

Nuclear Materials Safety: Microstructure Matters

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Abstract

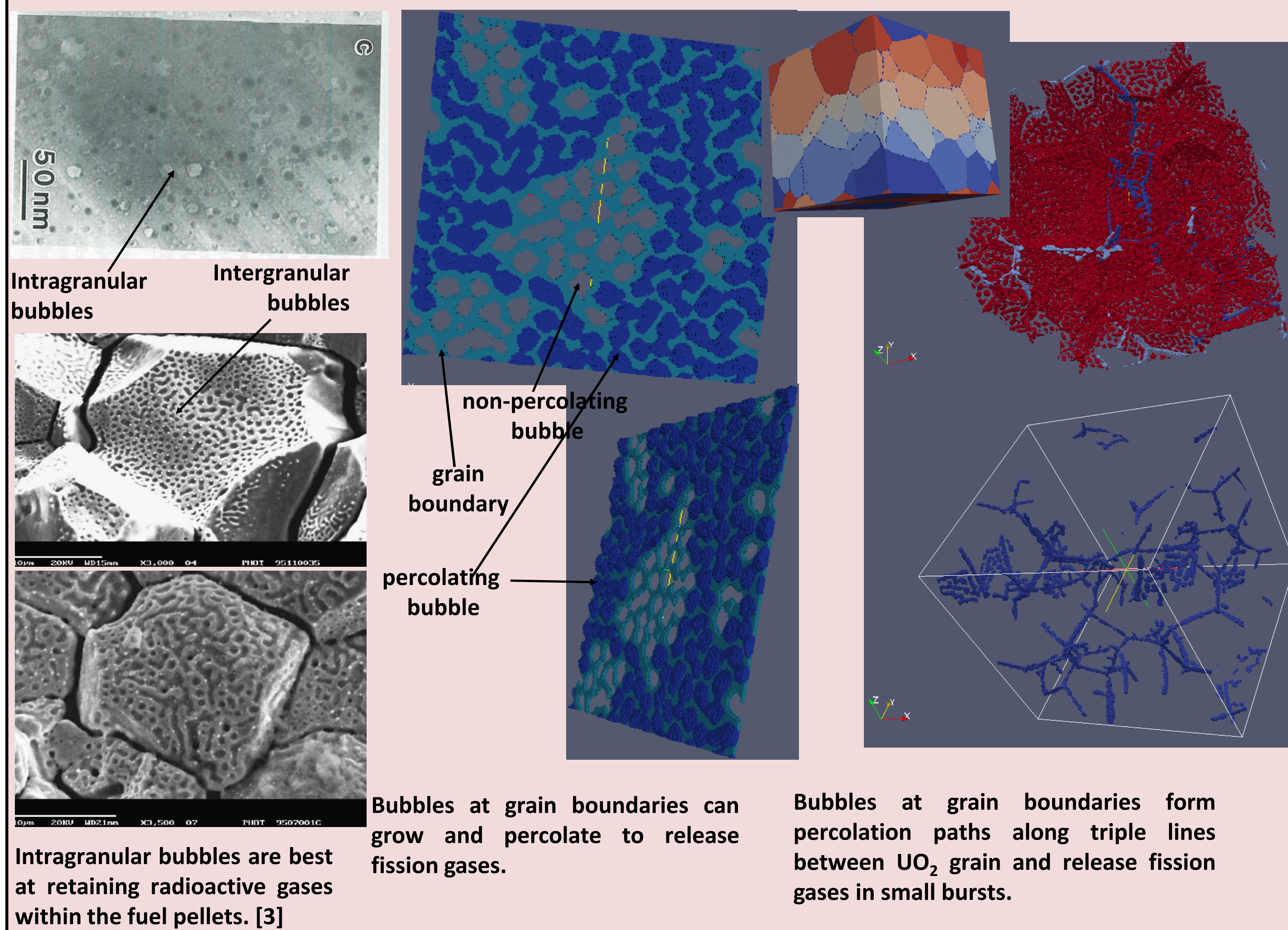
While most nuclear safety focuses on the chemical and isotopic composition of materials, the microstructure of the material and distribution of isotopes in the materials are integral to the safety of radioactive materials, as they influence the release of radioactive materials under different conditions. In this poster, three examples of how microstructure influences the safety of nuclear materials will be presented.

