July 25, 2023

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TRISO Fuel Performance Modeling in Bison

Modeling of TRISO coating layer fracture due to buffer debonding

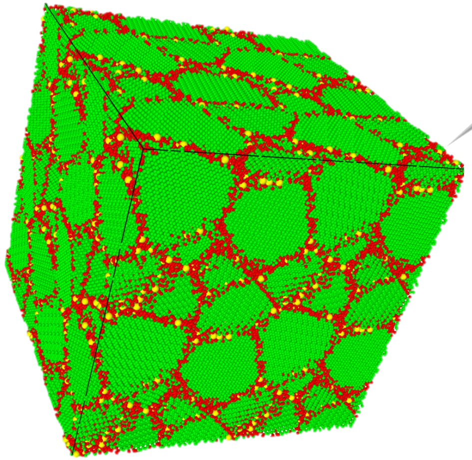
DOE ART Gas-Cooled Reactor (GCR) Review Meeting
Virtual Meeting
July 25 – 27, 2023

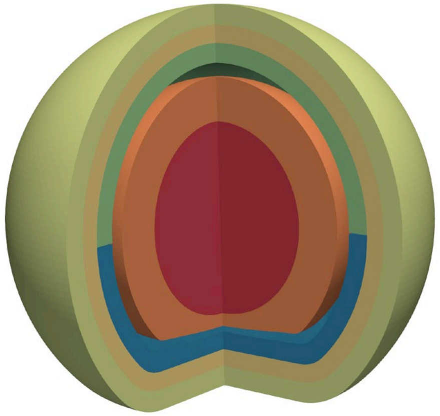
ART
Advanced Reactor Technologies

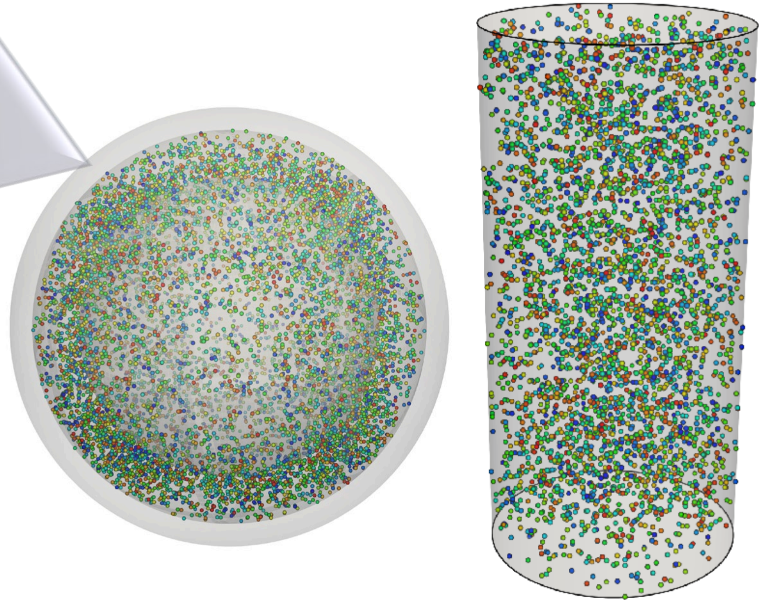
Outlines

- Background and overview of BISON
- BISON debonding modeling
- Coating layer fracture modeling
- Buffer partial debonding

BISON Overview







Lower-length scale modeling
- **Fission gas release model:** Xe, Kr diffusivity in UCO
- **Fission product diffusivity:** Silver diffusion in SiC, Pd Penetration

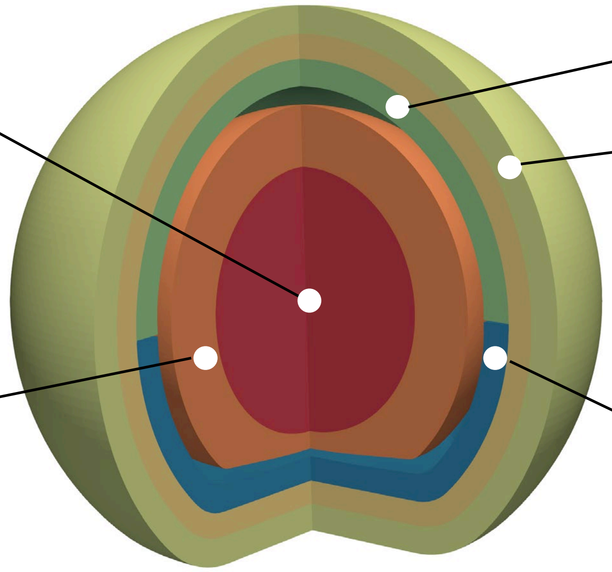
TRISO particle
- **Thermal-mechanical modeling**
  - **Failure analysis:** asphericity, IPyC cracking and debonding
- **Fission product diffusion through layers**

Pebble and Compact modeling
- **Failure probability calculation**: Monte Carlo and Fast Integration Approach
- **Fission product diffusion through matrix**
- **Particle-Matrix interaction**

TRISO Fuel Particle Modeling

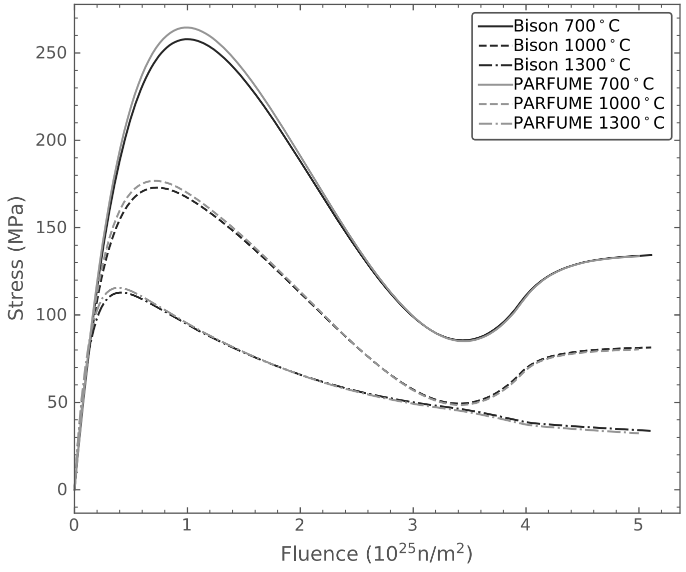
Kernel
Thermal
Burnup
Elasticity Tensor
Volumetric Swelling
Fission Gas Release

