

Machine Learning Enabled Multiscale Uncertainty Propagation For Fission Gas Swelling In UN

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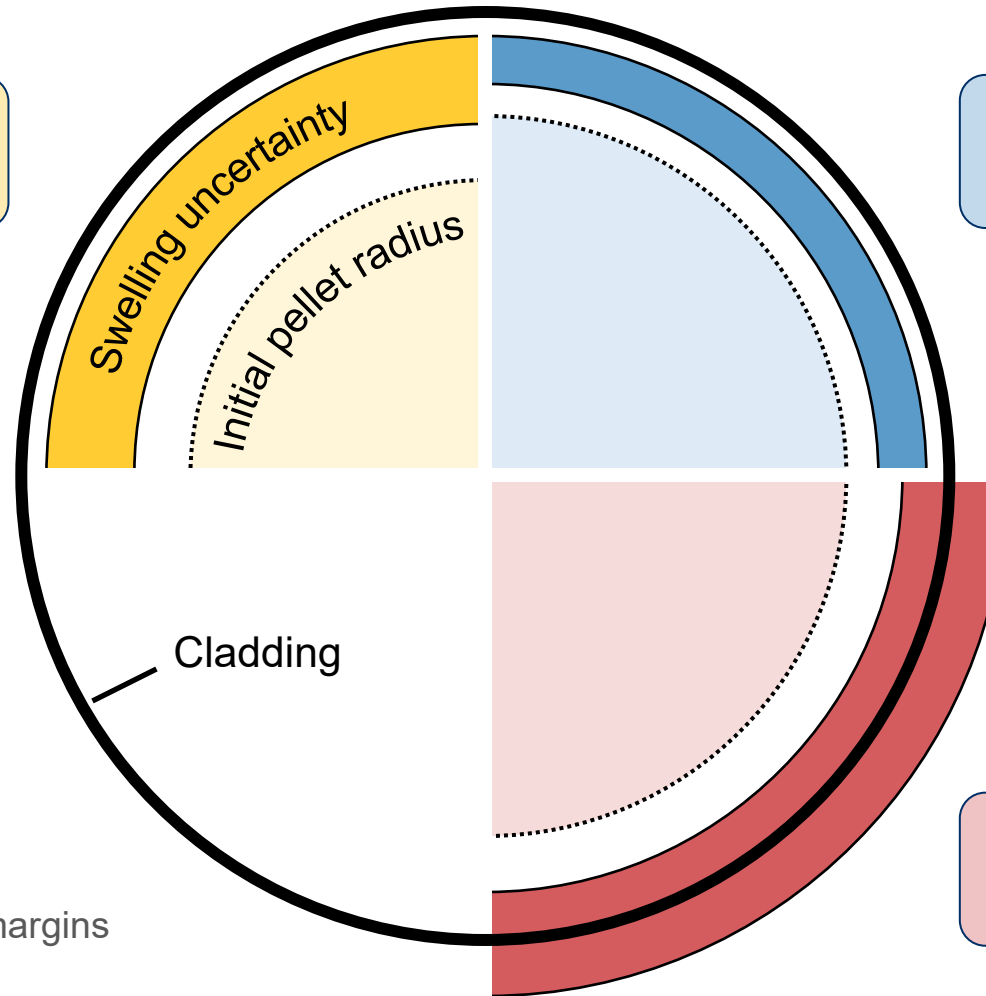
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Swelling uncertainty matters for fuel licensing