Background, What is microstructure?

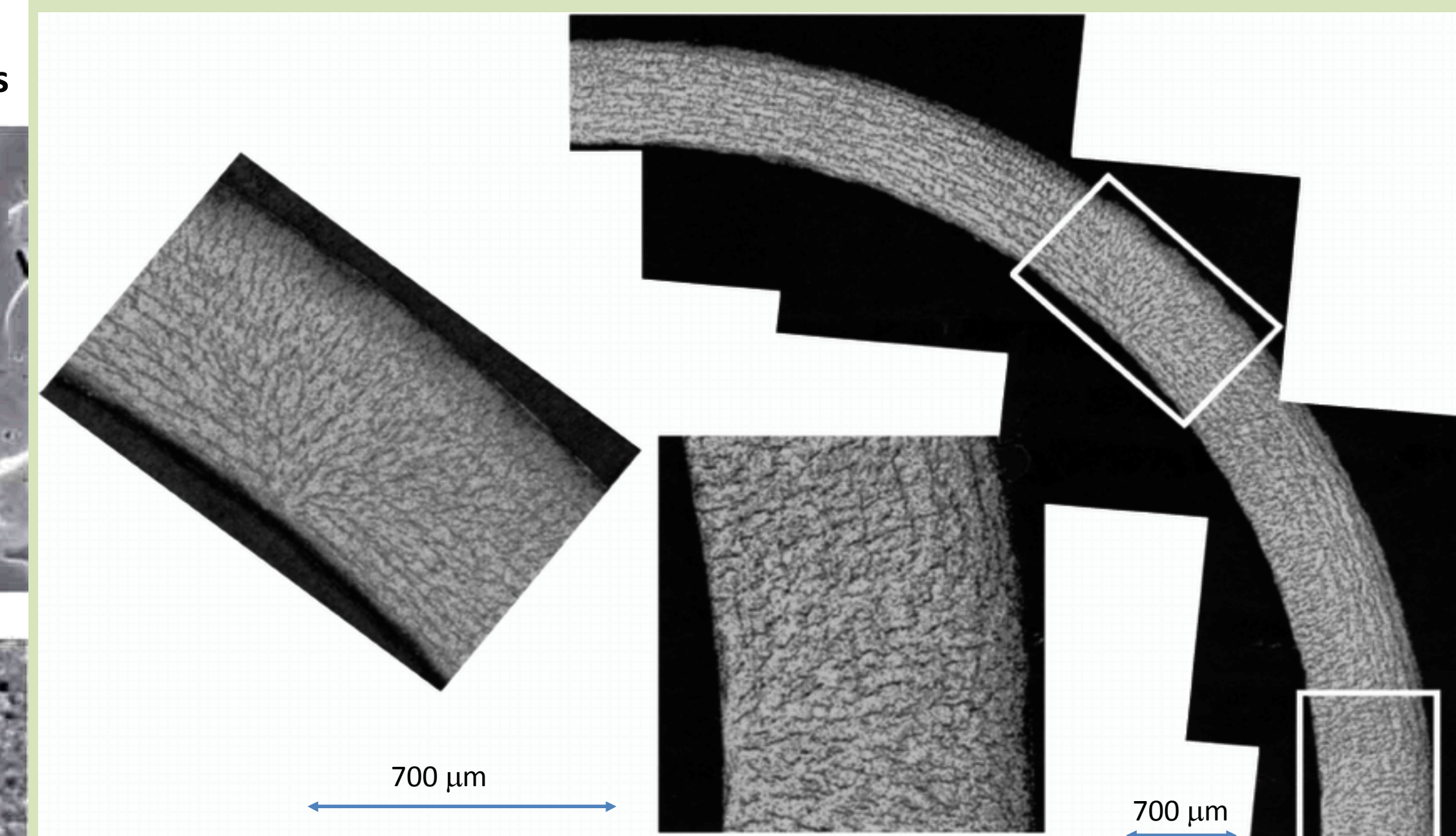
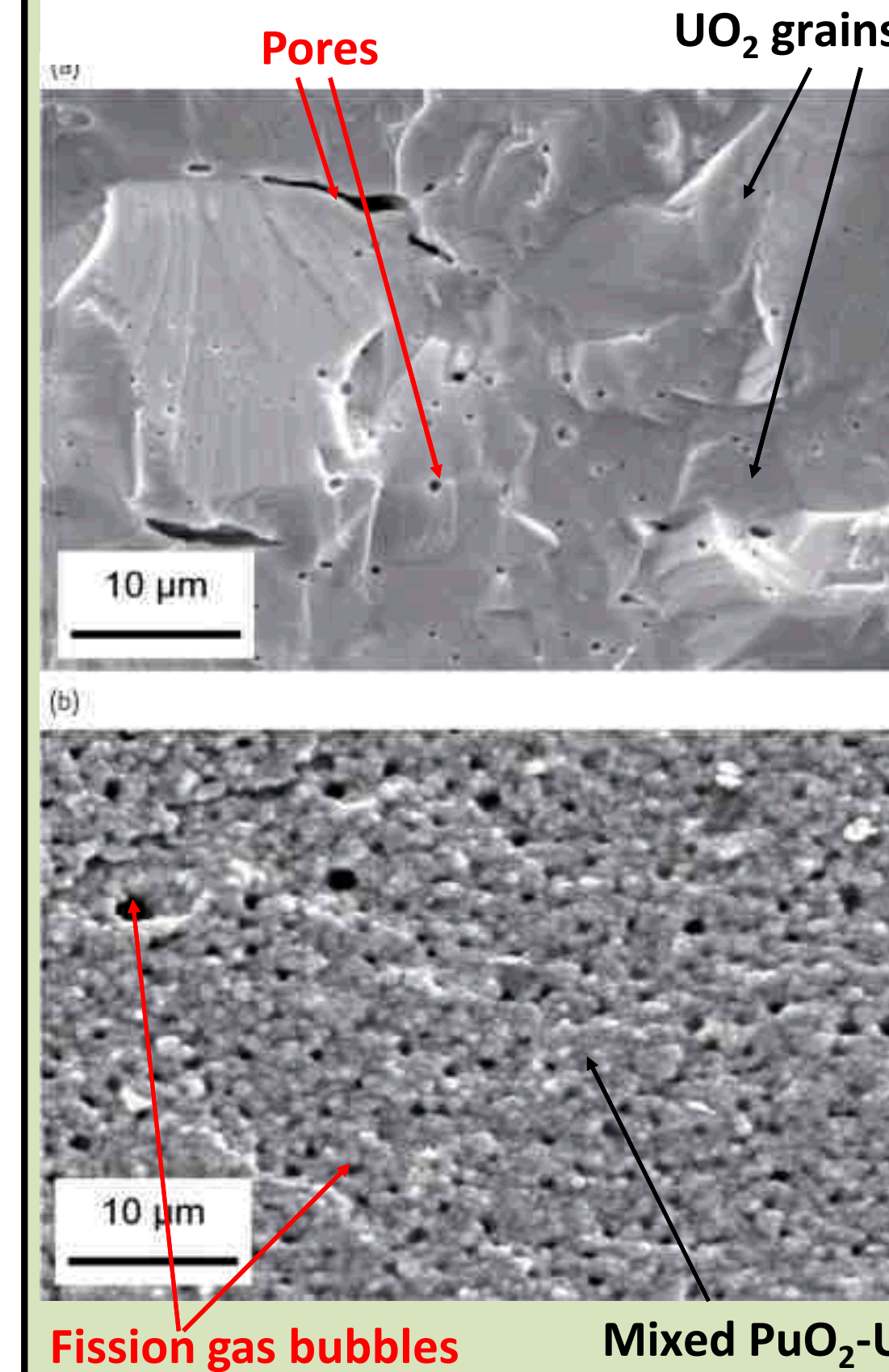
Most materials, and all functional and structural nuclear energy materials (i.e. fuel pellets, claddings, reactor structural materials) have structure and features as shown below at the micron scale, $\sim 10^{-6}$ meters, which influence performance and safety.