Buffer
Thermal
Elasticity Tensor
Creep
Thermal Expansion
IIDC

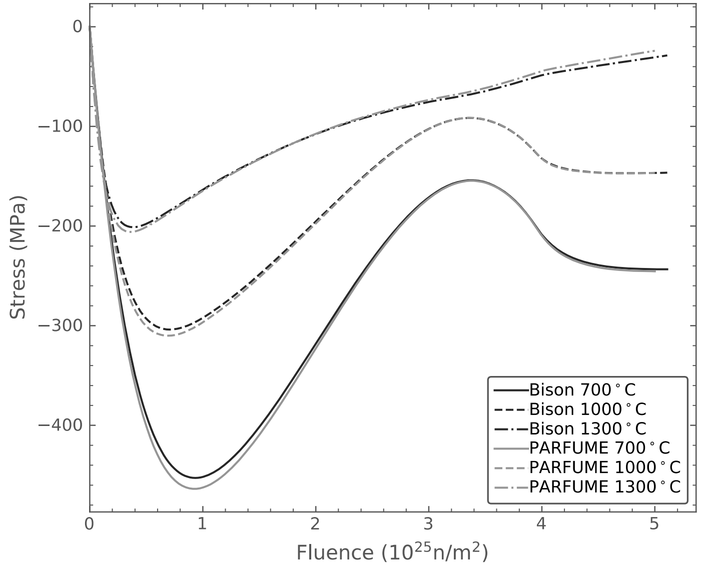


IPyC and OPyC
Thermal Expansion
Elasticity Tensor
Creep
IIDC

SiC
Elasticity Tensor
Thermal Expansion



Tangential stress in IPyC

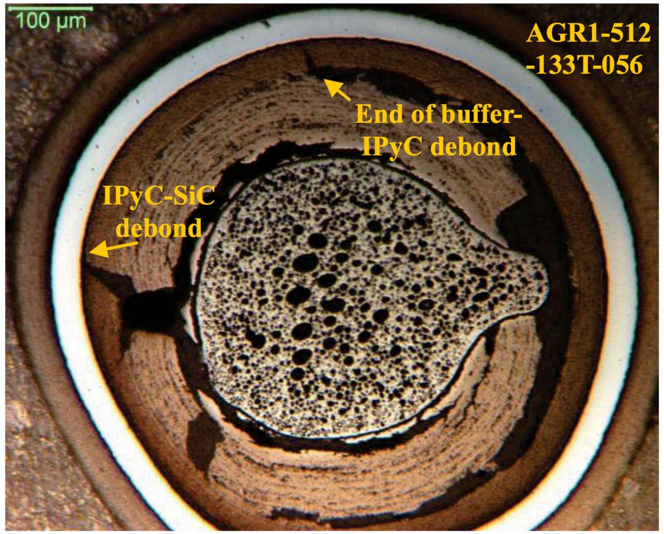


Tangential stress in SiC

Coating layers debonding

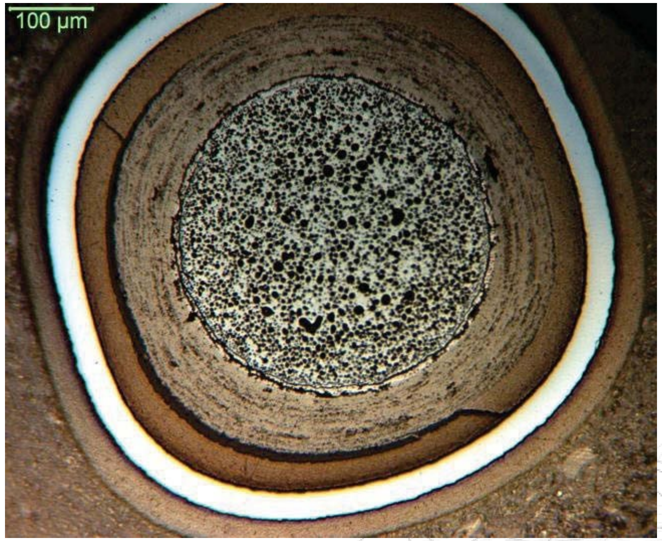
Partial debonding of the IPyC from the SiC

- Partial debonding between the IPyC and the SiC has also been observed in PIE of the NP-MHTGR fuel particles.
- During irradiation, shrinkage of the IPyC layer induces a radial tensile stress at the interface between the IPyC and SiC layer.
- If the stress exceeds the bond strength between layers, then debonding of the IPyC from the SiC occurs.
- A stress concentration occurs in the SiC layer at the tip of the debonded region, containing tensile stress components that could contribute to failure of the SiC.

