AN OVERALL ESTIMATOR TO ASSESS THE DEVELOPMENT OF VERY HIGH DENSITY FUELS FOR RESEARCH AND TEST REACTORS

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Why is needed an overall estimator?

- The development process to select adequate new very high density dispersed fuels to fulfil GTRI acceleration on RERTR program is facing some difficulties.
- Main candidates for standard MTR technology (U-Mo solid solution powder dispersed in Al powder, hot rolling process) decompose at grain boundary giving place to reaction phases which degrade the thermal regime.
- These degradation (in high fission rate – high temperature scenario) led to the appearance of huge porosity which determined the suspension or failure of several irradiation experiments

Why is needed an overall estimator?

- This situation remarks that in parallel to try to find a fix for the aforementioned problems, other very high density fuel candidates, ruled out from the very beginning, due to sub-optimal neutronic properties or to other early selection process, should be reconsidered.
- A given candidate might have good neutronic properties but it is needed that *all critical properties of the candidate are acceptable. No matter when, if failures appear, it would lead to discard the candidate at an advanced, time and resources consuming stage.*
- *To help to have an integral sight on these properties for an adequate alternative fuel selection an overall estimator is proposed*

CRITICAL PROPERTY: NEUTRONICS

- An estimator capable to depict the overall neutronic ability of a given fuel should reflect the U density and the loss of core excess reactivity (% $\Delta k/k$) due to parasite neutron capture cross section
- Following Bretscher et al, the most suitable one is the relative cycle length CL (on a standard conceptual experiment in a 10 MW reactor power, 3 x 3 fuel array, D2O moderation, central beryllium reflector). The normalization of such estimator is conventionally referred as a fraction of the greatest CL value (U5%Mo)
- So the relative cycle length as neutronic estimator will be chosen.

NEUTRONIC ESTIMATOR

DISPERSION FUELS RANKED BY RELATIVE CYCLE LENGTH (VF = 50%)

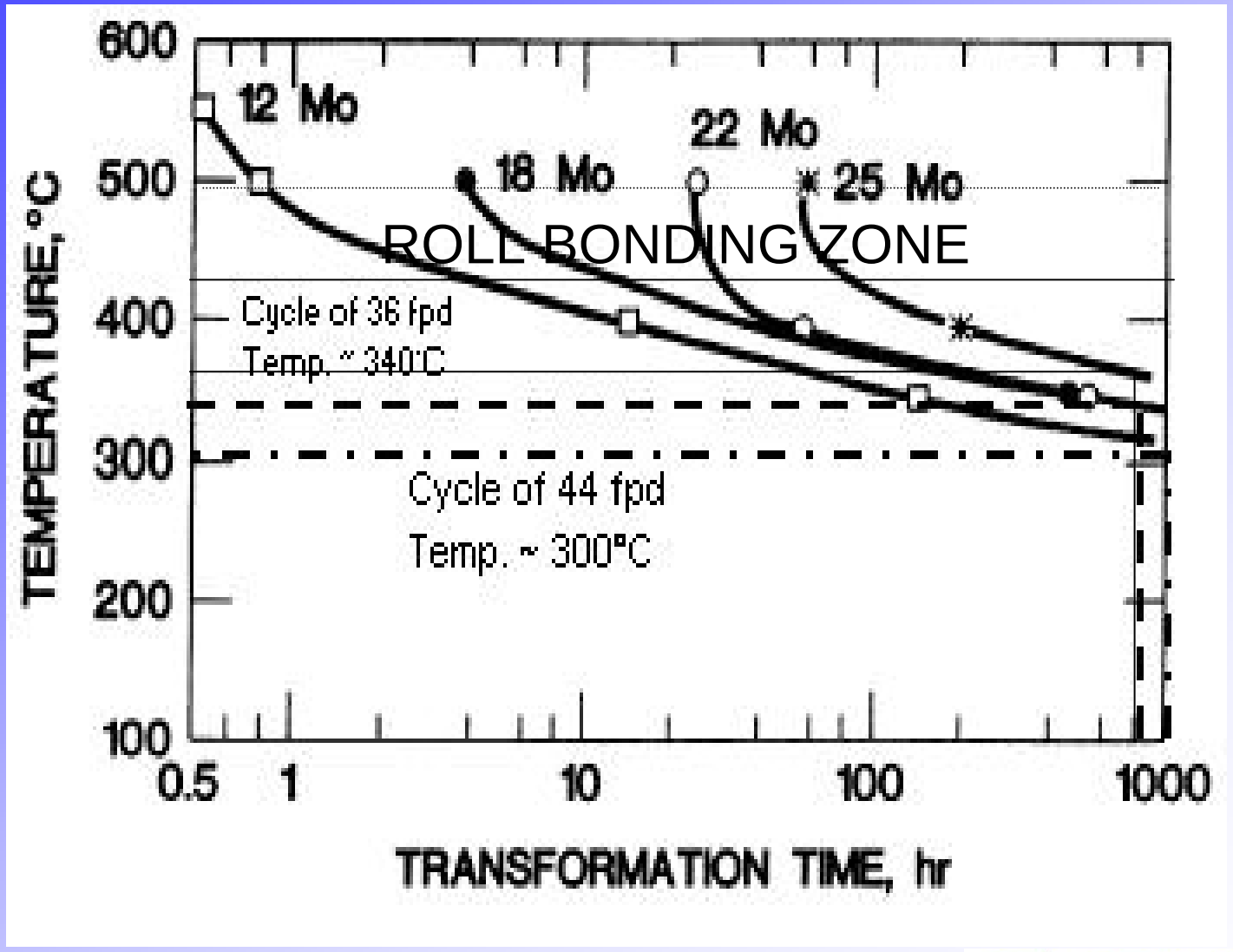
FUEL	ρ U g/cc	CL FPD's	Relative CL
U5%Mo	8.50	44.60	1.00
U4%Zr2%Nb	8.13	43.10	0.97
U6%Mo	8.31	42.50	0.95
U7%Mo	8.12	40.35	0.90
U9%Mo	7.74	36.1	0.81
U10%Mo	7.55	34.0	0.76
U3%Zr9%Nb	7.13	33.0	0.74
UN (100% TD)	6.75	26.5	0.59
U2Mo	6.9	25.6	0.57
UN (90% TD)	6.08	20.1	0.45
U3Si2	5.65	20.1	0.45

