Materials for nuclear fission and fusion reactors

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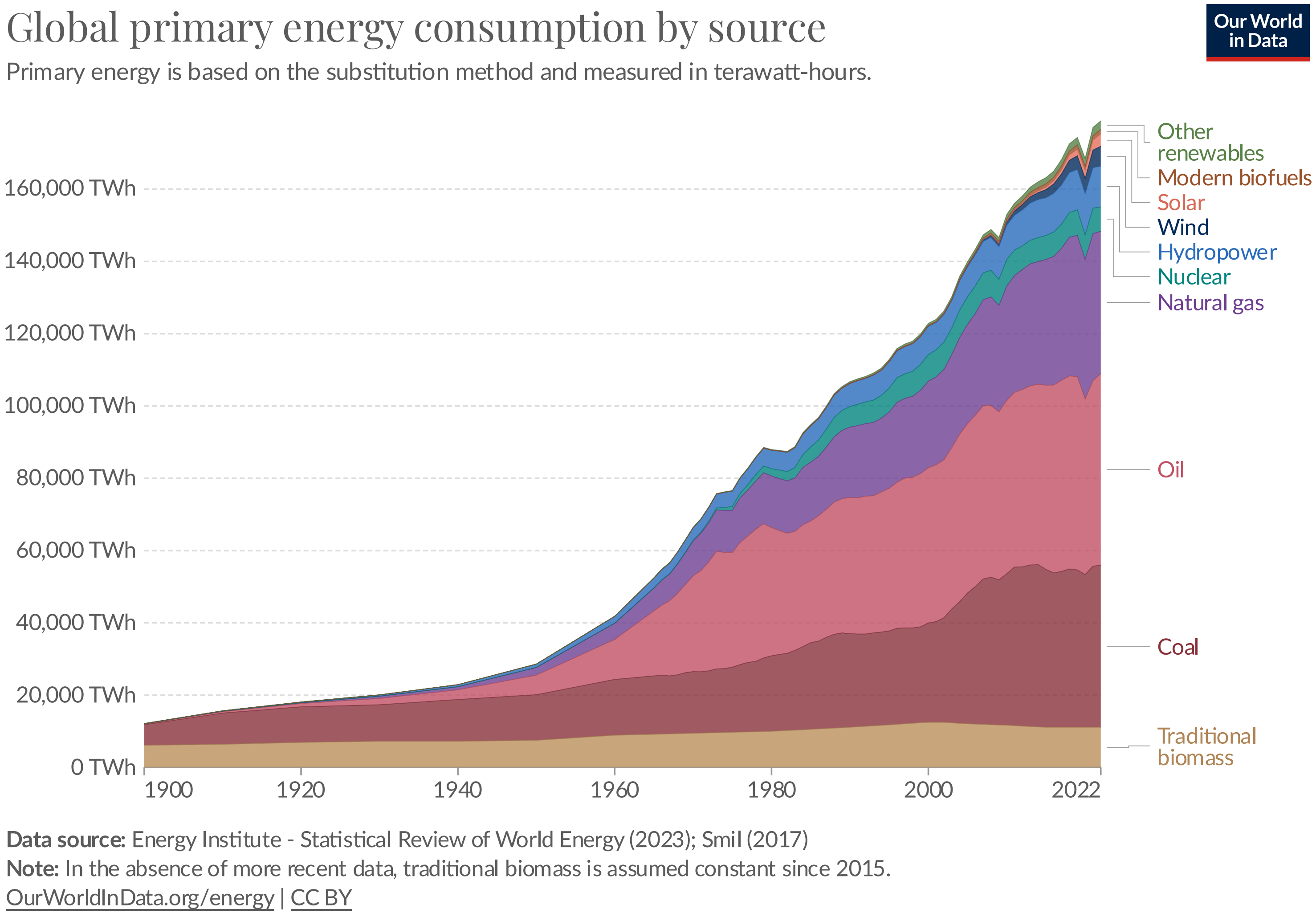
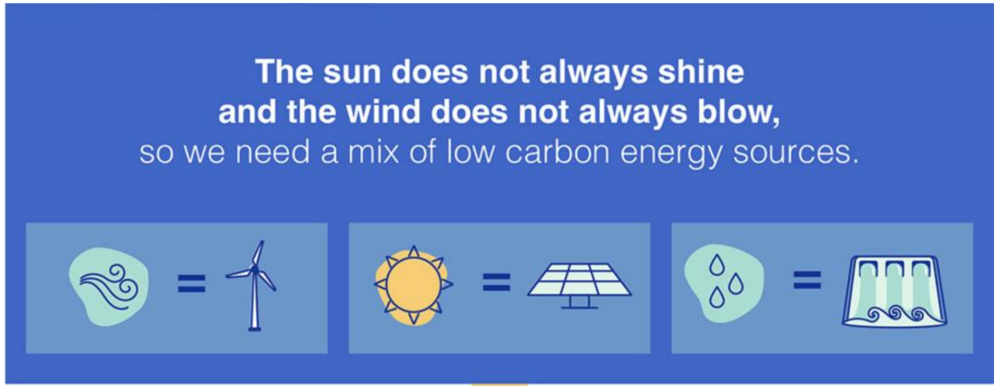
Global Energy Consumption



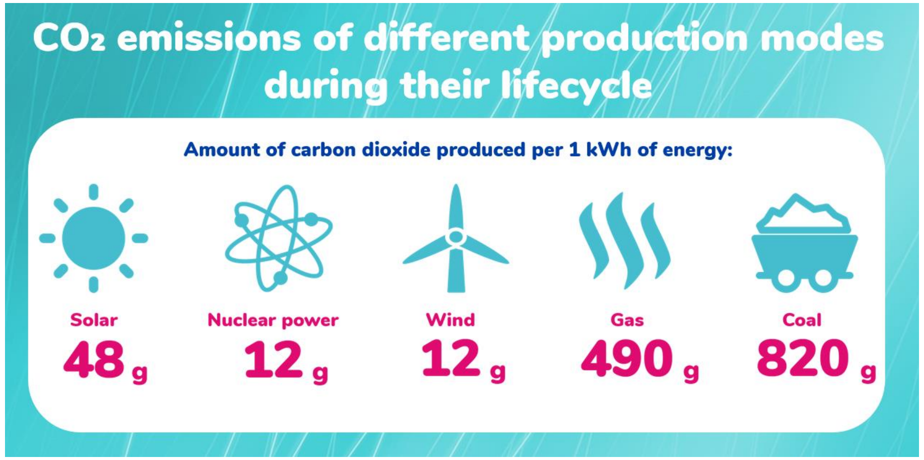
Global primary energy consumption by source

Primary energy is based on the substitution method and measured in terawatt-hours.

Data source: Energy Institute - Statistical Review of World Energy (2023); Smil (2017)
Note: In the absence of more recent data, traditional biomass is assumed constant since 2015.
OurWorldInData.org/energy | CC BY



The sun does not always shine and the wind does not always blow, so we need a mix of low carbon energy sources.



CO₂ emissions of different production modes during their lifecycle

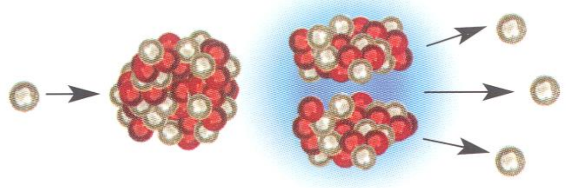
Amount of carbon dioxide produced per 1 kWh of energy:

Solar	Nuclear power	Wind	Gas	Coal
48 g	12 g	12 g	490 g	820 g

Nuclear energy: Low-carbon source of energy, Nearly emission free operation, generate 1/3 of low-carbon electricity

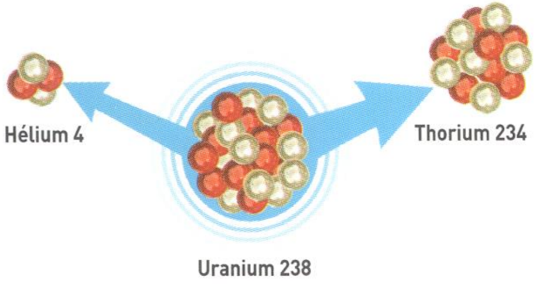
Nuclear energy: Fission and fusion

Fission



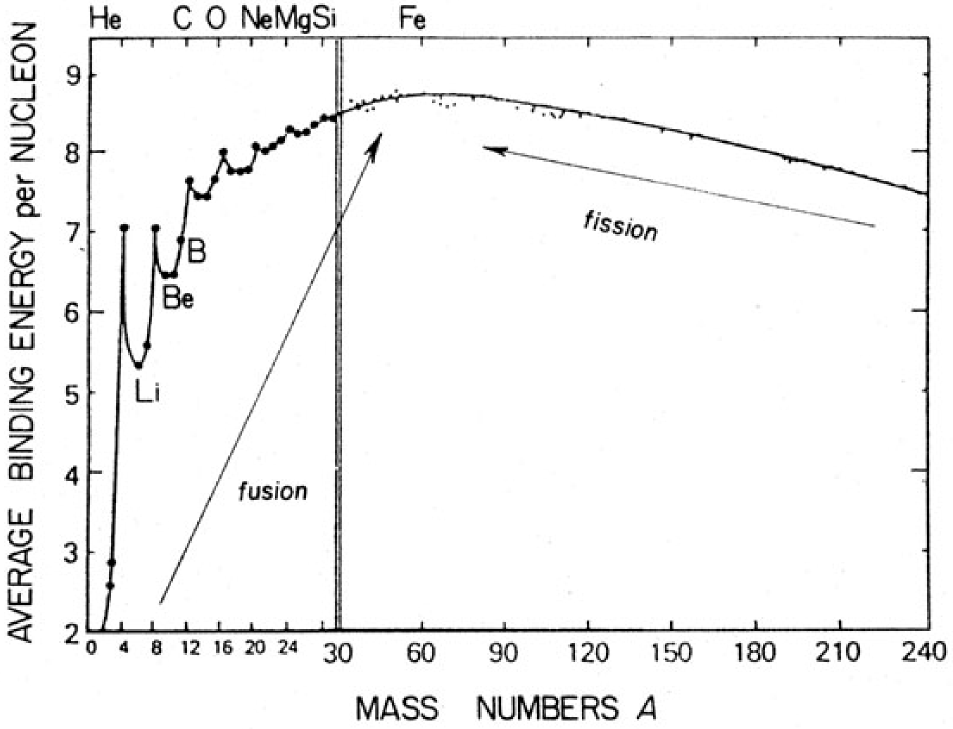
Neutron damage, Fission products in fuel, in particular volatile elements (Kr, Xe, I, Cs...)

Alpha decay

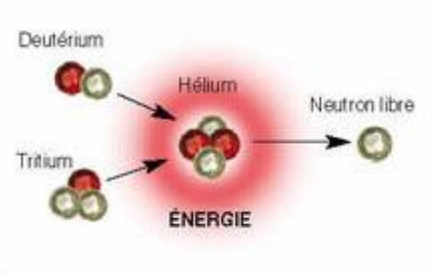


Helium + Recoil nuclei

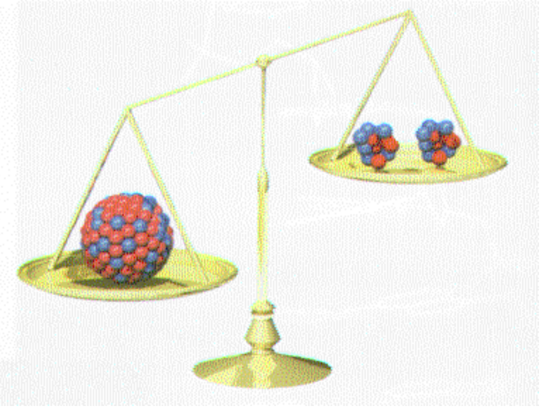
Collision cascades → Defects



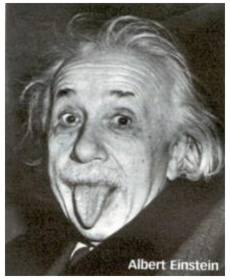
Fusion



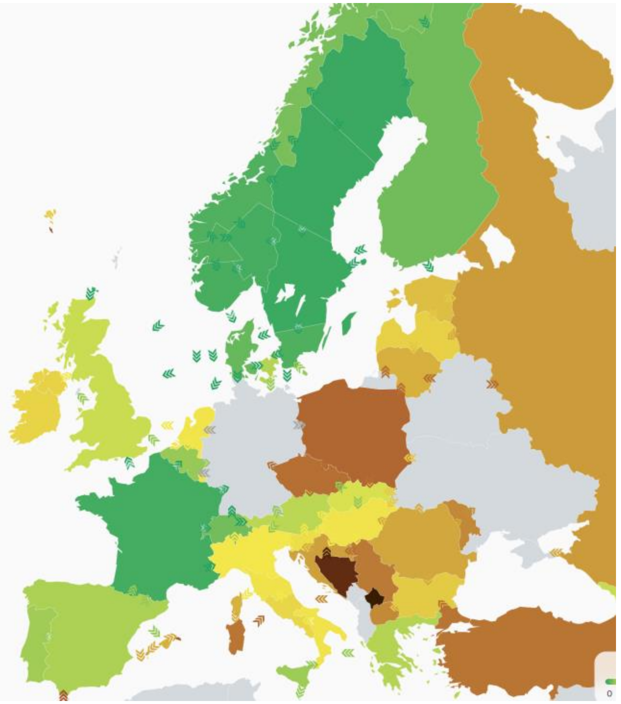
Neutron damage, Activated materials



$E=mc^2$

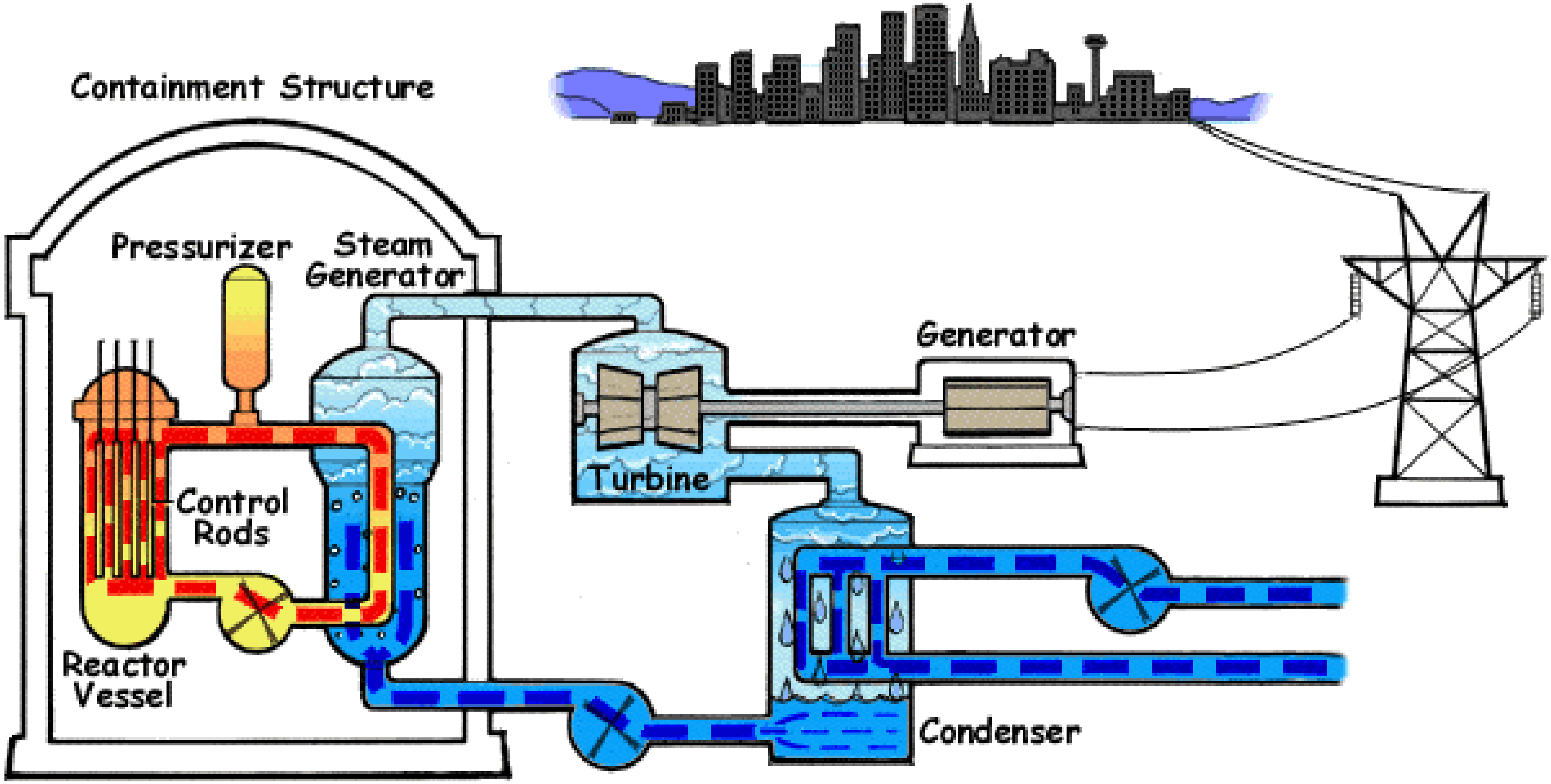


Why Nuclear Energy?



- Negligible emission of CO_2: As low as wind, with much higher availability
- Dense energy source
  - Fission produces 1 million times more energy than a chemical reaction such as the burning of coal, oil or gas (at equal mass)
  - Fusion produces four times as much as nuclear fission
- Nuclear fission energy exists and produces >1/4 of the baseload electricity in Europe and ~50% of low CO_2 electricity
- Other strengths
  - Stable prices, comparable to other sources
  - Stable supply of energy: high availability and reliability
  - Security of supply: uranium available in many and stable countries, easily stored, currently abundant + possibility of producing more fissile than used in fast reactors
- To limit the global temperature increase to the 2°C mark, the International Energy Agency suggests that carbon intensity of electricity generation must decrease by 90 % by 2050
- Nuclear must continue to play a role in electricity production to counteract climate change

How does a current nuclear power plant work (fission)?



