Overview of reactor materials investigation with modelling and experimental studies at CNL

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Canadian Nuclear Laboratories (CNL) is among the largest hot cell and nuclear R&D facilities worldwide.

- **9,100 acres with 200 acres of lab complex**
- **17 nuclear facilities, 70 major buildings**
- **3,000 employees**
- **1,600 engineering, scientific & technical staff**

Overview of research areas

- New investments and projects
  - NRU component harvest
    - Inventory of material from well characterized irradiation conditions
  - Tritium handling laboratory
  - SMR siting
- Molten salt behaviour
  - Material properties, FG retention, corrosion
- Degradation of reactor components during irradiation
  - He bubbles in Ni, H in Zr

NRU Artefacts for Research & Investigation

National Research Universal reactor operated from 1957-2018

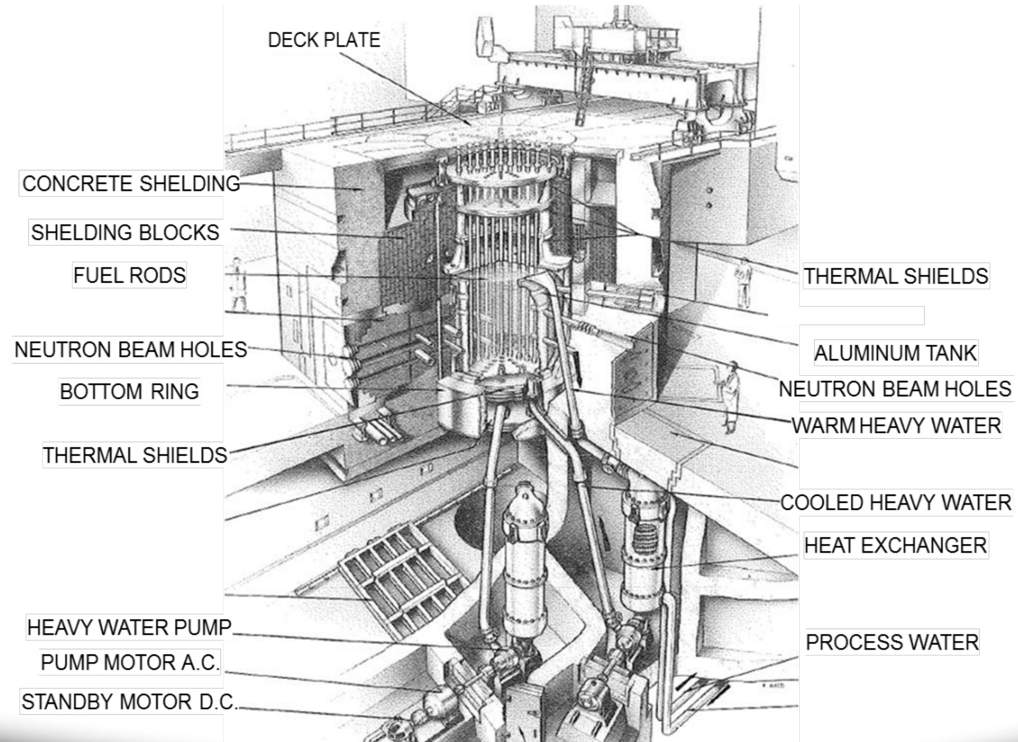
Wide range of temperature (35 °C to 310 °C), flux and neutron spectra.

The NRU inventory includes:

- Structural materials

steels, Inconels, zirconium, aluminum, concrete;

- a thermal graphite column;
- flux detectors;
- equipment (including pumps);
- elastomers/seals;
- electrical cables.