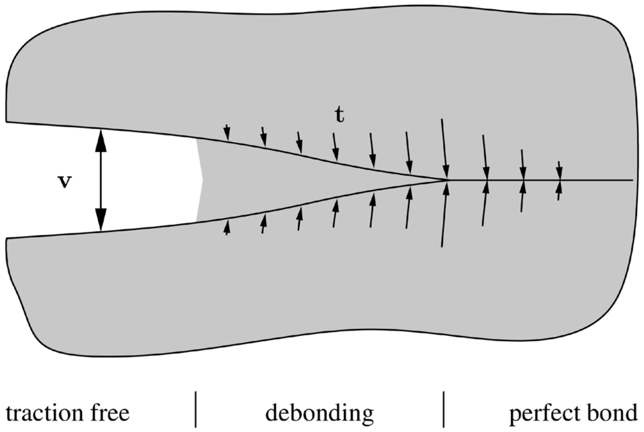


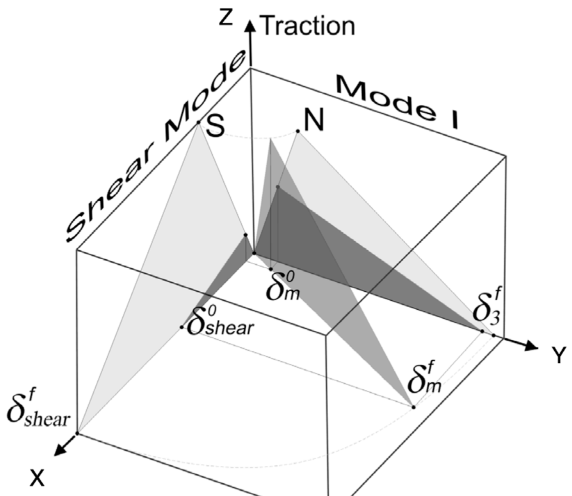
Buffer-IPyC partial debonding in AGR-1

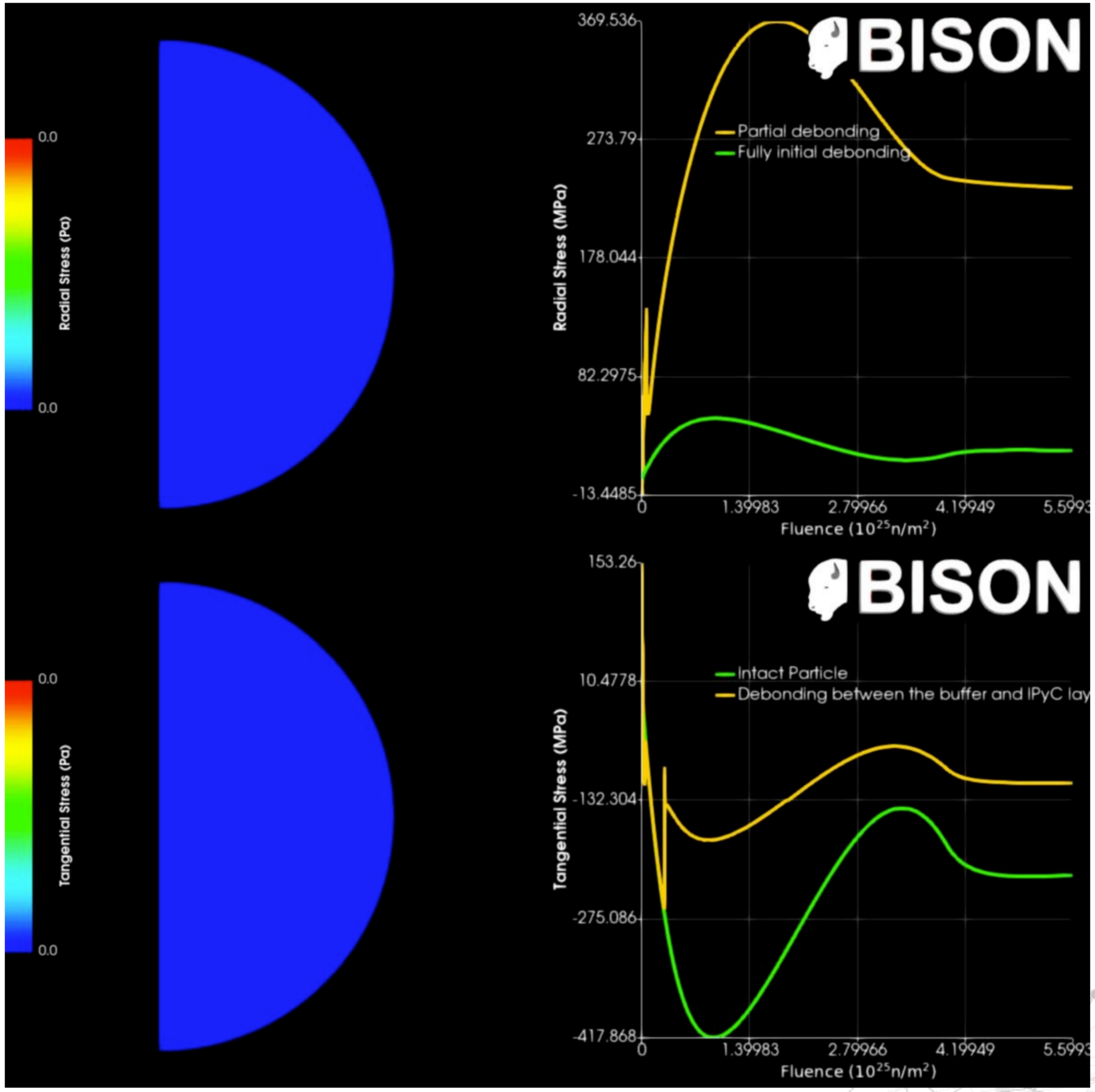
- Buffer-IPyC partial debonding were found with intermediate frequency in AGR-1 compacts and it can lead to IPyC cracking and separation from SiC layer.
- Allows localized attack of SiC layer by fission products (especially Pd)
- Pd attack can eventually result in loss of FP retention by SiC layer.
- Degradation is worse at higher safety test temperatures



