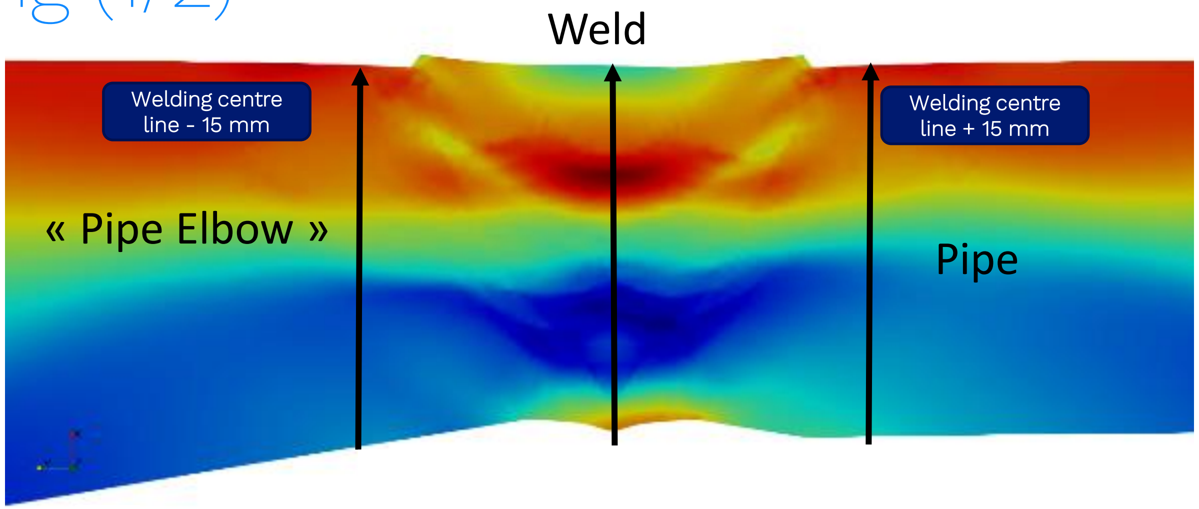




**[1]** *Mike C Smith, Ann C Smith, Carsten Ohms, Robert C.Wimpory, The NeT Task Group 4 residual stress measurement and analysis round robin on a three-pass slot-welded plate specimen,* **International Journal of Pressure Vessels and Piping**, Volume 164, July 2018, pp. 3-21.
**[2]** *L. Depradeux, R. Coquard, Influence of viscoplasticity, hardening, and annealing effects during the welding of a three-pass slot weld (NET-TG4 round robin), International Journal of Pressure Vessels and Piping, Vol. 164 (2018) pp. 39-54.]*
**[3]** *S. Hendili, L. Le Gratiet, M. Abbas, Un nouveau modèle simplifié de la restauration d'écrouissage utilisé dans la simulation numérique du soudage, CSMA 2017, 13ème Colloque National en Calcul des Structures, Mai 2017*

