MATERIAL STUDIES AT NCBJ

NARODOWE CENTRUM BADAŃ JĄDROWYCH
ŚWIERK

dr inż. Łukasz Kurpaska

w zastępstwie za

prof. Jacek JAGIELSKI

NOMATEN

Horizon 2020 Teaming

and

MAB/IRA PLUS Programme

BOUNDARY CONDITIONS

- **Development of nuclear technologies is too expensive for medium-sized countries alone**
- All countries need to combine their efforts in R&D activities
- Multinational cooperation is thus an obvious solution
  - V4G4
  - Baltic cooperation
  - EU programs: **JPNM**, **GEMMA, M4F**, **VINCO, BRILLIANT**
  - NCBJ-CEA-CNRS-VTT-JAEA-UK agreements

ALFRED i ASTRID (2017-21)

- **Similar equipment and competences needed to develop materials for nuclear, power, chemical and general engineering**

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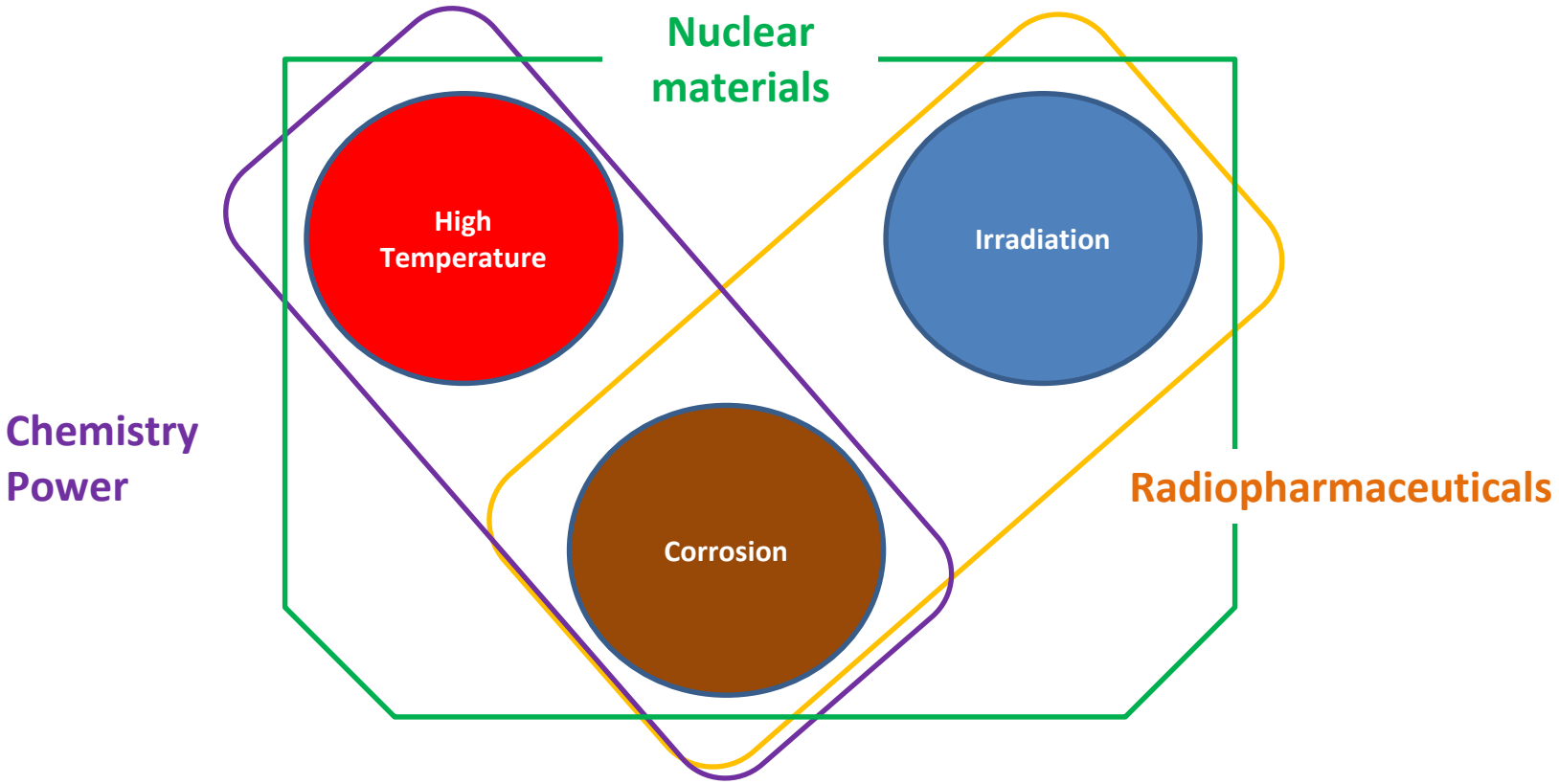
BOUNDARY CONDITIONS

Novel materials resistant to high temperature, corrosion and radiation for industrial applications