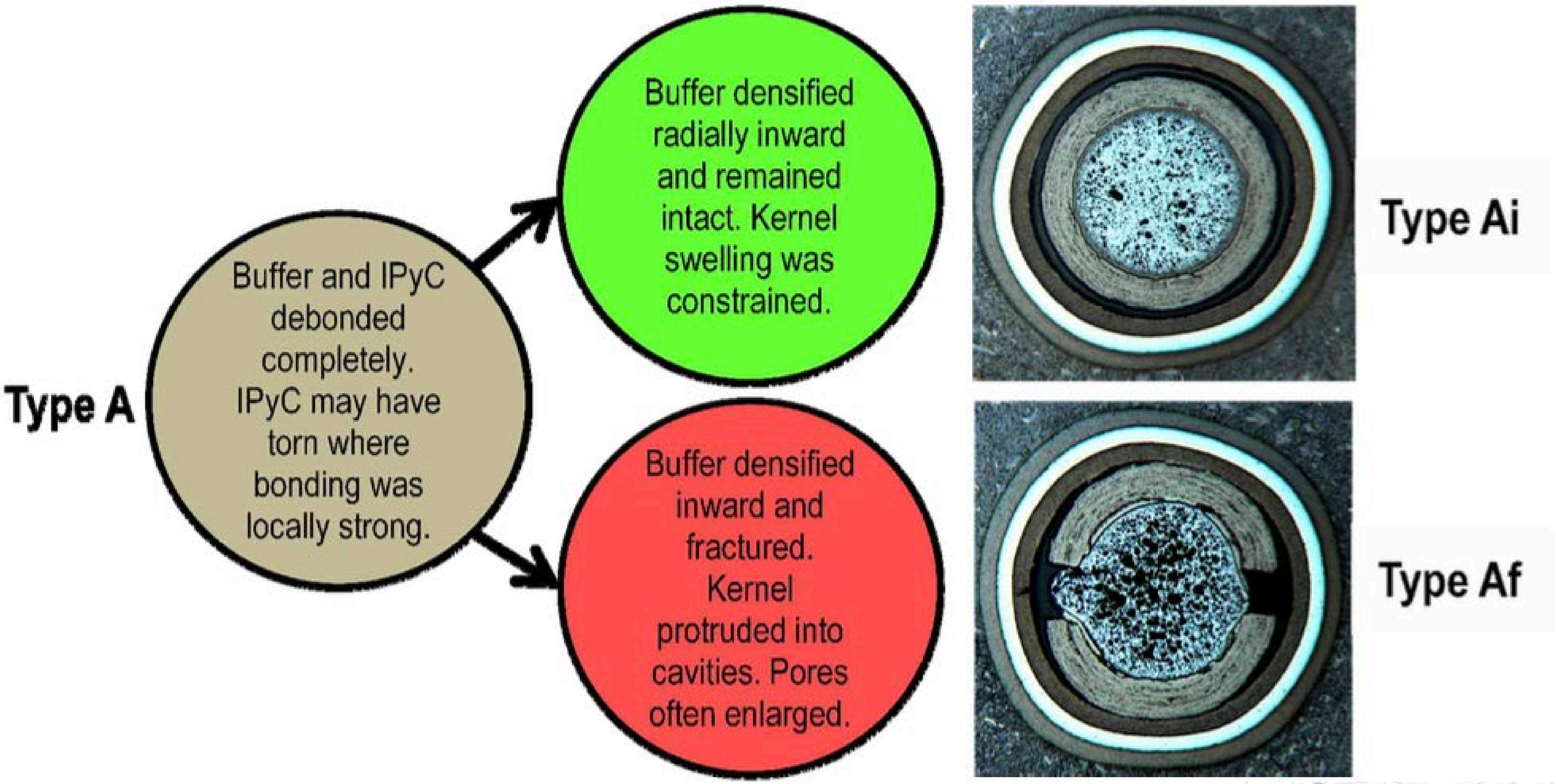
Debonding with cohesive-zone method



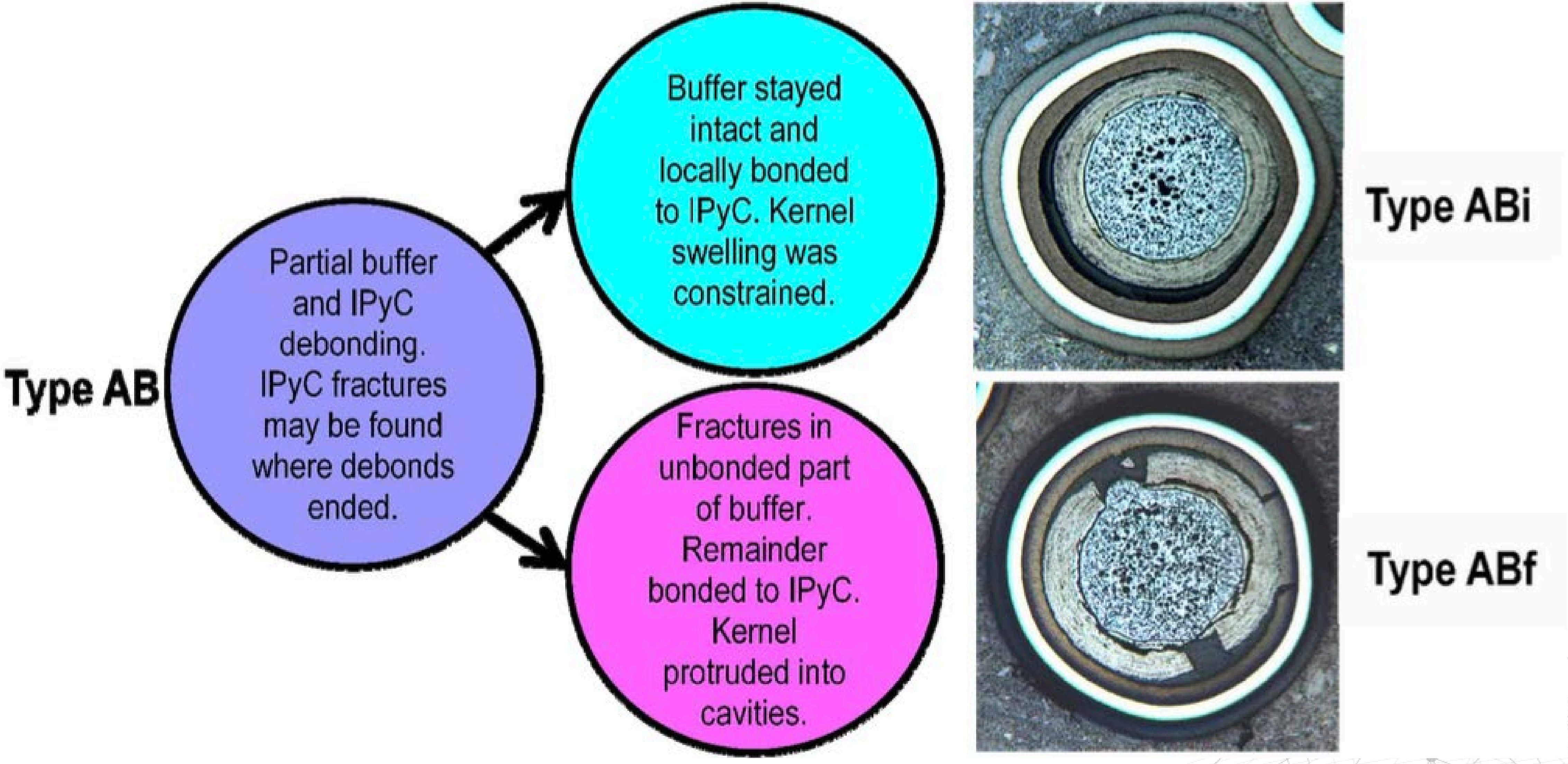




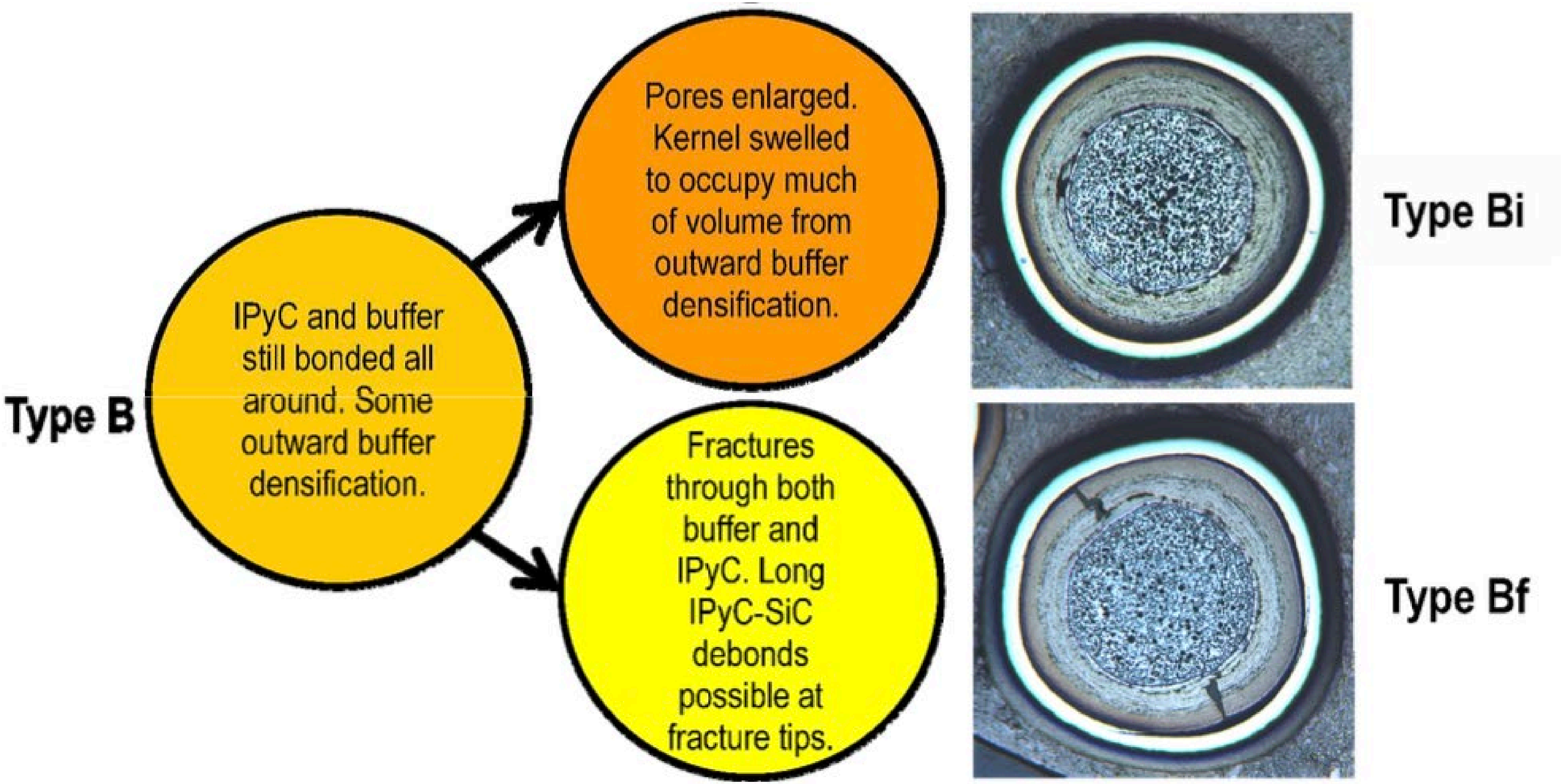
Fracture types observed in AGR-1 – Type A