Example 1: Accumulation of Fission Gas in Nuclear Fuels

Radioactive fission gas in UO_2 nuclear fuel can accumulate within grains or at grain boundaries to form bubbles. Keeping the fission gas trapped within grains is safest, but under some conditions, fission gas bubbles at grain boundary can grow and eventually percolate to form paths that release radioactive gases from fuel. Thus controlling microstructure of grains and bubbles is important. Here we show how fission gases can percolate leading to unsafe release.

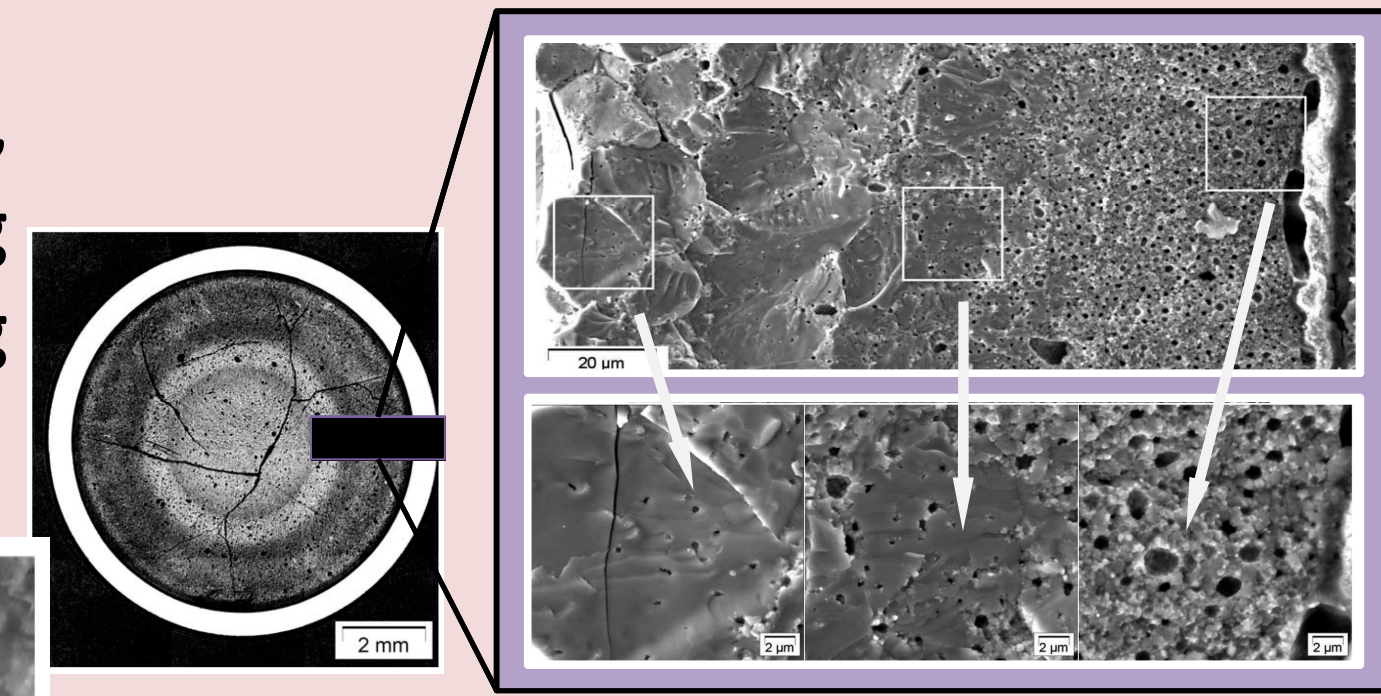
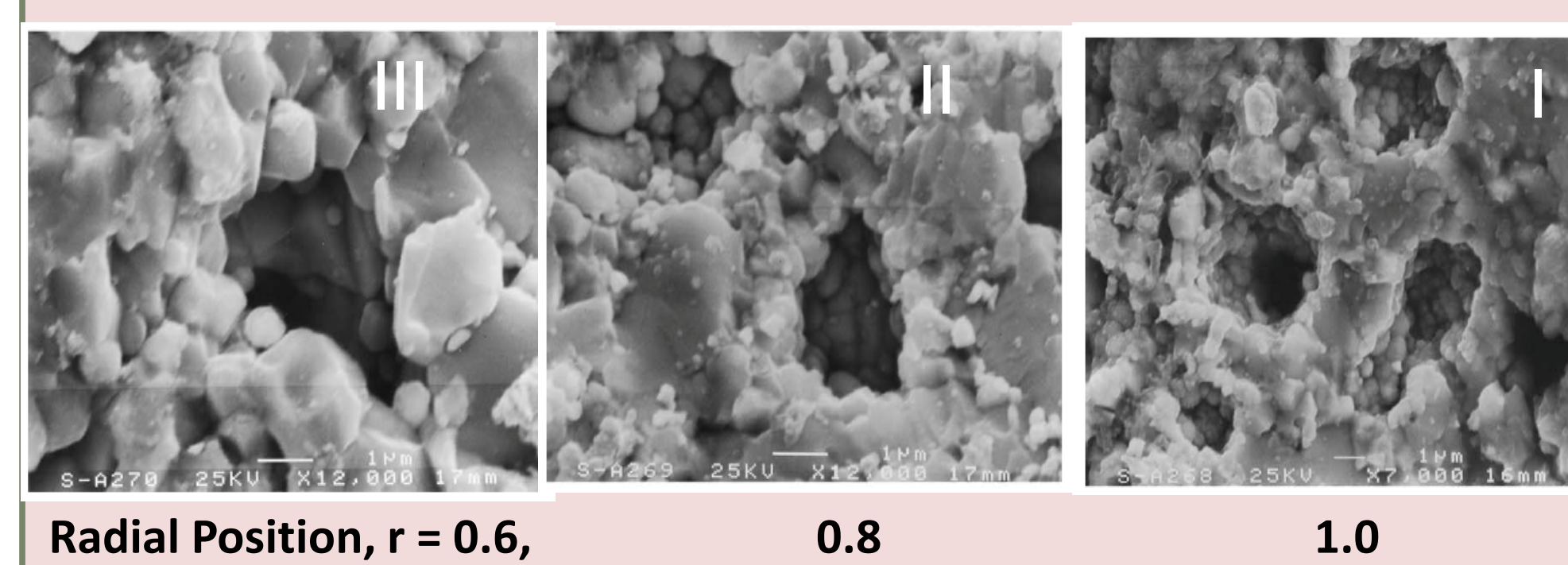


