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Radiation tolerance of gradient grain-structured copper processed by surface mechanical attrition treatment

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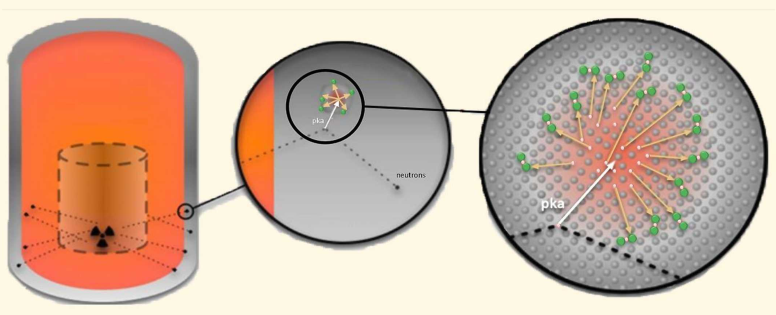
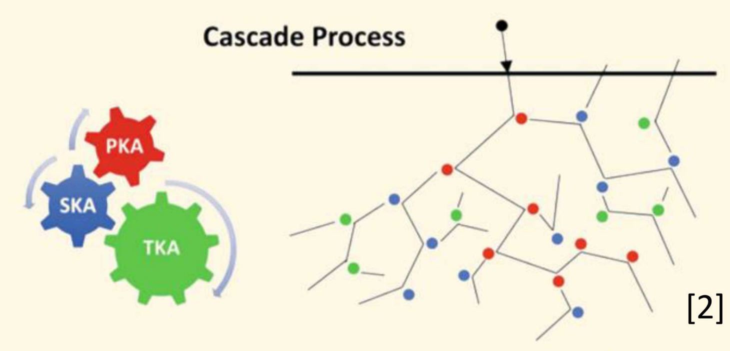
RADIATION DAMAGE



[1]

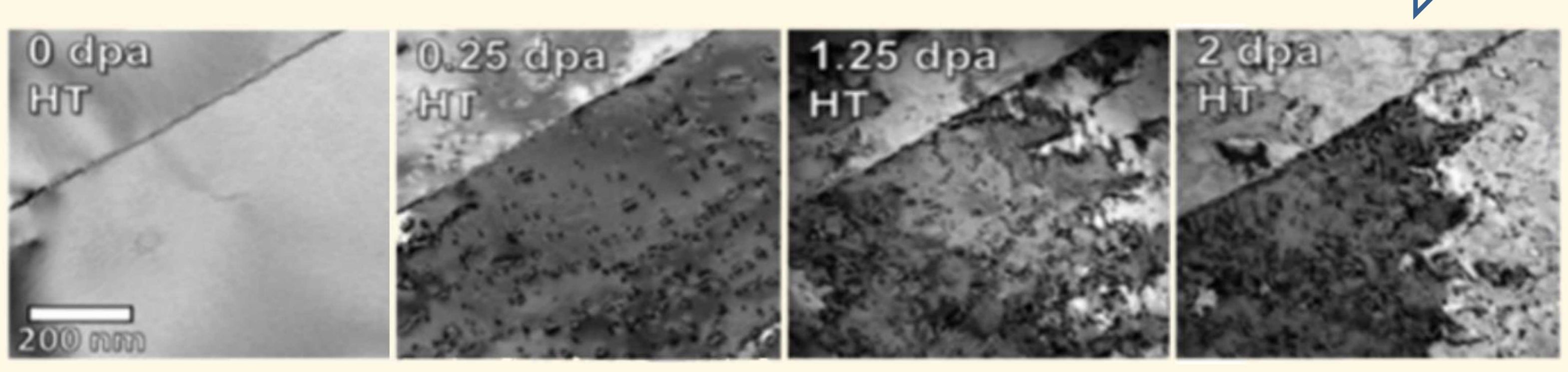
Ion and neutron particle bombardment can cause damage cascades in metals as well as transmutation reactions.