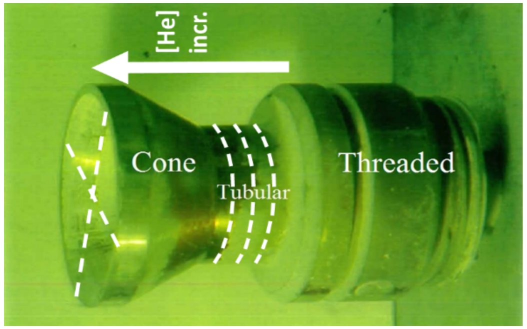


NRU Artefacts for Research & Investigation

Stainless steel header cups

Study weldability of 304 stainless with high helium content

Elevation cm	dpa	appm Helium
-180	2.2	992
-182	1.2	523
-184	0.03	2.8
-186	0.02	0.3

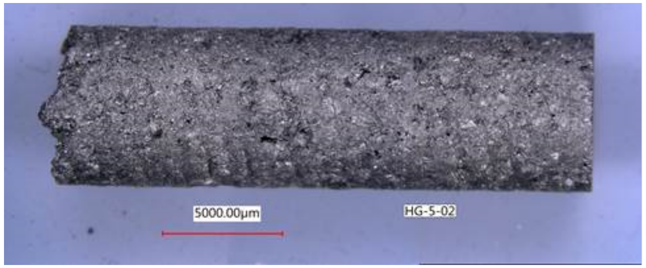


Graphite sections

Microstructural degradation of graphite irradiated at low temperatures

44 year operation, <230 °C

7.1×10^{22} n/cm^2 (E<0.625 eV)



Tritium Processes and R&D

- Tritium Processing Expertise:
  - Detritiation of heavy water for CANDU
  - Detritiation of light water for emission control and environment
  - Air clean-up (recombination and scrubbing)
  - Process modeling
- Tritium R&D:
  - Thermal cycling adsorption isotope separation absorbents
  - Immobilization of tritiated water for waste disposal
  - Permeation of tritium through materials at high temperatures
  - Tritium tolerant electrolytic cells
  - Beta-voltaic power sources
  - Organically-bound tritium in the environment

SMR siting progress

STAGE 1: Prequalification	STAGE 2: Due Diligence	STAGE 3: Negotiation	STAGE 4: Project Execution
UBATTERY Local Modular Energy	TERRESTRIAL ENERGY	GLOBAL FIRST POWER	
VENDOR A	STARCORE NUCLEAR		
VENDOR B			

** Have not publically announced their participation.

Molten salt properties

Thermal conductivity, Corrosion, FP release

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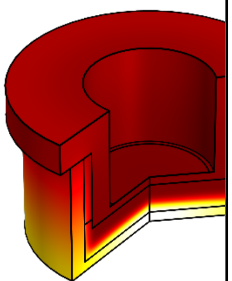
Thermal conductivity of Molten Salt

- Determining thermal diffusivity of molten salts
- Co-development of model led to improved crucible design
- Concurrent prediction of thermal conductivity from MD