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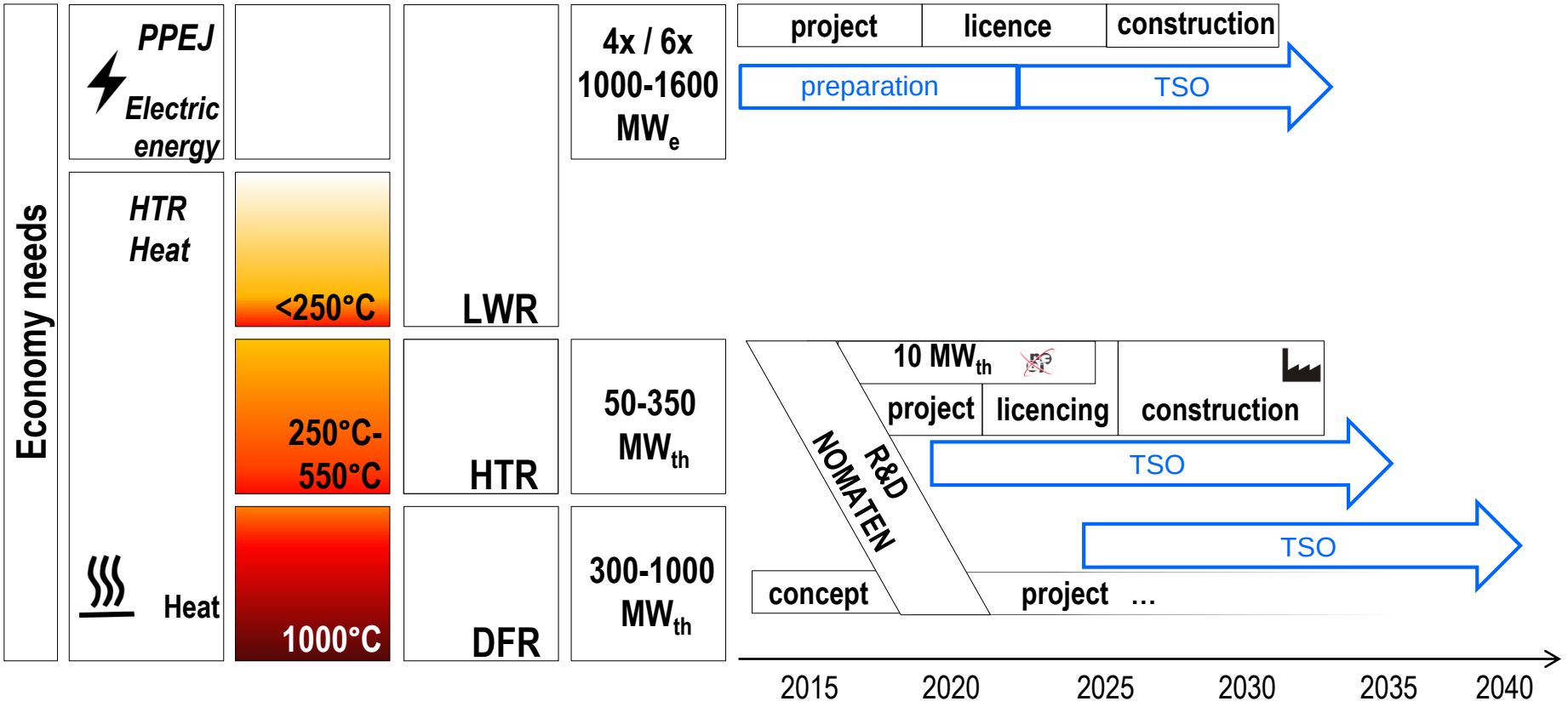
BOUNDARY CONDITIONS



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BOUNDARY CONDITIONS

- **Real collaboration requires long-term (and FINANCED !) frames**
- **Typical grants are only 1-3 years long: do not fit well to this idea**
- **Solution: apply for a big, long lasting project which may constitute a basis for typical, short-term, research grants, Ph.D. theses etc.**
- **Only one possibility found: Teaming for Excellence projects**

NOMATEN

NOMATEN Concept

MECHANICAL PROPERTIES

LONG TERM PREDICTIVE MODEL

MSDA

MOLECULAR DYNAMIC

EXPERIMENT

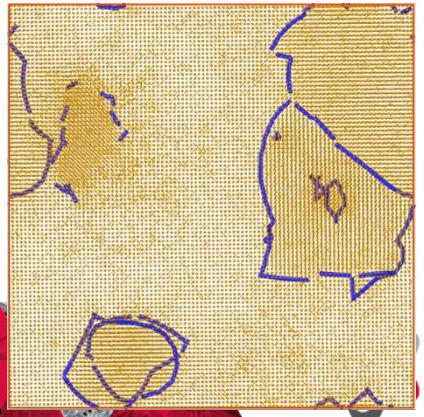
RBS/C

TEM

XRD

Raman

Monte Carlo



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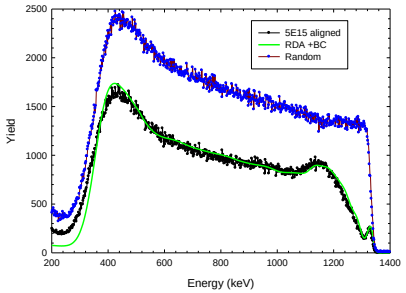
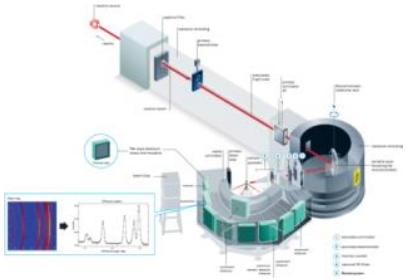
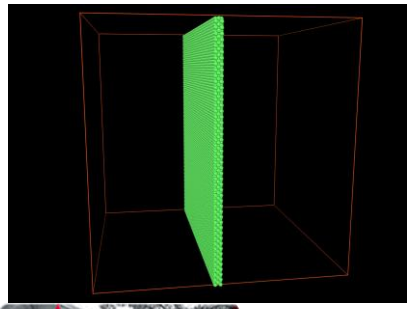
NOMATEN Concept