Fresh UO_2 fuel pellet and same fuel irradiated in a FR. [2]

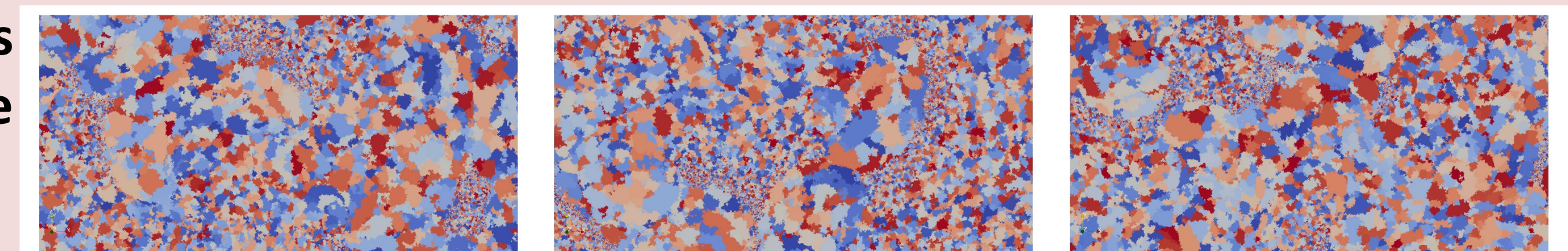


Example 3: High Burn-up Rim Structure in LWR Fuels

LWR fuels rims are enriched by resonance neutrons, which are preferentially absorbed by ^{238}U forming ^{239}Pu at the rim. ^{239}Pu also fissions; thus generating more energy and fission products in the rim. [5]