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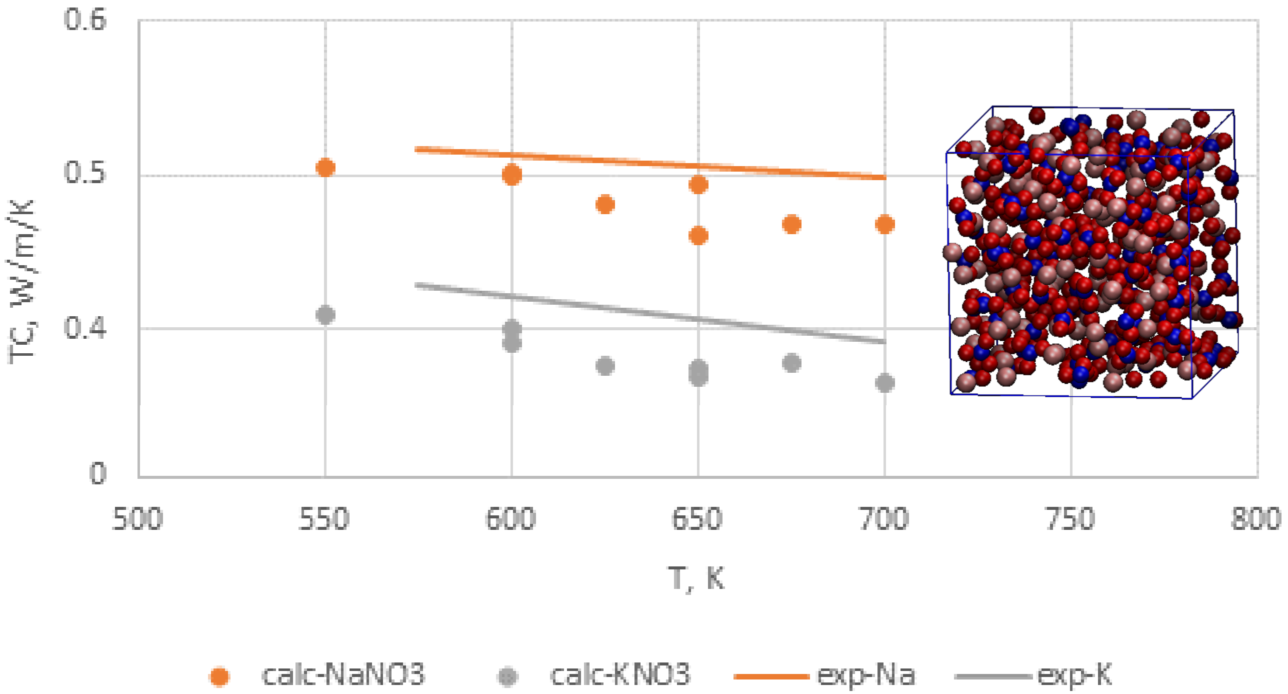