90 % of NPP around the world are pressurized light water reactors (LWRs)
GenII / III / III+ reactors

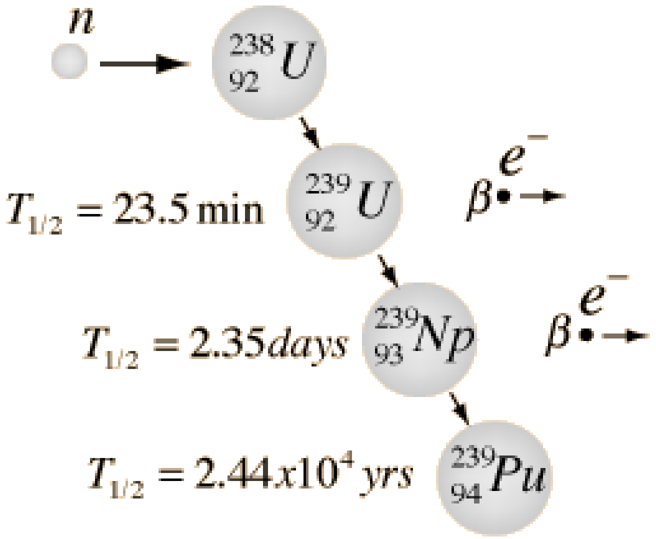
Challenges for sustainable nuclear fission

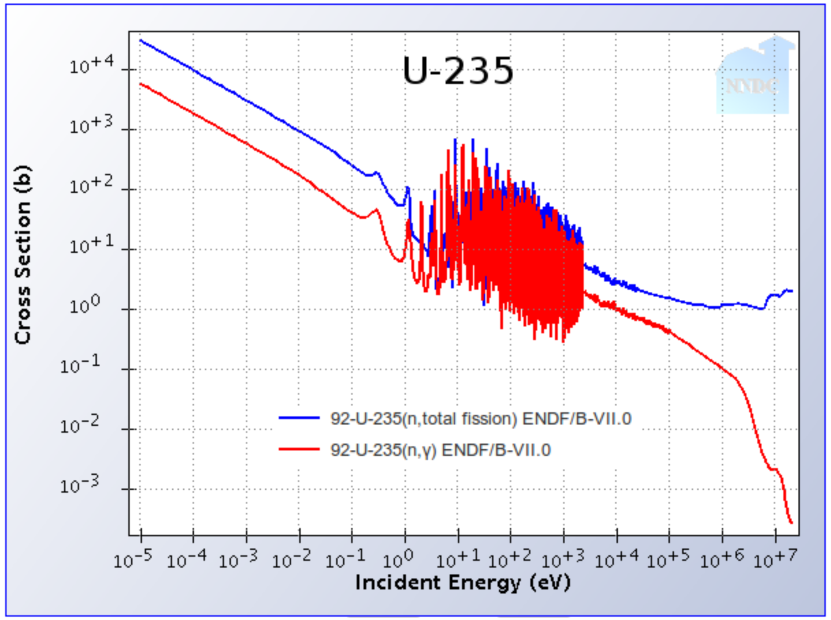
- Long-lived nuclear waste (highly radioactive)
- Consequences of severe accidents (e.g. Fukushima)
- Exhaustion of resources (non-renewability)
- Proliferation (misuse to build weapons)

It is imperative that these issues be faced

Sustainable nuclear energy: fast reactors

- In addition to fission reactions, use of fertile nucleus reaction:
  n + ^{238}U → ^{239}Pu fissile nucleus
- For transuranics, neutron energy needs to be >~100 keV (instead of 0.025 eV for thermal neutrons)
- Neutrons must NOT be slowed down (moderated)! → Water cannot be used as coolant
- Neutron density (flux) must be high
- Push the burnup of fuel as high as possible → very high irradiation dose (0.1 → >100 dpa)
- Push the coolant temperature as high as possible from ~300°C to 500-1000°C
- Possible coolants: gases, liquid metals, molten salts, (Supercritical water) → problems of corrosion, erosion, embrittlement, dissolution





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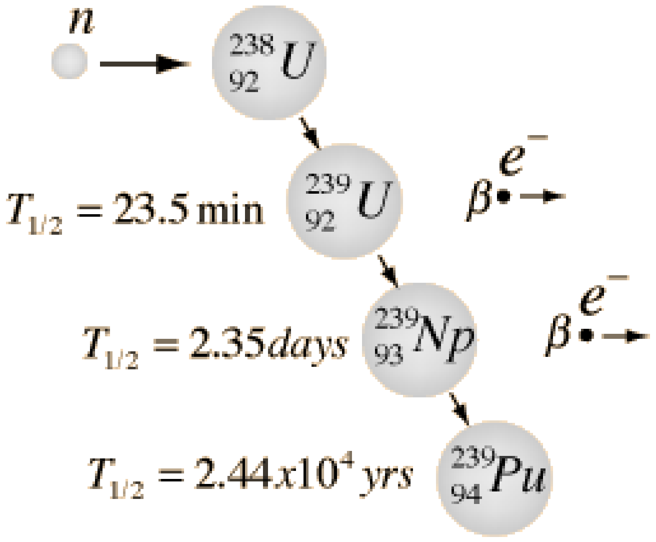
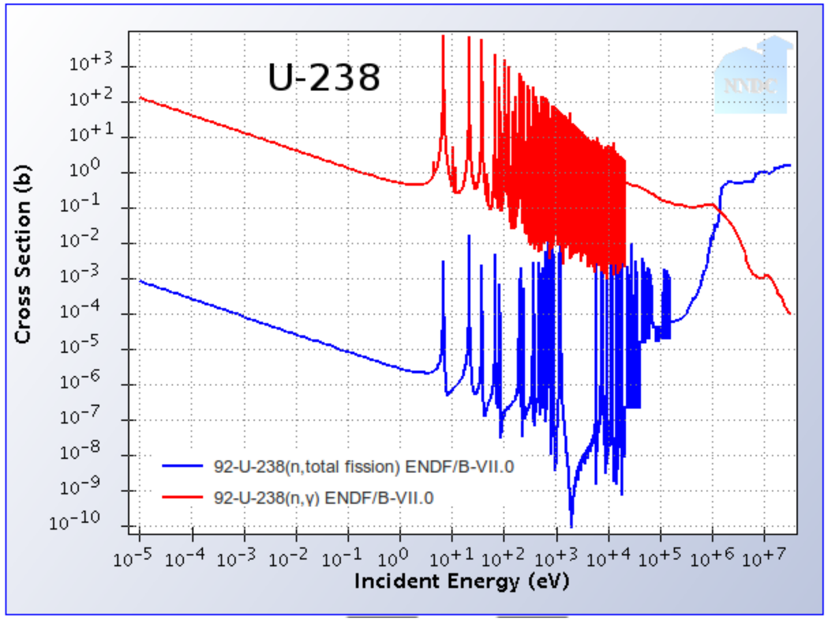


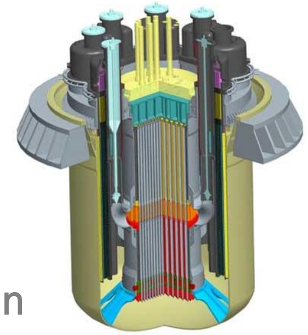


$$^{238}_{92}\mathrm{U} \rightarrow {}^{239}_{93}\mathrm{Np} \rightarrow {}^{239\text{-}242}_{94}\mathrm{Pu} \rightarrow {}^{241\text{-}244}_{95}\mathrm{Am} \rightarrow {}^{242\text{-}245}_{96}\mathrm{Cm}$$

Sustainable nuclear energy: fast reactors

- Produce more fuel than they use → recycling in a logic of circular economy ensures energy for millennia without mining + recycling on-site increases proliferation resistance
- Work at higher temperature → are energetically more efficient, allow use of gas turbines instead of steam turbines, produce industrial heat, …
- Burn spent nuclear fuel while producing energy → minimisation of quantities, reduction of waste quantity, lifetime (< 1000 years) and hazard
- Use passive safety systems (based on physical laws rather than human/computer intervention) → ♓■♦❒♓■⬧♓♍♋●●⍓ safer

Lead Cooled Fast Reactor (LFR)



e.g.
ALFRED
BREST
SEALER
Newcleo
…

Accelerator driven system (ADS)

MYRRHA
…

Gas Cooled Fast Reactor (GFR)

e.g. ALLEGRO
HTR-PM
HTGR
…

Sustainable nuclear energy: fast reactors

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Lead Cooled
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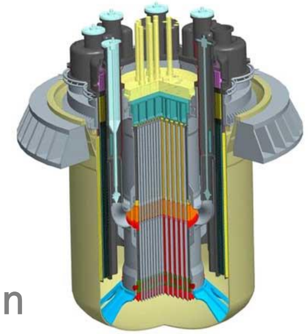

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BREST
SEALER
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…

Accelerator driven
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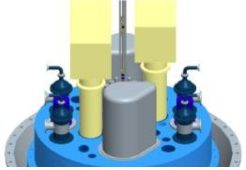
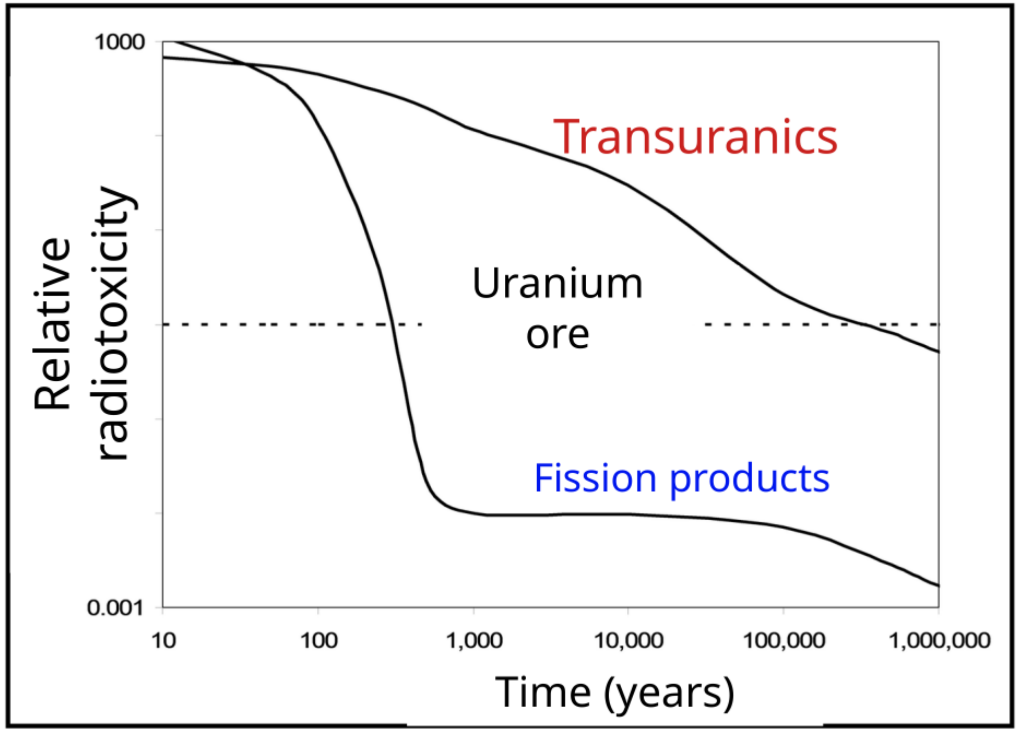
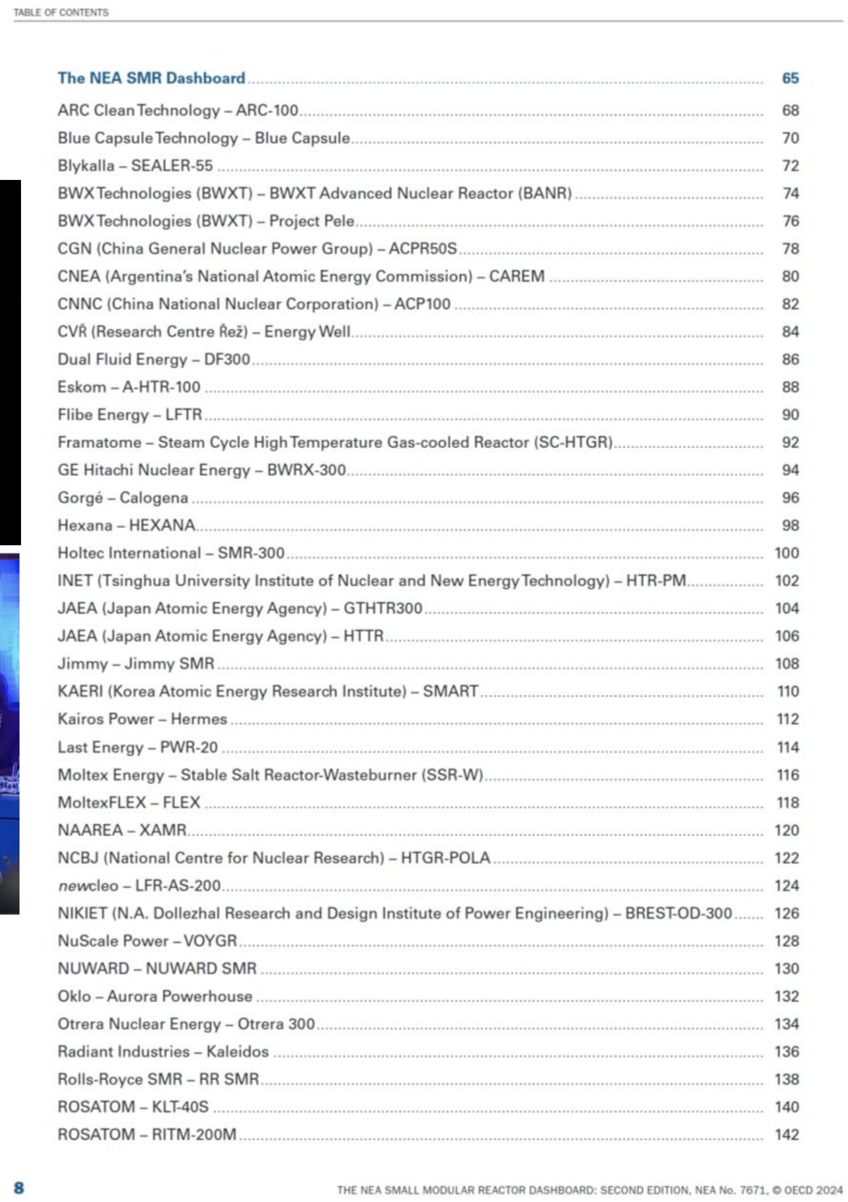
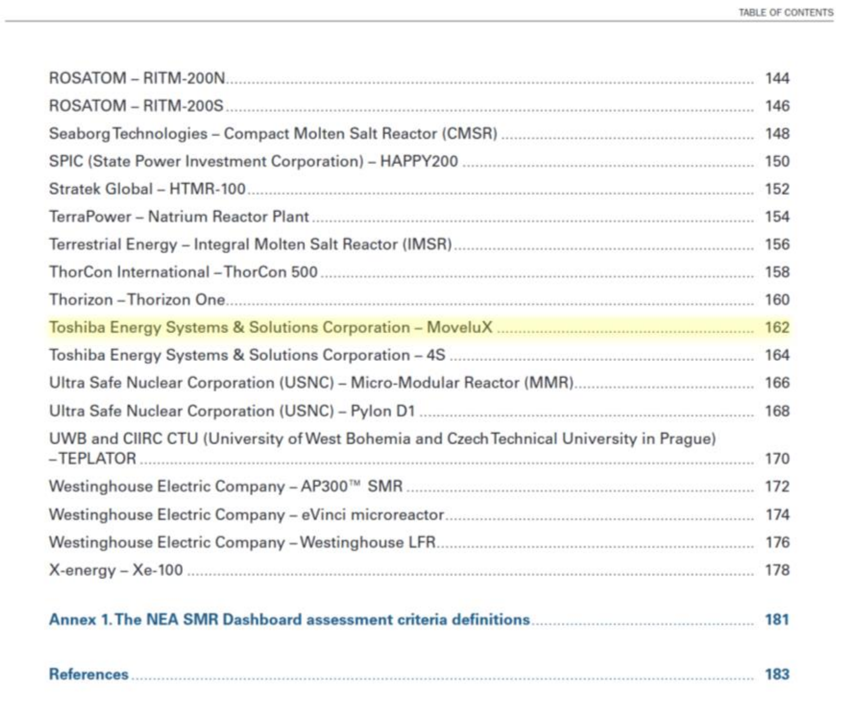


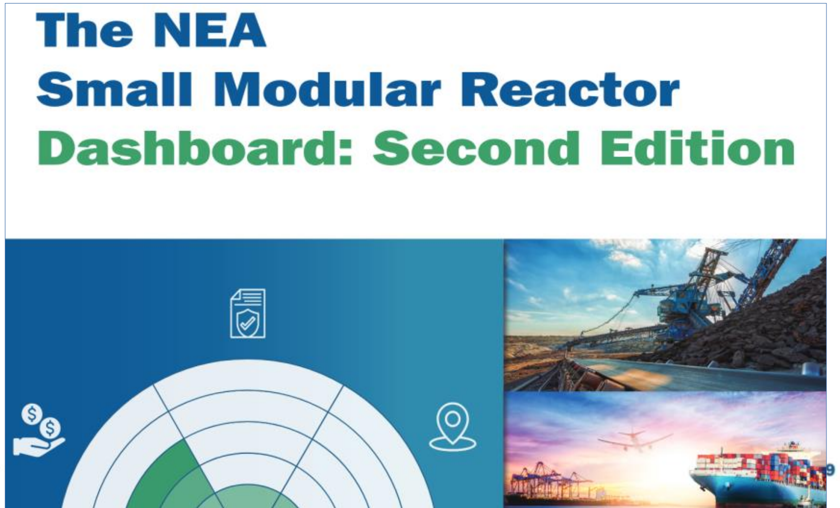
Gas Cooled Fast
Reactor (GFR)



World development (focus SMR/AMR)






The NEA Small Modular Reactor Dashboard: Second Edition

SMR in the world

2020

Water

NuScale
RITM
ACP
CAREM
SMART
BWRX
RR SMR
NuWard
AP300

2021

Helium

Xe-100
HTR-PM
U-Battery
USNC

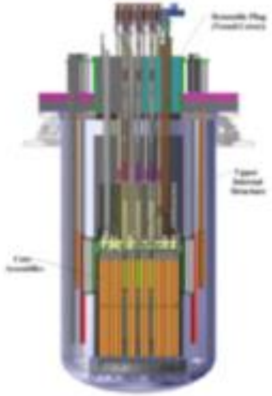
2026

Lead

SEALER
BREST
SVBR
ALFRED
Mini-LFR
URANUS
CLFR
BLESS

2027

Sodium



ARC
Natrium
e-Vinci
Oklo

20XX

Salt

TMSR-LF1
Terrestrial
Moltex
Elysium
TerraPower
Kairo
Flibe
Thorcon
Seaborg
Copenhagen Atomics
Naarea

Fourth Generation Technology

SMR in the world

2020

Water

NuScale

RITM

ACP

CAREM

SMART

BWRX

RR SMR

NuWard

AP300

2021

Helium

Xe-100

HTR-PM

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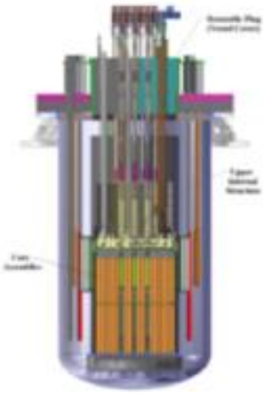
Sodium



ARC

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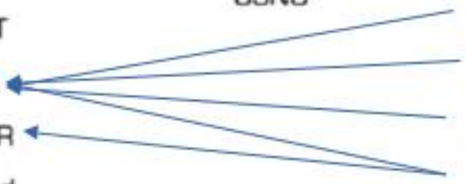
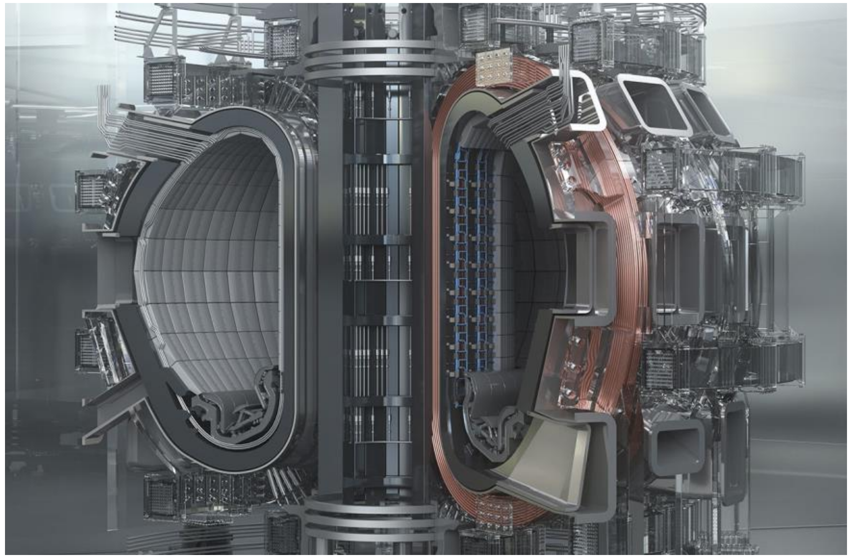


- Darlington (Kanada) **2029**
- Kärnfull Next (Sverige)
- Fermi Energia (Estland)
- Syntos (Polen) – företag, ej stat!
- Vattenfall (Sverige, reaktor tbd)

What about fusion?