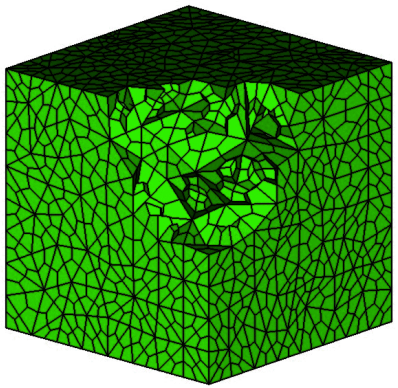




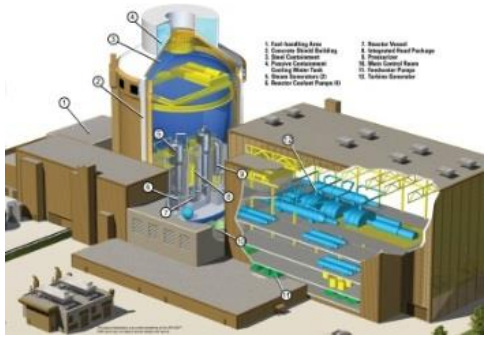


Molecular Dynamics
Structural analysis

Constitutive models
Finite elements



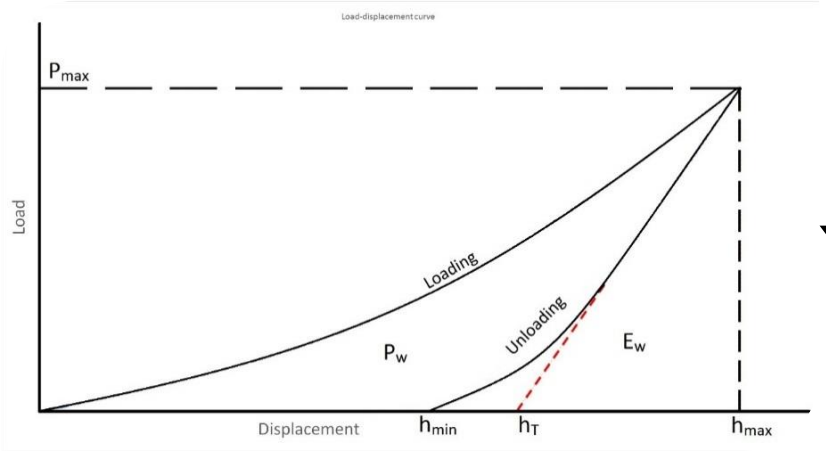
Functional properties

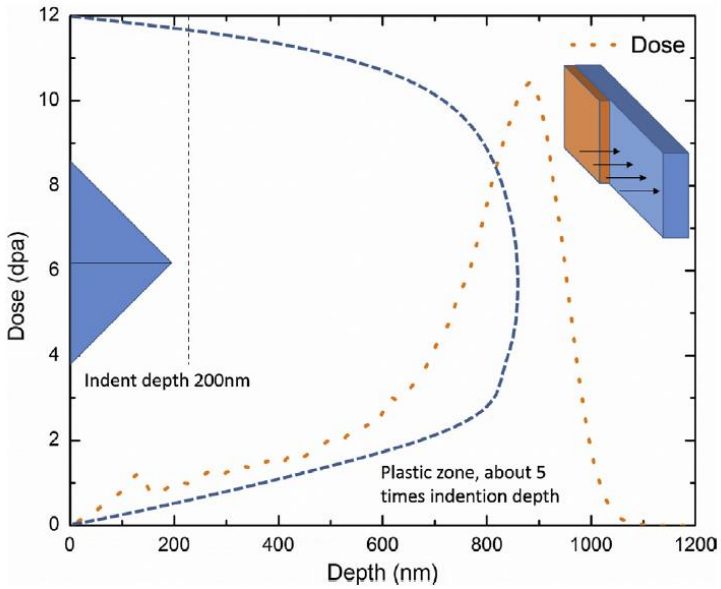


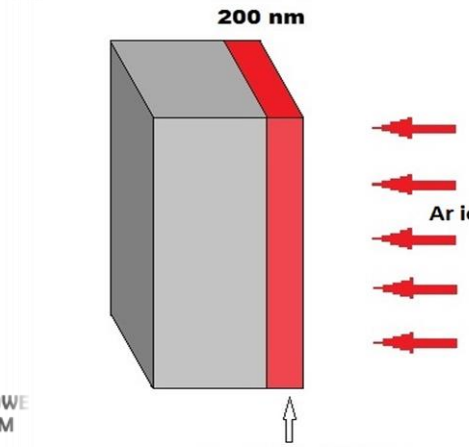
Industrial installations

1 nm — 1 mm — 1 cm — 10 m

Mechanisms of damage creation and mechanical analysis

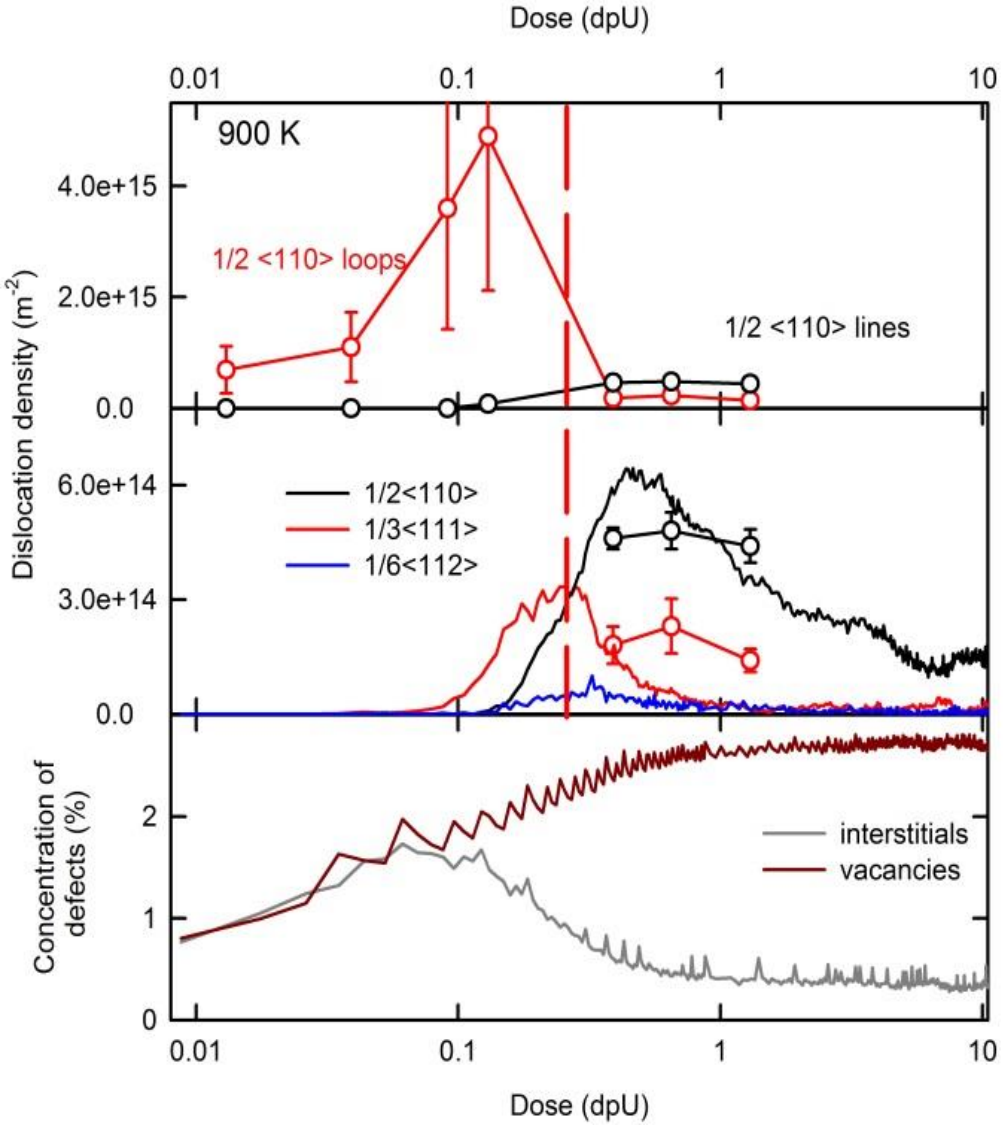






Some examples: Mechanisms of damage creation

Comparison between experimental (top) and calculated (middle) dislocation density (rescaled to experimental dose rate) and uranium interstitials and vacancies concentration (bottom) as a function of dose (in dPU, displacement per uranium).



