

# Transmission Electron Microscopy Characterization of He-Bubble Evolution in Naturally Aged and Annealed $\delta$ -Plutonium

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The  $\alpha$ -decay process in Pu-Ga alloys leads to significant microstructural damage in the form of vacancies and self-interstitial atoms. As the  $\alpha$ -particles come to rest, they acquire electrons to form He atoms, which become trapped at microstructural defects – like vacancies – and accumulate in the microstructure at a rate of about 41 appm/yr per  $10^6$  atoms of Pu-239<sup>a</sup>. Over time, the trapped He atoms build up to nucleate and grow He bubbles. Recently, He bubble sizes and distributions across naturally aged  $\delta$ -Pu microstructures have been reevaluated with probe-corrected scanning transmission electron microscopy (STEM)<sup>b, c</sup>, and a series of isothermal dilatometer experiments were performed to understand their evolution as a function of time and temperature. With the naturally aged parent material as reference, the present study builds from our STEM results to resolve bubble evolution in the dilatometer samples to specific microstructural features characterized with electron diffraction and STEM electron energy loss spectroscopy (EELS). As in the dilatometer studies of He bubble evolution performed by Wheeler and Kitching – for which TEM results were not published – significant He bubble growth is observed at higher temperatures, and these samples are the primary focus of the STEM characterization presented<sup>d, e</sup>.

<sup>a</sup>) W. G. Wolfer, “Radiation Effects in Plutonium,” *Los Alamos Science*, vol. 26, p. 274-285, 2000.

<sup>b</sup>) D. S. Smith, T. M. Kucinski, and M. A. Grismer, “Revisiting He Bubble Measurements in Aged Pu Using Modern S/TEM Techniques,” at *TMS*, San Diego, 2026.

<sup>c</sup>) T. M. Kucinski, D. S. Smith, M. A. Grismer, and G. M. Moore, “Improved Characterization of Helium Bubbles in Naturally Aged Plutonium with Scanning Transmission Electron Microscopy (STEM),” at *Plutonium Futures*, Edinburgh, 2026. Abstract submitted.

<sup>d</sup>) D. W. Wheeler, and P. D. Bayer, “Evaluation of the Nucleation and Growth of Helium Bubbles in Aged Plutonium,” *Journal of Alloys and Compounds*, vol. 444-445, p. 212-216, 2007.

<sup>e</sup>) Unpublished work referenced in: D. W. Wheeler, and P. Roussel, “Review of the Behavior of He Bubbles in Aged Plutonium and their Influence on Material Properties,” *Journal of Vacuum Science and Technology*, vol. 43, no. 020802, 2025.