This can cause embrittlement, hardening, swelling, and grain growth



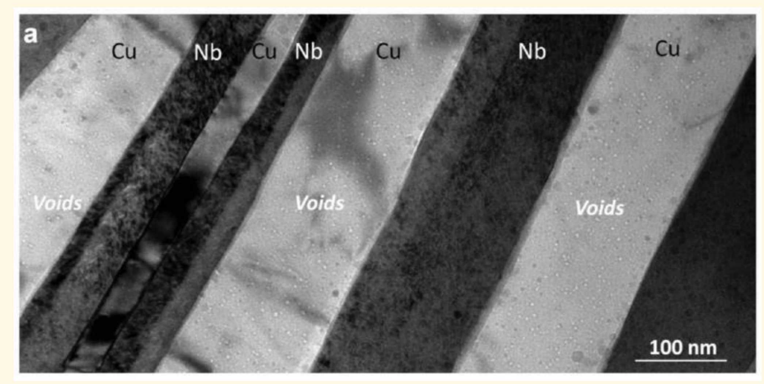
[2]

Increasing point defect generation, migration, and interaction



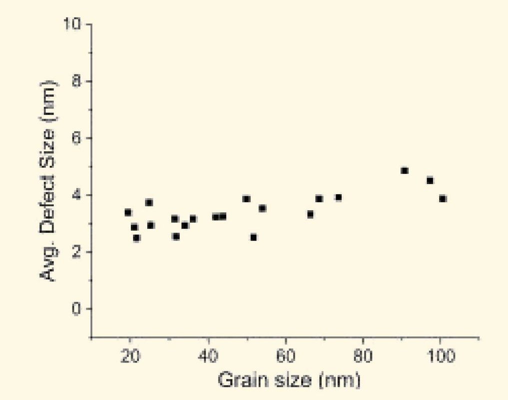
[3]

SMALLER = BETTER (?)

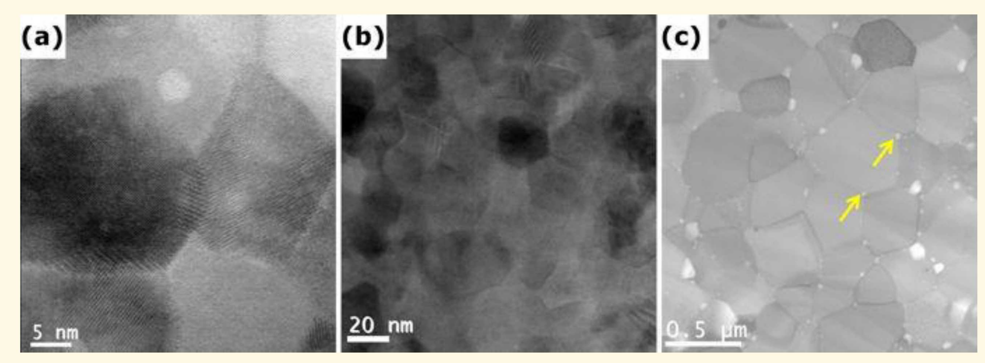


[4]

Interfaces have been shown to be effective sinks for collecting and annihilating radiation defects

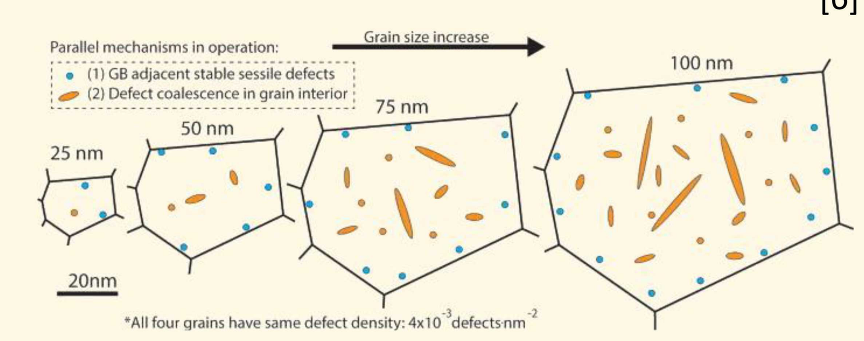


[6]