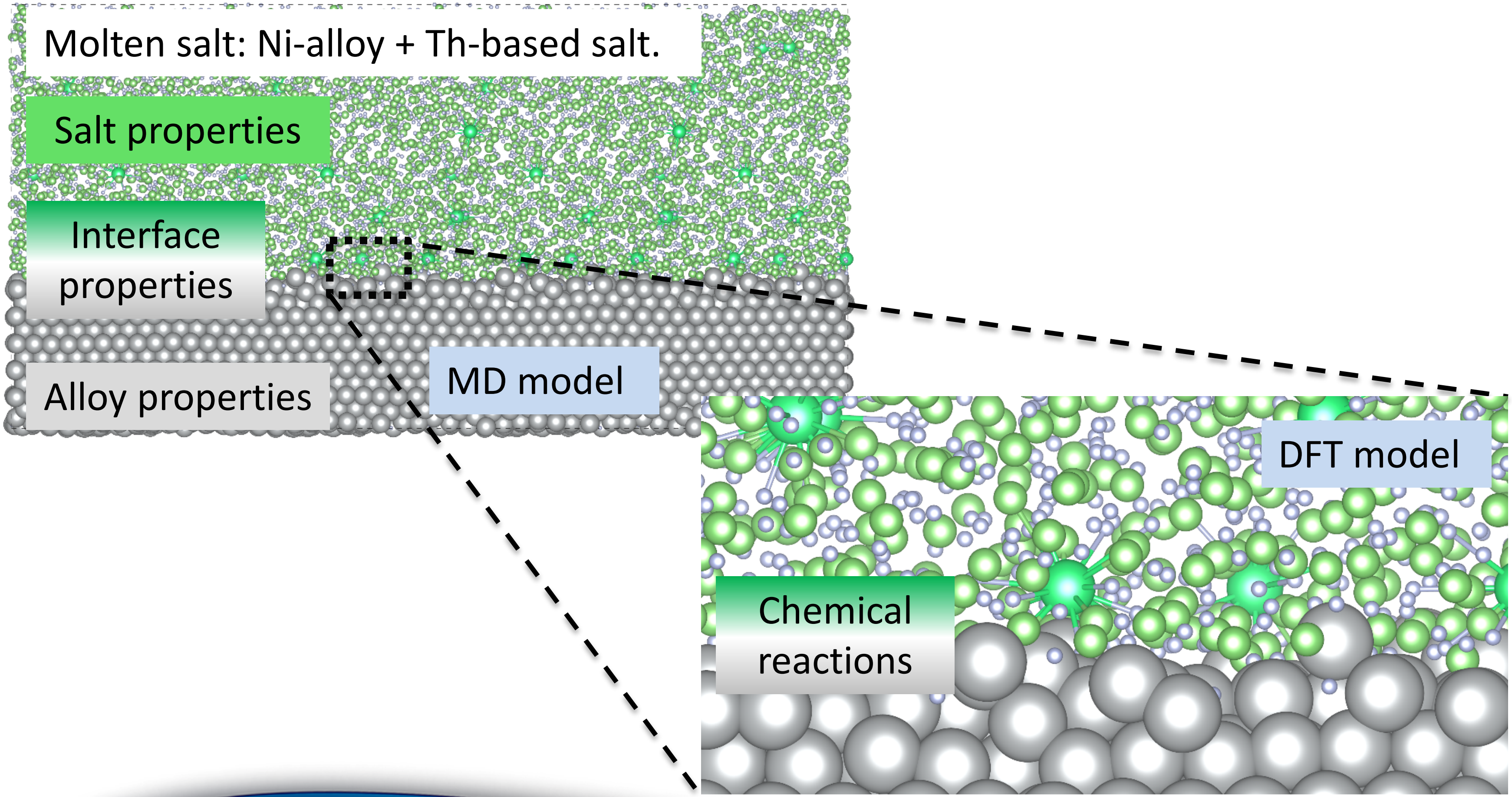
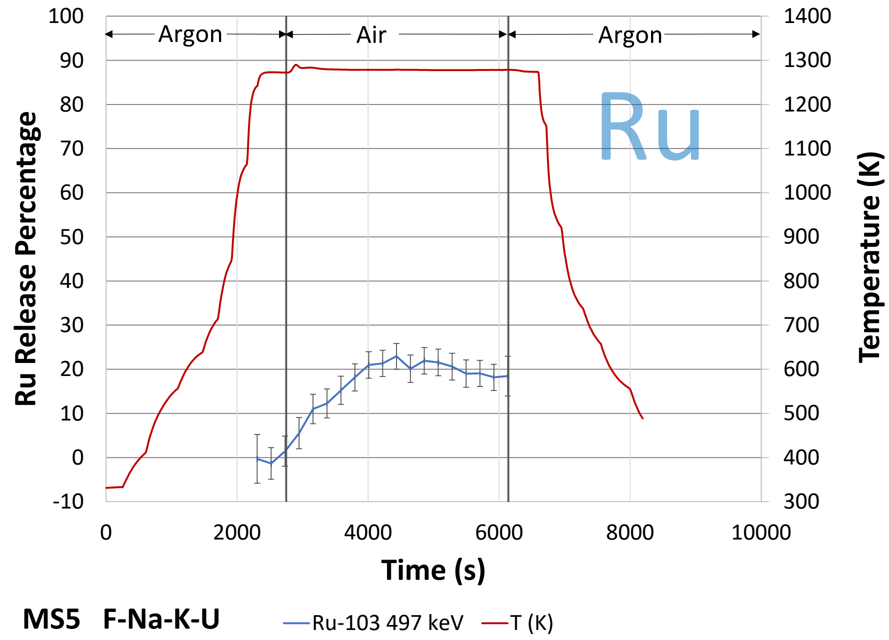