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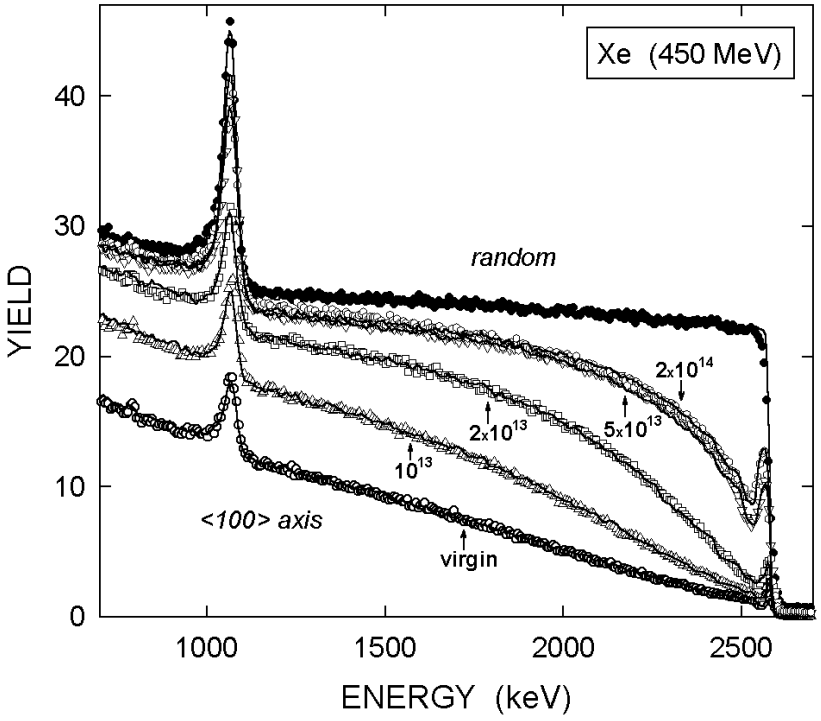
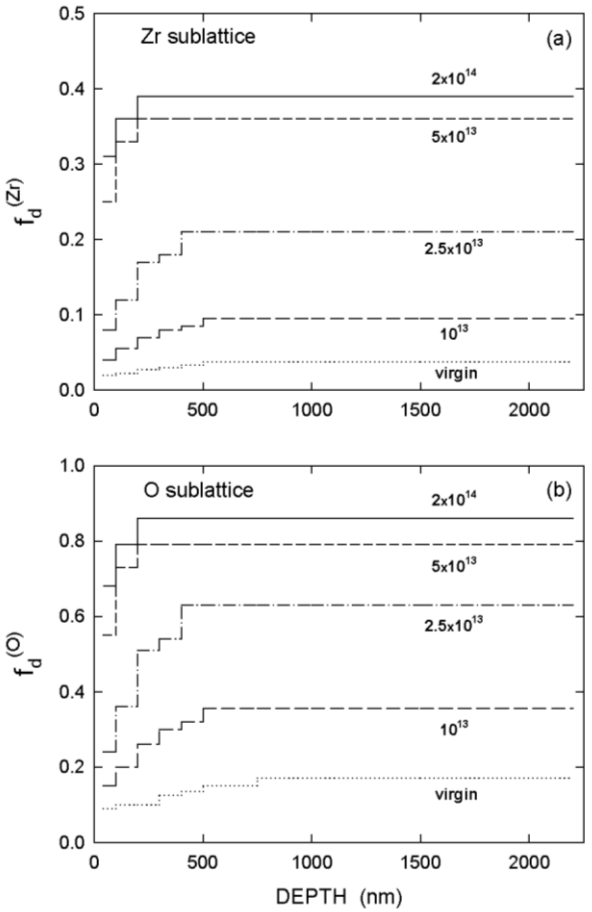
Some examples:
Quantitative assessment of damage level

