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Attempt to Solve the Instability in the Irradiation Behavior of Low Enriched U-Mo/Al Dispersion Fuel

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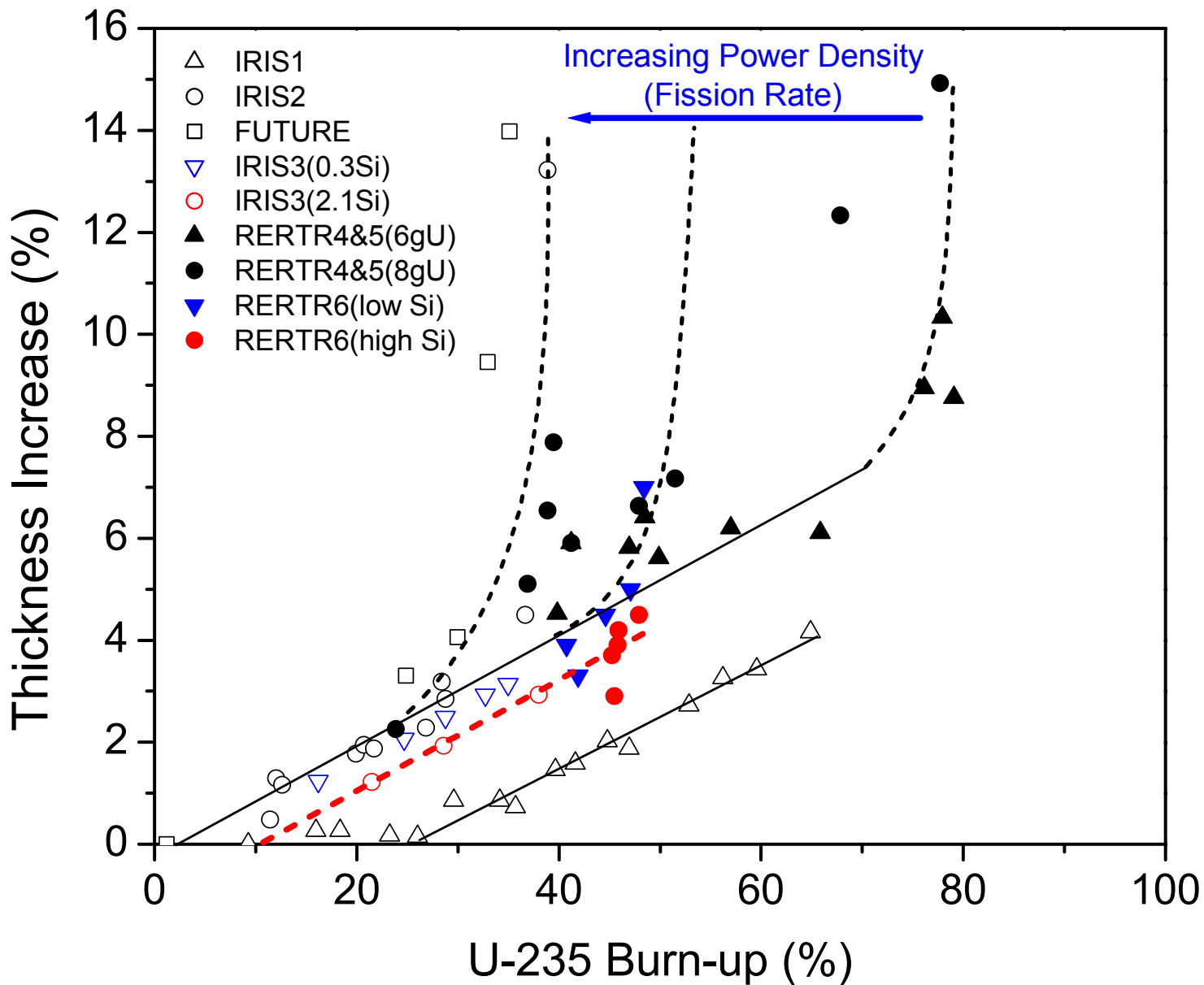
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** On assignment from ANSTO*





The Problem

- The formation of relatively large fission gas pores was first observed in several nano-plates from the first highly loaded-high power test: RERTR-3. The extent of the porosity was relatively minor and no clear pattern of its occurrence with respect to the test variables was apparent.
- The PIE results for micro-plate tests RERTR-4 and 5 showed that the porosity formation is clearly an irradiation behavior characteristic U-Mo/Al interdiffusion product and that it appears to occur above a certain fission rate level.
- Irradiation tests of full-size plates in France and full-size tubes in Russia have confirmed the generality of the phenomenon.