- Abundant fuel
- Sustainability: Fusion fuels are deuterium and tritium:
- D + T → He + n + 17.6 MeV
  - Deuterium can be distilled from all forms of water
  - Tritium does not exist in nature ($t_{½}$=12y), but can be produced by nuclear reaction of neutrons with lithium:
  - ^{6}Li + n → He + T → isotopically enriched lithium is the actual fusion fuel (7.5% abundance)
- However lithium is widely available: terrestrial reserves of lithium would permit the operation of fusion power plants for more than 1,000 years, sea-based reserves of lithium would fulfill needs for millions of years
- Fusion reaction does not emit carbon dioxide or other greenhouse gases into the atmosphere - Its major by-product is helium: an inert, non-toxic and reasonably valuable gas

Fusion reactors

- Nuclear fusion reactors produce no high-level long-lived nuclear waste
- However, radiation damage and activation are serious issues. Tons of structural materials become activated. The activation of components in a fusion reactor are challenging from a recycling perspective – certain materials could need cooling for > 1000 years
- Limited risk of proliferation: Fusion does not employ fissile materials like uranium and plutonium. There are no enriched materials in a fusion reactor like ITER that could be exploited for nuclear weapons. Tritium could be extracted from fusion power plant
- No risk of meltdown: A Fukushima-type nuclear accident is not possible in a tokamak fusion device. It is difficult enough to reach and maintain the precise conditions necessary for fusion — if any disturbance occurs, the plasma cools within seconds and the reaction stops
- The quantity of fuel present in the vessel at any one time is enough for a few seconds only and there is no risk of a chain reaction. However, tritium inventory needs to be kept ALARA. Most fusion safety issues come from the need of tritium containment
- Like GenIV fission, thermonuclear fusion is another approach towards **sustainable nuclear energy**

Nuclear Materials

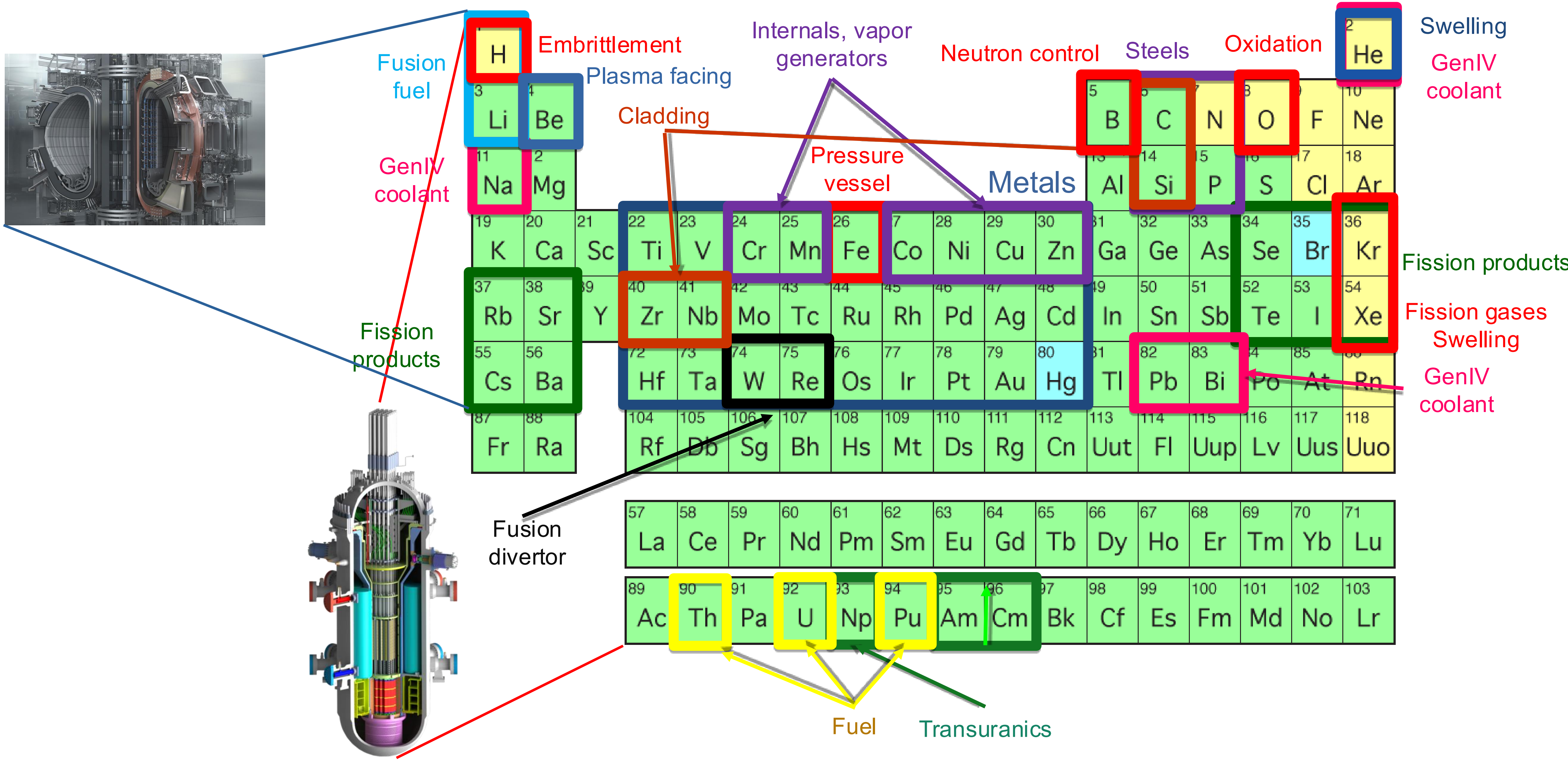
Which materials?

Materials present in a fission or fusion reactor: several families of materials with various functions

Examples for fission

- Concrete
- Polymers for structural applications
- Metallic alloys for structural components
- Refractory materials for structural components
- Fuel cladding materials
- Nuclear fuel materials (fissile and fertile)
- Materials for neutron control: absorbers, moderators, reflectors

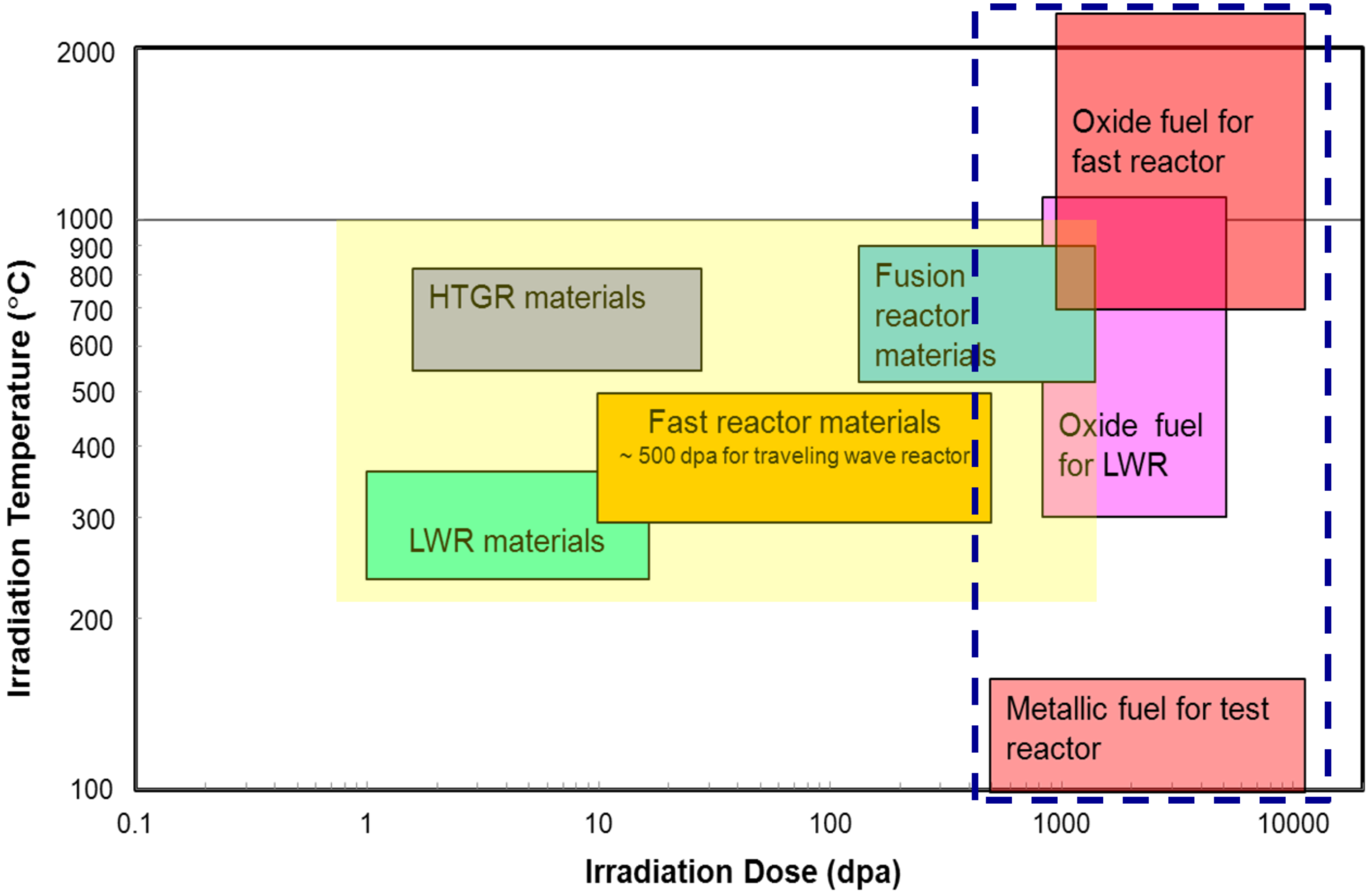
Elements of interest



Properties required for nuclear materials

Structural materials

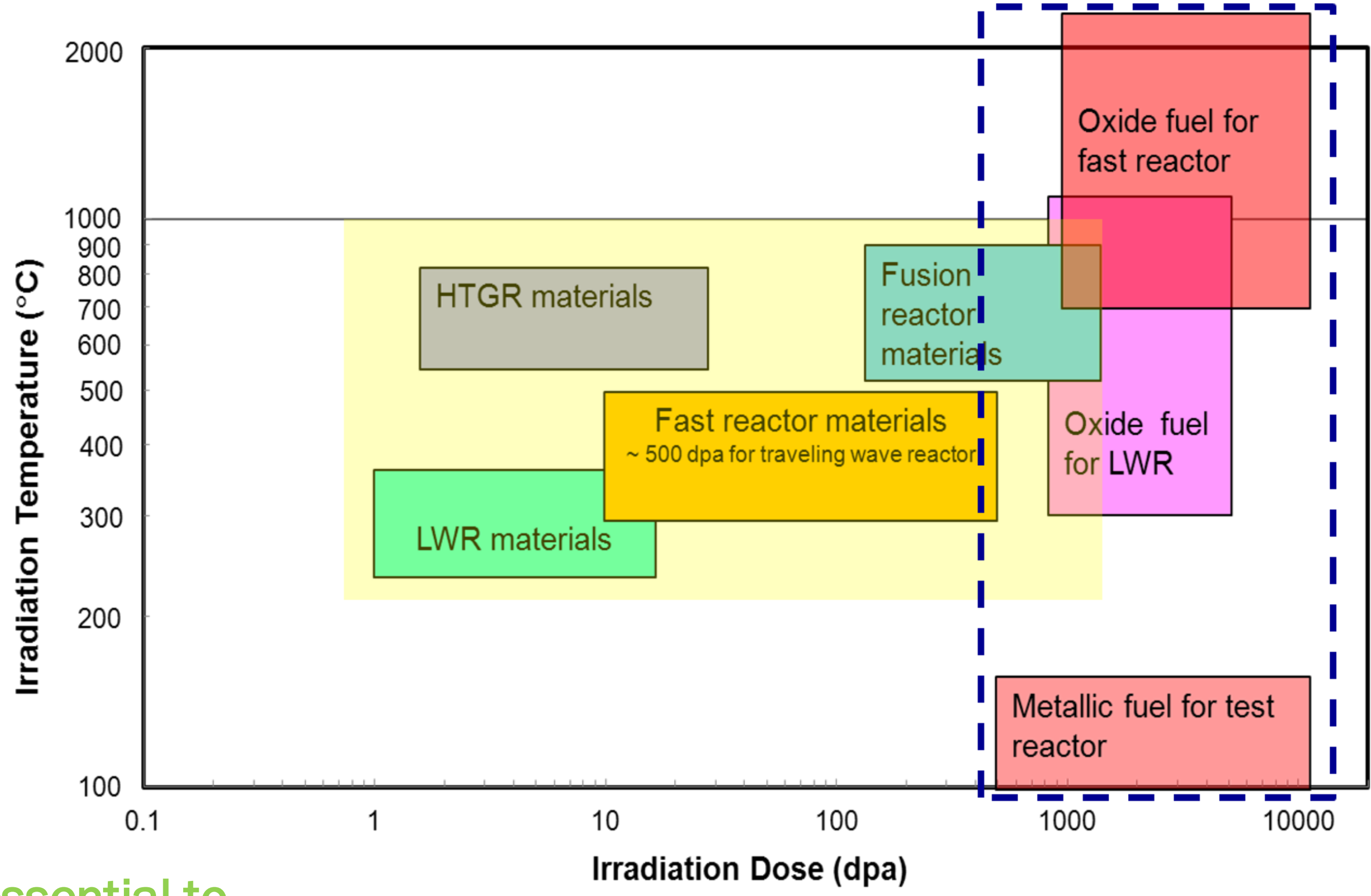
- Radiation resistance
  - Low swelling / Irradiation creep
  - Limited embrittlement
  - For fusion, limited He effect
- High temperature-resistance: creep strength, creep-fatigue resistance
- Compatibility with (Heavy) liquid metals (Na liq, Pb liq, PbBi, PbLi), gas (He), molten salts, supercritical water



Properties required for nuclear materials

Fuels

- Homogeneous compositions, especially for high Pu contents
- High melting temperatures
- High thermal conductivity
- Good mechanical properties: creep
- Resistance to corrosion from fission products
- Low swelling

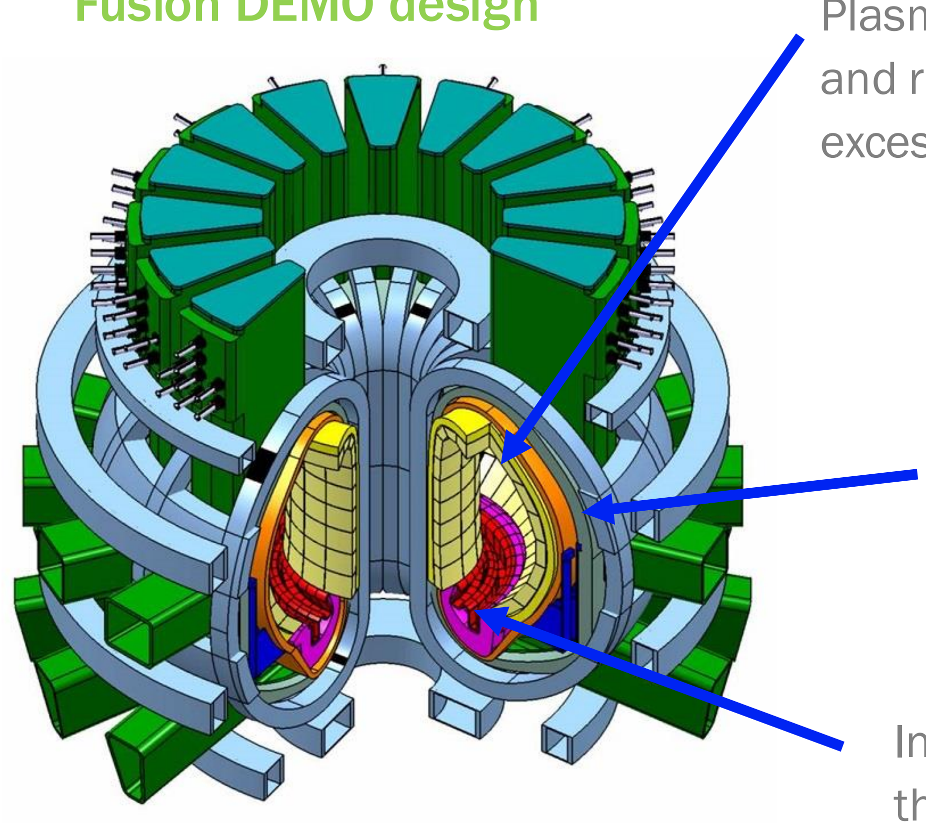


The performance of nuclear materials is essential to make Gen IV and fusion reactors a reality

Materials for fusion

First wall materials will receive around 10 dpa/fpy (displacements per atom per full-power year)

Fusion DEMO design



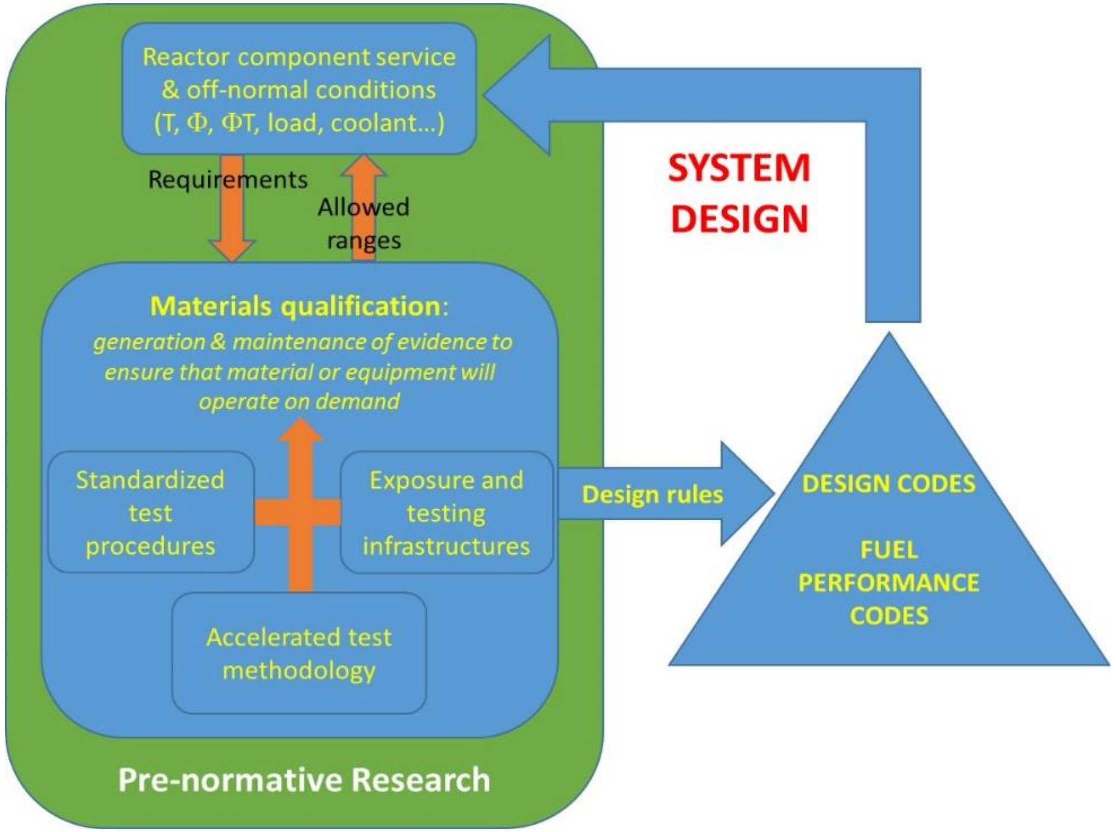
Plasma facing materials will be subjected to plasma erosion and receive 5-10 MW/m^2 heat, reaching temperatures in excess of 1000°C

Structural materials will also receive high doses of neutrons, ~4 dpa/fpy and will be in contact with flowing water (~300°C) or He (~500°C) for heat extraction and in some designs with liquid PbLi for tritium breeding

In the divertor the dpa/fpy may be somewhat less but the thermal shocks may reach 15-20 MW/m^2, with serious erosion problems that may be the real technological bottleneck

Qualification of materials

- Materials with the required properties must be selected, optimized or developed
- One of the main tasks of materials engineers: define lifetime of systems and components
- It implies knowing what happens to materials and how properties change in normal operating but also in off-normal conditions
- This qualification of the material has traditionally relied upon testing materials or components under relevant conditions, as well as by monitoring it during operation
- Acquired knowledge of the behaviour of a material is then transferred to models, more or less detailed, specific or general, which are capitalized in design codes (for structural materials and components) or fuel performance codes (fuel elements)



Reactor component service & off-normal conditions (T, Φ, ΦT, load, coolant...)