[5]

Smaller grains and twin boundaries should be more effective radiation defect sinks due to the increase in interfacial boundary area

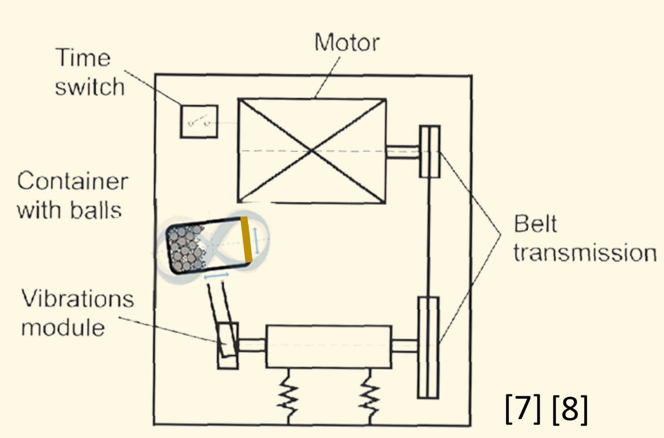


BUT, some research suggests that smaller may not be better, and defect density does not change dramatically with grain size

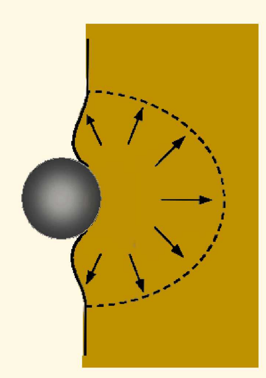
ONE SAMPLE WITH ALL THE GRAINS

Is smaller better? Many studies use separate samples with varying initial conditions and processing parameters to achieve the desired grain sizes for study.

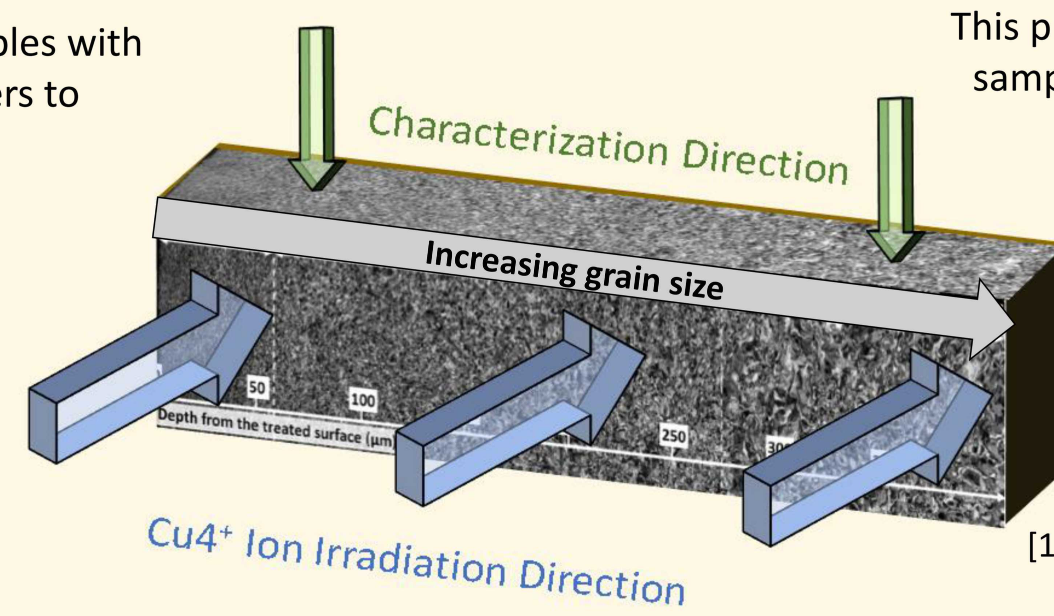
Cu plates severely plastically deformed by 8mm-440C steel ball impacts in a process called surface mechanical attrition treatment (SMAT).