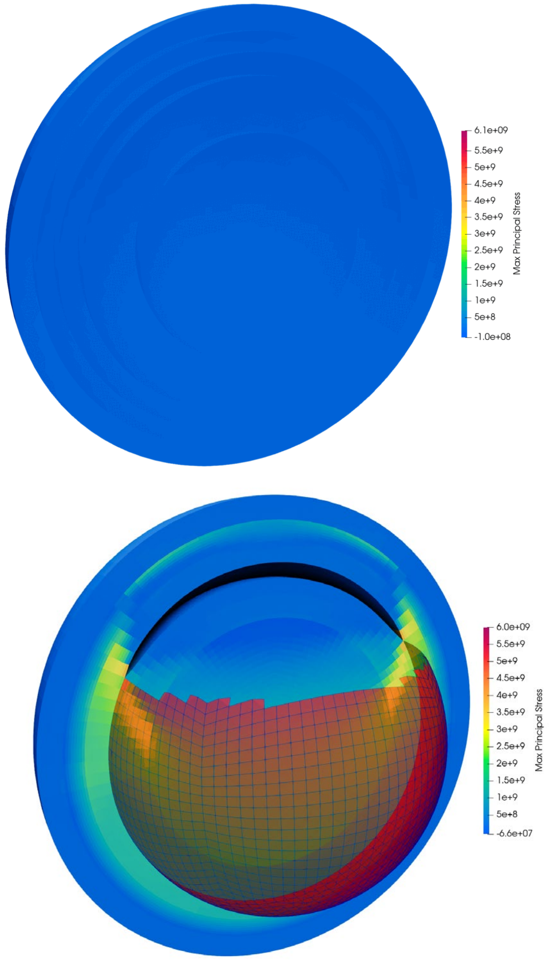
Fracture types observed in AGR-1 – Type AB



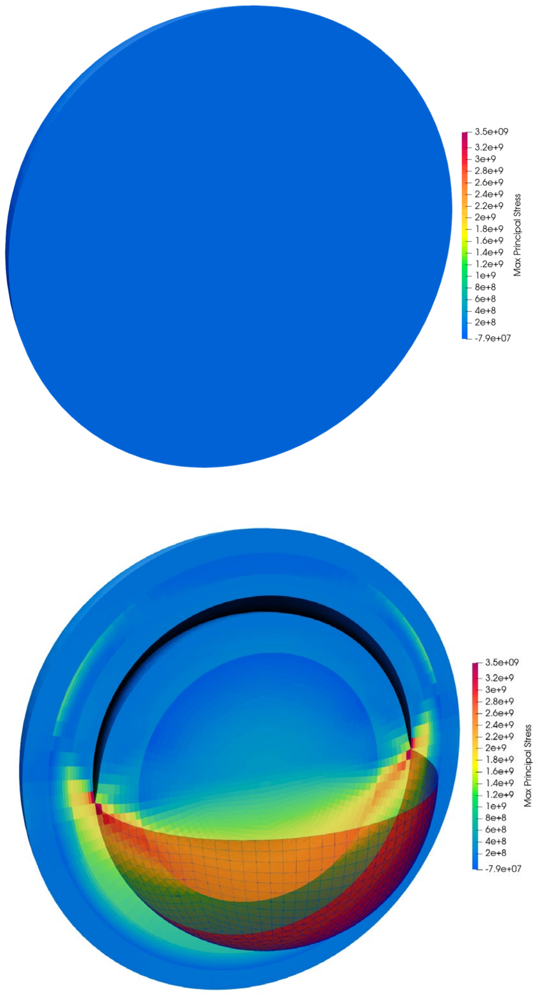
Fracture types observed in AGR-1 – Type B



