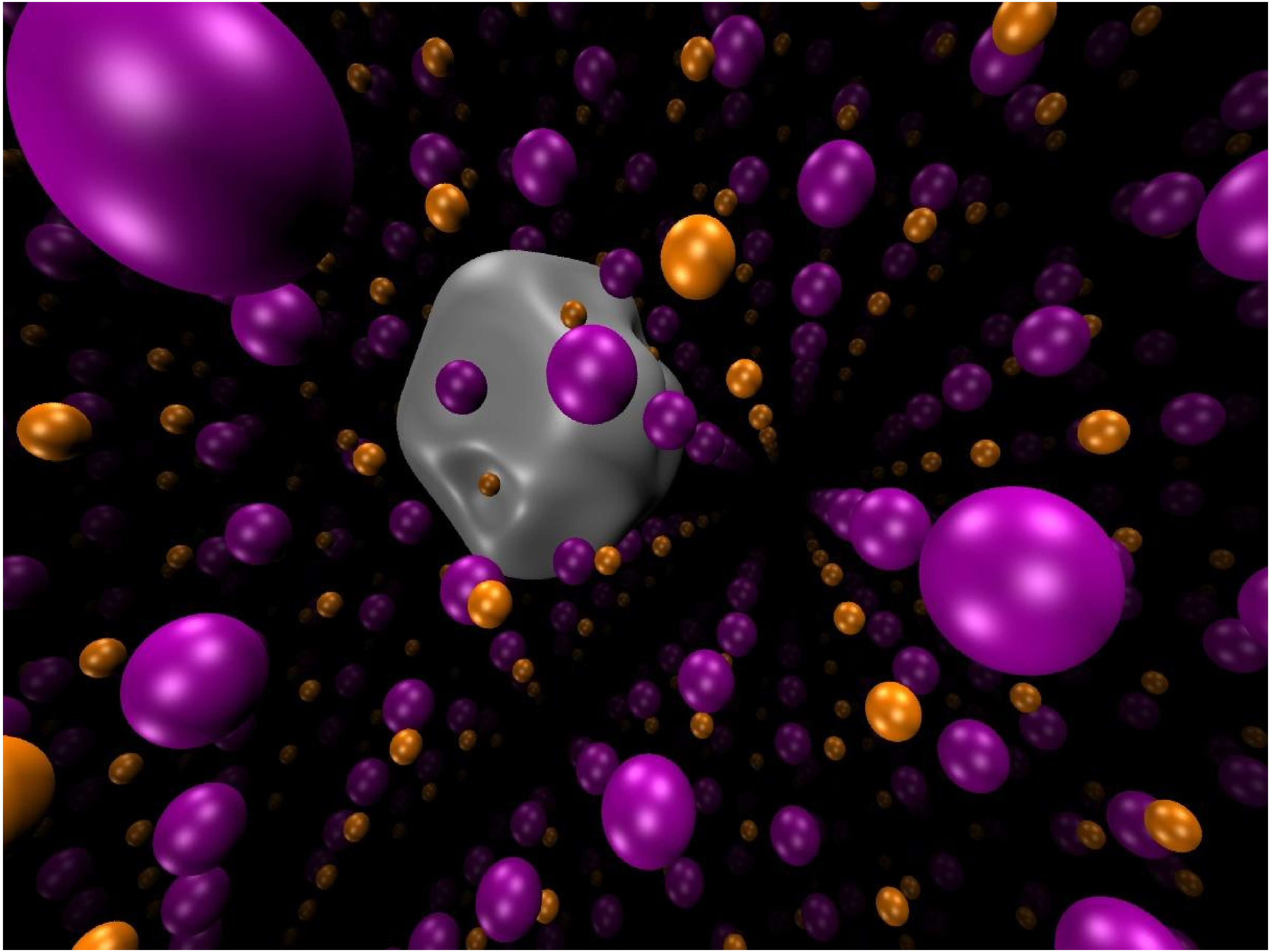

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Science of Nuclear Materials: from Condensed Matter Physics to Engineering Challenges