# 5. Residual stresses in welding (1/2)



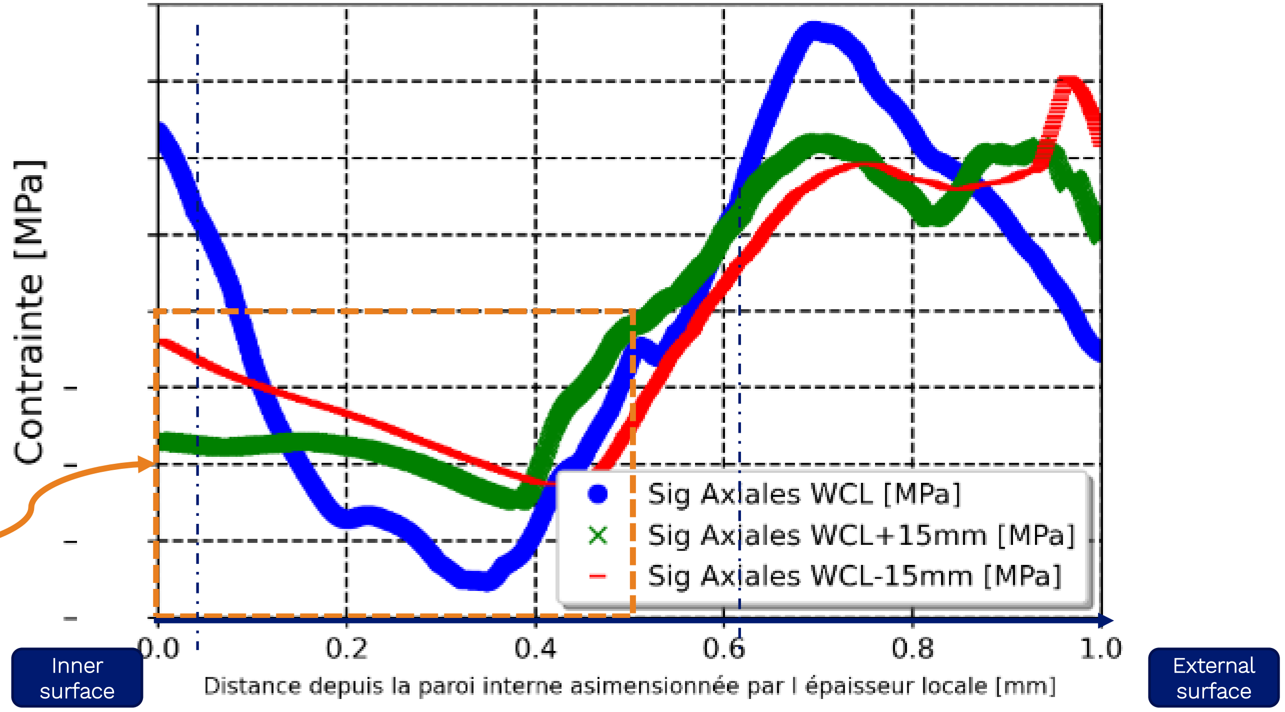

Automatic TIG welding

*Based on welding procedure records*

Comparison of the stress profiles on the welding center line, at -15 mm and +15 mm

- Slight dissymmetry of the stress profiles on both sides of the weld depending on the modeled stiffness (pipe-bend).
- Compression confirmed far from the weld (including thermo-meca affected zone
- Tension close to the surface disappears far from the root

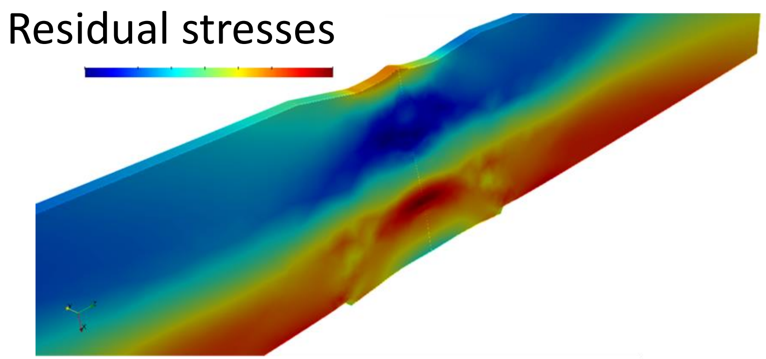
Compression zone at half height close to the inner surface

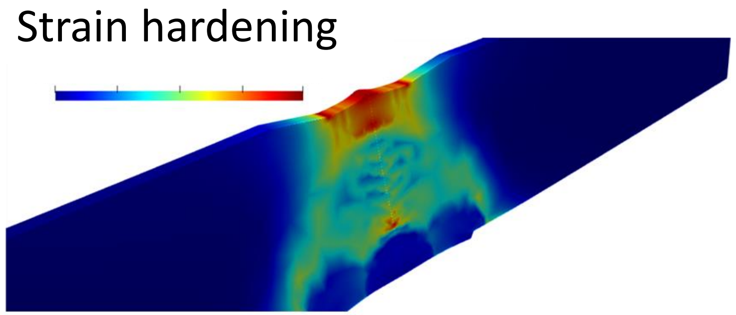


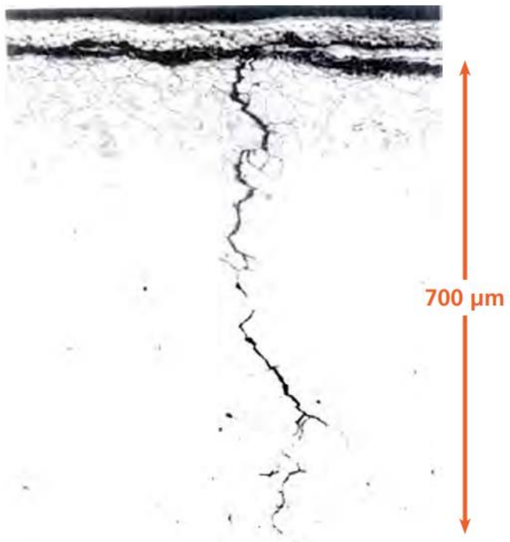
# 5. Residual stresses in welding (2/2)