[7] [8]



[9]

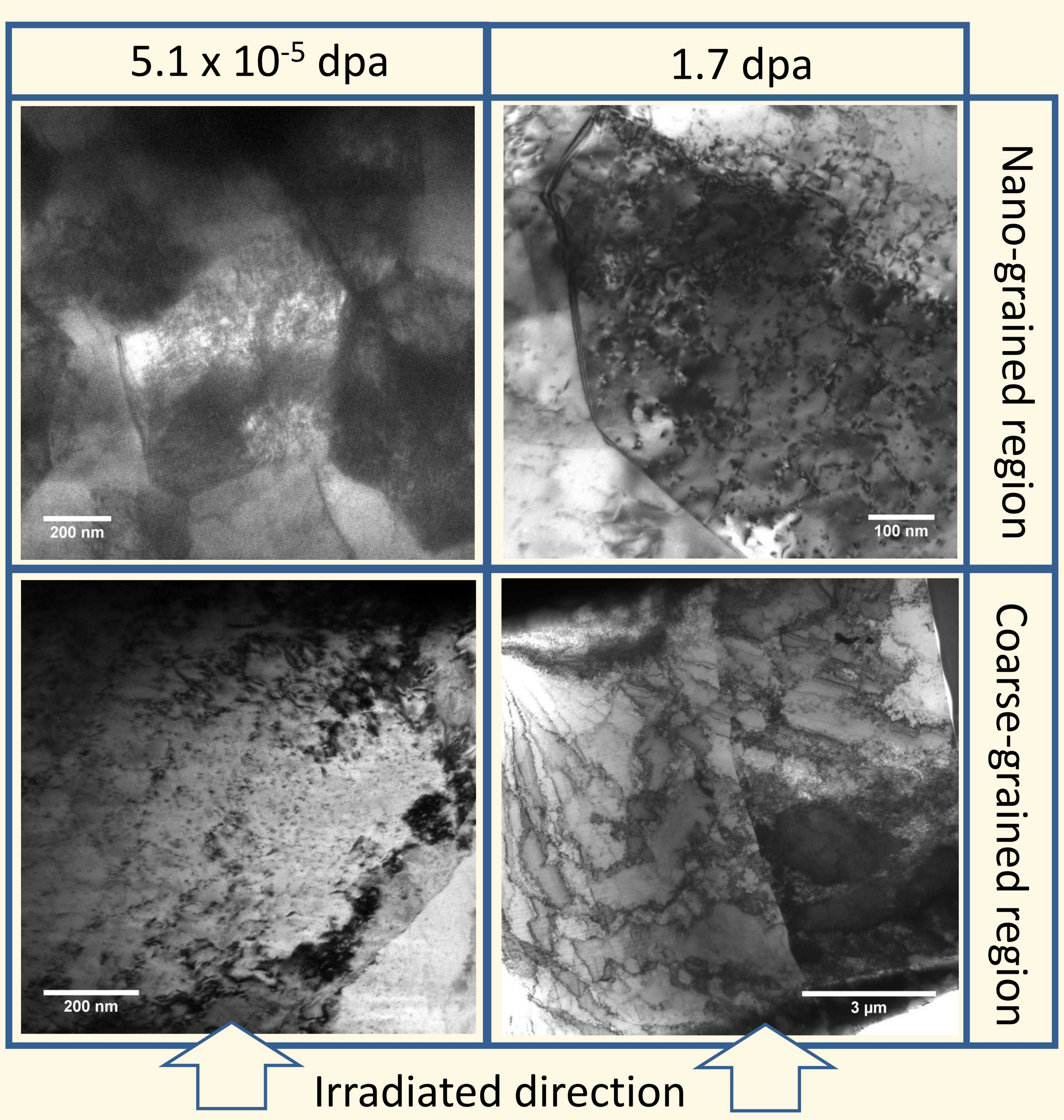


[10]

This process can produce a gradient of grain sizes in one sample with the same initial conditions and processing parameters.

