

Three Falsifiable Experimental Tests of a Sub-Picosecond Scission Pressure Pulse: Mechanistic Insights into High Burnup Structure in Irradiated UO_2

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The High Burnup Structure (HBS) in irradiated UO_2 —characterised by sub-micron grain subdivision ($\sim 0.1\text{--}0.3\ \mu\text{m}$), fission gas bubble arrays, nanoscale amorphous clustering, and athermal uranium redistribution at effective diffusivities of $\sim 10^{-18}\ \text{cm}^2/\text{s}$ —remains mechanistically unresolved. These anomalies emerge sharply beyond $\sim 60\text{--}70\ \text{GWd/tU}$ at temperatures ($\sim 700\ \text{K}$) where purely Arrhenius bulk diffusion is negligible, implicating a non-thermal energy source beyond standard thermal-spike models.

We propose HBS formation is driven by a sub-picosecond ($\sim 10^{-13}\ \text{s}$) spherically symmetric mechanical pressure pulse (SPP) generated at nuclear scission. Arising from a fraction of the mass-defect energy release prior to primary Coulomb-driven fragment acceleration ($\sim 168\ \text{MeV TKE}$), this channel provides the missing mechanical work. We estimate the SPP reaches peak stresses of $\sim 1\text{--}3\ \text{GPa}$ within $\sim 5\ \text{nm}$ of scission, decaying over a mechanical coherence radius of $\sim 0.5\text{--}1\ \mu\text{m}$. Crucially, sub-grain nucleation at the observed $\sim 0.1\text{--}0.3\ \mu\text{m}$ scale is governed by competing defect sink densities within this pulse envelope, successfully decoupling the nucleation scale from the absolute coherence radius.

Three falsifiable experimental tests are proposed. First, using muscovite mica as a high-resolution morphological proxy, AFM of ^{252}Cf spontaneous fission tracks isolates pressure-specific lateral branching nodes predicted by the SPP. Second, comparative HRTEM of ^{252}Cf and equivalent-LET heavy-ion tracks at matched stopping powers ($\sim 20\ \text{keV/nm}$) discriminates scission-specific amorphous core morphology from purely electronic deposition. Third, synchrotron SAXS/WAXS strain mapping (beam size $< 50\ \text{nm}$) around fission tracks in UO_2 probes the predicted compressive annular zone, distinguishing the SPP strain profile from the monotonic tensile signatures of thermal-spike models. This escalating programme—from proxy morphological screening to quantitative UO_2 strain characterisation—offers a rigorous pathway to validate or falsify the SPP hypothesis.