WRS + in-service loads

Stress intensity Factor approach based on stress profiles and full PWSCC initiation and propagation modelling using Code Coriolis (CWM results as input)



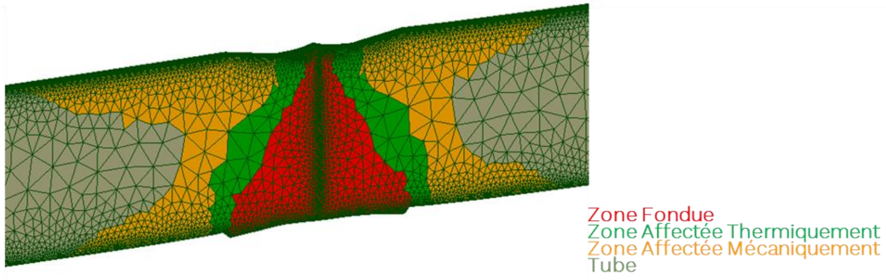




Example of IGSCC in a partition plate of a steam generator (alloy 600)

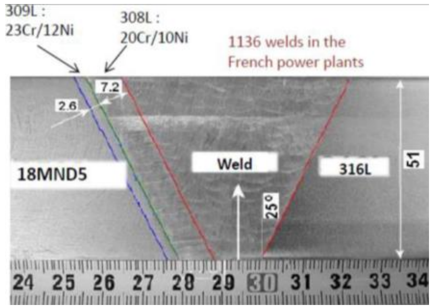
CODE CORIOLIS

Entrée CSC - Coriolis



# 5. Residual state and fitness for service assessment

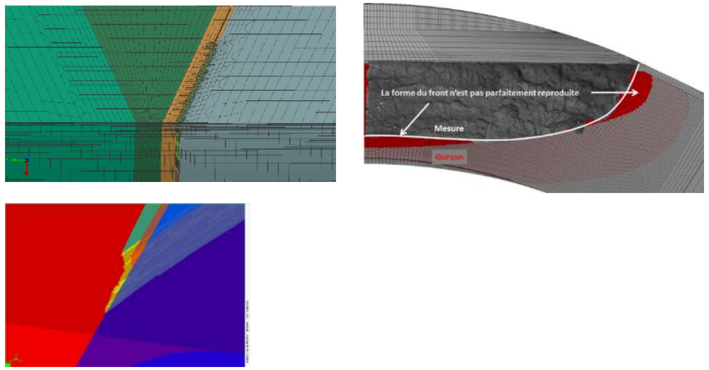
## Global and local approach of fracture mechanics to quantify the residual stress effects



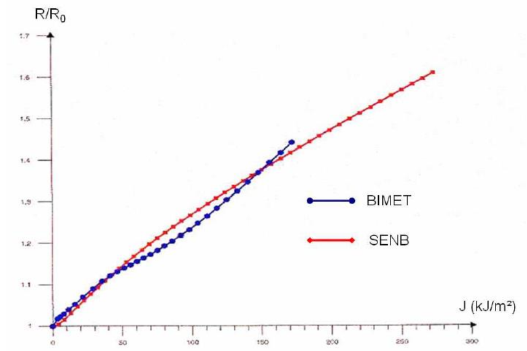

BIMET, ADIMEW, MULTIMETAL… EC Projects

Demonstration of break preclusion for Dissimilar Metal Welds

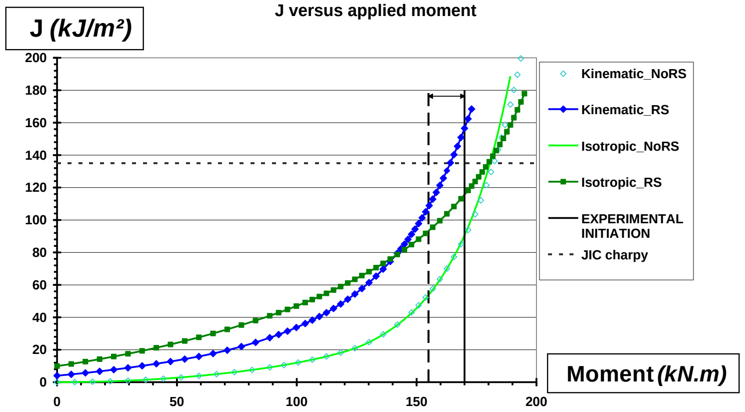
- Break preclusion concept
- Considering material ageing and presence of a virtual defect
- FE modelling can be performed considering or not residual stresses to quantify margins