Observations and Deductions

- Large pores nucleate at the aluminum-interaction zone interface.
- Pores grow into the interaction zone and interlink when the zone formation is extensive.
- Pore growth appears to be very sensitive to fission rate in the immediate vicinity.
- The pore structure resembles amorphous fuel behavior as observed in U_6Fe and U_3Si .

Deductions

- The cubic $U(Al,X)_3$ interdiffusion phase (such as occurs in U_3Si_2/Al dispersions) appear stable with respect to pore formation.
- The presence of Mo in the interdiffusion some allows high Al phases to form due to the existence of $MoAl_{12}$, $MoAl_7$, $MoAl_5$ in the Mo-Al system.
- These phases are relatively low temperature peritectoid compounds; such compounds have exhibited amorphization and viscous irradiation behavior (U_3Si , U_6Fe and U_6Mn) in previous irradiation experiments.
- PIE of the interdiffusion zone in various U-Mo/Al irradiation tests have indeed determined the composition of the zone to vary from $(U-Mo)Al_7$ to $(U-Mo)Al_3$ depending on operating conditions.
- The microstructure of the interdiffusion zone appears to be uniform (single phase) regardless of composition, indicating that its structure may have been amorphous during irradiation.

Remedy

- Prevent the occurrence of high Al compositions by promoting the formation of UAl_3 equivalent composition as an interdiffusion product.
- This may be accomplished (in principle) by adding elements to the system that form XAl_3 compounds in equilibrium with Al.
- The most promising candidates are elements of group IV A and IV B. Zirconium and silicon represent these groups.
- These elements, among others, were previously employed in an effort to improve the fabricability of U-Al alloy fuel by promoting the formation of UAl_3 over that of UAl_4 during solidification. Elements of group IV were indeed found most effective (ORNL, BMI, Max Planck Inst.)

Recent RERTR Effort Cont....