Requirements

Allowed ranges

SYSTEM DESIGN

Materials qualification:
generation & maintenance of evidence to ensure that material or equipment will operate on demand

Standardized test procedures

Exposure and testing infrastructures

Accelerated test methodology

Design rules

DESIGN CODES

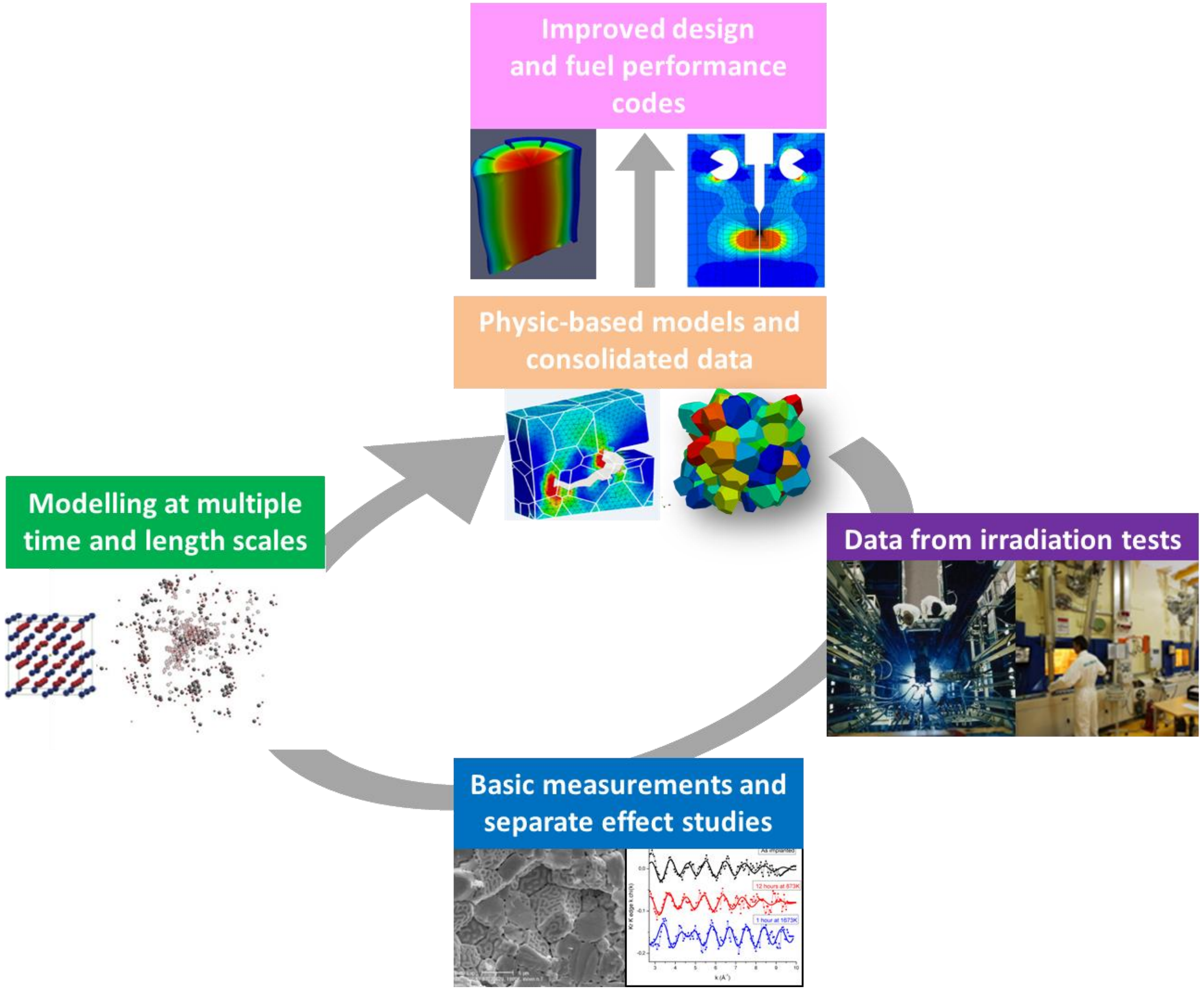
FUEL PERFORMANCE CODES

Pre-normative Research

Why Nuclear Materials Science?

Science-based approach for materials qualification

- Though successfully deployed for thermal and fast reactors operated in Europe thus far, empirical qualification is are neither reliably, nor easily, extrapolated to other conditions
- Operation conditions more stringent, very few materials testing reactors in Europe, and none in fast spectrum, safety requirements much stricter after Fukushima accident
- A better understanding of the underlying phenomena of materials behaviour is a prerequisite for a significant improvement of codes and effective qualification of materials for Gen IV and fusion reactors
- Shift in paradigm from ”Observe and qualify” to “Design and control”



Improved design and fuel performance codes

Physic-based models and consolidated data

Data from irradiation tests

Basic measurements and separate effect studies

Modelling at multiple time and length scales

CONNECT-NM

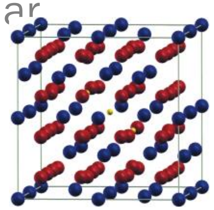
Coordination of the European Research Community on Nuclear Materials for Energy Innovation

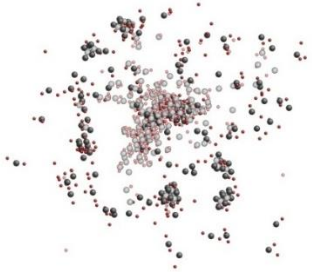
Main methods and techniques applied

ML/AI methods!

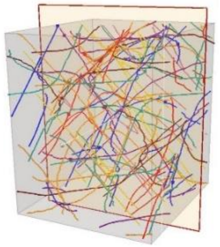
Modelling

- Electronic structure calculations (energy minimizations, molecular dynamics)

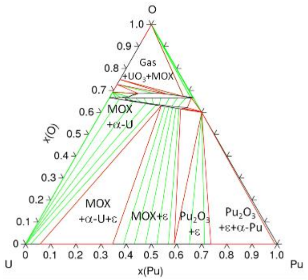




- Empirical interatomic potential (MD, MC energy minimizations)
- Models at the mesoscopic scale: rate theory methods, dislocation dynamics



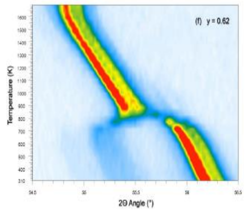
- Thermodynamic modelling: CALPHAD method
- Finite elements methods

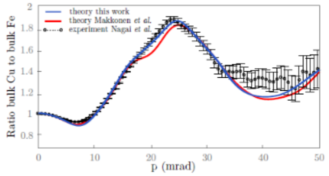


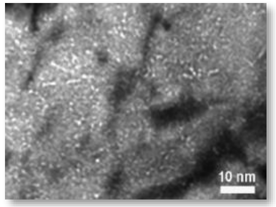
Experimental techniques

Detailed characterisation at relevant scale of materials, including surrogates, ion irradiated, implanted or model materials to simulate specific aspects of irradiation

- X-Ray diffraction and absorption
- Positron annihilation spectroscopy
- Small angle neutron scattering
- Atom Probe tomography
- Raman spectroscopy
- Thermal desorption spectrometry
- High temperature mass spectrometry
- Electrical conductivity measurement
- Transmission and Scanning Electron Microscopy
- Electron Back Scatter Diffraction
- Electron energy loss spectroscopy
- Atomic Force Microscopy
- Atom probe tomography
- Nano and micro-indentation
- Mechanical testing on miniature or components
- Differential scanning and drop calorimetry

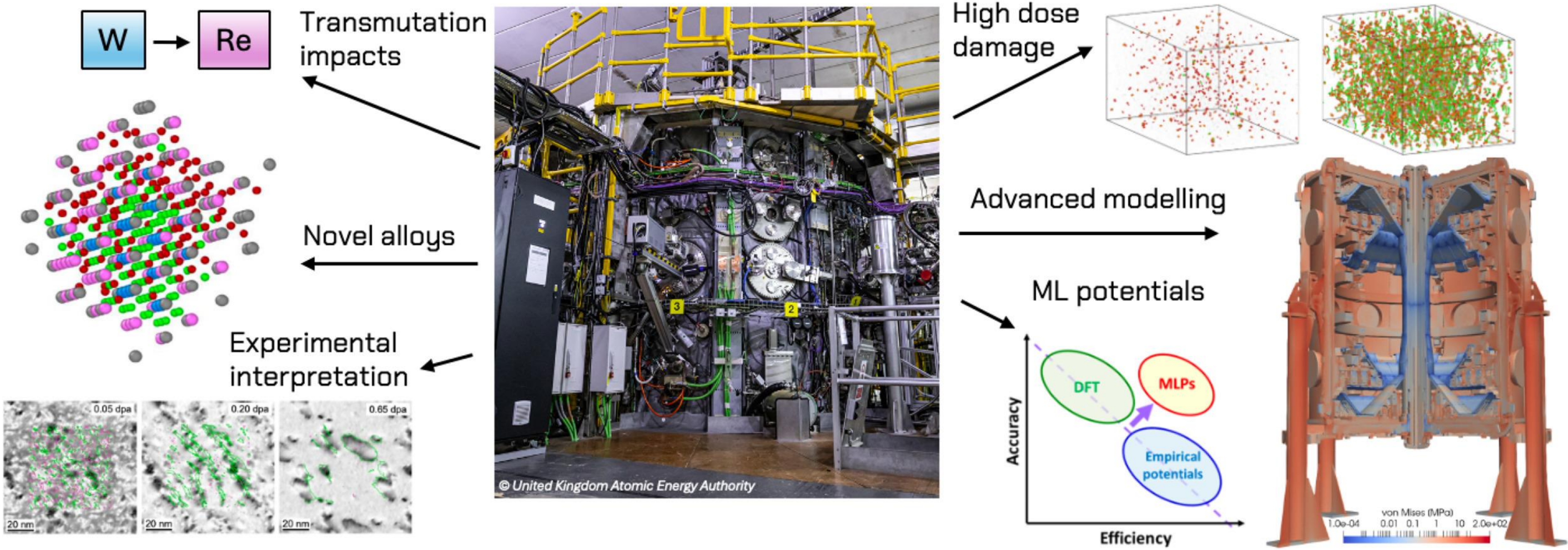






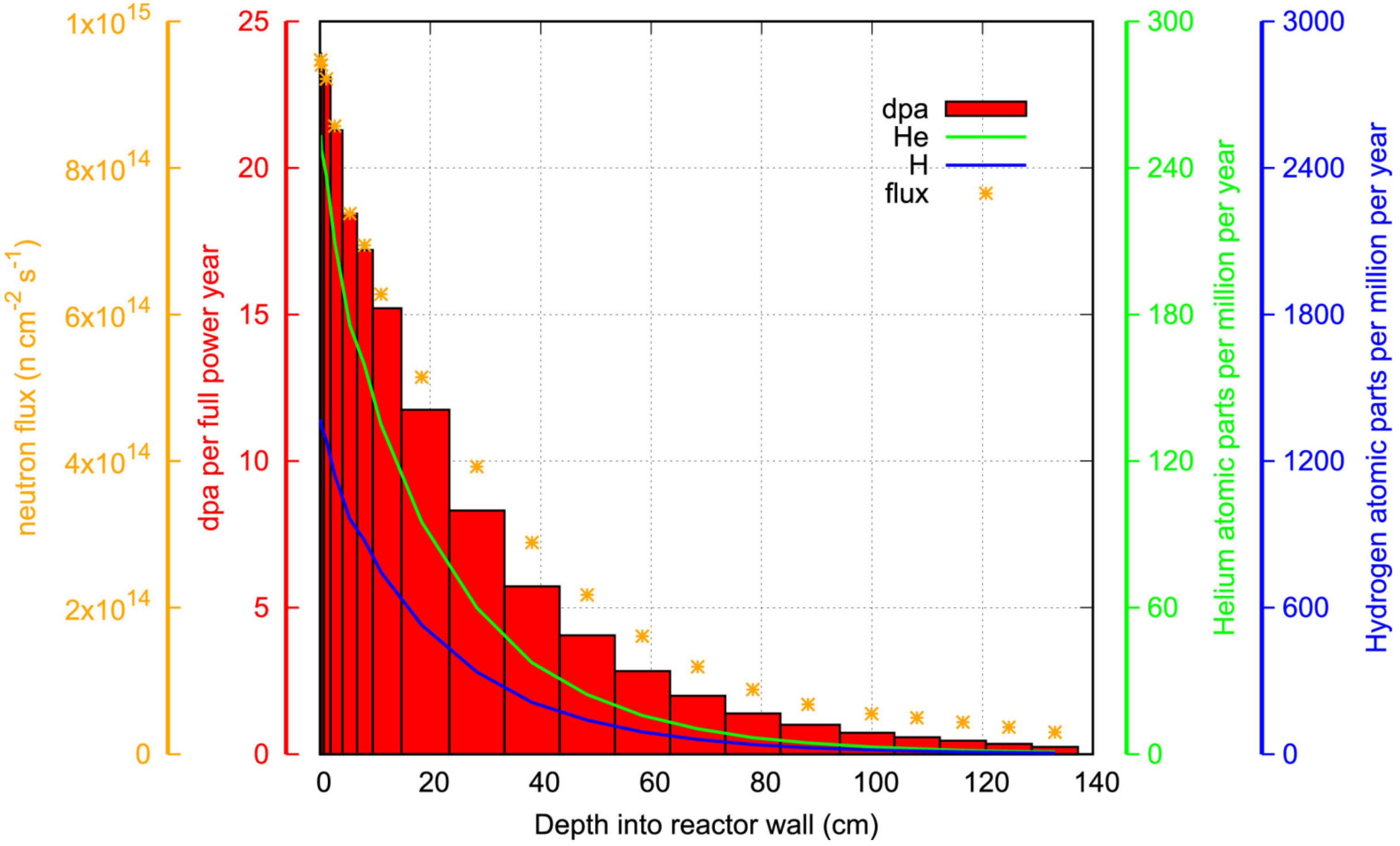
Materials for fusion

Fusion materials modelling: present gaps and future opportunities



Reali et al, JNM 625 (2026) 156512

Radiation damage in fusion reactors



STEP tokamak design:

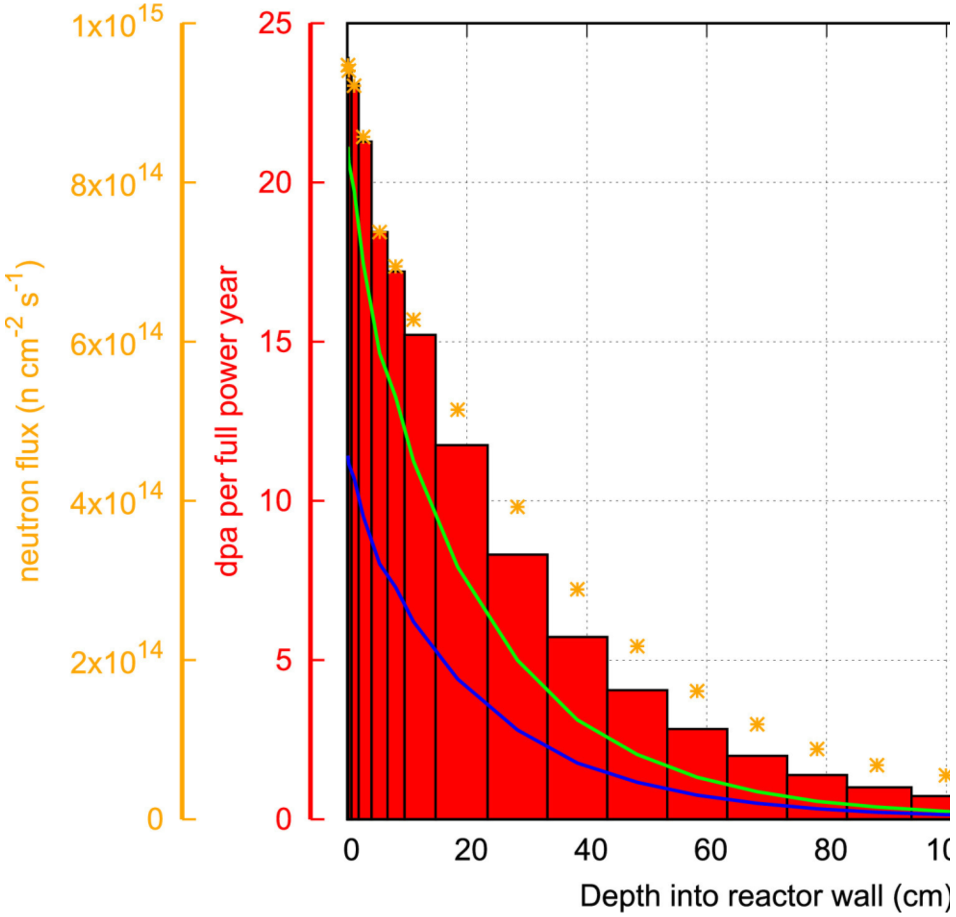
Assuming reactor wall is pure Fe

Intense radiation damage (in dpa)

Significant light element build up

Reali et al, JNM 625 (2026) 156512

Microstructural evolution in fusion reactors



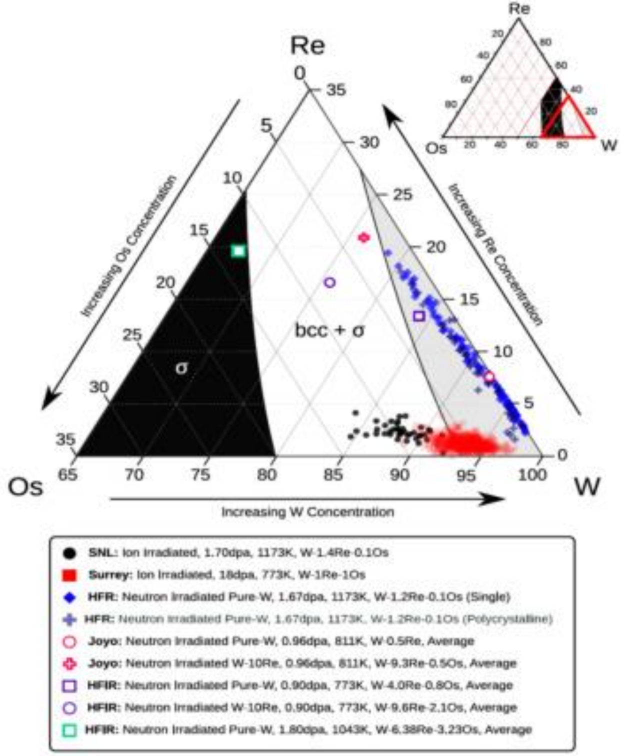
Chemical evolution of fusion materials:

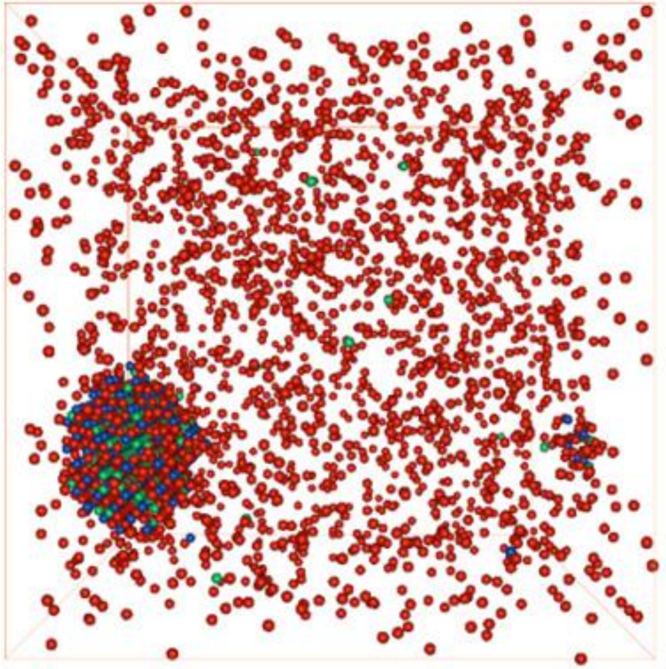
Significant cross sections for transmutation from fast neutrons (2.5 and 14 MeV)