**Local approach criteria**

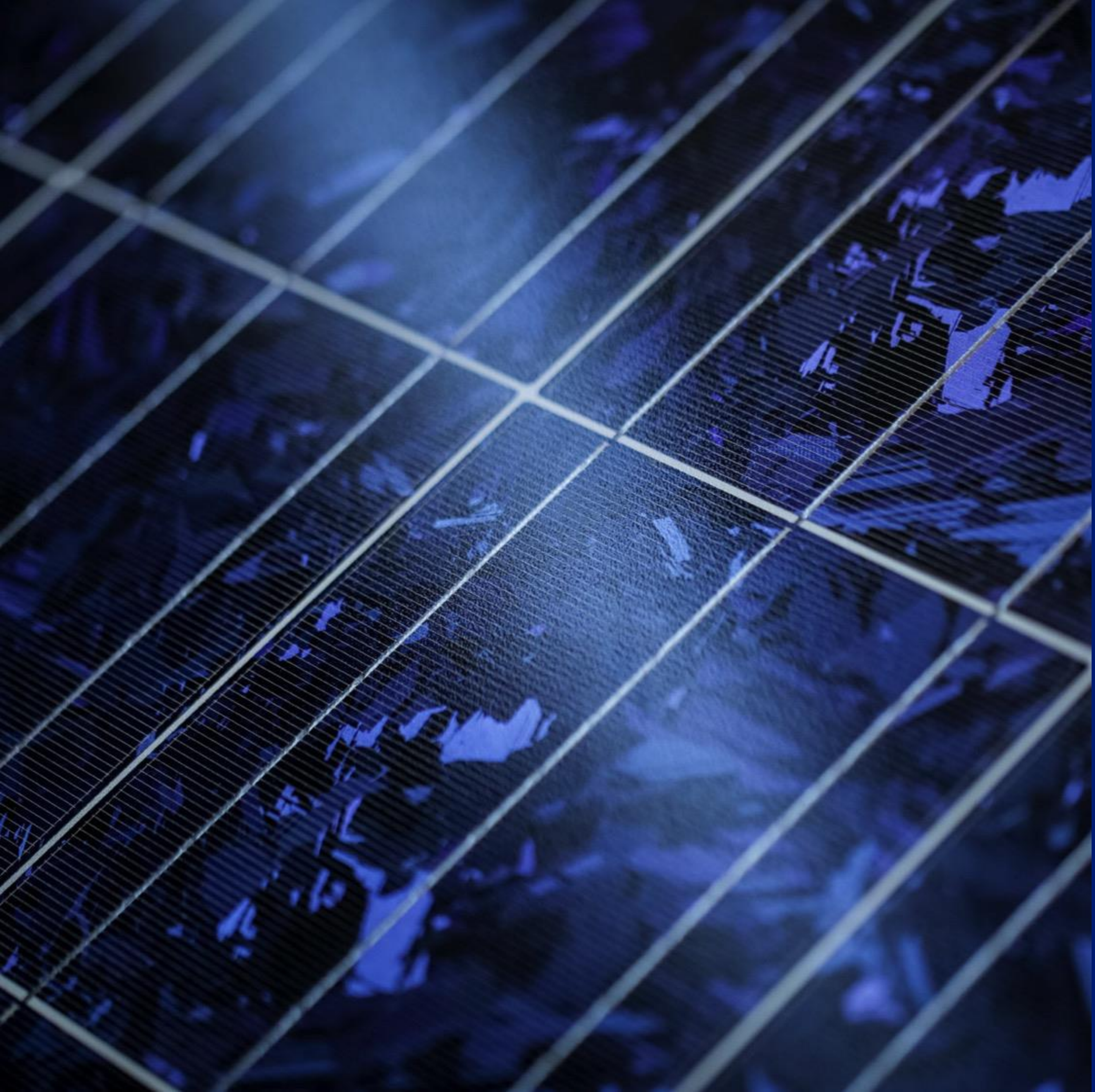



**Global approach criteria**




*[1] Ph. Gilles, V. Robin and M. Fontaine, **Welding residual stress effect on dissimilar metal weld junction fracture**, 12th International Conference on Pressure Vessel Technology, ICPVT 12th, September 2009, Jeju Island, South Korea.*