First principle calculations of behaviour



Scoping tests of FP release

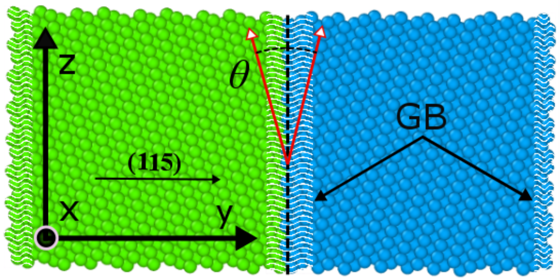
- Six tests at 1000 °C, exposed to argon, air and steam
- Samples: F-Na-K-U, F-Na-K-Th, F-Cl-K-U
- Release of Cs, I, Ru measured in oxidizing conditions
- Uncertain results from argon tests due to chemistry control



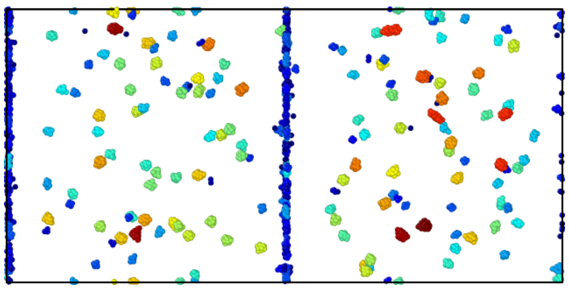
Material degradation during irradiation

Embrittlement, grain boundary perforation, Hydride formation

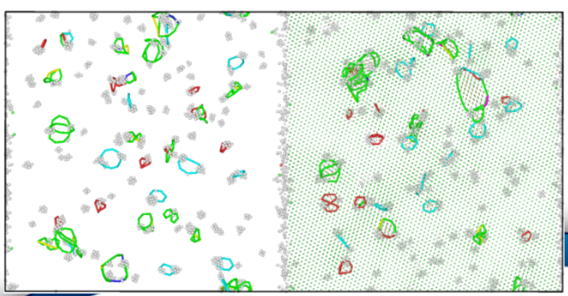