W plasma facing wall slowly turning into W-Re-Os-… alloy

Phase- and microstructure evolution affected

Reali et al, JNM 625 (2026) 156512





Sustainable Nuclear Energy Research in Sweden (SUNRISE) & Nuclear Materials Platform (numap.se)

SUNRISE
Sustainable Nuclear Energy Research in Sweden

- SUNRISE was formed by KTH, UU and LTU together with large parts of the Swedish nuclear and steel industry (and global partners).
- **Goals:**
  - Design a lead-cooled research reactor to be ready by 2030.
- **Stages:**
  - *Stage 1*: Research and development to license the research reactor
  - *Stage 2*: Build an electrically heated prototype and conduct experiments
  - *Stage 3*: Build and operate the SUNRISE reactor
- International academic partners, Industry stakeholders, Societal stakeholders

Stiftelsen för Strategisk Forskning

KTH Vetenskap och Konst

Uppsala Universitet

Luleå Tekniska Universitet

UNSW Australia

Massachusetts Institute of Technology

Alleima

Oskarshamns kommun

outokumpu

Jernkontoret

Blykalla

Strål säkerhets myndigheten
Swedish Radiation Safety Authority

Prifysgol Bangor University

KANTHAL®
Part of Sandvik Group

Westinghouse

uniper

Vysus Group

PROMATION nuclear

Studsvik

Safetech

SUNRISE

Motivation for SUNRISE

- Nuclear power is the only carbon neutral and long-term, sustainable source of base load electricity that can be scaled up slow-down the changing climate
- Recent constructions of large NPPs turned out to be expensive and run over budget
- Automated serial production can be utilised
- The use of lead coolant implies that passive safety can be achieved in the most compact format.
- Can be included in a circular Gen-IV for increased long-term sustainability

Strainless steel

Steel alloys developed at KTH

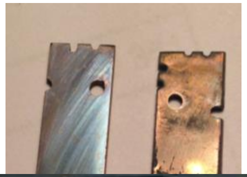
Five Work Packages within SUNRISE

- **WP1**: Design and safety analysis of research reactor (LFR)
- **WP2**: Steel performance and testing
- **WP3**: Manufacturing methods and testing on reactor components
- **WP4**: Nuclear fuel development
- **WP5**: Erosion-corrosion test facility

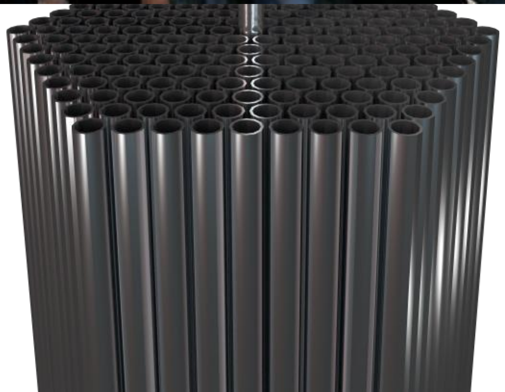
Motivation for SUNRISE

- Nuclear power is the only carbon neutral and

Strainless

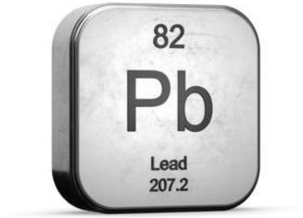


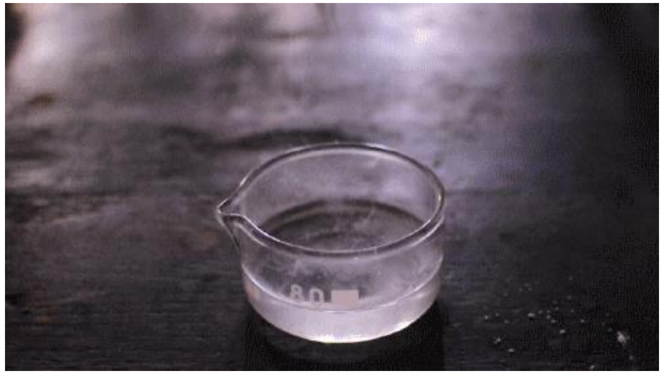
Steel alloys developed at KTH



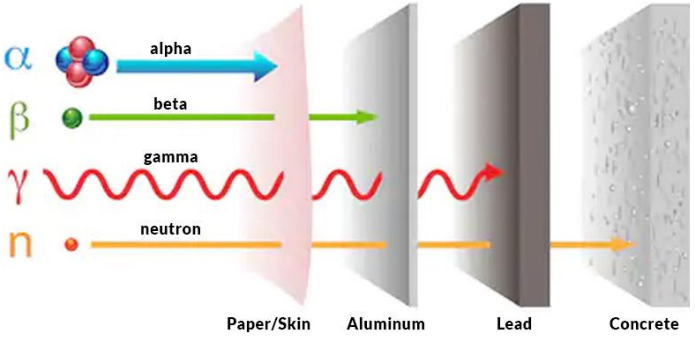
- **WP5**: Erosion-corrosion test facility

Benefits of using liquid lead as a coolant





Sodium in water



- No need to pressurise the reactor → Thinner reactor vessel → lower cost and manufacturing complexity
- High boiling point (1749 °C), no coolant loss
- No high-energetic exothermic reaction in contact with water or structural material
- Passive safety through natural circulation is achievable in a compact format
- Fast neutron spectrum, higher fuel yield
- In case of fuel rod damage, iodine and cesium will form compounds with lead, reducing their release to environment
- Efficient shielding from gamma radiation

Challenges with liquid lead

Sustainable Nuclear Energy Research in Sweden

- Opaque – visual inspections impossible. New methods must be developed
- High melting point (327 °C)
  - Maintenance at high temperatures.
  - Risk of freezing issues. Design must mitigate risks with ”overcooling”
- Nickel dissolution from steels in lead - requires a stable oxide layer for protection
  - Erosion of the oxide layer must be avoided
- High density – many components float

Anvil floating in mercury

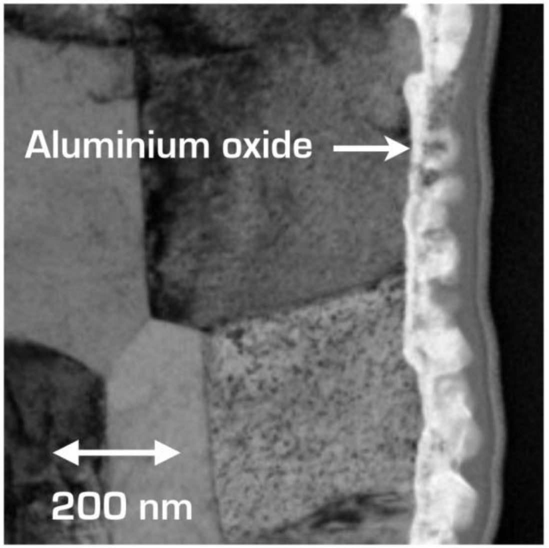
SOLUTIONS ARE NEEDED..

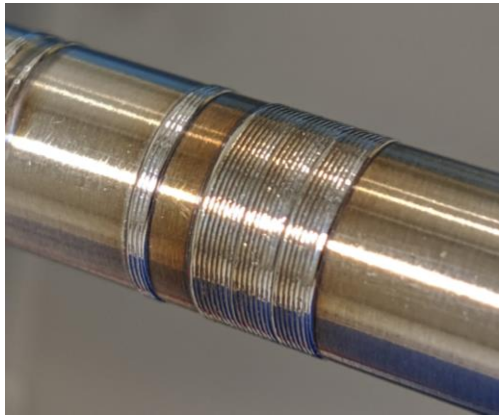
NEW ADVANCED MATERIALS AND PROCESSES!

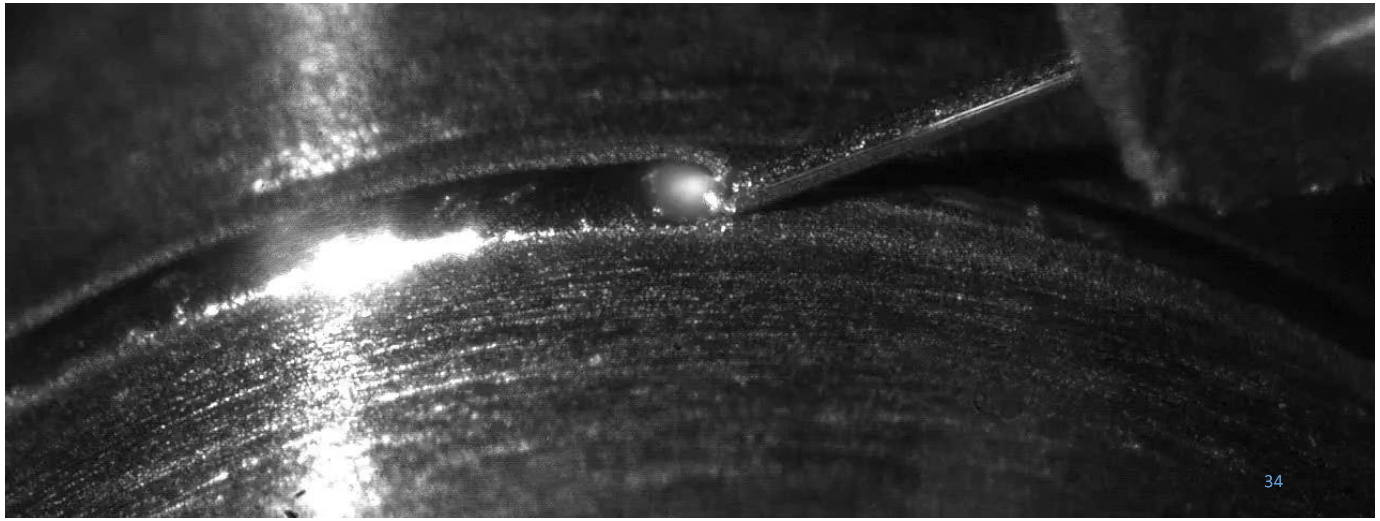
Novel steel performance

Development of a lead-compatible steel

- **FeCrAl** steel alloy developed at KTH forms thin, self-healing and protecting, layers of alumina (sapphire) on the surface.
- Reactive elements have been added to ensure t oxide layer stable of a high quality.
- **FeCrAl** alloys have demonstrated exceptional performance in high-temperature lead.
  - **2 years at 550 °C**
  - **10 weeks at 850 °C**
- Laser welding of FeCrAl on bulk 15-15Ti
  - Process development ongoing at LTU
- Development ongoing of other alumina forming steels for other applications (AFA)



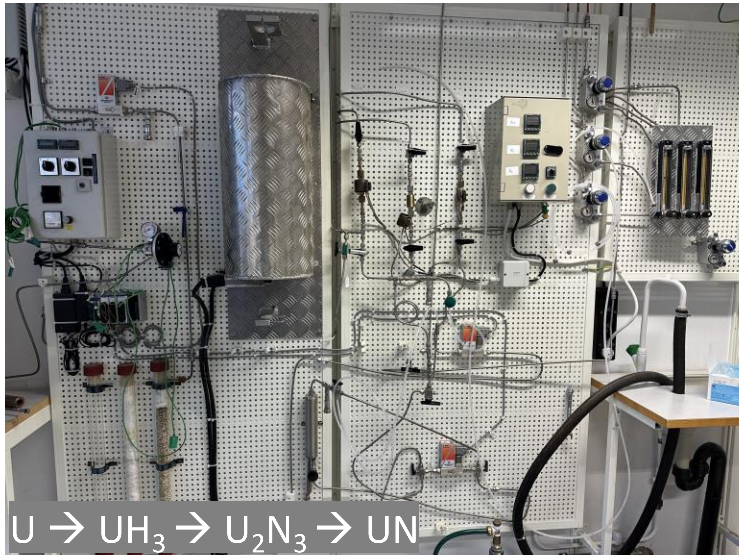




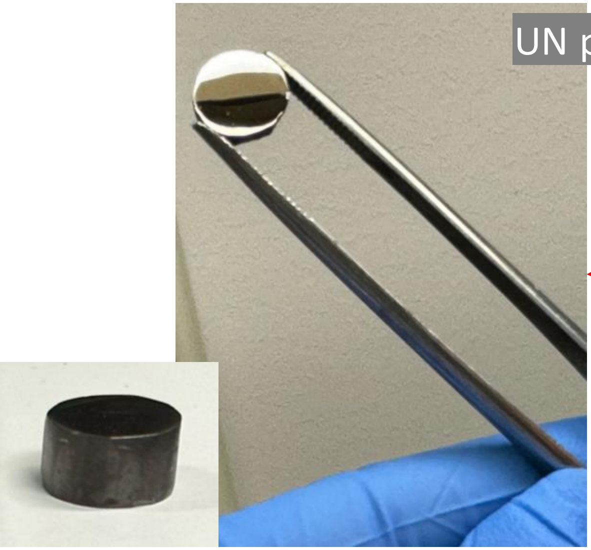
Nuclear Fuel Development – uranium nitride (UN)

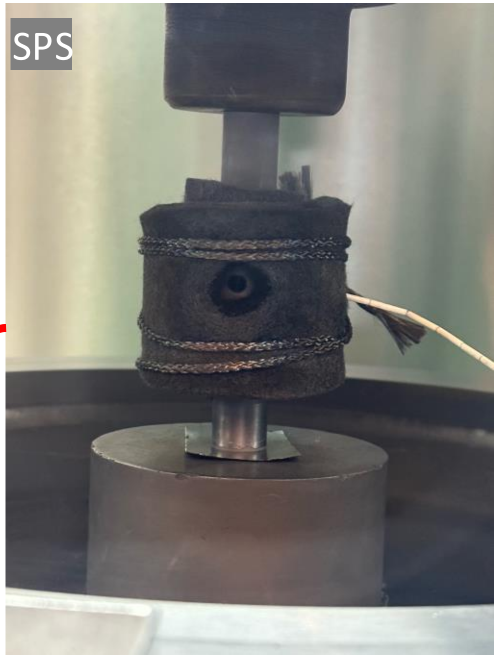
- + Higher uranium density (40 % compared to UO_2)
  - ↪ Allows 20 years of operation in a SMRs
- + Higher ability to conduct heat compared with UO_2
- + High melting temperature (2850 °C)
- + Sintering fuel in a few minutes
- + Study of the simulated fuel
- – ^{15}N enrichment required, as a reaction of ^{14}N with neutrons produces radioactive ^{14}C
- – Low operational experience – additional time to qualify