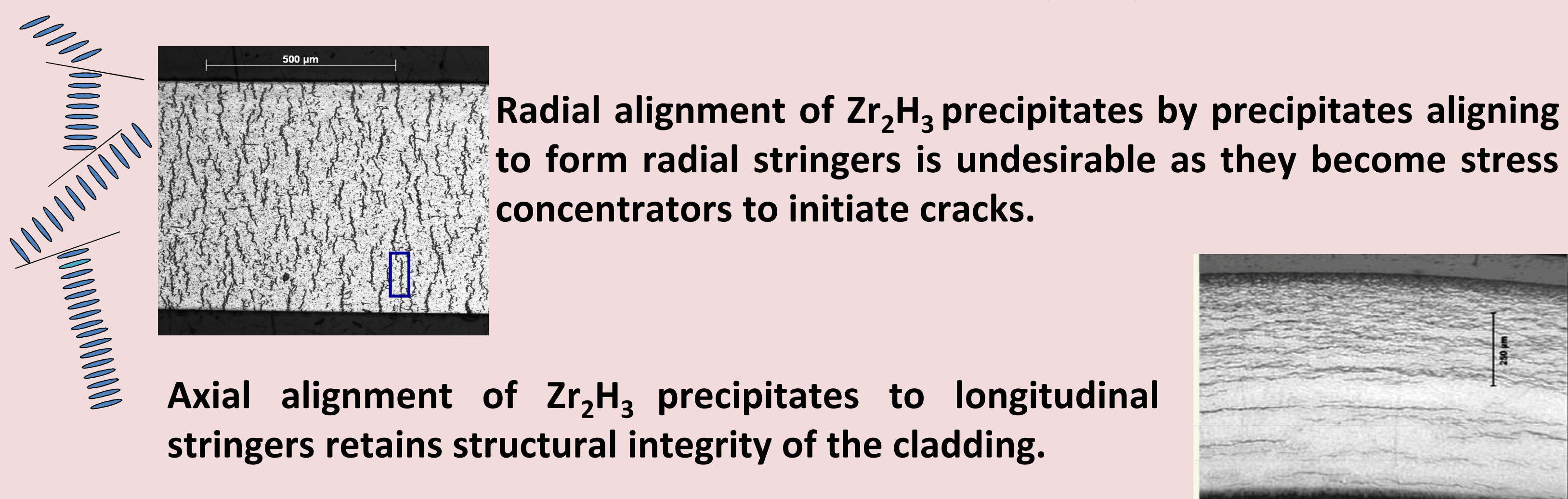


See accompanying movie for details on mechanisms for rim structure formation [7].



Example 2: Zirconium Hydride Formation in Zr-Based Claddings

In reactor, Zr-based claddings absorb H to form lenticular-shaped Zr_2H_3 precipitates. These precipitates can align themselves radially (undesirable) or axially (desirable) under different loading conditions. Promoting axial alignment prevents the cladding from rupturing, thus retaining a barrier for radioactive material.



Concluding Remarks

The microstructure consisting of grain shape and size, pore and bubble size and distribution, precipitate shape, placement and alignment, phases, and much more influence the engineering properties and safety of the nuclear materials; thus, microstructure must be considered when handling, transporting, storing and disposing of these materials. We have several models to simulate the microstructure and its formation for many of these processes.

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1. R. Daum, S. Majumdar, Y. Liu, M. Billone, J. Nuc Sci & Tech., Sept 2006. 2. V. Rodinello and T. Weiss, Materials Today, Dec. 2010 3. R.J. White, J. Nucl. Mat., 2004 4. Bradbrook et al, J. Nucl. Mat., 1972 5. Noirot, et. al NE&T, vol. 41 2009 6. J. Spino et al., JNM vol. 354, 2006 7. Madison, Tikare, Holm, J. Nucl. Mat., 2011