Quantitative assessment of amount of damage: RBS/C + MC simulations





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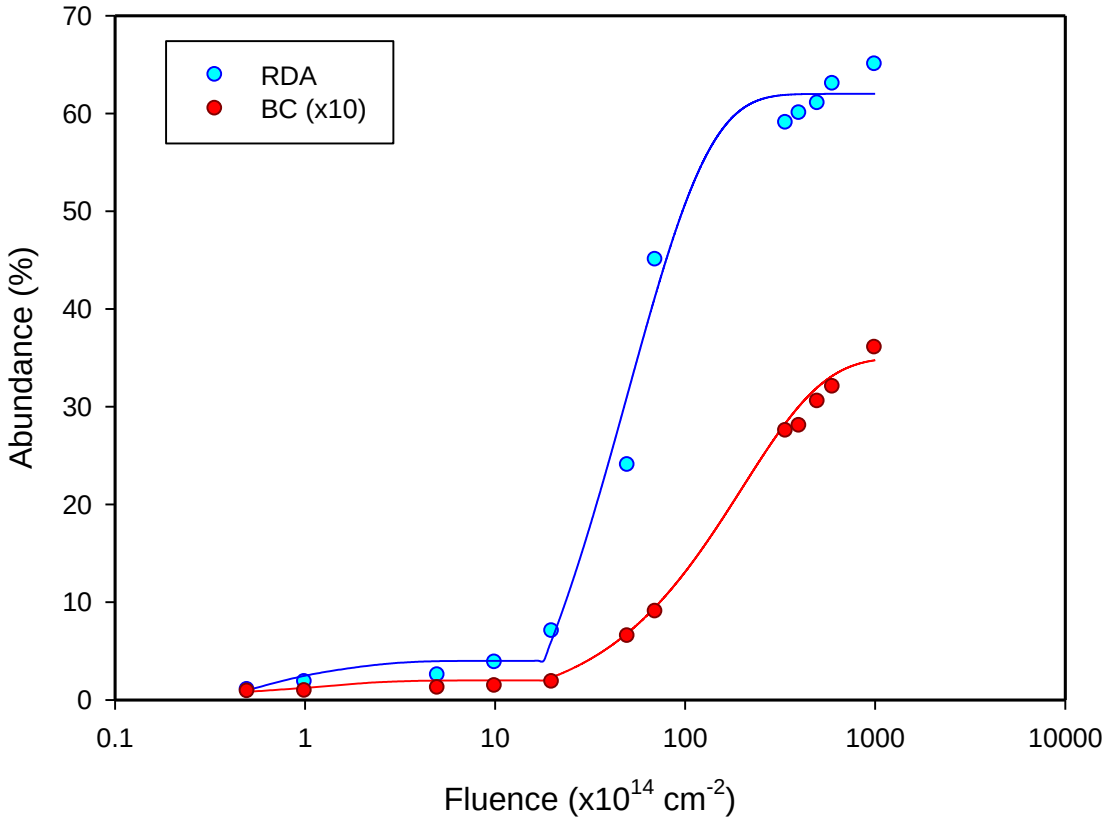
Some examples:
Quantitative assessment of damage level

Quantitative assessment of amount of damage: RBS/C + MC simulations

Two contributions to the RBS/C spectra can be individually quantified:

1. Direct backscattering on randomly displaced atoms (RDA): ~*amorphous fraction*, $\sigma_{RDA} = 2x10^{-15}\ cm^2$
2. Defocusing of the analyzing beam on bent channels (BC): ~*dislocations*, $\sigma_{BC} = 5x10^{-17}\ cm^2$



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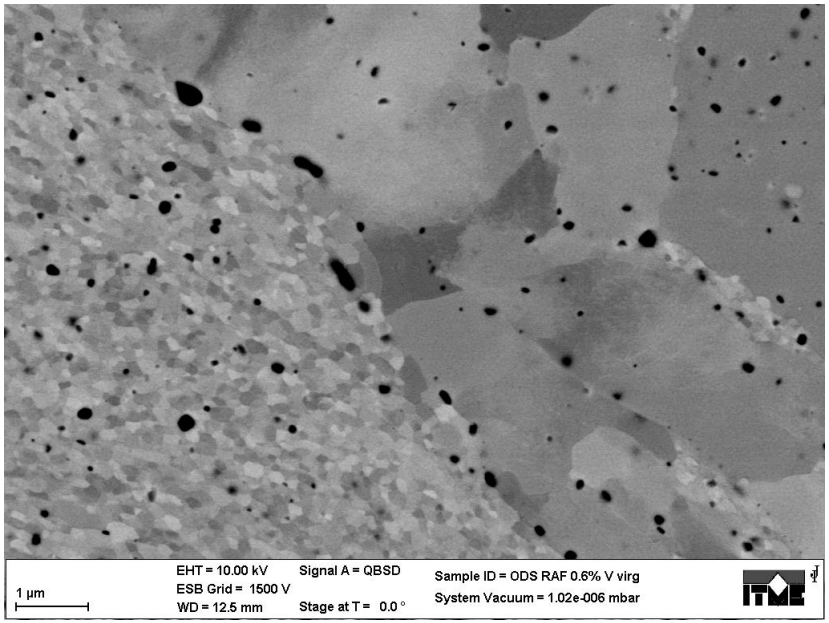
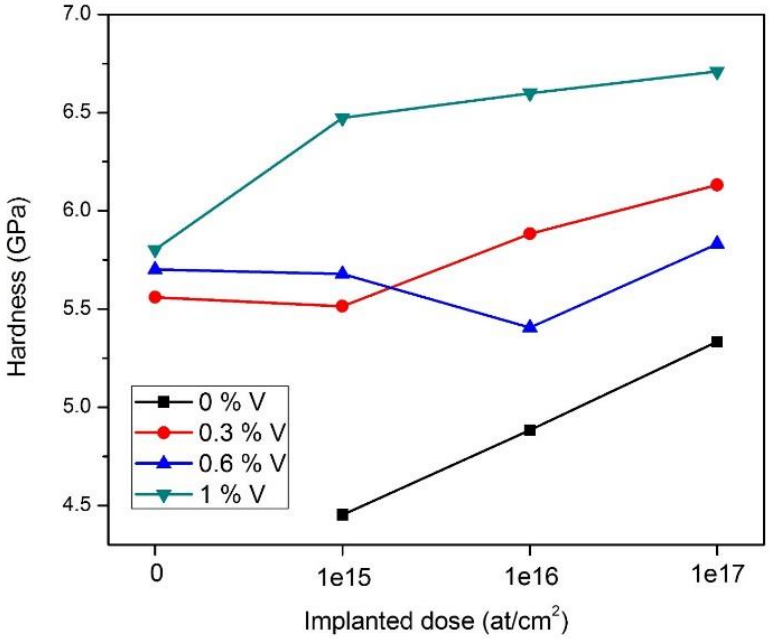
Some examples: nanomechanical studies





Nanomechanical properties of the implanted **ODS steels**

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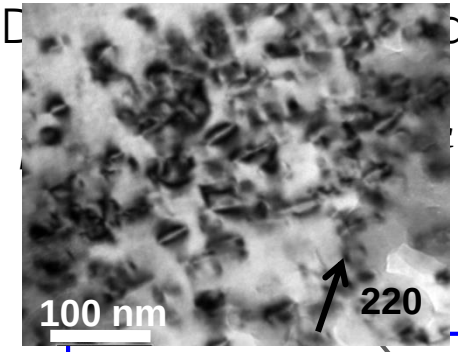
Some examples:
Modellization of damage accumulation