U metal


$U \rightarrow UH_3 \rightarrow U_2N_3 \rightarrow UN$

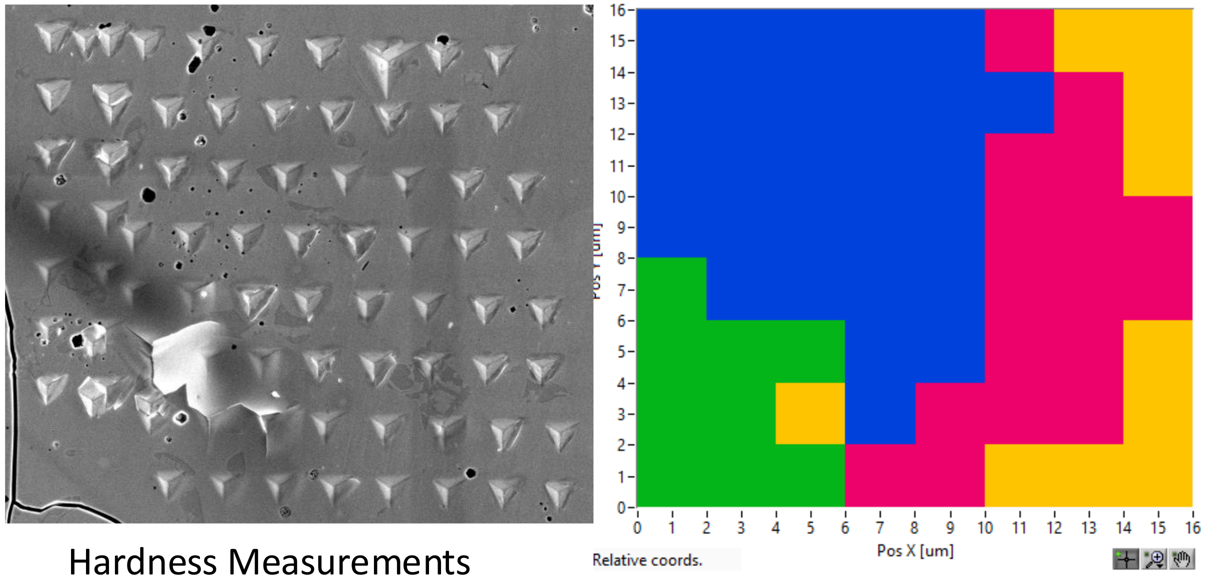

UN powder


UN pellet

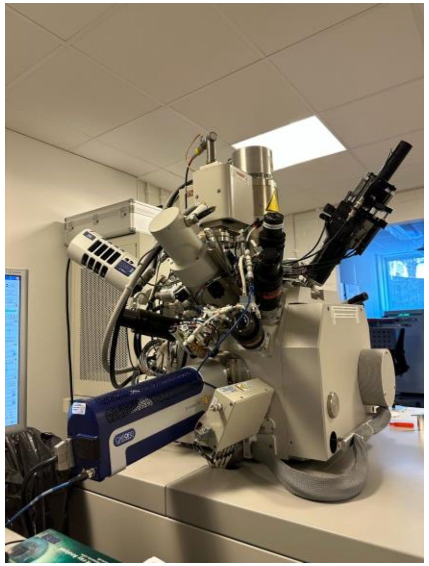

SPS

Nuclear Fuel Development

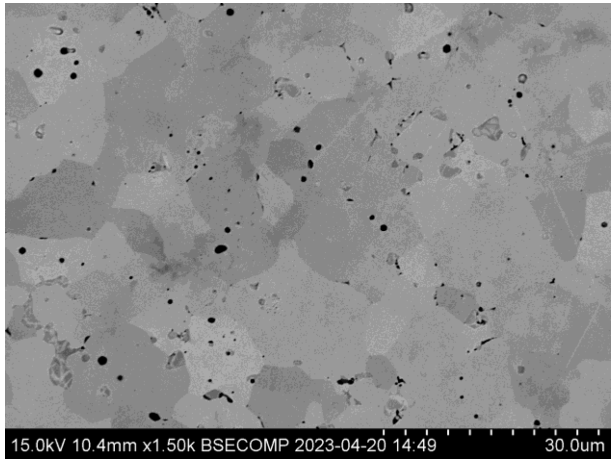
Irradiation facility

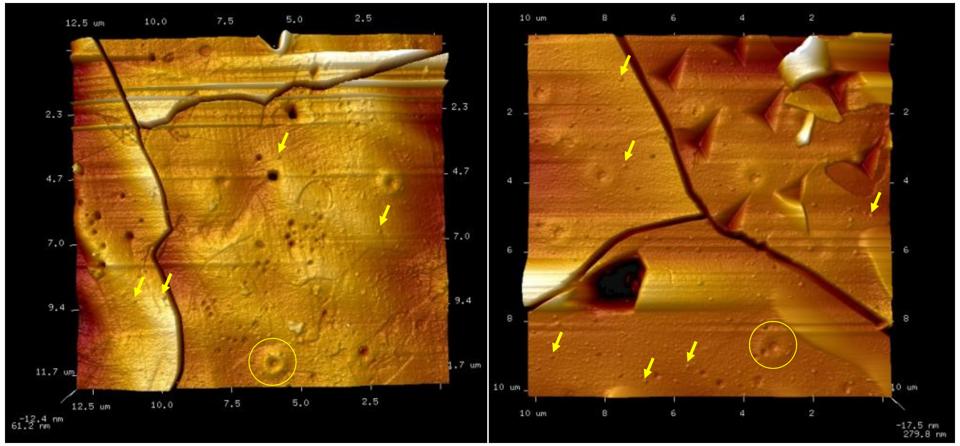


Hardness Measurements



Microscopy

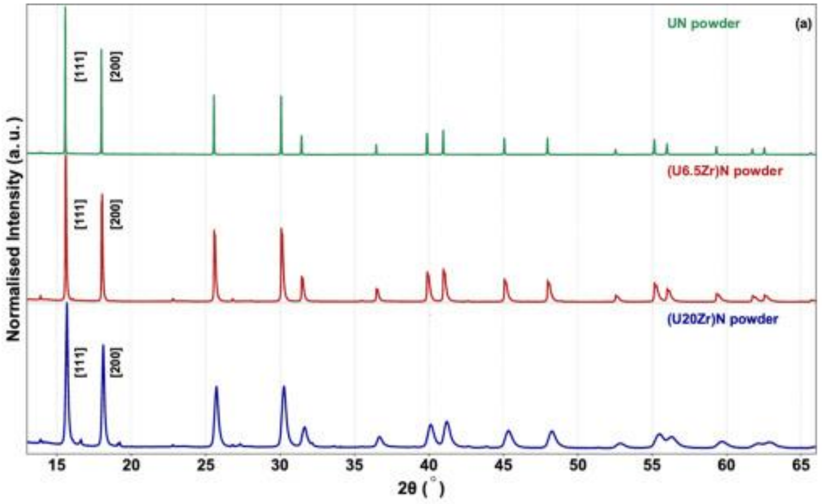


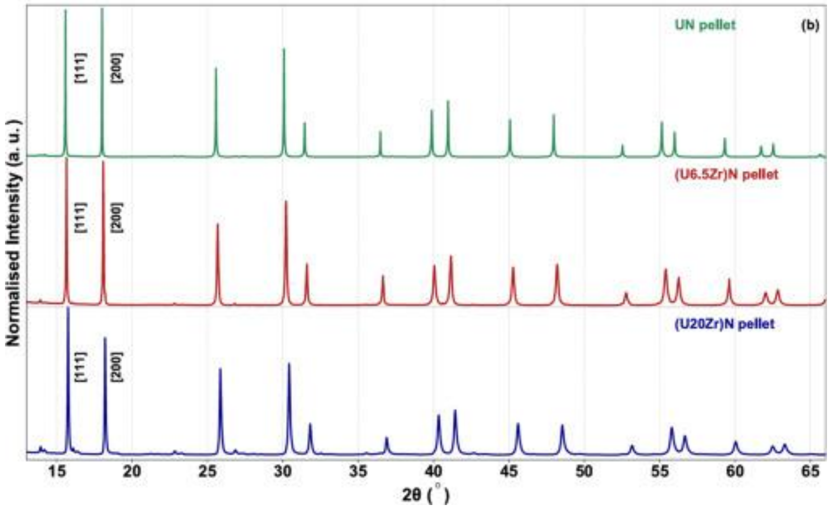


Charatsidou et al, J Materiomics 10 (2024) 906

Separate effect studies in UN fuels

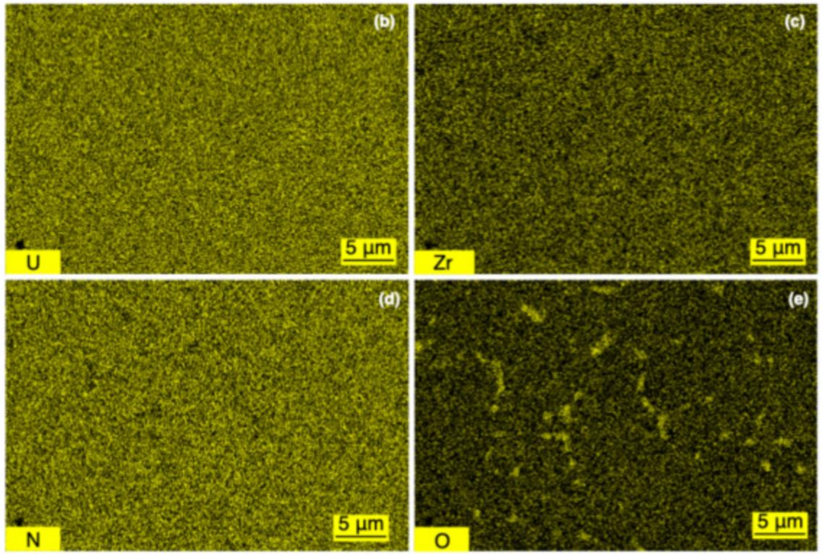
- Separate effect studies on simulated burn-up UN fuels
- Doping UN with Th, Zr, Mo, Ru, Xe, Kr, …
  - Powder mixing, precursor alloying, ion implantation, ...
- Secondary phase formation, swelling, shrinkage, etc



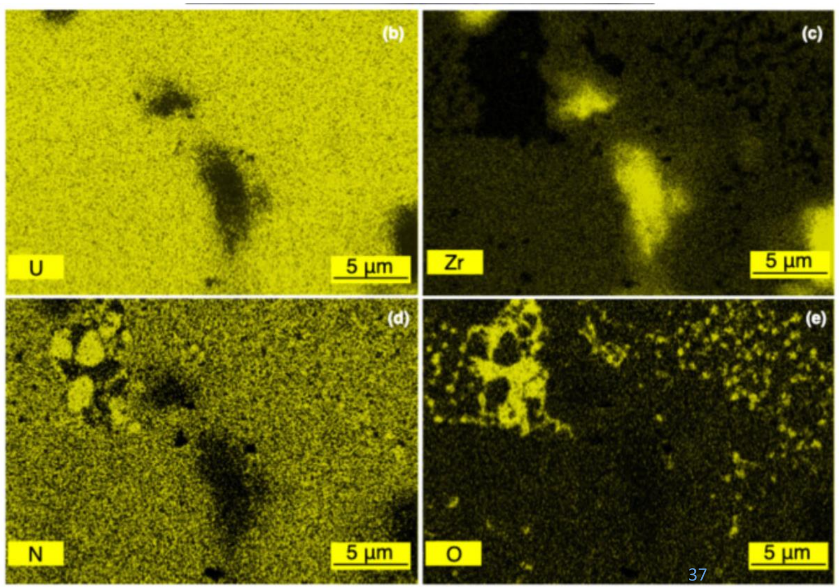


Charatsidou et al, JNM 623 (2026) 156467

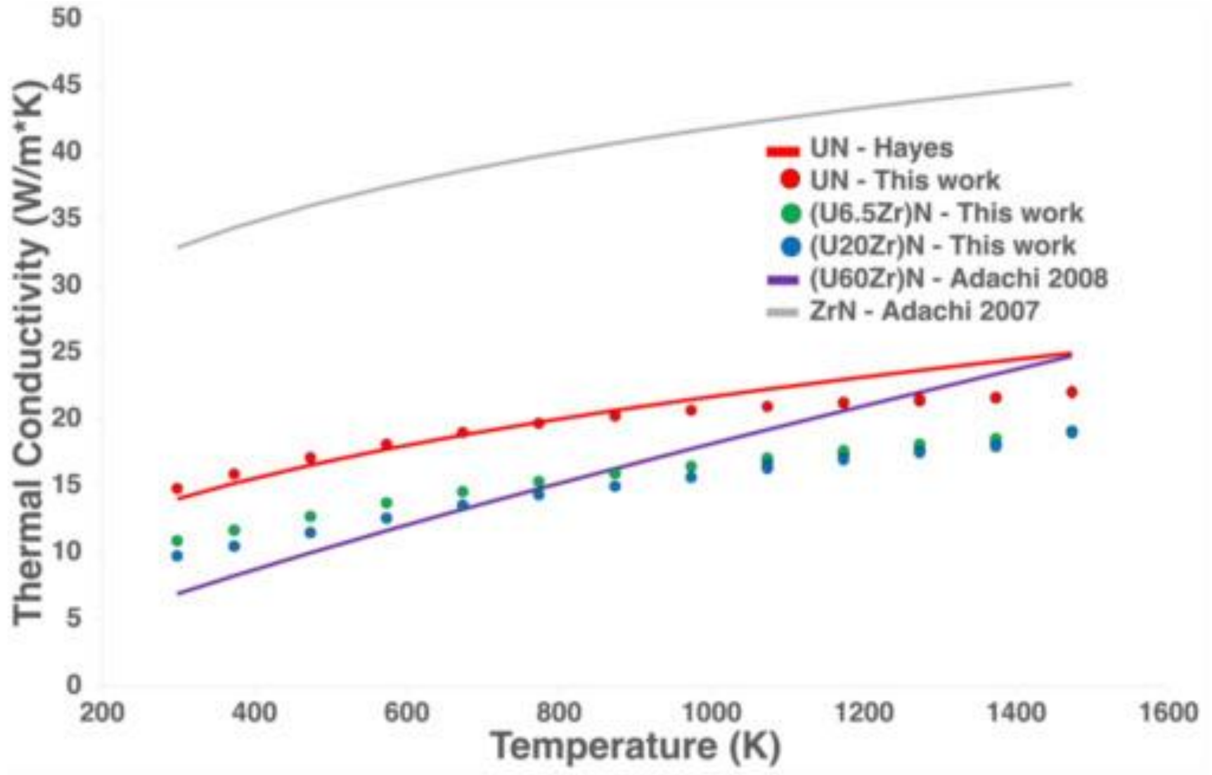
- 6.5 at.% Zr in UN



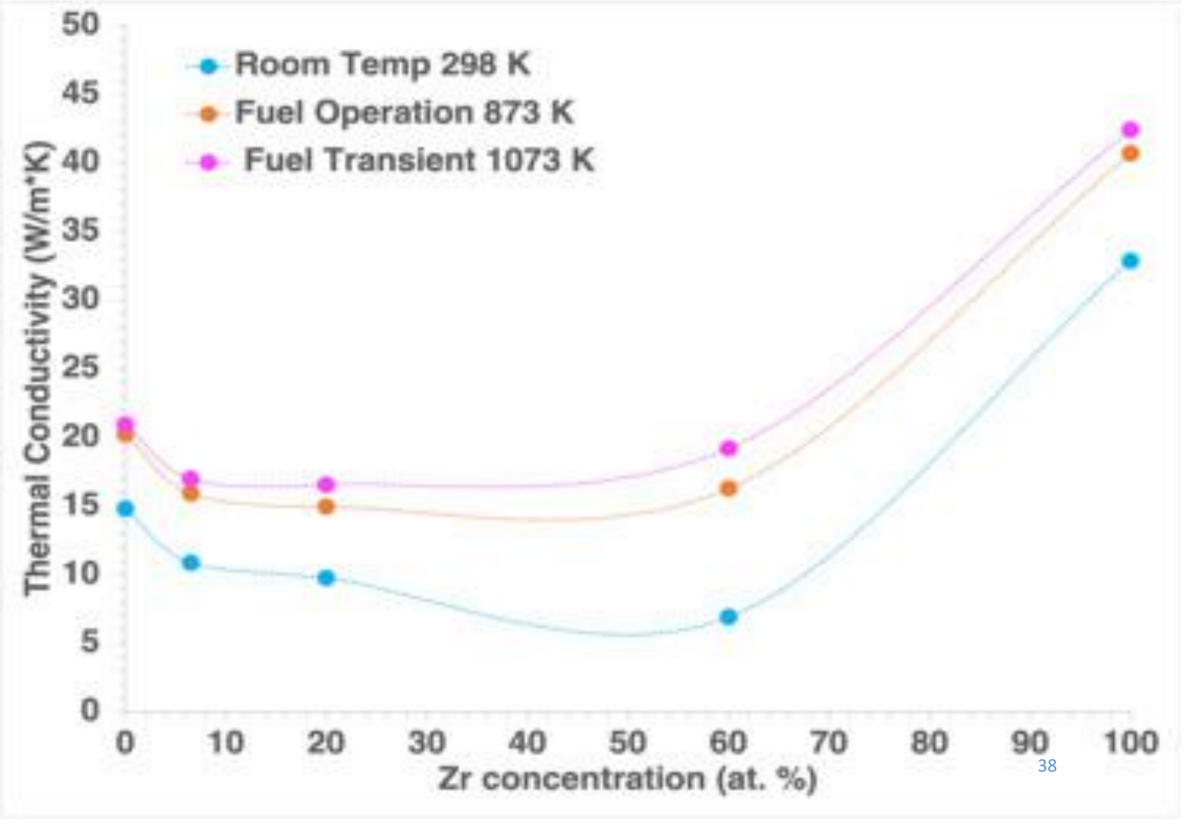
20 at.% Zr in UN



Fuel thermal degradation

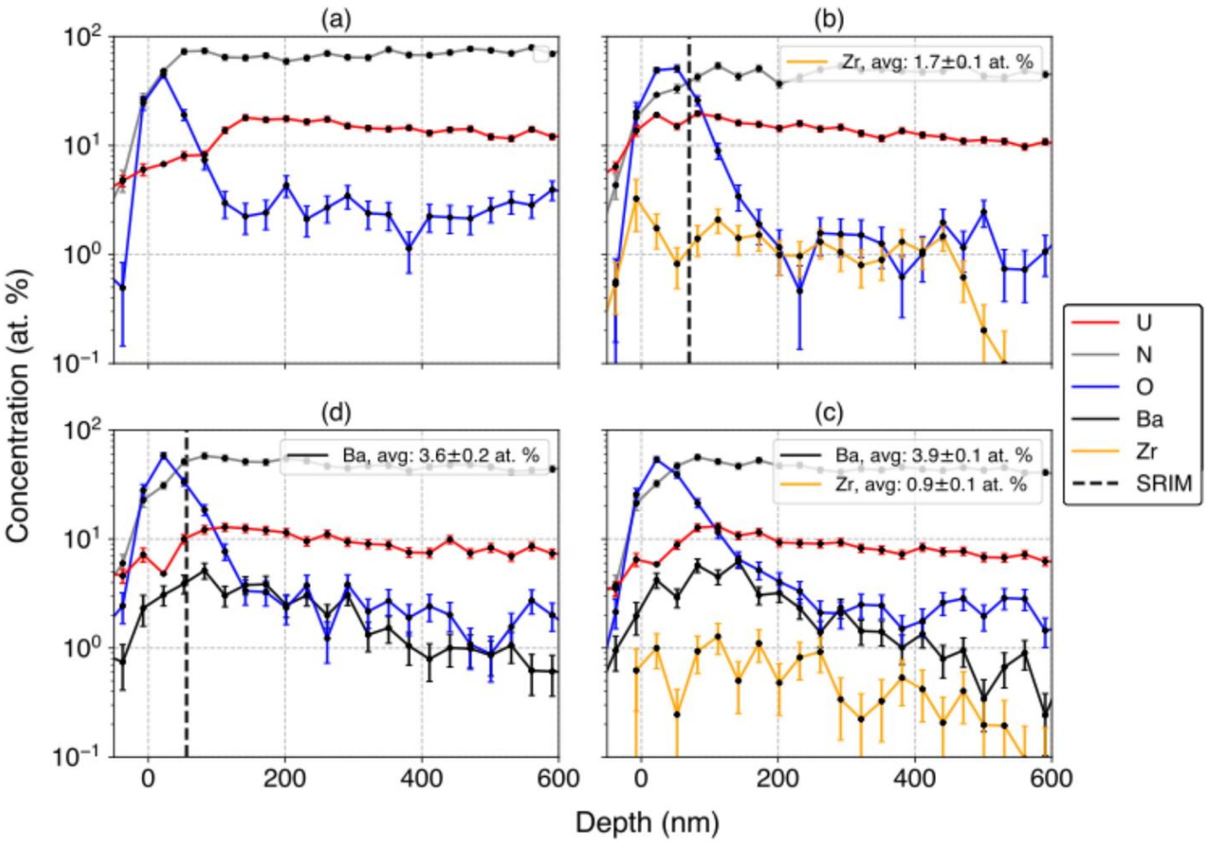


- Zr doping generally lowers thermal diffusivity and conductivit
  degrades the fuel safety margins
- Surprising given the high k of ZrN!
- Impurity scattering dominant effect

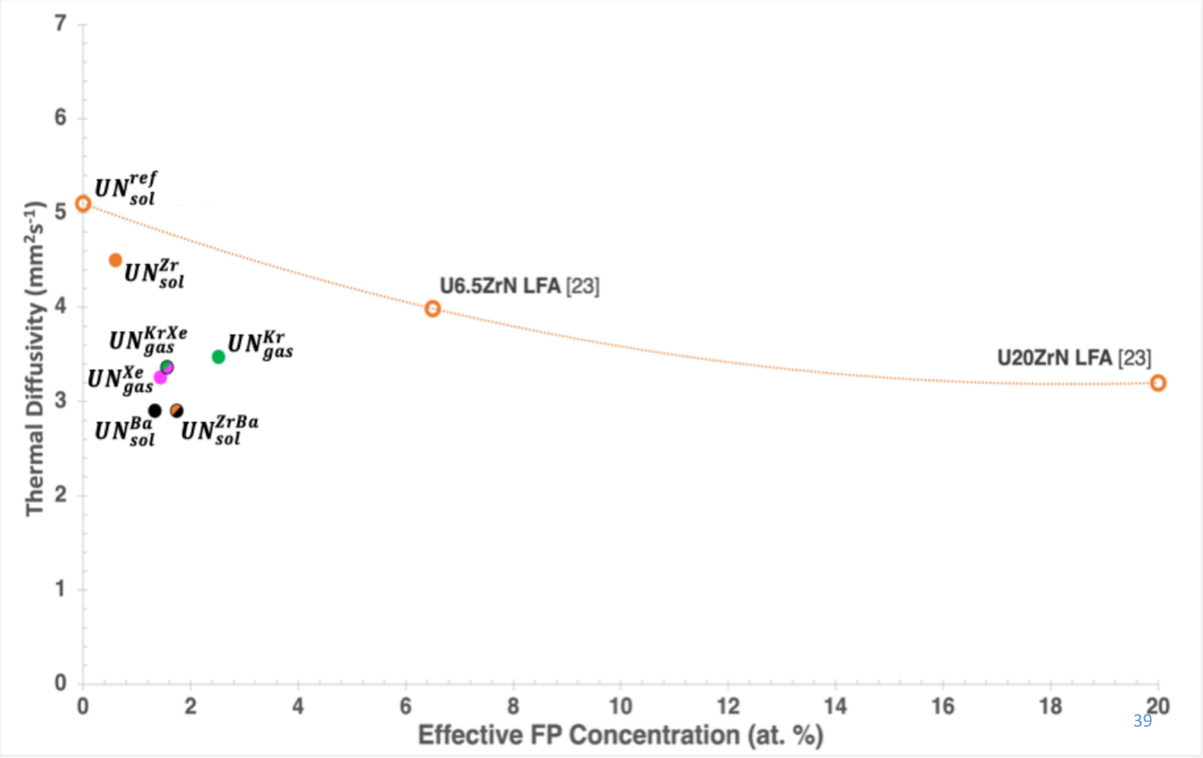


Charatsidou et al, JNM 623 (2026) 156467

Fuel thermal degradation



- Ion implantation give uniform chemical distribution, but significant damage doses as well
- Decoupling effects of chemistry and damage shows clear effect of chemical affinity on thermal property degradation