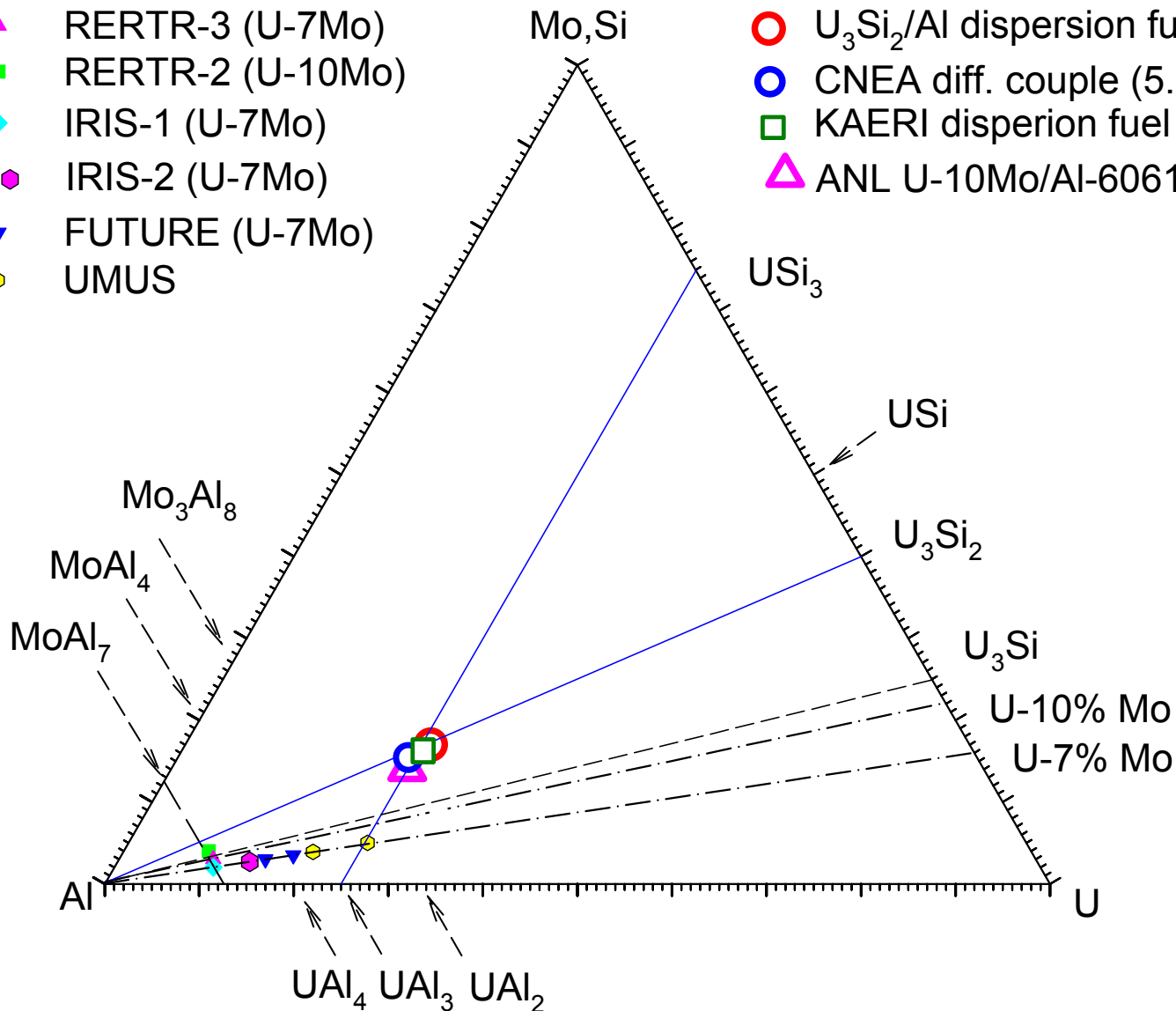
- The requirements of sufficient diffusion mobility is being assessed with atomistic modeling and confirmed with interdiffusion experiments.
- Si does indeed readily diffuse from the Al matrix into the interdiffusion zone where it helps form $(U-Mo)(Al,Si)_3$
- The information taken in total was the basis for including test miniplates containing Si in RERTR-6.
- Because there may be a limit to the amount of Si, imposed by reprocessors, the other elements from group IV A are being evaluated as partial or total replacement candidates for Si.