Embrittlement of Ni by He



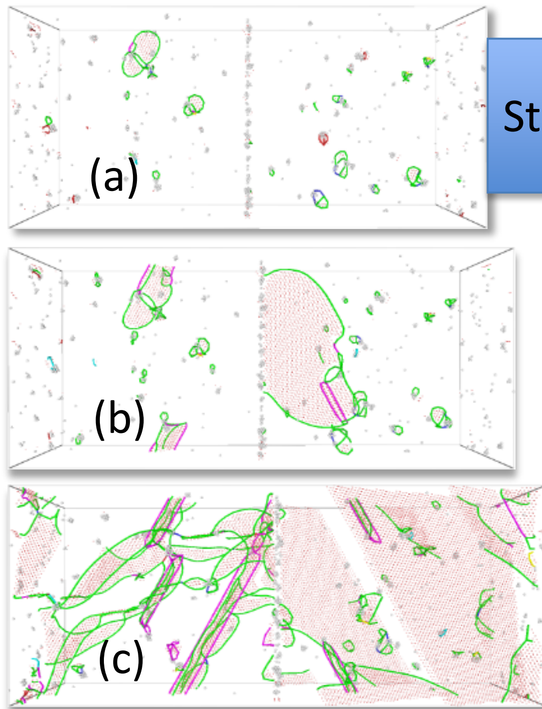
Grain boundary



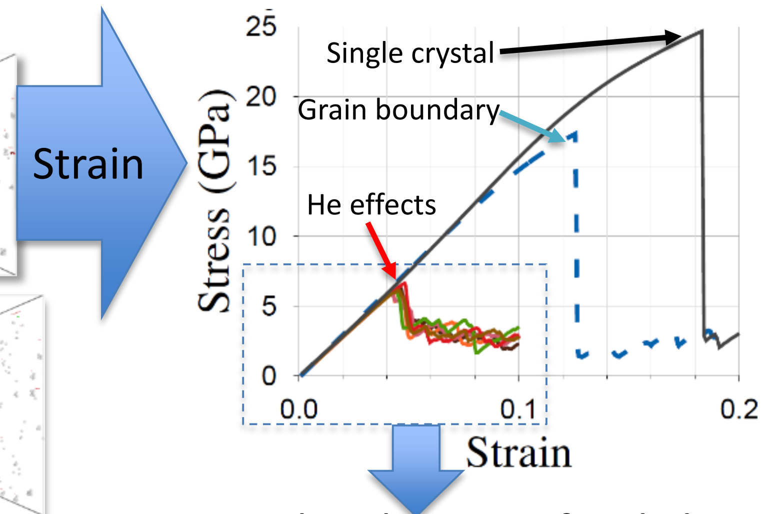
Impurities



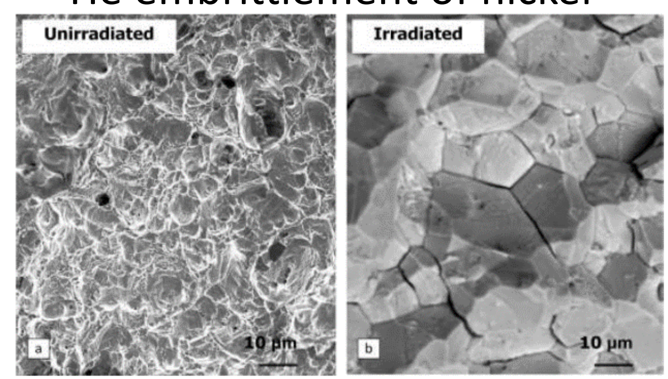
Induced dislocations



Tensile deformation

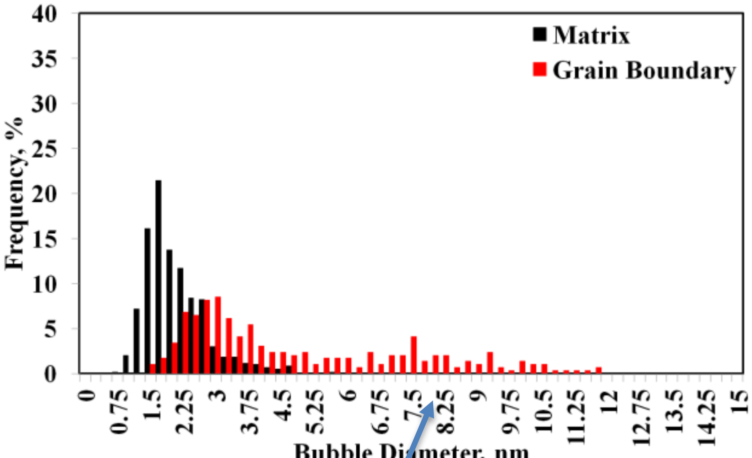


He embrittlement of nickel

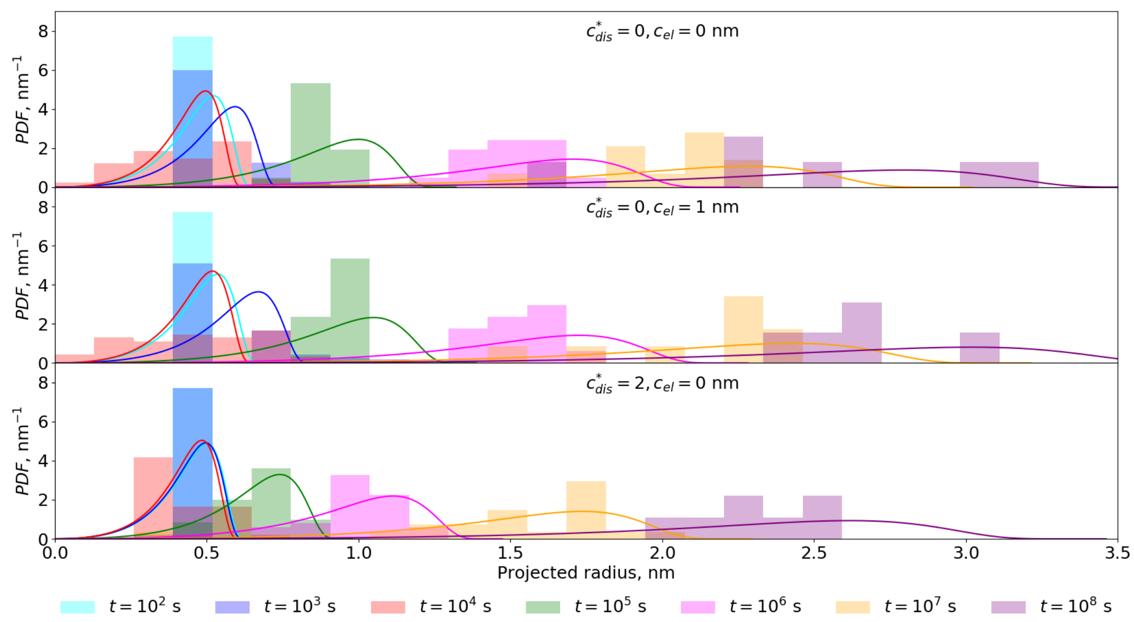


Perforation of Ni grain boundary by He bubbles

Included phase model for bubble behaviour



Intergranular bubble PDF differs from LSW substantially.