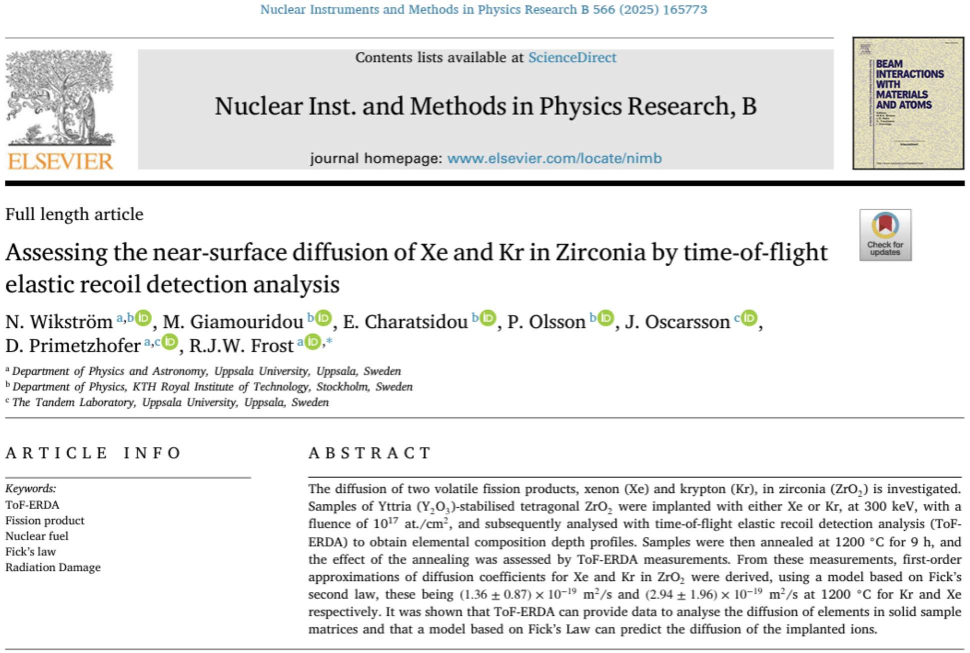


Charatsidou et al, JNM 2026 (under review)

Xe diffusion in surrogate materials and in UN

ZrO2 samples were used as surrogates to UO2 to study gaseous fission product diffusion:

- The samples were Xe implanted @TANDEM Lab, UU
- Time of flight measurements performed to identify depth of irradiation and concentration of Xe
- Annealing was performed to enhance Xe diffusion
- ToF-ERDA used again to measure the depth and concentration of Xe
- Model built to predict and estimate rate of diffusion of FP in fuels



Nuclear Instruments and Methods in Physics Research B 566 (2025) 165773

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, B

journal homepage: www.elsevier.com/locate/nimb

Full length article

Assessing the near-surface diffusion of Xe and Kr in Zirconia by time-of-flight elastic recoil detection analysis

N. Wikström [a,b], M. Giamouridou [b], E. Charatsidou [b], P. Olsson [b], J. Oscarsson [c], D. Primetzhofer [a,c], R.J.W. Frost [a,*]

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[b] Department of Physics, KTH Royal Institute of Technology, Stockholm, Sweden
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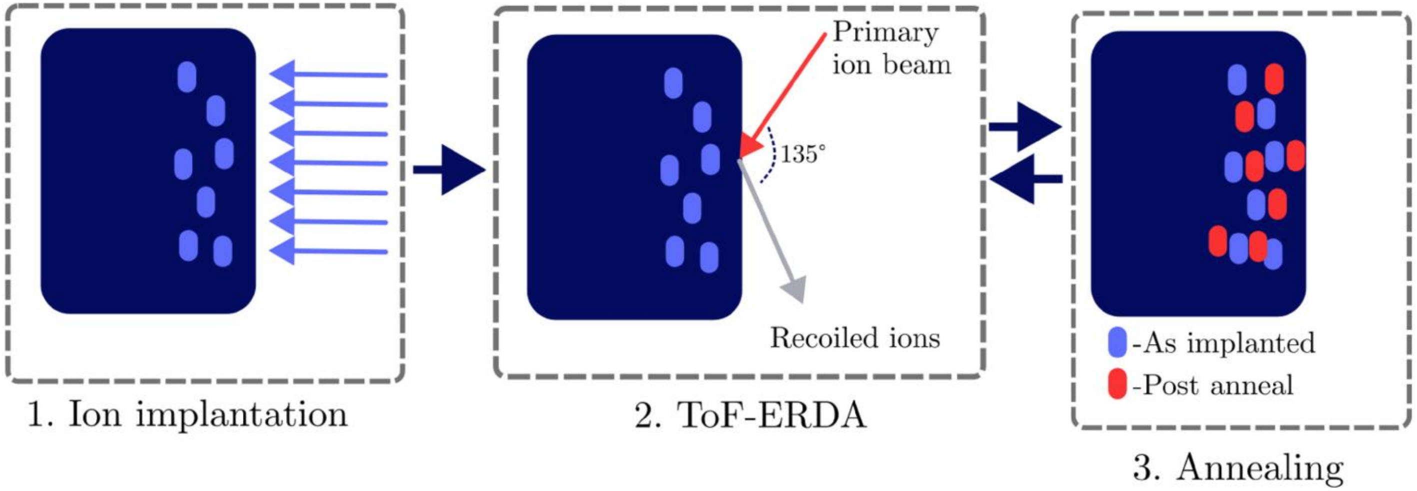
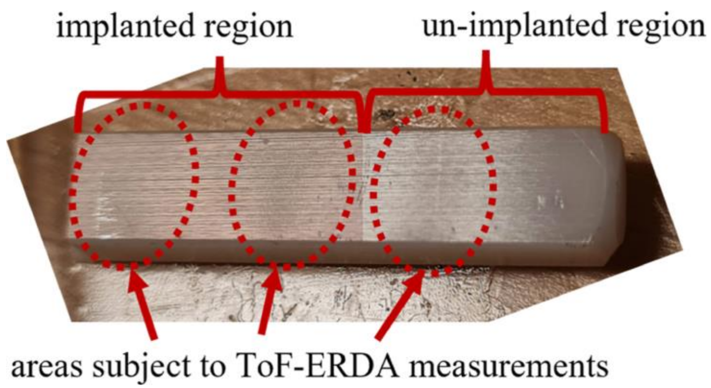
ARTICLE INFO

Keywords:
ToF-ERDA
Fission product
Nuclear fuel
Fick's law
Radiation Damage

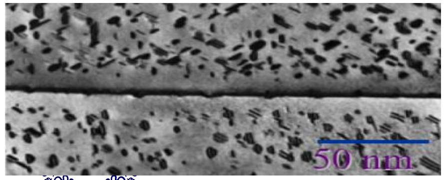
ABSTRACT

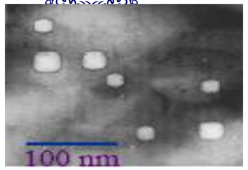
The diffusion of two volatile fission products, xenon (Xe) and krypton (Kr), in zirconia (ZrO_2) is investigated. Samples of Yttria (Y_2O_3)-stabilised tetragonal ZrO_2 were implanted with either Xe or Kr, at 300 keV, with a fluence of 10^{17} at./cm^2, and subsequently analysed with time-of-flight elastic recoil detection analysis (ToF-ERDA) to obtain elemental composition depth profiles. Samples were then annealed at 1200 °C for 9 h, and the effect of the annealing was assessed by ToF-ERDA measurements. From these measurements, first-order approximations of diffusion coefficients for Xe and Kr in ZrO_2 were derived, using a model based on Fick's second law, these being $(1.36 \pm 0.87) \times 10^{-19}$ m^2/s and $(2.94 \pm 1.96) \times 10^{-19}$ m^2/s at 1200 °C for Kr and Xe respectively. It was shown that ToF-ERDA can provide data to analyse the diffusion of elements in solid sample matrices and that a model based on Fick's Law can predict the diffusion of the implanted ions.

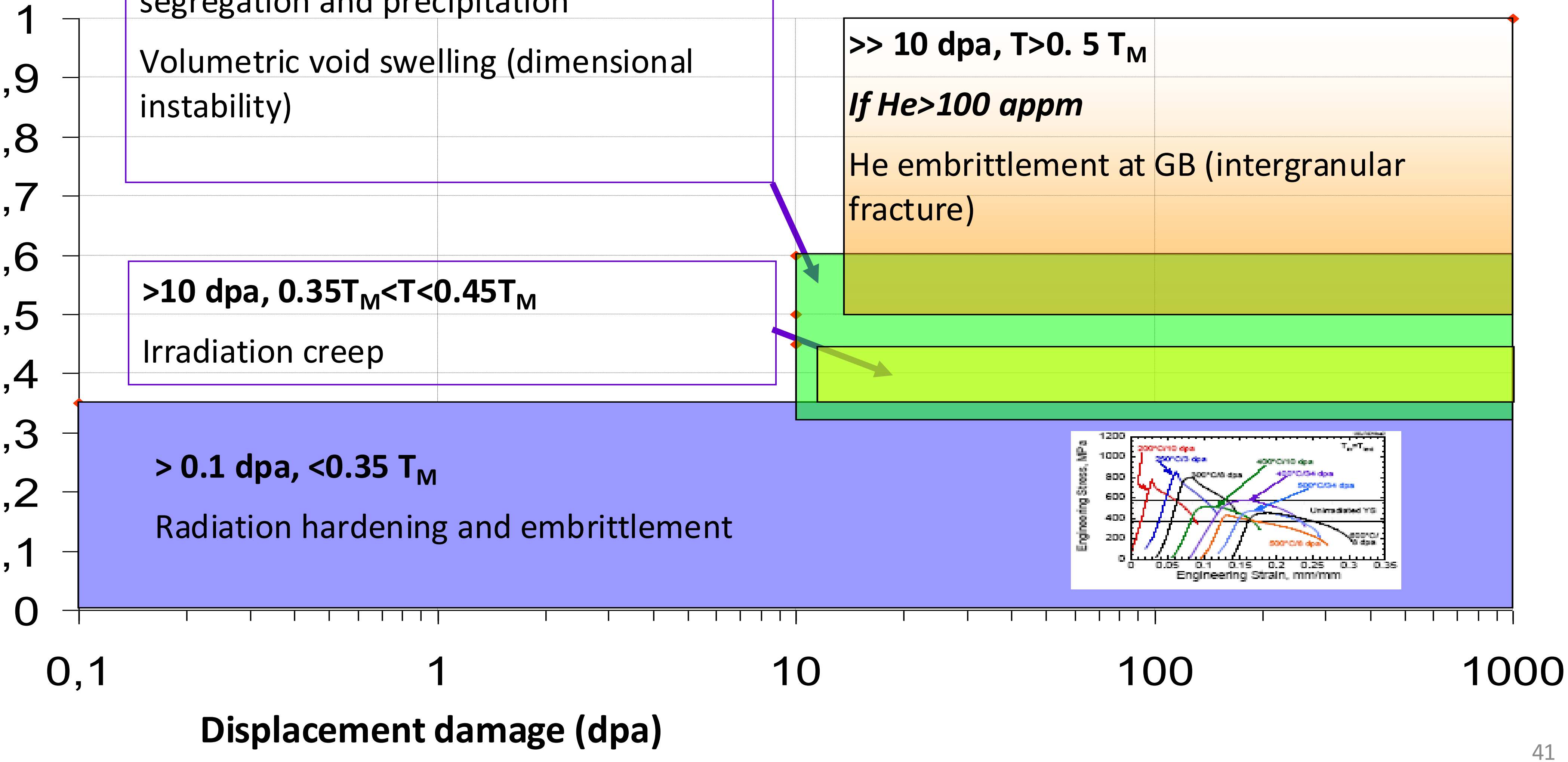




Radiation effects in structural materials







>10 dpa, $0.3T_M<T<0.6T_M$

Phase instabilities from radiation-induced segregation and precipitation

Volumetric void swelling (dimensional instability)

>> 10 dpa, $T>0.5\ T_M$

If He>100 appm

He embrittlement at GB (intergranular fracture)

>10 dpa, $0.35T_M<T<0.45T_M$

Irradiation creep

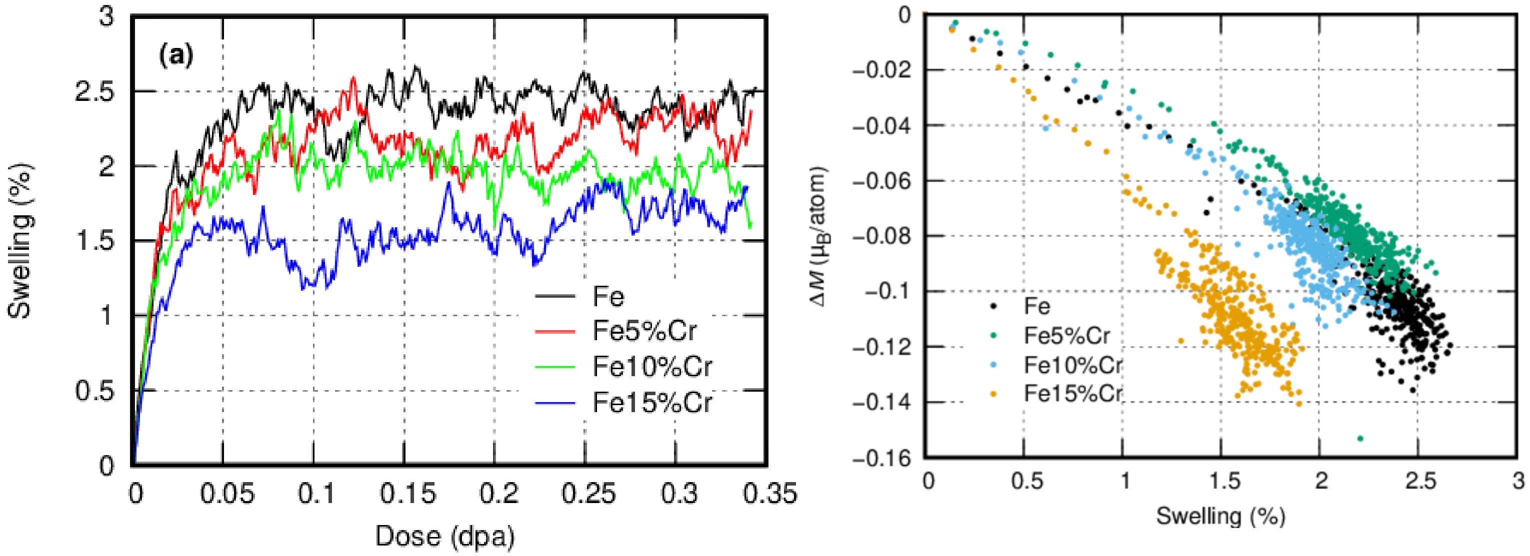
> 0.1 dpa, $<0.35\ T_M$

Radiation hardening and embrittlement

Radiation damage studies in advanced steels

➢ Modeling irradiation-induced microstructure evolutions in Fe and FeCr

- The linear accumulation of defects and the achievement of steady-state saturation in microstructure evolution observed experimentally were theoretically replicated
- Experimental evidence and DFT-CRA simulations both show a decrease in total magnetization
- Alloying effects are significant and correlated with irradiation-induced changes in magnetization



Irradiation-induced structural change (swelling) and global magnetization (M) in Fe and FeCr alloys

Publications

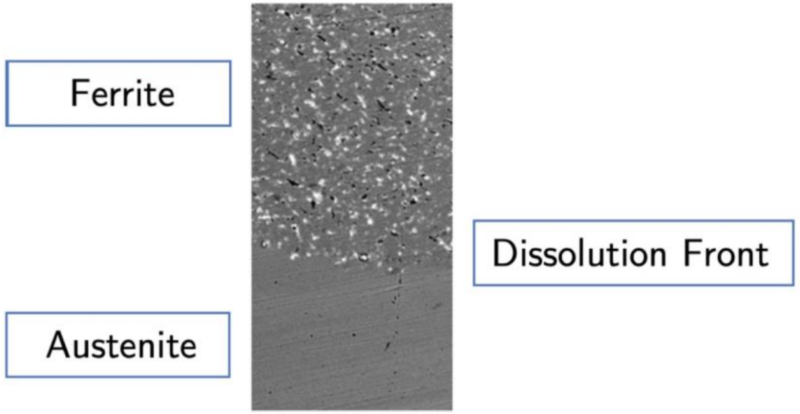
- *Nature Scientific Reports 15 (2025) 35050*
- *Materials Research Letters* 12 (2024) 477
- *Computational Materials Science* 236 (2024) 112852
- *Physical Review Materials* 7 (2023) 123604
- *Journal of Nuclear Materials* 588 (2024) 154829
- *Nuclear Materials and Energy* 34 (2023) 101403

Studies outlook

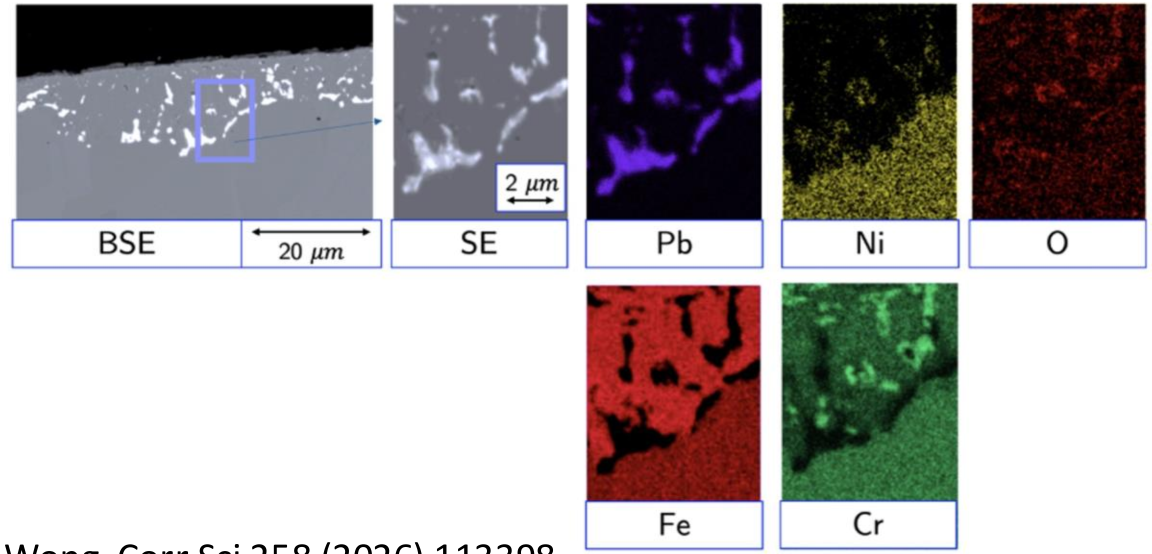
- Multi-scale simulation of LME in FeCrAl
- Effect of radiation on LME
- Publication of mechanical testing of AFA
- Mechanical testing on AFM alloys

Mechanistic Understanding of Austenite Ferritization in Pb

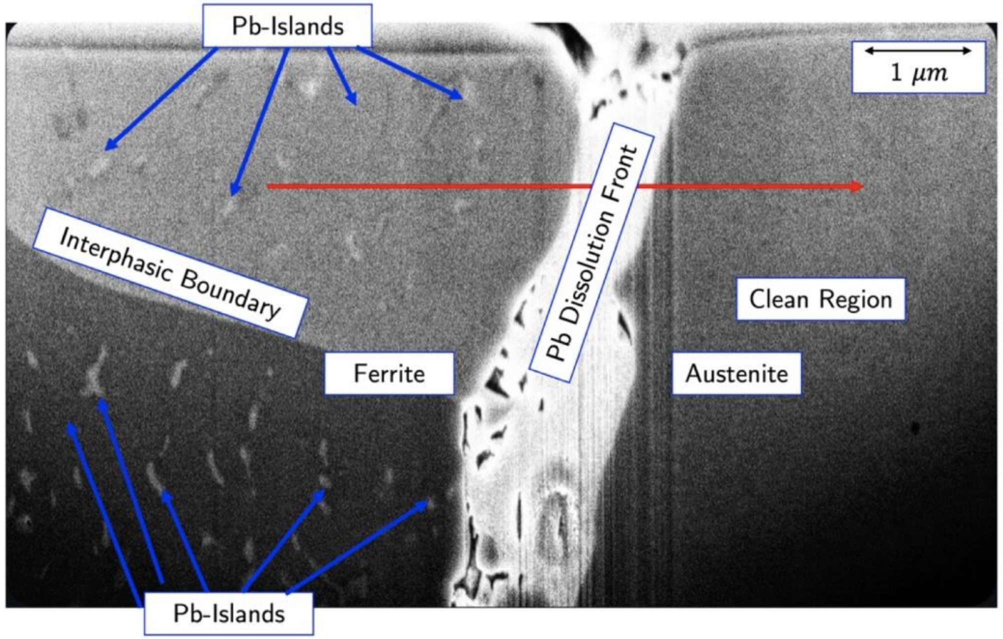
➢ Improved understanding of ferritization of austenitic steel in liquid Pb



- **Austenitic steels** are widely employed in industrial applications.
- When exposed to **direct contact with liquid Pb-alloys**, they undergo a phenomenon known as **ferritization**.
- At the **dissolution front**, a **discontinuous elemental profile** is observed.
- To date, **no comprehensive theory** has been able to fully explain this phase transformation.
- **Focused Ion Beam (FIB) analysis** provides clear evidence of the formation of a **Pb liquid film** around the reaction front.