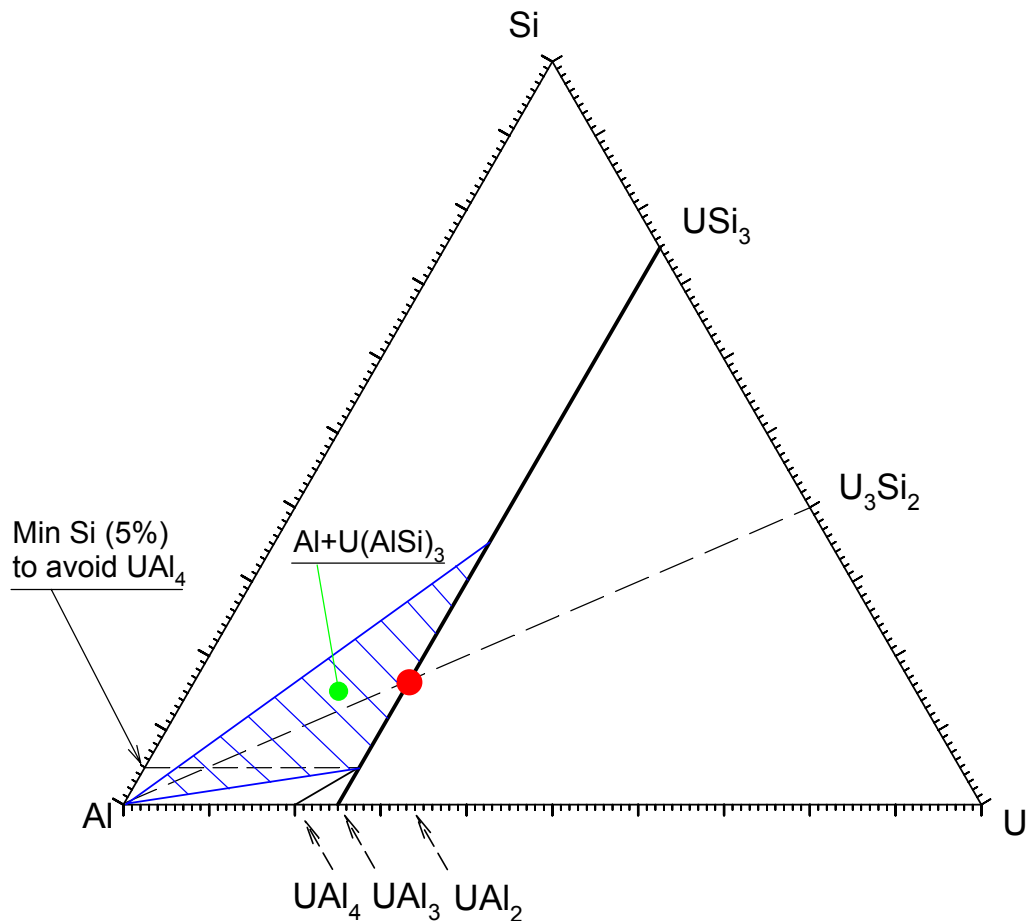
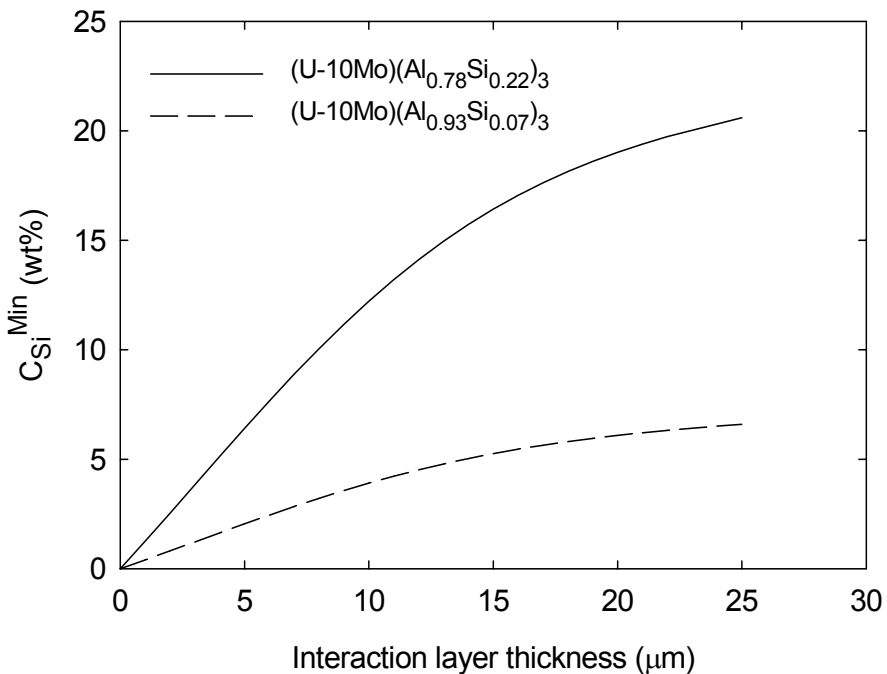
Irradiation data