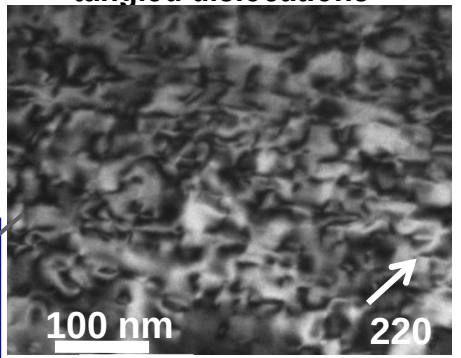
Multi-Step D… …ation model (MSDA)

Dislocation loops

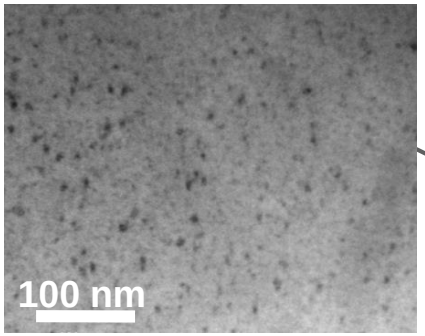


Relaxation of the elastic strain

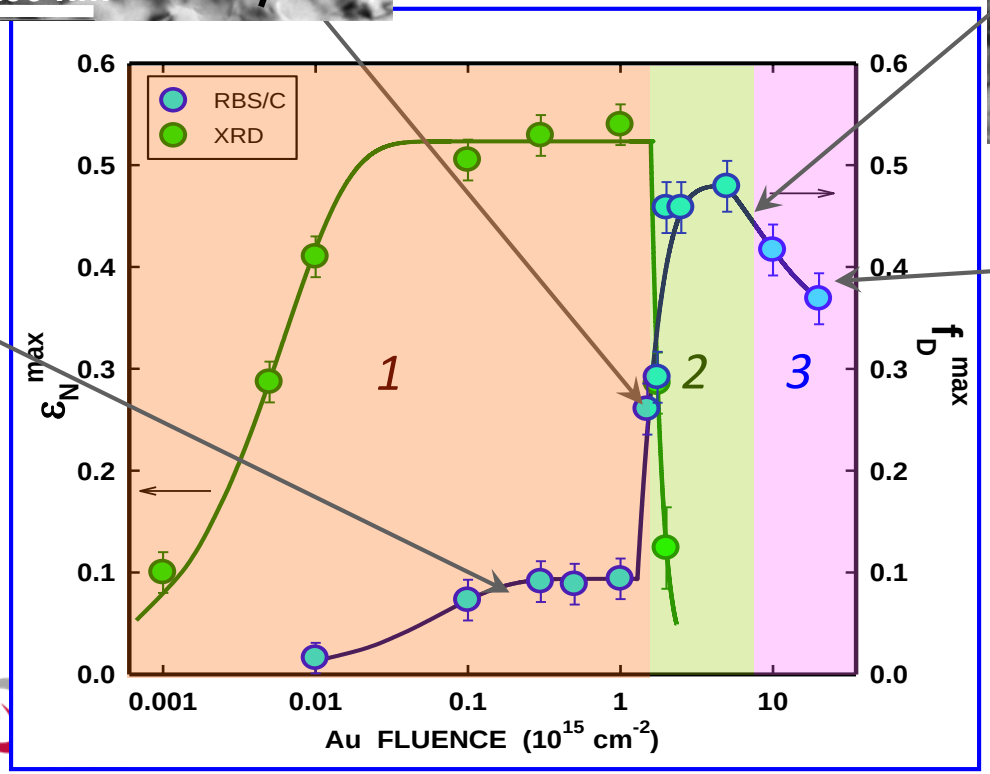
Network of tangled dislocations



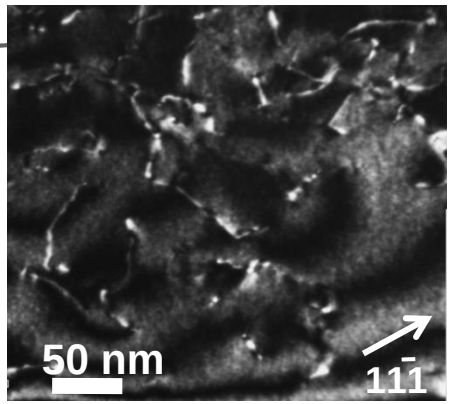
Small defect clusters



Increase of the elastic strain

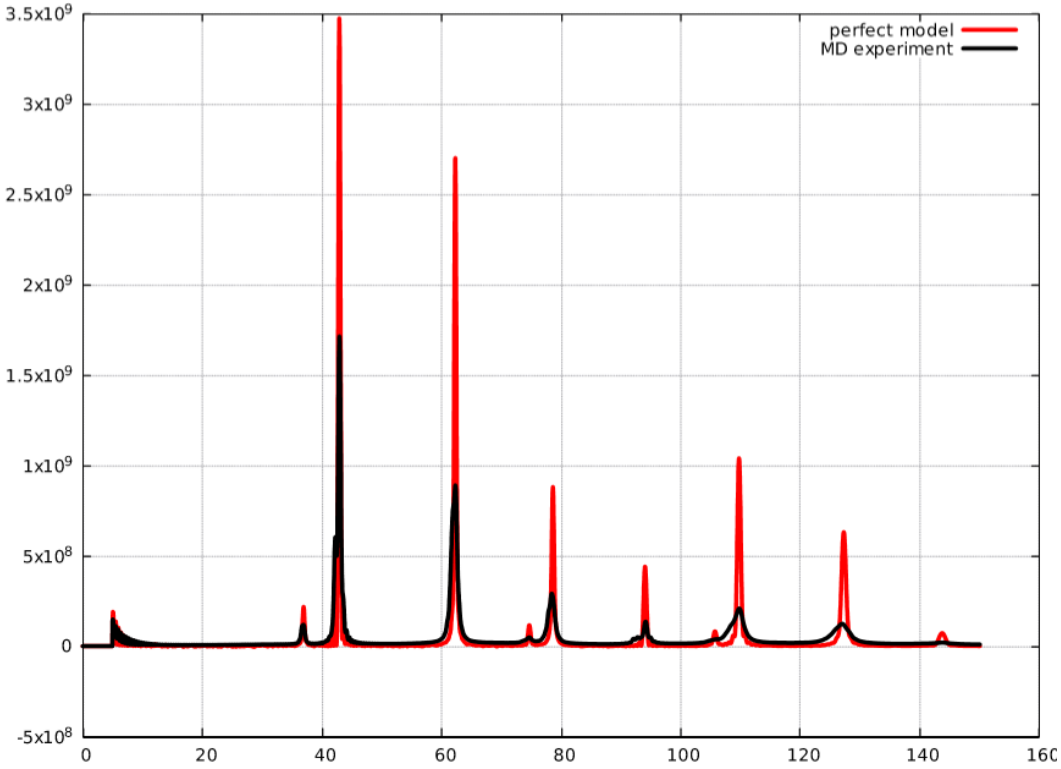


Long dislocations



Some examples: Modellization of damage accumulation

X-Ray diffraction spectra from MD simulations