High swelling uncertainty

Large gap (conservative margin)
Poor reactor efficiency



Low swelling uncertainty

Thin gap but negligible risk of
fuel-cladding contact

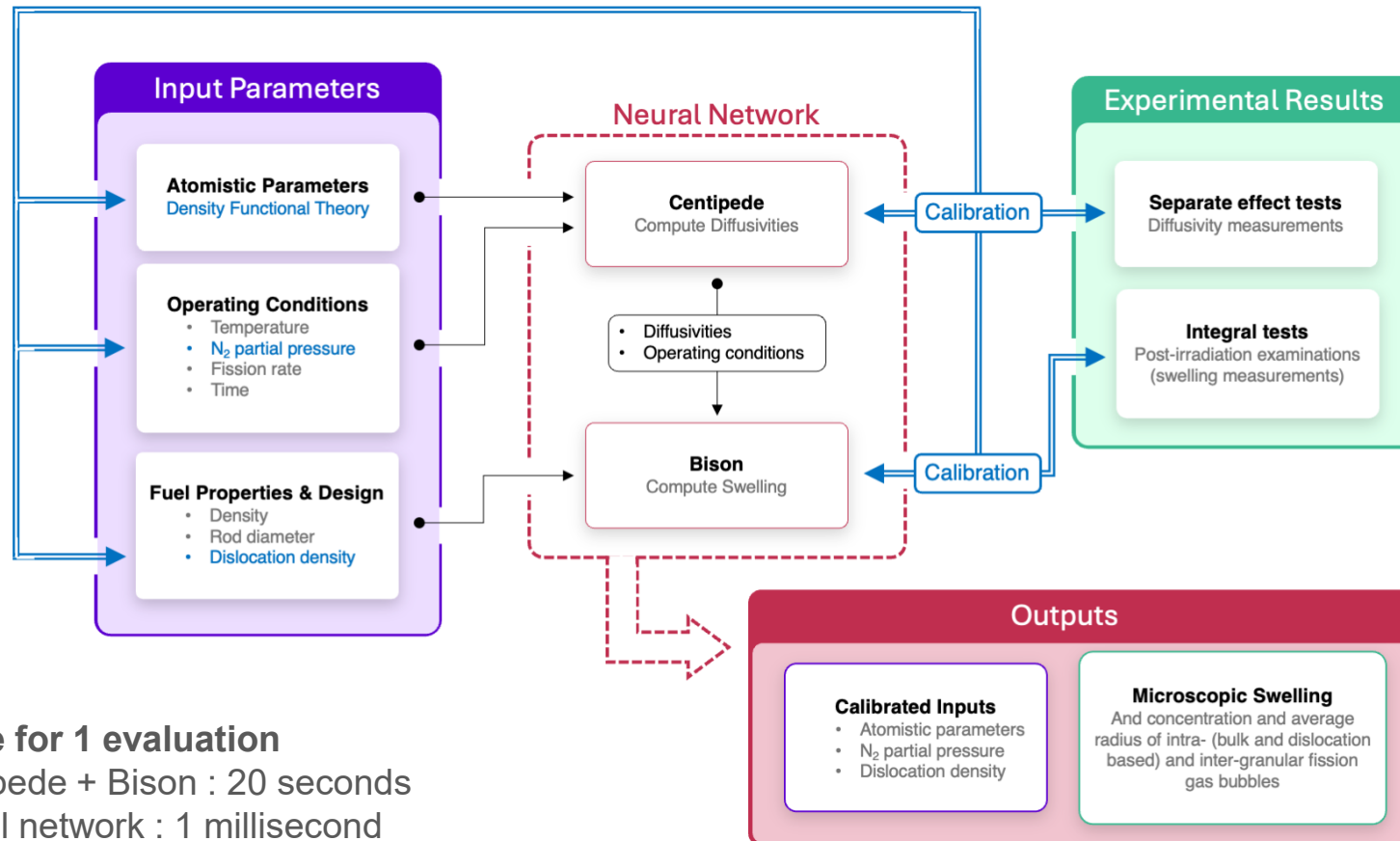
High swelling uncertainty

Thin gap (aggressive margin)
Risk of contact

- Swelling drives fuel-cladding contact risk
- Large uncertainty forces conservative safety margins