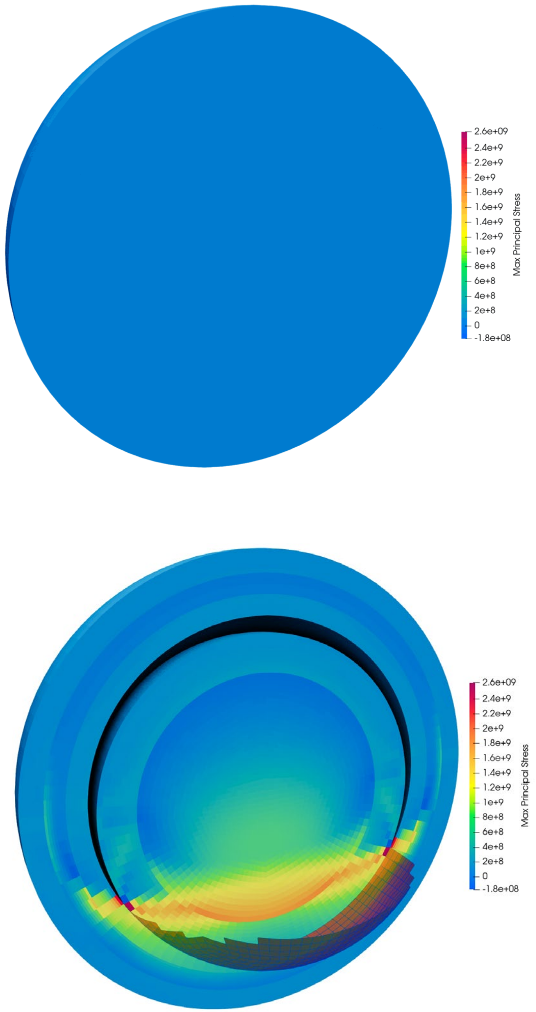
Buffer Partial Debonding



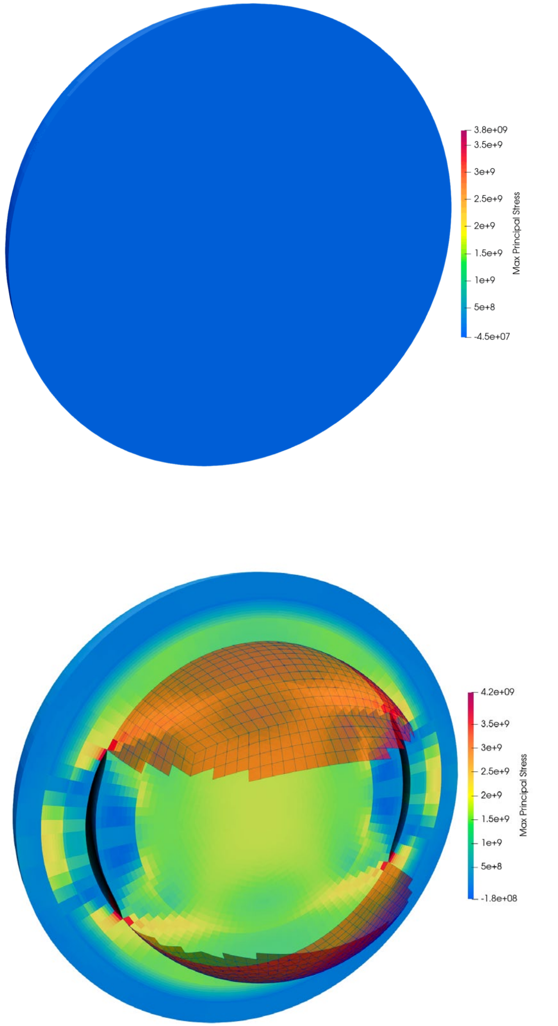
Case1:
Max Principal Stress 6e9Pa



Case2:
Max Principal Stress 3.5e9Pa



Case2:
Max Principal Stress 2.6e9Pa



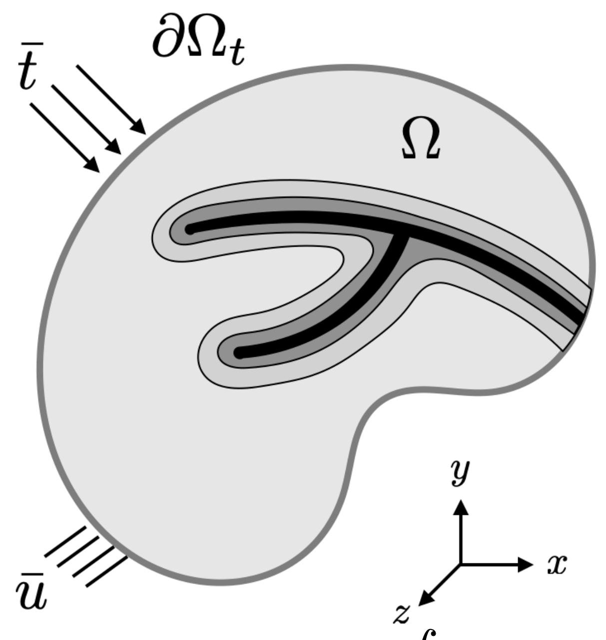
Case4:
Max Principal Stress 4.2e9Pa

Phase-field Fracture Modeling

$$\{\boldsymbol{u}, \Gamma\} = \arg\min_{\boldsymbol{u},\Gamma} \Psi(\boldsymbol{u}, \boldsymbol{\nabla}\boldsymbol{u}, \Gamma),$$

$$\text{subject to} \qquad \boldsymbol{u} = \boldsymbol{g}, \quad \forall \boldsymbol{x} \in \partial\Omega_D,$$

$$\Gamma(t) \subseteq \Gamma(t'), \quad \forall t' \in [t, T]$$



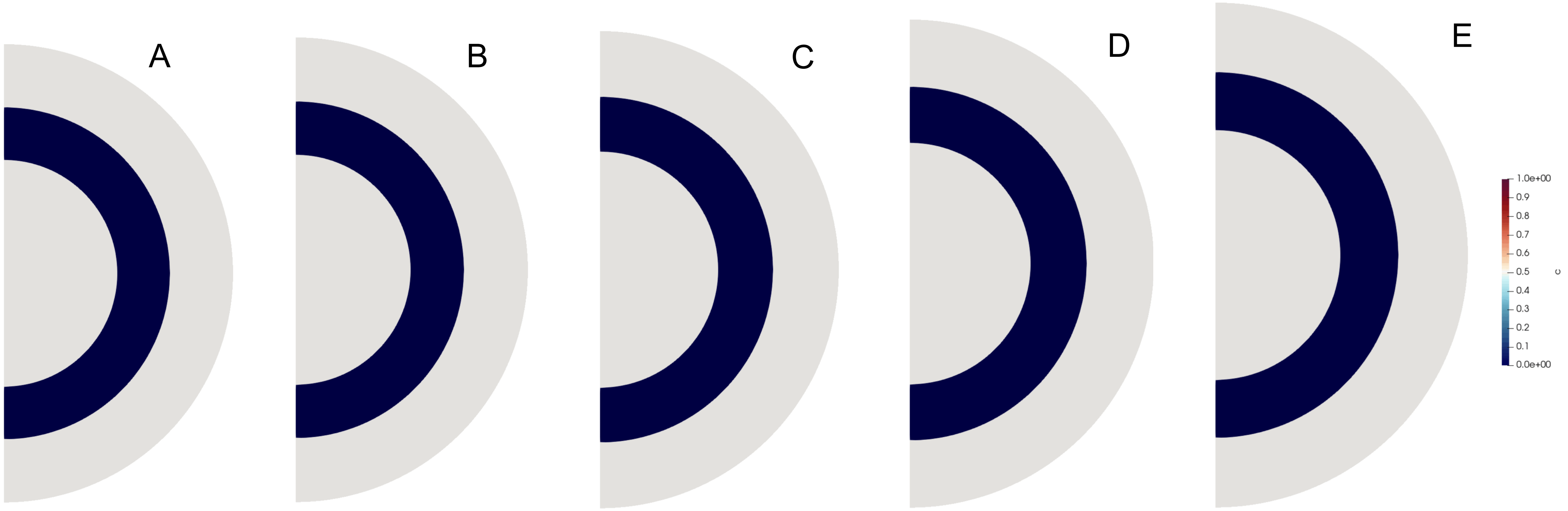
$$\Psi^l_{fracture}(c, \nabla c) = \int_\Omega \mathcal{G}_c \gamma_l(c, \nabla c) dV$$