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Nuclear Materials

- Structural materials: steel, concrete
- Fuel: oxide, cladding
- Also: anything else at an NPP

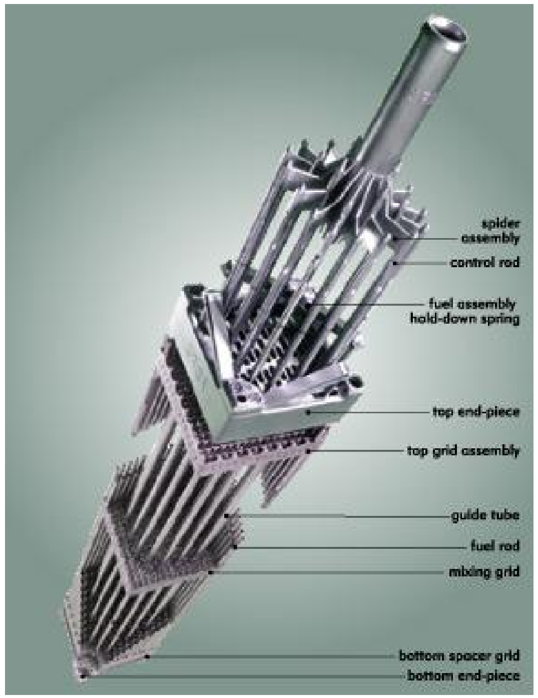
- Important properties: thermal conduction, load-bearing capabilities (strength, ductility/brittleness), integrity, …

- The materials face rather harsh conditions: high temperature, strong particle and EM radiation, corrosive agents, heavy loads, …

Engineering challenge

- Challenge 1: choose (or manufacture) materials with optimal properties for the targeted function
- Challenge 2: these properties should not deteriorate with time (scale is important) in the harsh conditions

- In (non-ideal) real life:
  – Cost vs properties
  – Lifetime vs properties
  – How to predict the lifetime?
  – When do you need to change a component because of material property degradation?