Cu^{4+} ion irradiation accelerated at 20MeV performed at Sandia National Laboratories along the range of grain size (5.1×10^{-5} dpa, 0.5 dpa, and 1.7 dpa).

Characterization conducted in plane containing both radiation damage and grain gradient



THE PUNCHLINE?

Is Smaller Better?

Radiation Damage is inconclusive
Radiation damage seen at all grain size regimes. More detailed defect density calculations will better answer this

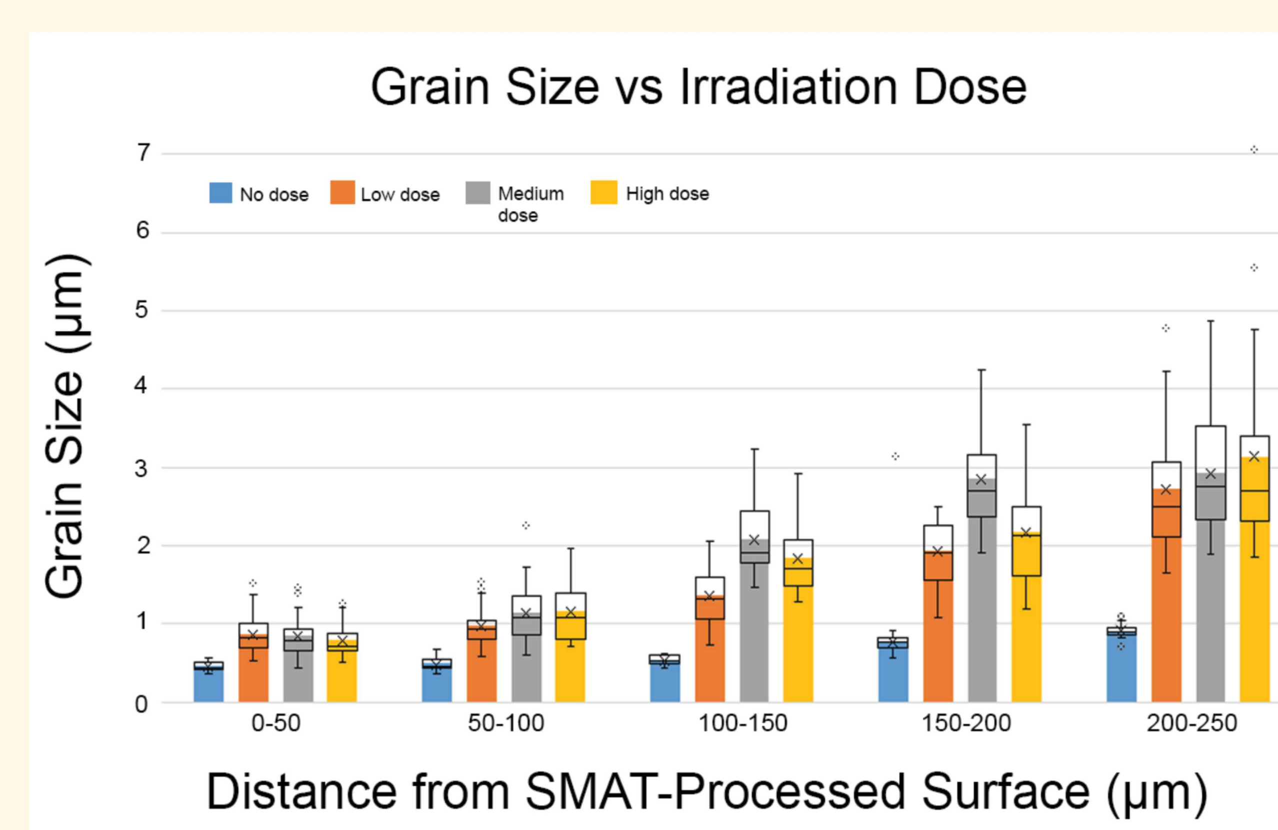
Grain size suggests yes
Grains grew across all regimes. No evidence of nanocrystalline grains growing more rapidly than coarse grains.