The objective function $\Psi(\boldsymbol{u}, \boldsymbol{\nabla}\boldsymbol{u}, \Gamma)$ is defined as:

$$\Psi(\boldsymbol{u}, \boldsymbol{\nabla}\boldsymbol{u}, \Gamma) = \Psi_{\text{elastic}}(\boldsymbol{\nabla}\boldsymbol{u}) + \Psi_{\text{fracture}}(\Gamma) - \Psi_{\text{dissipation}}(\boldsymbol{u}, \Gamma) - \Psi_{\text{external}}(\boldsymbol{u})$$

- Advantages of phase-field model
  - Avoids re-meshing
  - Determine crack nucleation and propagation automatically
  - Handle joining and branching of multiple cracks

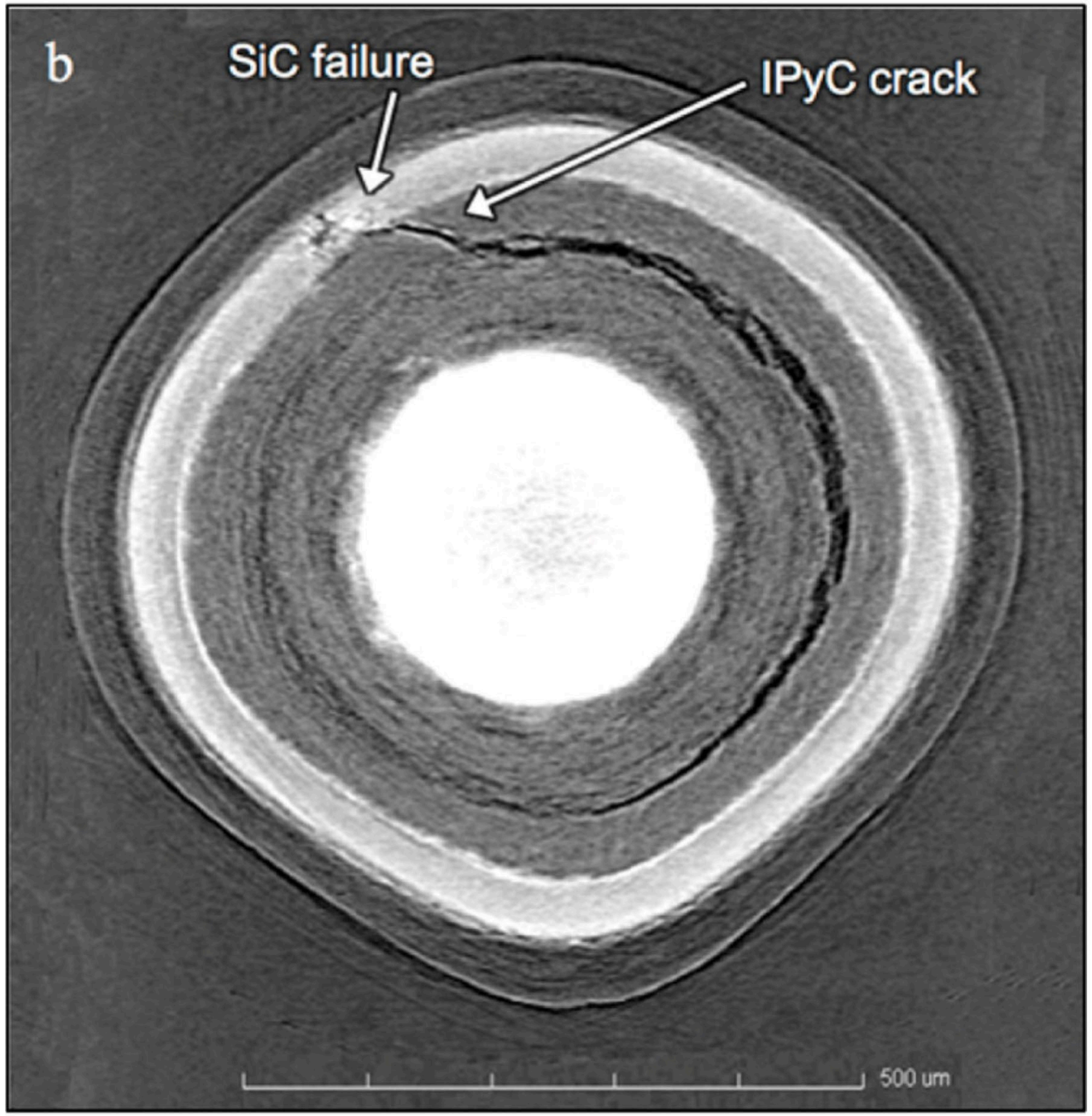
Buffer Fracture Modeling

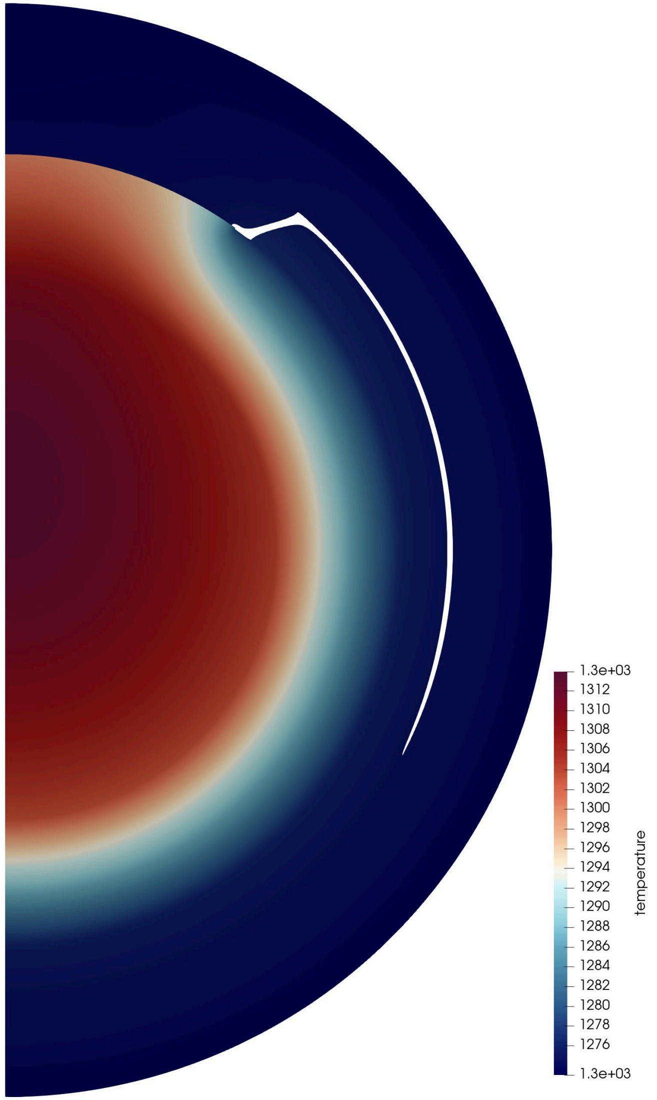


Bonding area: A > B > C

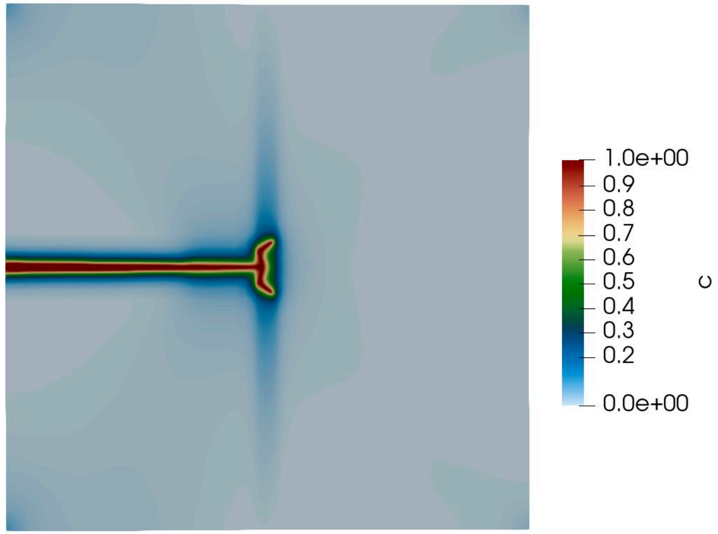
Fracture Strength: D > A > E

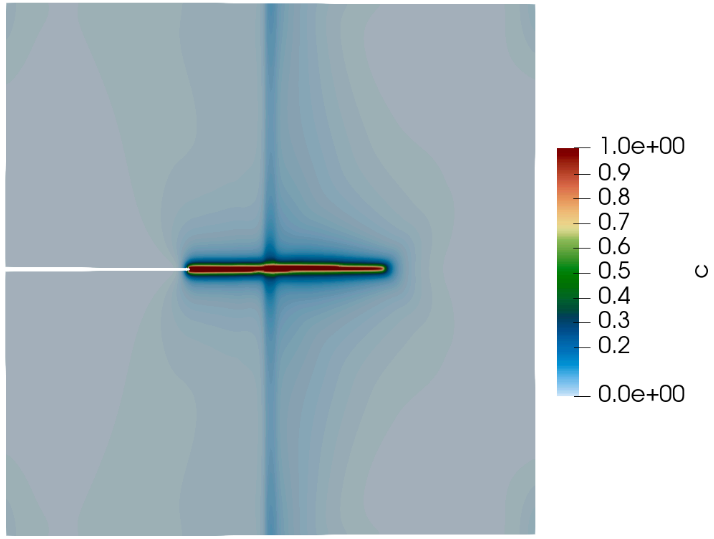
Buffer and IPyC fracture modeling

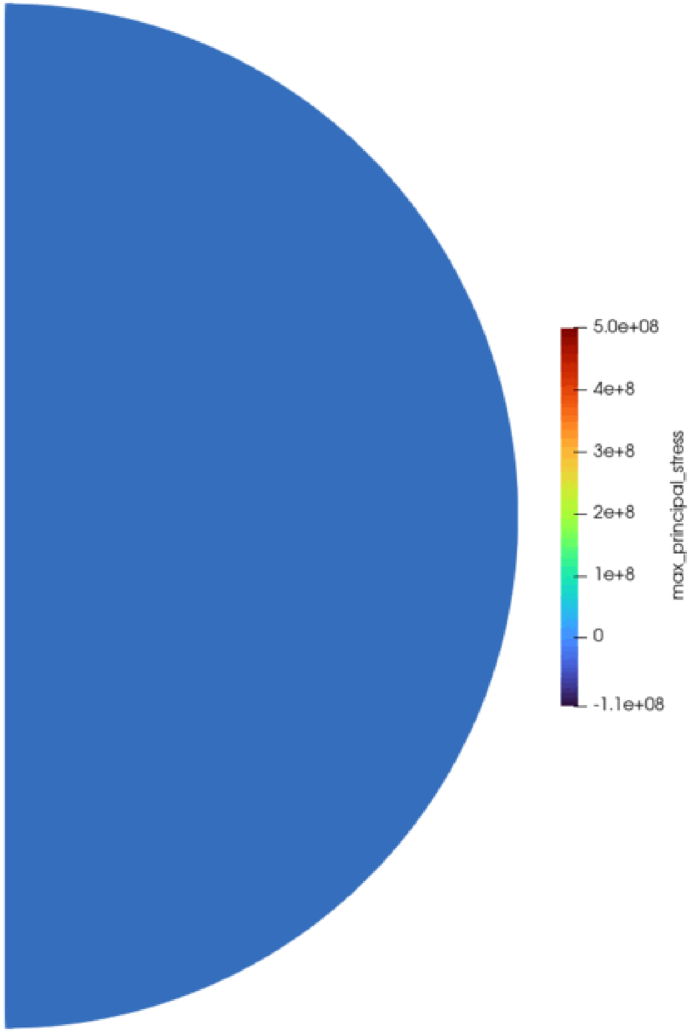




SiC fracture modeling







Story
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TRISO coating layers fracture modeling

- Fracture stresses of buffer, IPyC and SiC were set to 300MPa, 300MPa and 400MPa respectively.