Perforation of grain boundary by He bubbles

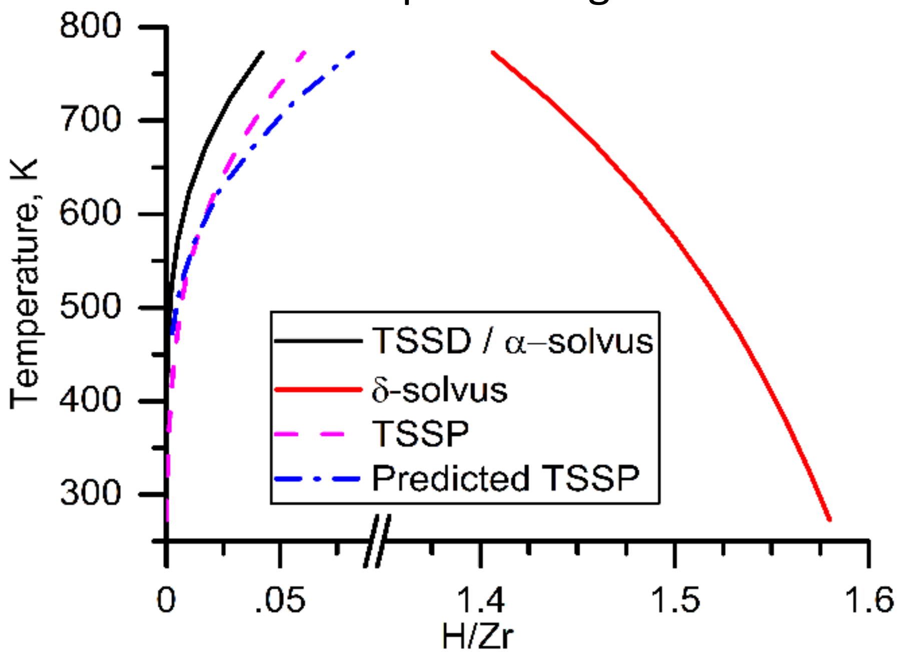
Included phase model for bubble behaviour

Zirconium hydride TSSP simulation

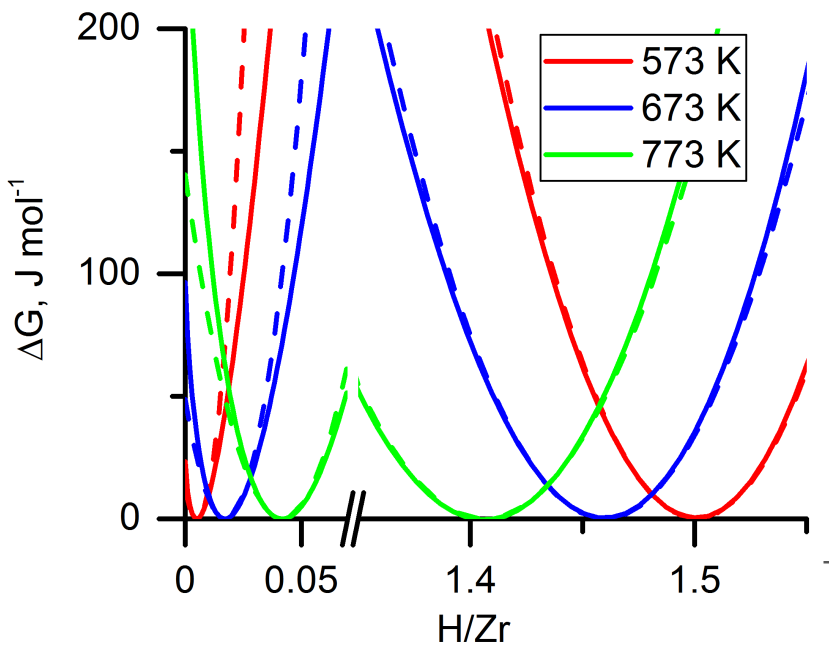
Predicting the TSSP with a modern computational approach

- Elucidate the source of δ-ZrH_x precipitation / dissolution hysteresis from α-Zr
  - Revisit elastic penalty thesis with a modern, sophisticated phase-field approach
- Multiphysics phase-field model incorporating bulk thermodynamics (CALPHAD)
  - 3D anisotropic elasticity, concentration-dependant properties
  - Anisotropic interfacial energy (coherent lattices)
  - Stress driven diffusion of H in both phases