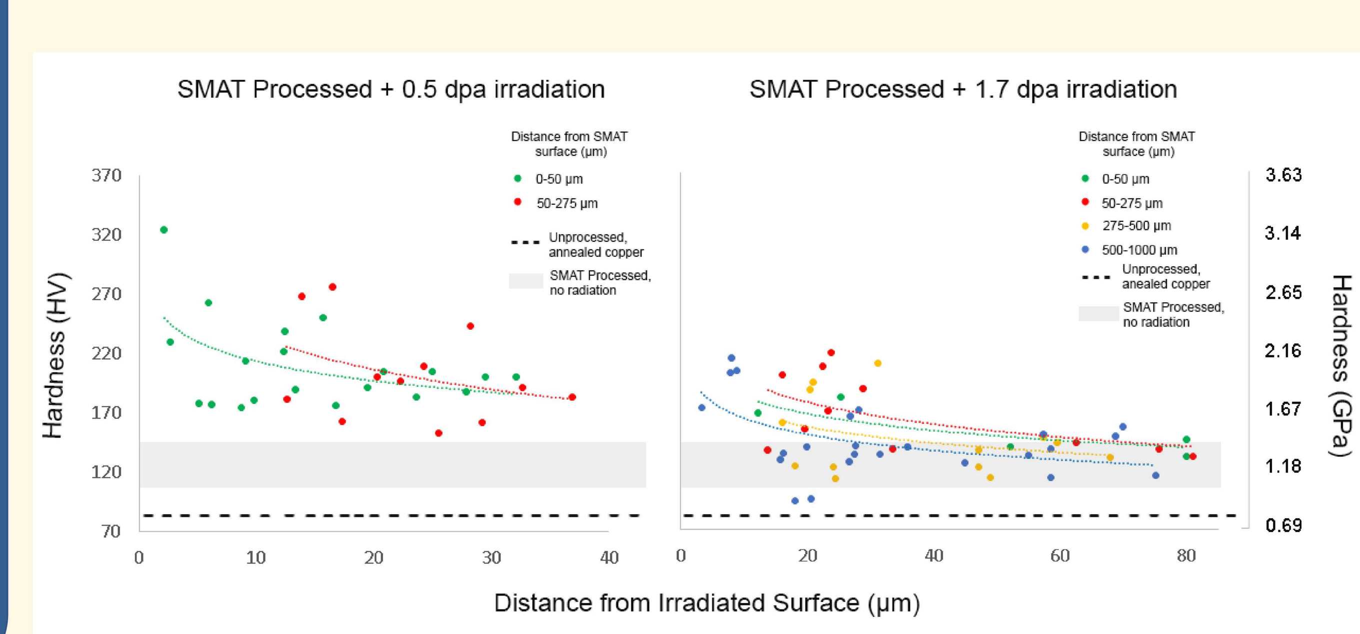
Grain size decreased at the high dose in the mid-ranged grain size regimes → dose-dependence of grain growth

Hardness results show
Radiation hardening occurred across all grain size regimes at low doses.

At higher doses, the material softens close to the unirradiated samples → more capacity for radiation defect annihilation

Interestingly, the 50-275µm region consistently showed higher hardness than the 0-50 µm region → something more than Hall-Petch is playing a role.





FUTURE WORK:
The results so far point towards smaller being better in terms of grain growth. While the mid-ranged grain sizes show interesting trends in grain growth and hardness that are not intuitive. Continuous stiffness measurements and EBSD analysis can be added to this study to understand the extent of radiation damage more precisely along these grain sizes, and to more definitively point towards one argument or another in terms of grain size benefits on radiation tolerance.

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