- ▲ RERTR-3 (U-7Mo)
- RERTR-2 (U-10Mo)
- ◆ IRIS-1 (U-7Mo)
- ◆ IRIS-2 (U-7Mo)
- ▼ FUTURE (U-7Mo)
- UMUS

Out-of-pile annealing data

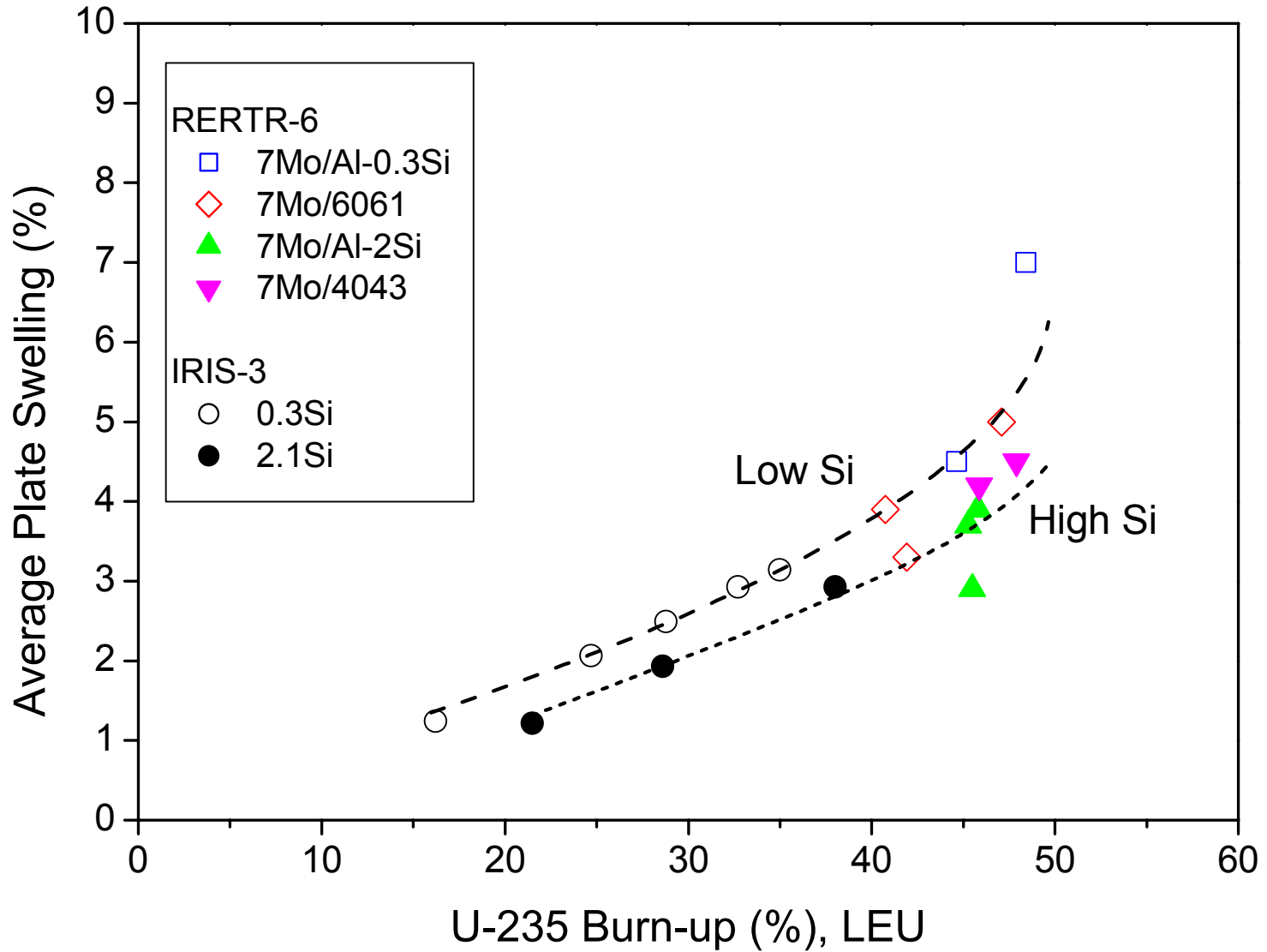
- U_3Si_2/Al dispersion fuel
- CNEA diff. couple (5.2 wt%Si)
- KAERI dispersion fuel (2 wt% Si)
- △ ANL U-10Mo/Al-6061





Minimum Si content in the Al matrix needed to avoid formation of $(U,Mo)Al_{4-7}$

Ternary diagram illustrating the range of minimum Si content to stabilize UAl_3 in the U-Al system.