A Bayesian inference framework for UQ



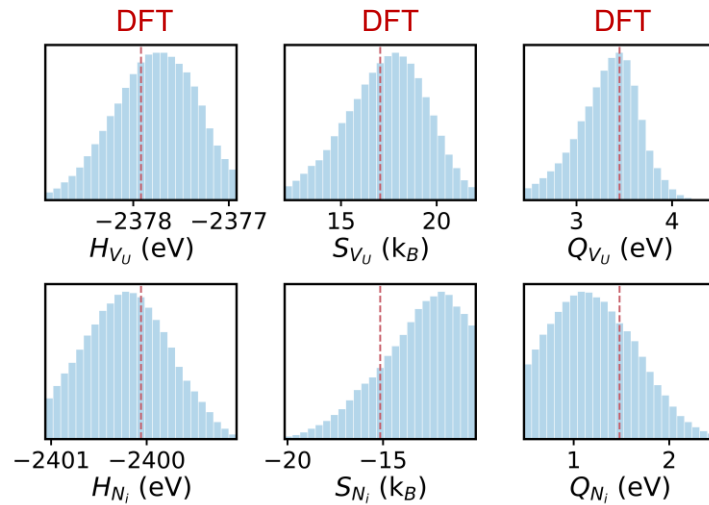
CPU time for 1 evaluation

- Centipede + Bison : 20 seconds
- Neural network : 1 millisecond

ML is instrumental to mechanistic UQ

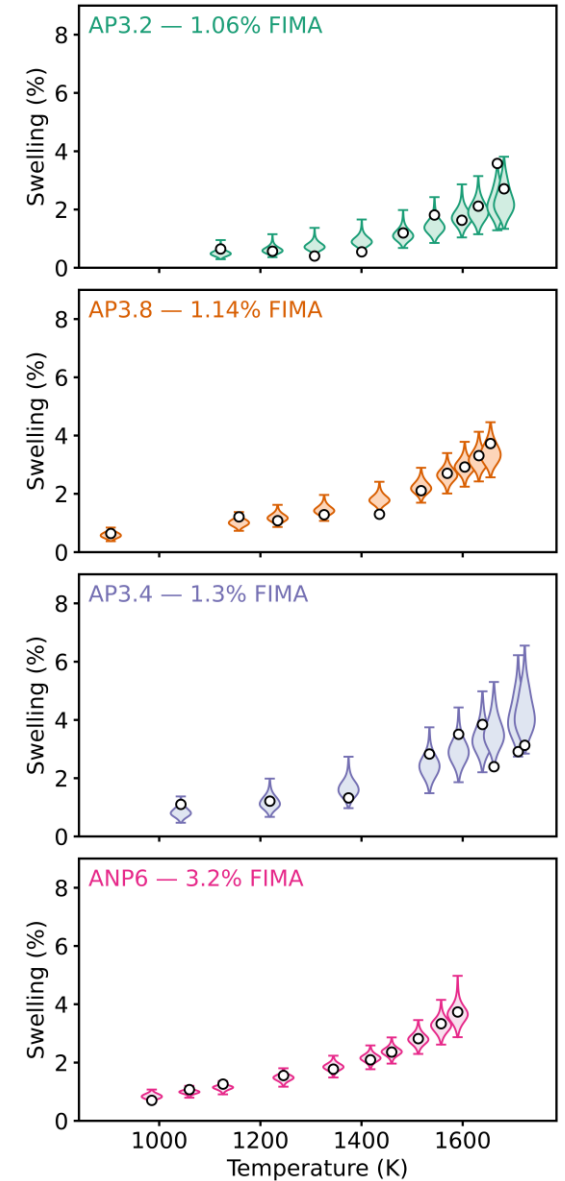
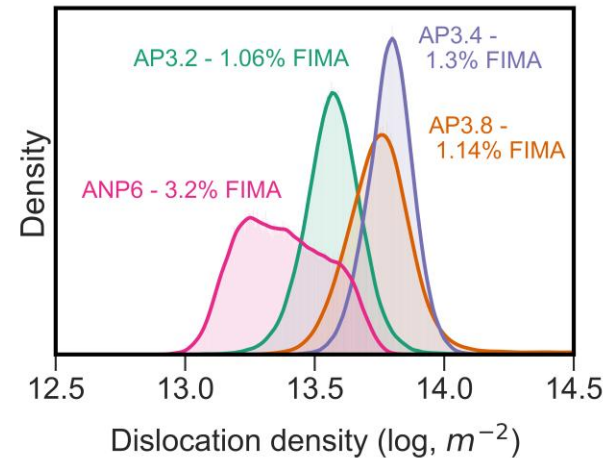