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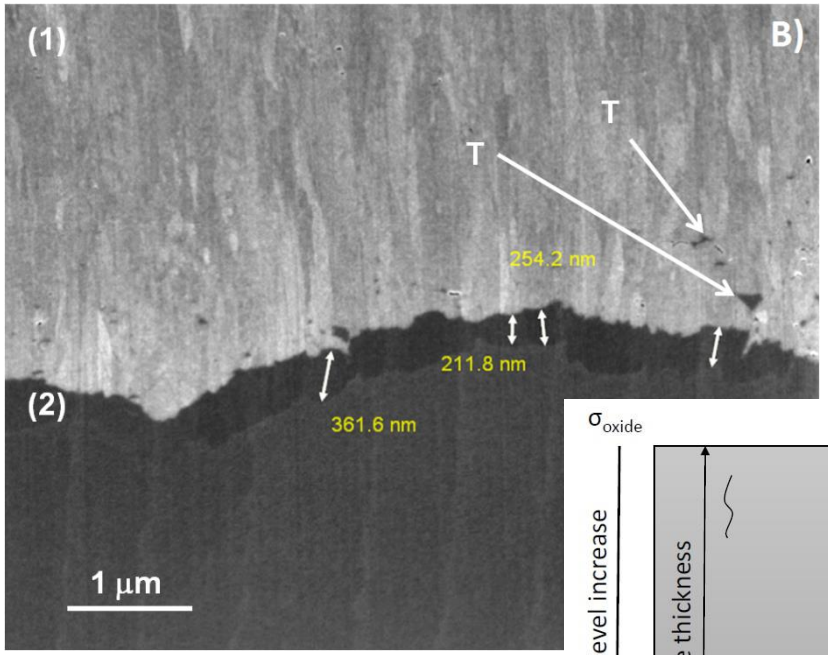
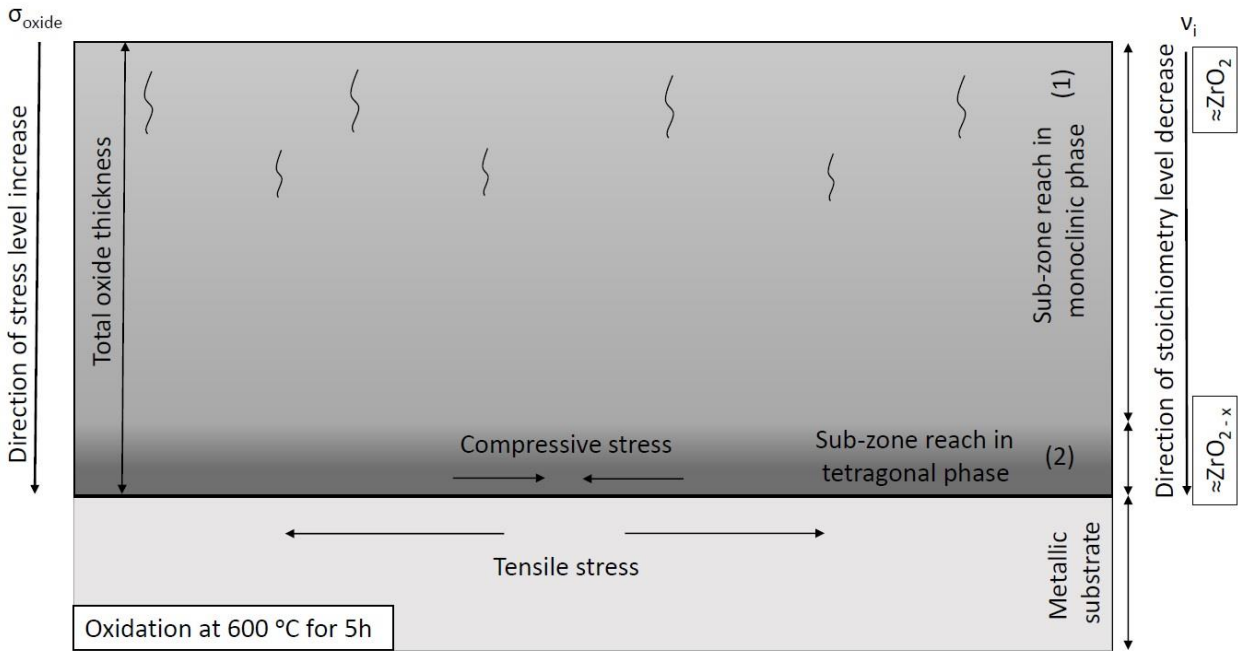
Some examples: HT corrosion



Zirconia grown on pure zirconium at 600 C

$Zr/ZrO_{2(t)}//ZrO_{2(m)}$

Interphase model



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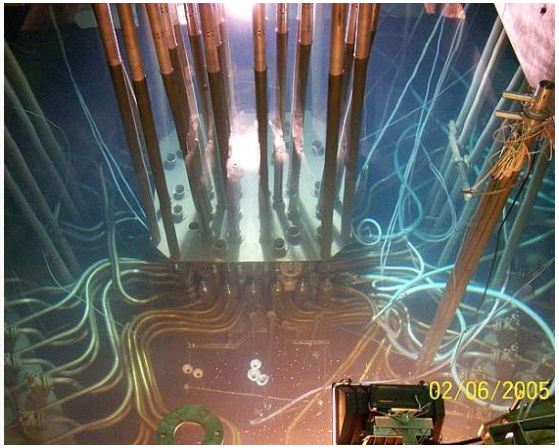
Equipment:

Many of the costly devices are available at NCBJ, VTT and CEA; need to complement them with analytical tools, without unnecessary duplication