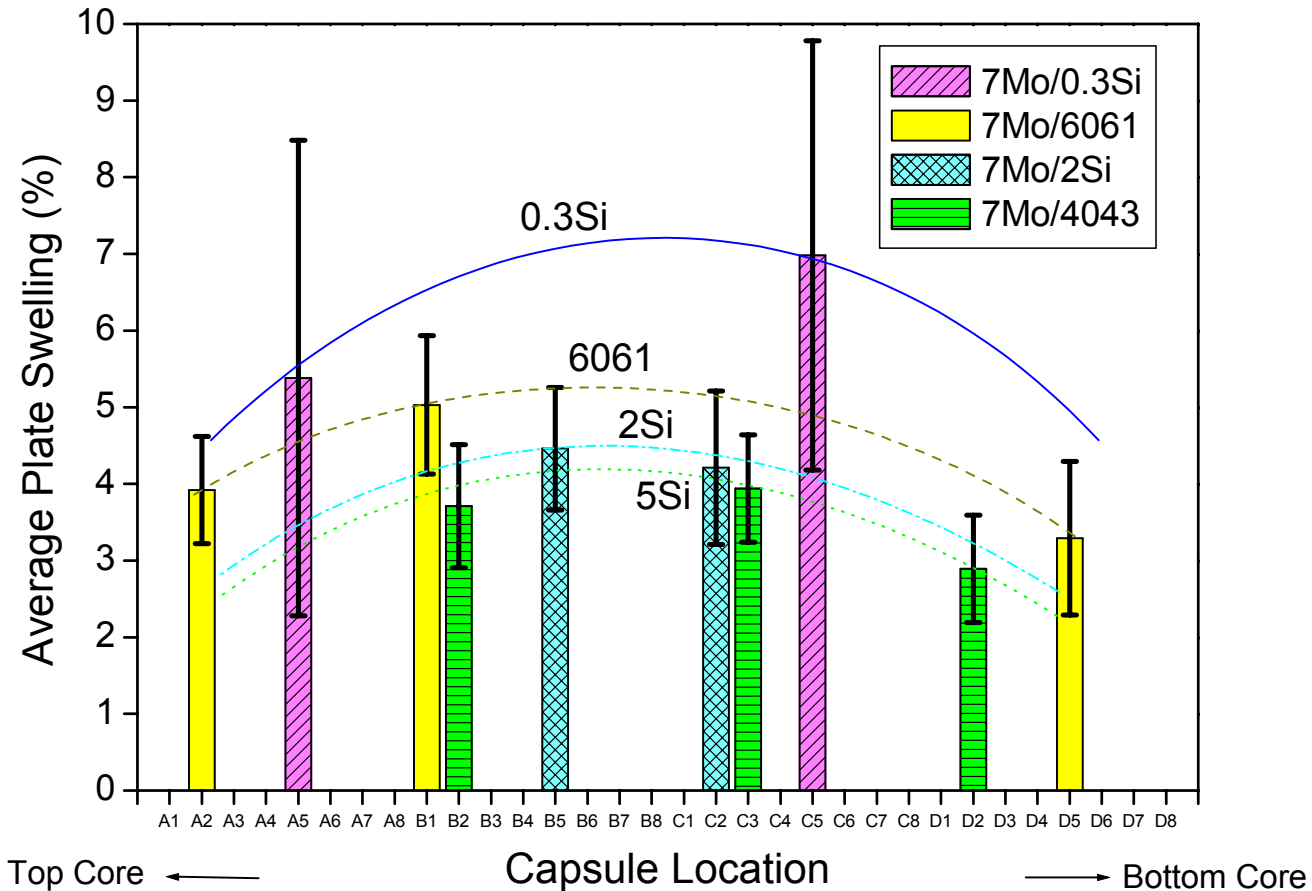


Fig. Average thickness and variation in thickness changes of U-7Mo dispersion fuel miniplates irradiated in RERTR-6. The individual miniplates were located at various axial distances from the ATR core midplane. Maximum burnup at location B and C is 50% U-235 with a peak heat flux of 150 W/cm².