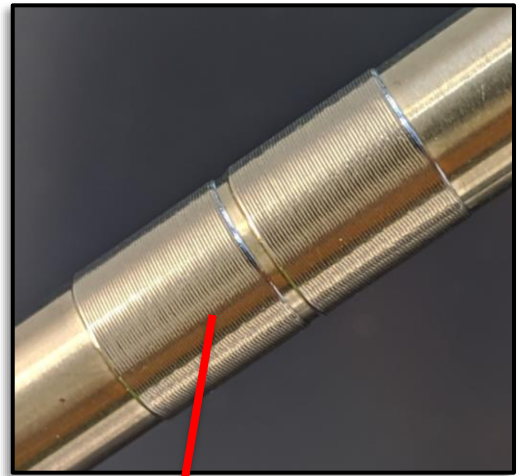


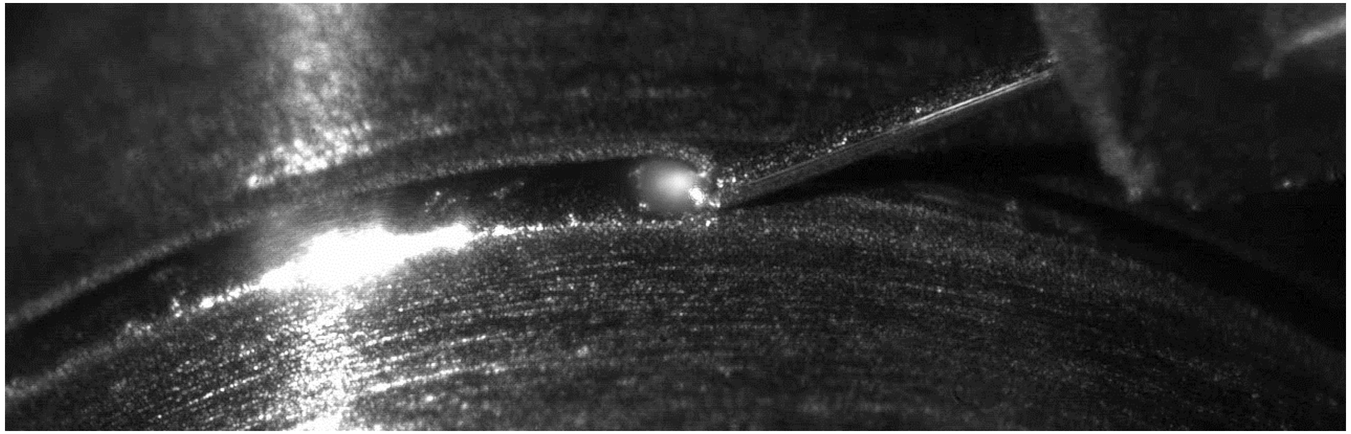
Wong, Corr Sci 258 (2026) 113398



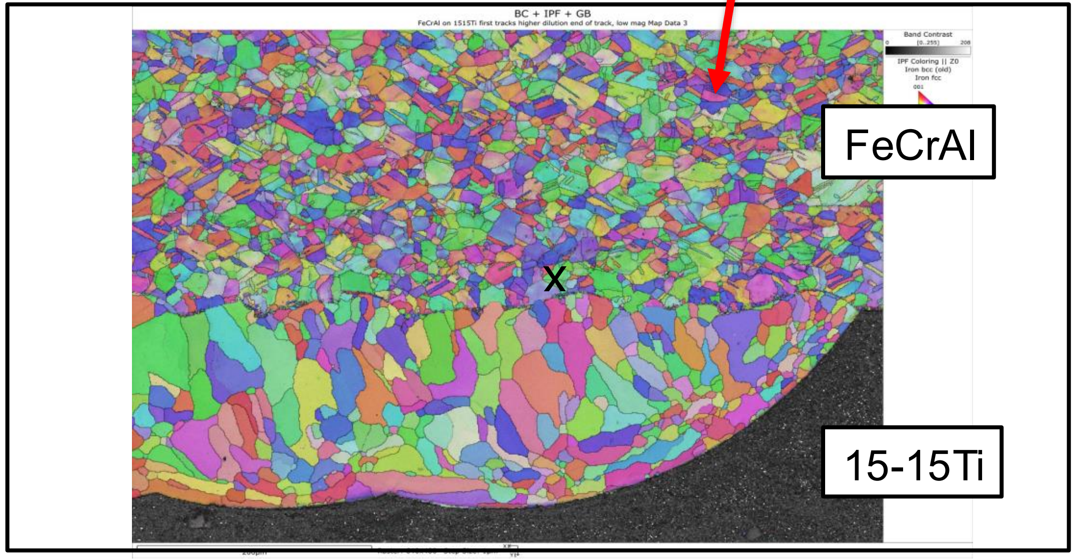
Fuel cladding tube protection

- Development of Laser Micro Wire Cladding (LMWC) process
- Manufacturing of test samples using **15-15Ti** and **316L** tubes with **Fe-10Cr-4Al** clad





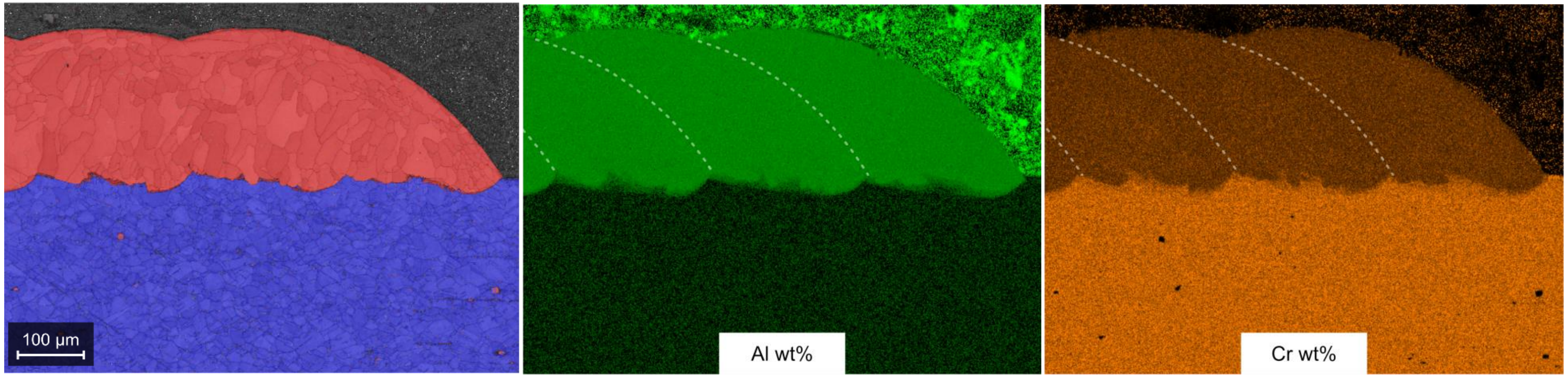
Laser micro wire cladding *(LMWC) process filmed using high-speed imaging.*



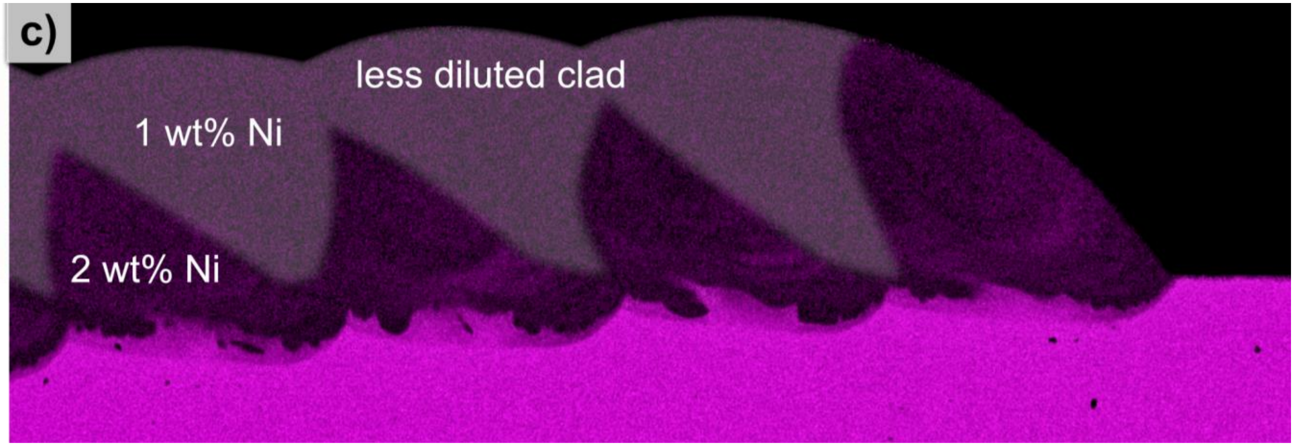
Cross-section of cladded fuel tube manufactured by ***laser micro wire cladding*** *(LMWC).*

Fuel cladding tube protection

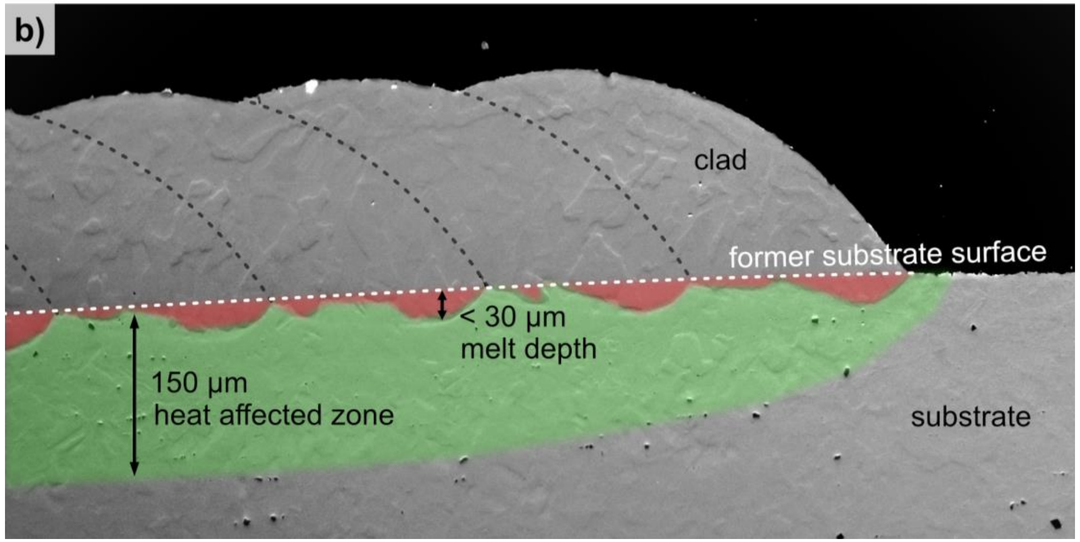
Homogeneous Cr and Al distribution in clad



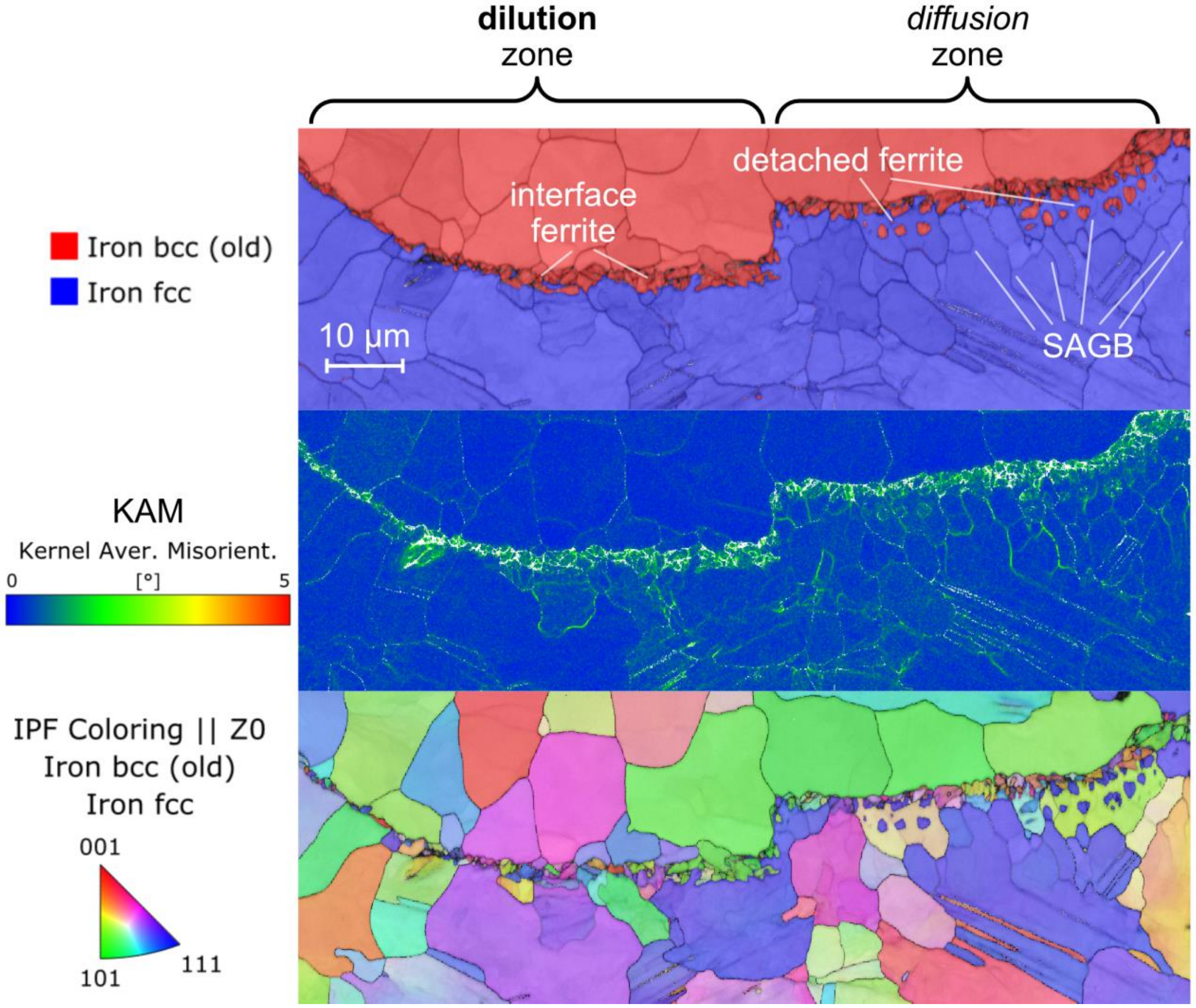
Less diluted outer layer



Changes in the base tube



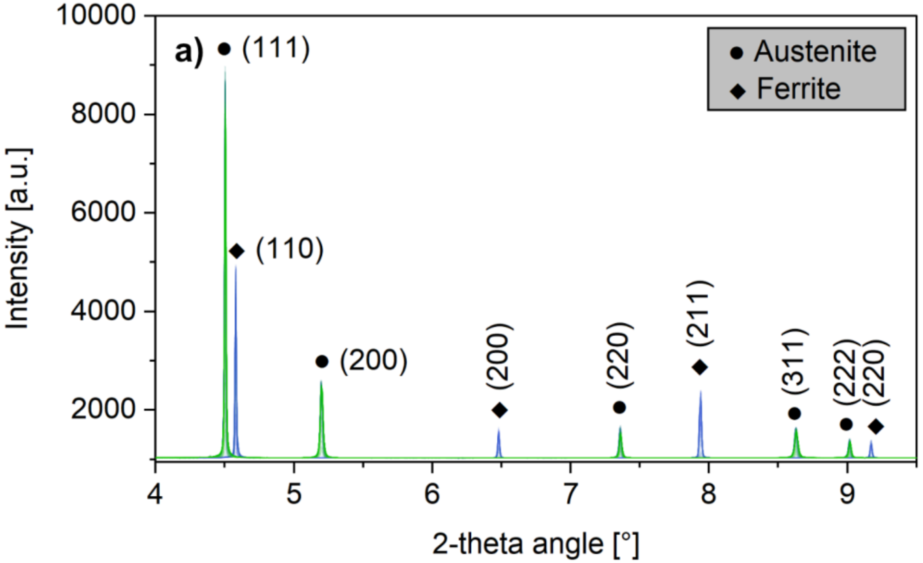
Fuel cladding tube protection



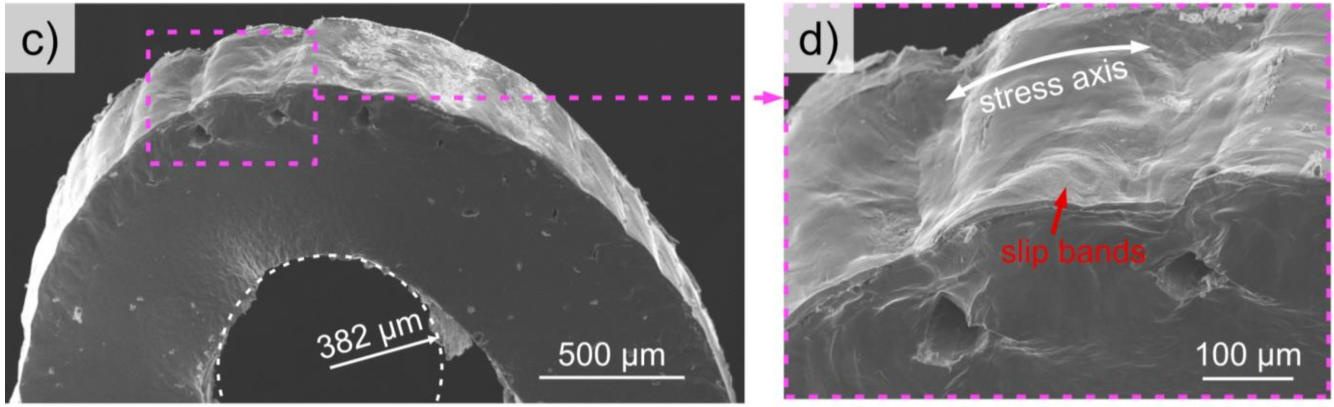
Interface characteristics

Gruber, J Manufacturing Proc 155 (2025) 214

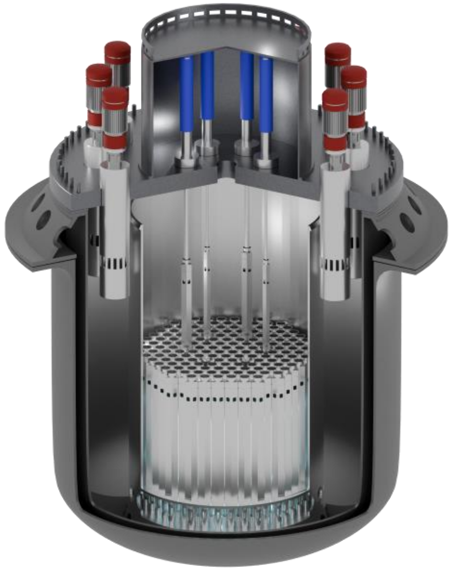
Synchrotron XRD



Mechanical behaviour under stress



Summary and conclusions



- Nuclear energy promising for climate action
- Industry and society needs fossil free energy
- Nuclear materials are complex and under intense research and development – both for fission and fusion
- Rapid momentum building in EU and Sweden, advancing nuclear engineering research
- CET conference, Oskarshamn 29/9-1/10 – high-level conference on the role of nuclear in the future energy system (cetconference.org)
- Reach out if you want to collaborate!

SUNRISE
Sustainable Nuclear Energy Research in Sweden

NuMaP
The Nuclear Materials Platform

NEXUS

Thanks for listening! Questions?

SUNRISE
Sustainable Nuclear Energy
Research in Sweden

Animation: Eloi Pallares Abril

Contact: polsson@kth.se