**Quantify in service margins using monolithic FE approaches**



# 6. Conclusions

# 6. Conclusion (1/4)

The ISO International Standard 21432:2019 on determining residual stresses by neutron diffraction *[1]* has been strongly supported by NeT studies, which have also contributed to ISO/TS 18166:2016 on numerical welding simulation *[2]*. NeT TG8 will complement this work considering a dissimilar weld repair.

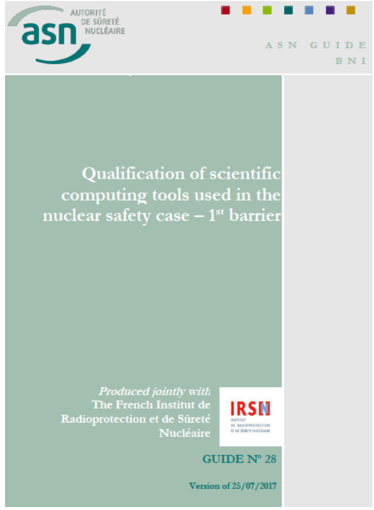
*[1] ISO 21432:2019, Non-destructive testing — Standard test method for determining residual stresses by neutron diffraction*
*[2] CEN, ISO/TS 18166:2016 Numerical welding simulation — Execution and documentation, ISO (2016) 36 pp.*

EDF

# 6. Conclusion (2/4)

## Guide of the safety authorities : Guide No. 28

*This guide was produced jointly by ASN and IRSN and presents the recommendations concerning the qualification of scientific computing tools (SCT) used to verify compliance with the safety criteria applicable to the first barrier, which is the fuel cladding.*




## Importance to consider VVUQ aspects in the ISO/TS 18166 - NUMERICAL WELDING SIMULATION - EXECUTION AND DOCUMENTATION

1. To cover an industrial sector need

Originally (2013), request for instruction at ISO/TC44 level of a standard on welding simulation proposed under the motivation of the automotive industry → did not cover the issue of pressure equipment → counter proposal and consensus through an expert group TC44 WG5 → ISO/TS18166 -2016.

2. To compensate for the absence of any ISO standard in a particular field touching on regulatory aspects

Design rules for the nuclear sector introduced in AFCEN publications (RCCM, RSEM…)

3. To facilitate the appropriation of best practices in the respect of certain quality requirements → give confidence for use in an industrial context

**The French Nuclear Institute CEA-EDF-FRAMATOME** - *Modelling and Numerical Simulation of Welding Project* ***[1]*** **- supports a revision of the current standard**

*[1] V. Robin, S. Hendili, J. Delmas, A. Brosse, F. Gommez, O. Doyen and H. Pommier, Benchmark in Computational Welding Mechanics to Model Residual Stresses in Weldments, European Conference on Residual Stresses - ECRS10, September 2018, Oral presentation, Leuven, Belgium.*

# 6. Conclusion (3/4) : Development of Scientific Computational tools for a standardized approach to CWM compliant with international standard and best practices

**Developped on open source FE plateform**

code_aster — salome_meca

- The « *PIPEWELD* » tools for an industrial approach to CWM developped at R&D – *Projet SAFER*

<u>Standardised</u> approach that allows to reduce uncertainty on missing parameters (in particular (U, Vs) in manual welding)

**Tableau des DMOS à étudier (configuration géométrique, matériau, paramètres de soudage)**

**U, I, Vs**

**Domaine de soudabilité numérique**

Comment atteindre une dilution [10 ; 50%] pour une section de métal déposé, une puissance et une vitesse de soudage

**Section, ratio**

**Paramètres STE**

**Matériau, Paramètres de soudage**

**configuration géométrique**

**PIPEWELD-MESH**

Maillage automatique 2D pour le raboutage de tuyau

*Hypothèses*
- *Pilotage par la géométrie du chanfrein*
  - *En nombre de passe*
  - *En section des passes de remplissage*