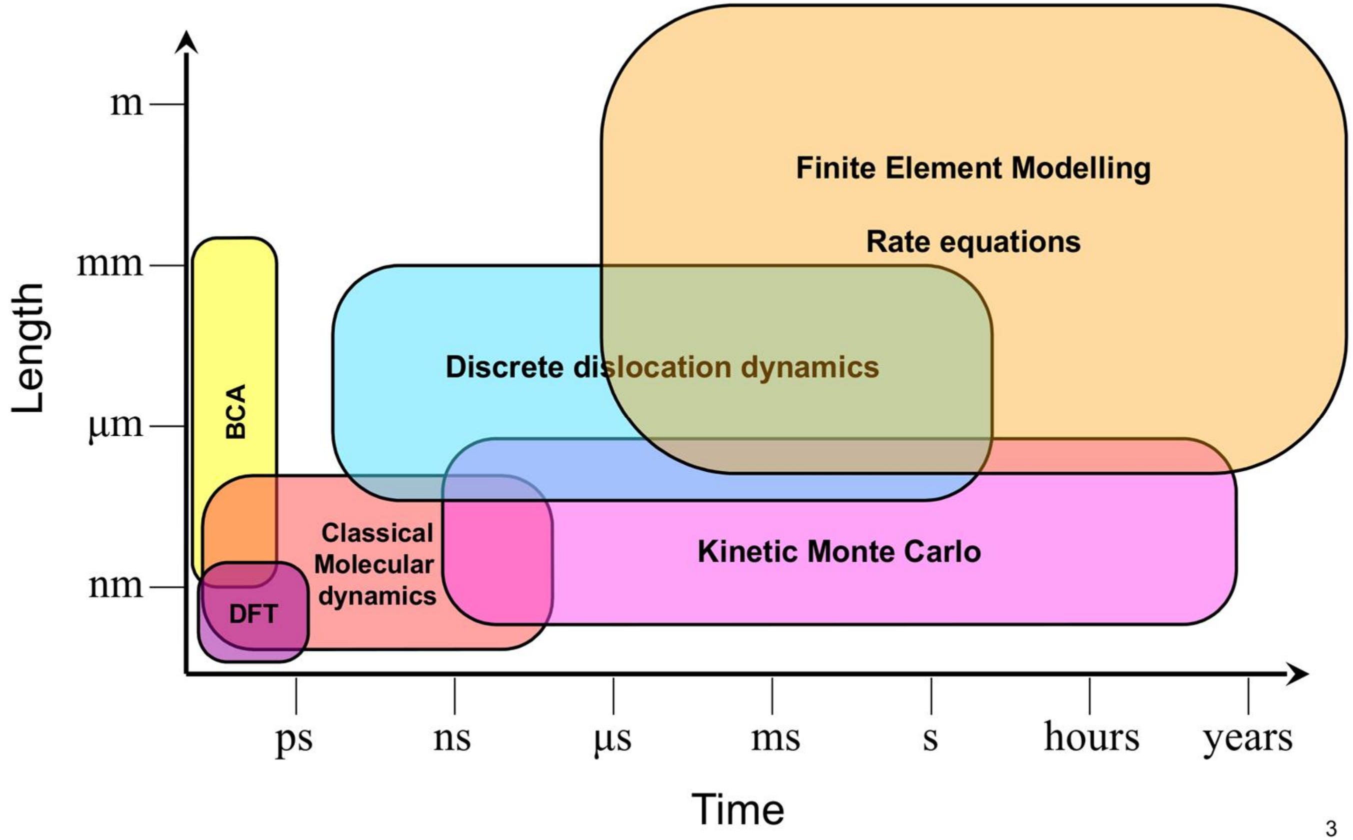
Science?

- All the properties of matter are dictated by the identities of the atoms and by how they are distributed in space (on scales from inter-atomic distances to meters)
- How does the environment affect the structure and the ensuing properties?
- How to design materials with improved properties and enhanced lifetimes?
- Experiments and simulations (theory) on multiple length and time scales!

The experimental materials physicist

- Shoot with something and see what comes out!
- Electromagnetic radiation
  - absorption, scattering of UV-VIS-IR light, X-rays, γ-rays, …
- Electron microscopes
  - electron scattering, secondary electrons, luminescence
- Ion beam methods
  - (fast) ions in, (other) ions or radiation out
- Magnetic resonances
  - electronic vsnuclear spins
- Exotic particles
  - muons, positrons

Multi-scale simulations



Linking scales and experiment to theory

- Multi-scale experiments: linking (atomic) structure to, e.g., thermal conductivity
- Atomic-scale phenomena limiting corrosion and, e.g., cracking
- Early stages of radiation damage evolution
- Atomic-scale experiments in well-defined systems can be used to validate simulation approaches!
- Challenges: detailed experiments and theory in real engineering materials

Finnish flagship for experiments: CNS

- Irradiated materials are often hot due to activation
- Challenge: handling and in some cases the experiments themselves
- VTT Centre for Nuclear Safety (among other things):
  - A-lab hot cells and pilot-hall
  - analytical microscopy
  - autoclave laboratory
  - radiochemistry and alfa-handling laboratories
  - clean-room and ICP-Mass Spectrometry
  - aerosol research laboratory
  - radioactivity measurements and device calibrations

Materials initiative: MExeCo

- Strong collaboration between Universities and VTT to tackle the outstanding challenges
- Multi-scale modeling: Aalto University, University of Helsinki, Tampere University of Technology, VTT
- Ion-beam based experiments: University of Helsinki
- Advanced atomic scale characterization: Aalto University, University of Helsinki
- Hot labs, macroscale testing: VTT, Aalto University
- Large scale facilities: Halden, JHR, JET, ITER, CERN, ESRF, …

Thank you!