M. M. Brestcher, J. E. Matos, "Neutronic performance of high-density LEU fuels in water-moderated and water-reflected research reactors", ANL, July 1996

CRITICAL PROPERTY: PLATE DIMENSIONAL STABILITY UNDER IRRADIATION

- This property depends on the fuel structure in a twofold way:
  - an adequate fuel phase to restrain the swelling due to the fission products.
  - the retention of this phase along irradiation.
- The estimator to be selected for this second aspect must keep track of the decomposition process.
- To rank different fuels candidates, we propose as estimator the transition temperature at which the fuel candidates starts to decompose at grain boundary, using as time reference the cycle length that each fuel candidate is supposed to provide for a given nuclear service.

TRANSFORMATION TEMPERATURE OF U-Mo AT CL



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FUEL STRUCTURE STABILITY ESTIMATOR (10MW scenario)

FUEL	CL FPD's	Tt (ºC) FOR CL	Relative Tt
U5%Mo	44.60	300	0.50
U4%Zr2%Nb	43.10	NOT INCLUDED	-
U6%Mo	42.50	310	0.52
U7%Mo	40.35	320	0.53
U9%Mo	36.1	340	0.57
U10%Mo	34.0	360	0.60
U3%Zr9%Nb	33.0	NOT INCLUDED	-
UN (100% TD)	26.5	580	0.97
U2Mo	25.6	NOT INCLUDED	-
UN (90% TD)	20.1	580	0.97
U3Si2	20.1	600	1.00

J. P. Durand, P. Laudamy, K. Richter, "Preliminary developments of MTR plates with uranium nitride", XVII RERTR Meeting, Williamsburg, VA, USA, September 18-23, 1994