Predicted phase diagram



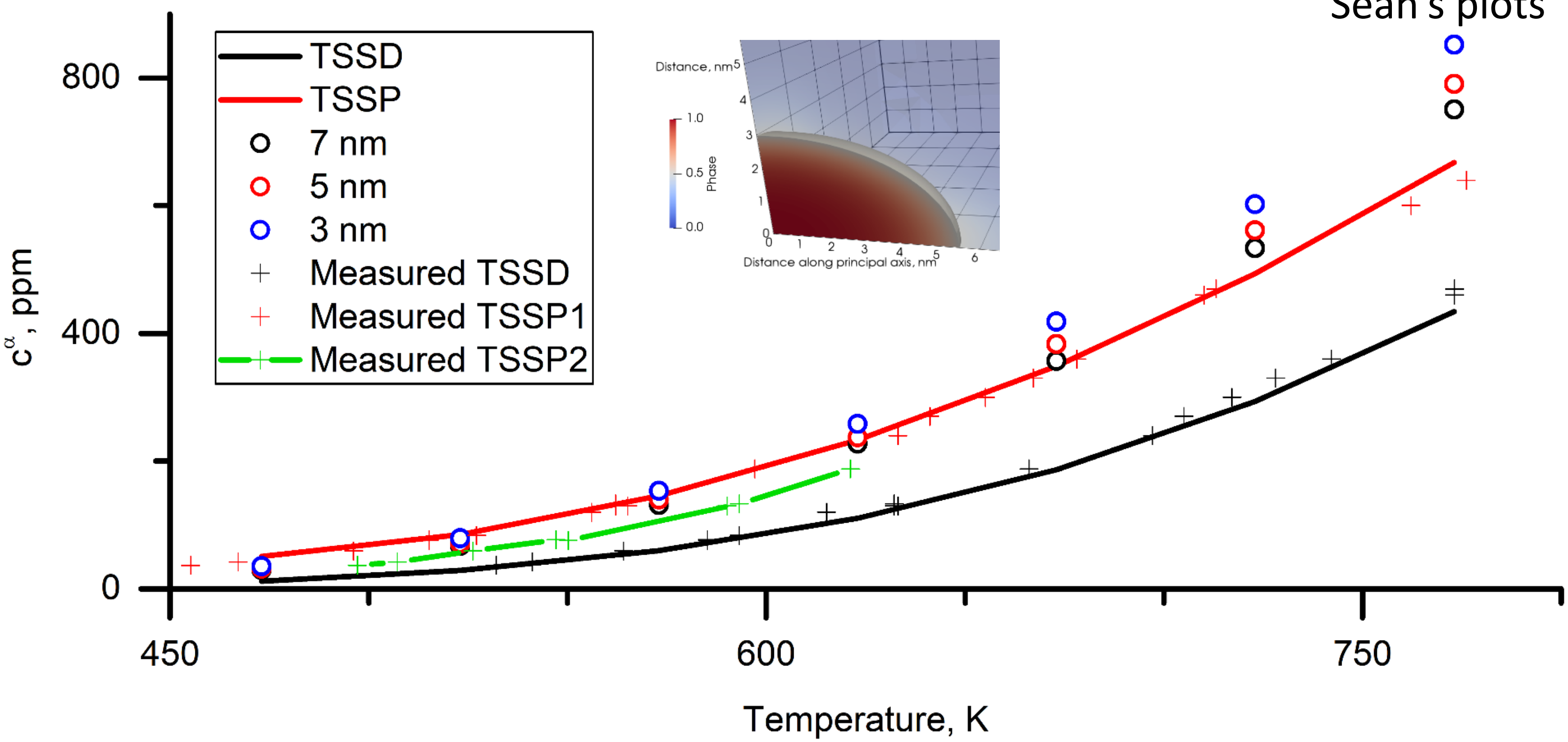
Underlying thermodynamics



Zirconium hydride TSSP simulation

Energy barrier to precipitation in a pristine material (defect free)

Sean's plots



Thank You!

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