**PIPEWELD-SIM**

Simulation thermo-métallurgique et mécanique du soudage

*Hypothèses*
- *Loi de comportement*
  - *Ecrouissage mixte*
  - *Restauration*
- *Température interpasse (20°C)*
- *Auto-bridage uniquement*

**PIPEWELD-POST**

Extraction des grandeurs d'intérêt à partir du dernier instant de calcul (20°C, libre, arasé)

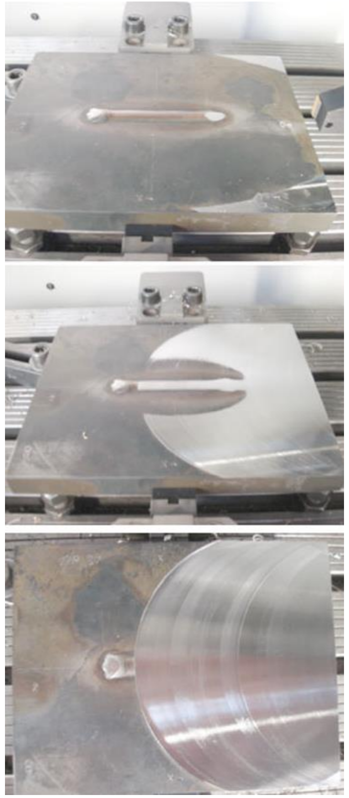
*Nature des sorties*
- *Allure de courbes*
- *Extrema*
- *Valeurs moyennes par zone*

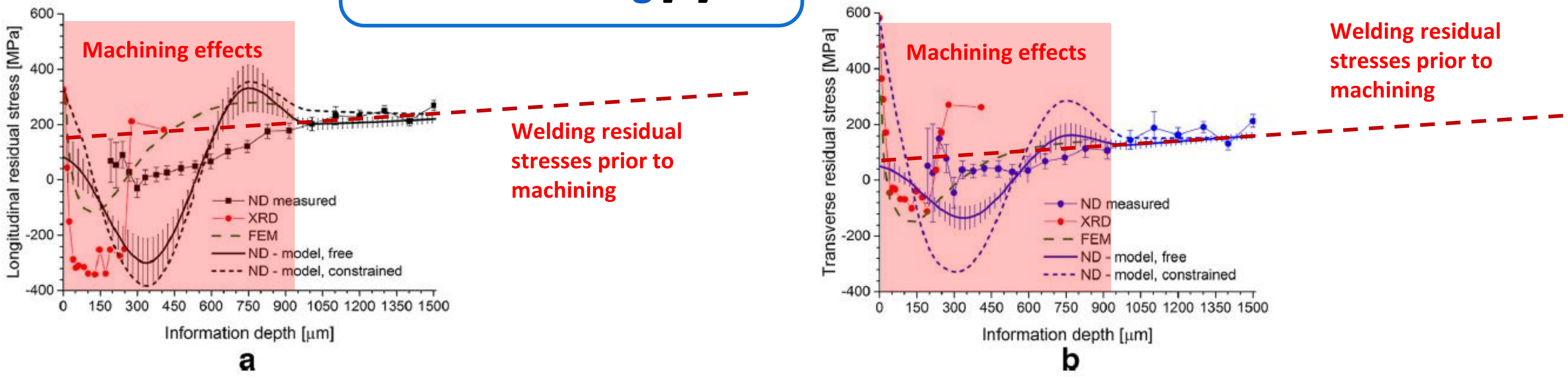
# 6. Conclusion (4/4)

Bulk + surface stresses are also of interest : interaction between surface and bulk residual state (stress and strain).

- Brittle fracture risk (bulk)
- Stress Corrosion Cracking and Fatigue crack initiation (surface)

**TG4 mock-up : Welding + Machining *[1]***






***[1]** J. Rebelo Kornmeier, M. Hofmann, W. M. Gan, V. Robin, F. Valiorgue, H. Pascal, J. Gibmeier, J. Saroun, Effects of finish turning on an austenitic weld investigated using diffraction methods, The International Journal of Advanced Manufacturing Technology (2020) 108:635–645*

**TG6 mock-up : Welding + Grinding *[2]***

***[2]** EASI-Stress EC Project, WP5*

➢ *Ease the comparison between simulation and measurment results : Gauge volume, reference coupon, elastic constants…*

# Thank you