- MARIA reactor
- LBM Hot Cell Lab
- Supercomputer Centre CIŚ
- POLATOM facilities
- CERAD project infrastructure
- CentriX project infrastructure
- Access to XFEL via NCBJ
- POLFEL project
- Neutron lab build with HZB support

NATIONAL CENTRE FOR NUCLEAR RESEARCH ŚWIERK



JĄDROWYCH ŚWIERK

Equipment:

Nanoindentation at NCBJ

Micro Materials Ltd. – NanoTest Vantage

- Berkovich, Vickers, Cube Corner and Conical type indenters available for rT testing
- HT measurements with diamond (up to 450 °C) and cBN (up to 750 °C) indenters
- Coupled Atomic Force Microscope
- Optical microscope (up to 40x)
- Covers range of forces from 0.1 mN to 20 N
- HT measurements up to 750 °C under controlled atmosphere
- Piezostage
- HT surface scan
- Impact/impuls indentation
- Humidity cell
- Nano-scratch, wear and fretting test

Studied materials:
ODS, 316L SS, pure Zr, Zr1%Nb alloy, ceramics, tungsten, cermetals, graphene …

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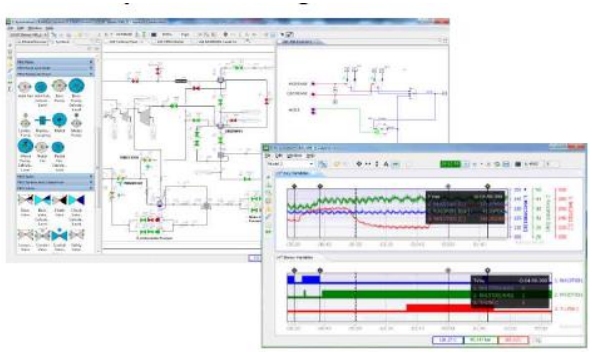
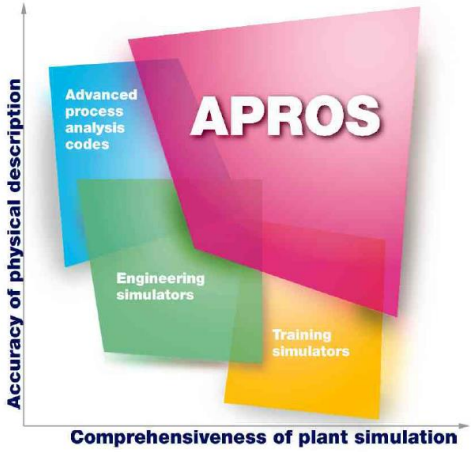
Equipment:

Some examples of CEA and VTT capabilities to be used in NOMATEN

- JANNUS accelerators
- Analytical devices
- Mechanical tests
- LECI Hot Lab
- Frederic Joliot Institute

- Modelling of functional properties
- Fracture mechanics
- Proper Tune software
- APROS model
- Biomedical labs





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Some statistics:

+25 years of continuous contacts with French institutions: CEA, CNRS-CSNSM, Univ. Claude Bernard Lyon, Ecole Centrale de Lyon, Univ. Evry, Univ. Aix-Marseille, Univ. Orleans, …

+10 joint Ph.D. theses including theses in co-tutelle

4 HDR theses *(+ 1 in the near future)*

102 common publications in international journals *(only JJ)*

NOMATEN organization:

Center of Excellence founded by **NCBJ** with **CEA** and **VTT**

Legal form: Scientific-Industrial Centre established by NCBJ and ENEA

Open for collaboration with various national and foreign organizations (CNRS, JAEA, JRC, Ciemat, HZB, HZDR, BEIS, Univ. of Lisbon, ORNL, …)

Current status: SIC (CNP) established, national financement secured (10 MEUR), proposal to Teaming Phase 2 submitted (15 MEUR), …

Perspective: 10+ years

We are offering new, challenging job for ambitious scientists willing to work in multinational environment.

All levels: Research Group Leaders, Ph.Ds., Ph.D Students

Main topics:

- Molecular Dynamics,
- Constitutive modelling,
- Analytical methods,
- Neutron diffraction and spectrometry,
- Functional properties

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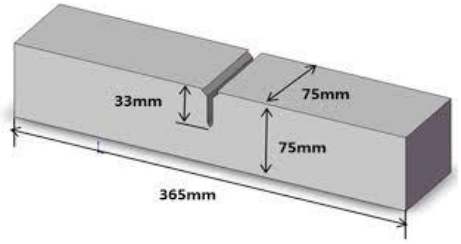
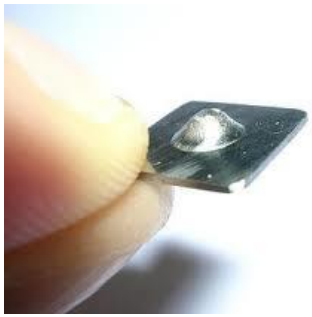
Thank you for your attention

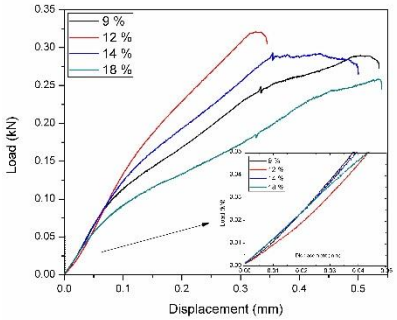
Mechanical studies at LBM/NCBJ



Standard/Macro scale

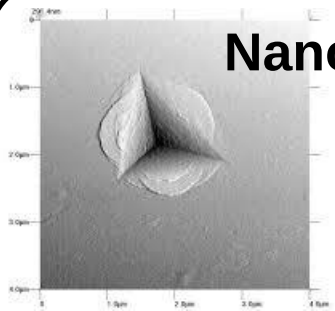
big samples
difficult to irradiate
expensive to manufacture
Valuable result,
ASTM and PN-EN standards



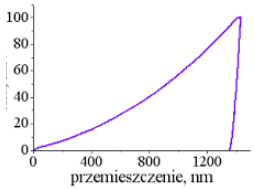


Micro scale

Easy to manufacture
No standards
Difficult to interpret
Possible neutron
ion/neutron irradiation



Nano scale



New method
Easy to irradiate
Fast test
Standards exist
Big test data needs

Atomic scale

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