The framework at work

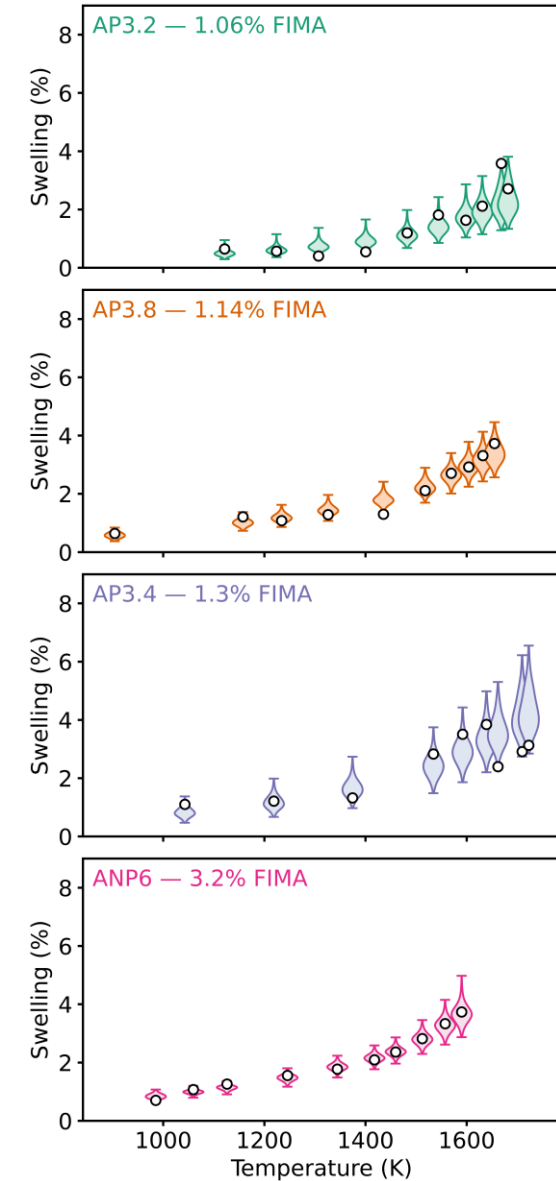
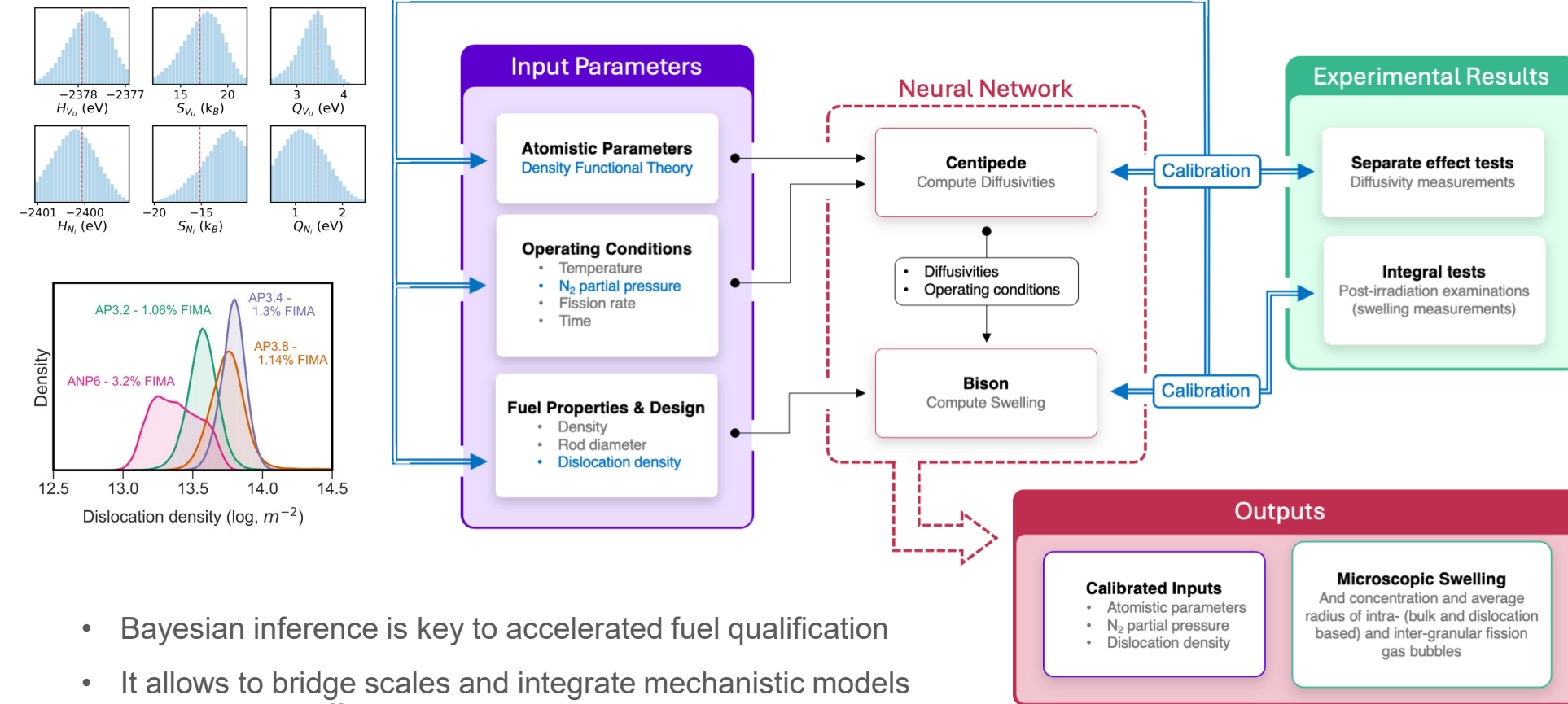


Computes probability distributions on both lower-length-scale parameters and swelling predictions

- Dislocation density inferred indirectly from the calibration against swelling measurements
- Consistent and physically plausible across samples
- Builds confidence in mechanistic interpretation



Takeaway



- Bayesian inference is key to accelerated fuel qualification
- It allows to bridge scales and integrate mechanistic models with separate effects and integral tests
- It is untractable without neural network surrogates



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Another example: Diffusional creep in UO_2

- Creep matters in pellet-cladding mechanical interaction
- Bayesian calibration reconciles decades of scattered creep data
- Uncertainty reduction achieved, confirming correct mechanisms
- **Again, unfeasible without neural network surrogate**