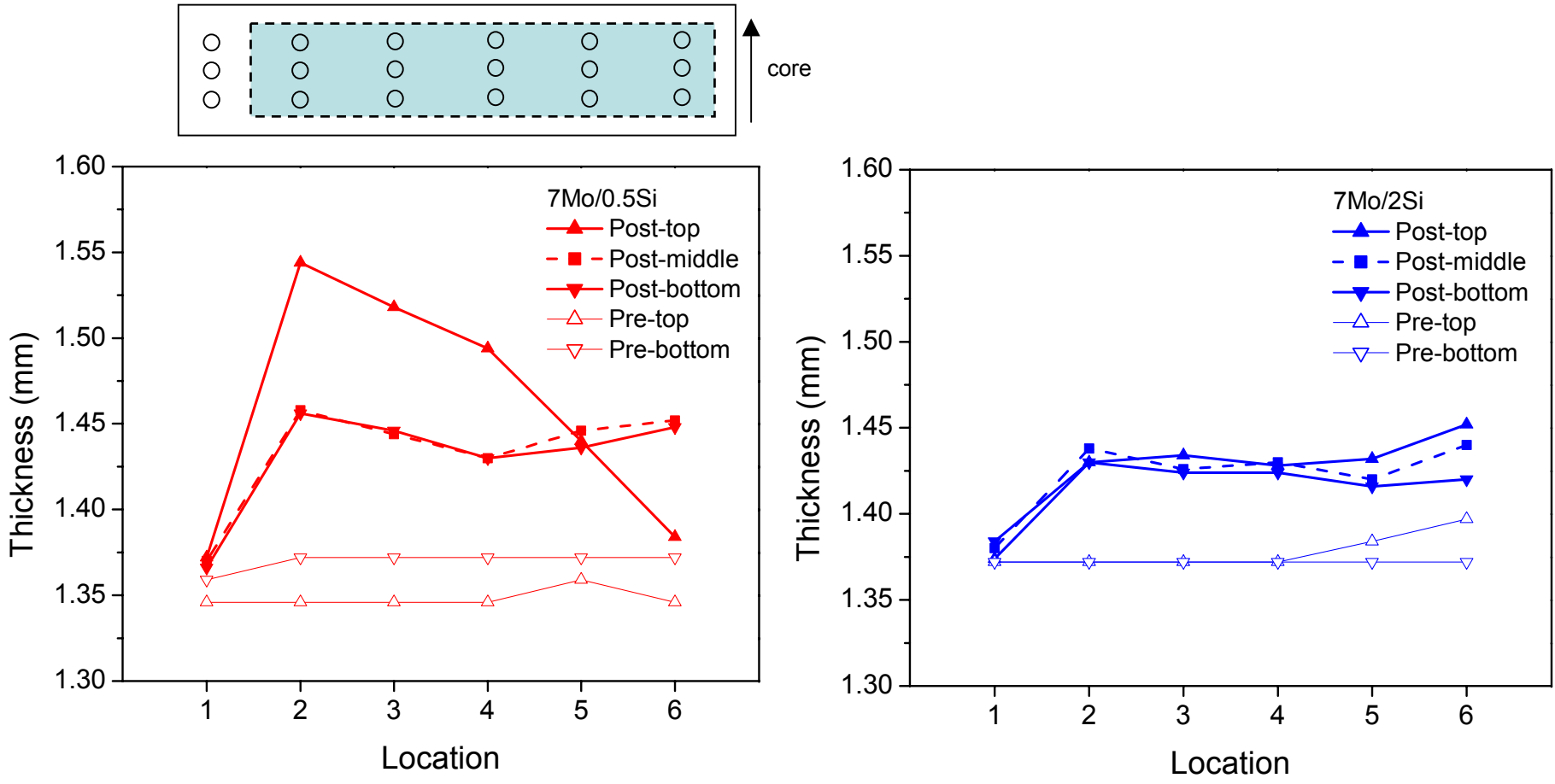


Fig. Axial thickness profiles of two RERTR-6 miniplates at 50% U-235 burnup, with low and high Si additions to the Al matrix.

Good News !

- The initial (non-destructive) PIE data, at ~ 50% burnup, from test RERTR-6 indicate that modest amount of Si (2-5 wt%) added to the Al matrix of U-7Mo dispersion fuel plates have a stabilizing effect on the swelling of the fuel plates.
- Whether, or to what extent, Si has eliminated the cause of unstable swelling, i.e. gross porosity formation in the U-Mo/Al interdiffusion zone, remains to be confirmed by metallographic examination of the RERTR-6 miniplates.