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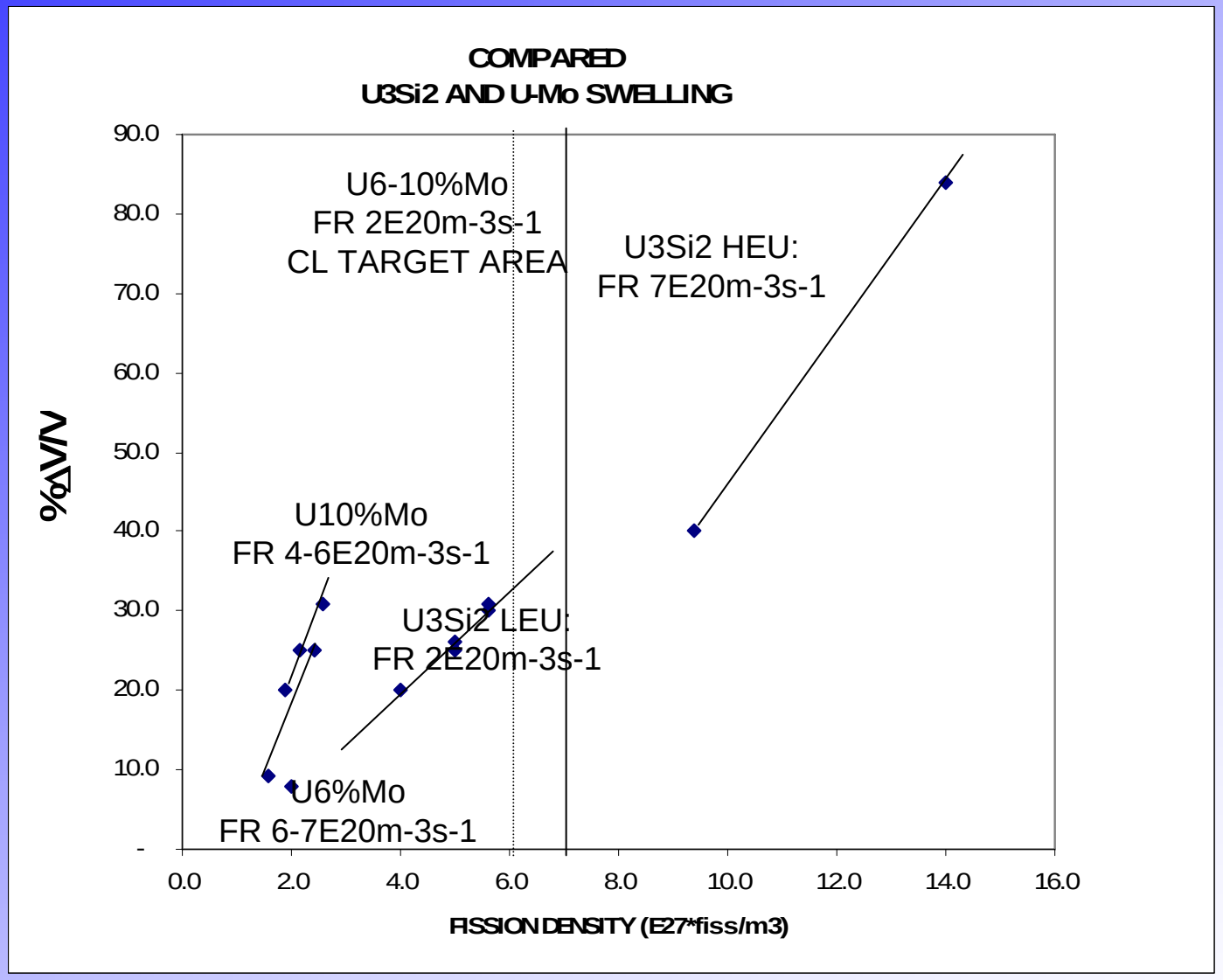
RESTRAIN OF FP SWELLING CAPABILITY

- It is not enough for a given fuel to have a higher transition temperature than other candidates, because it is decisive the kind of compounds it makes with the Al matrix (U3Si2 vs UMo case).
- How to quantify this property? As it is not easy to evaluate, we shall consider the behavior of the fuel particle, reacted or not.
- The estimator of the fuel candidate's structural capability for restrain fission product swelling should reflect the evolution of swelling along the irradiation, specially when gas bubble formation is the leading mechanism for swelling.
- The estimator proposed is the swelling gradient of the fuel candidate, after the knee point.

U_3Si_2 AND U6-10% SWELLING BEHAVIOR



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RERTR 3 SMALL FD EXPERIMENT

FUEL	FR (E20 m-3s-1)	%ΔV/V/FD (E-27m-3)	U3Si2 relative swelling slope
U5%Mo	NO DATA	NO DATA	-
U4%Zr2%Nb	NO DATA	NO DATA	-
U6%Mo	6.30	12.84	0.75
U7%Mo	FEW DATA	-	-
U9%Mo	NO DATA	NO DATA	-
U10%Mo	6.18	11.95	0.80
U3%Zr9%Nb	NO DATA	NO DATA	-
UN (100% TD)	NO DATA	NO DATA	-
U2Mo	NO DATA	NO DATA	-
UN (90% TD)	NO DATA	NO DATA	-
U3Si2	7.00	9.6	1.00

HIGH FR AND LARGE FD EXPERIMENTS

FUEL	FR (E20 m-3s-1)	%ΔV/V/FD (E-27m-3)	U3Si2 relative swelling slope
U5%Mo	NO DATA	NO DATA	-
U4%Zr2%Nb	NO DATA	NO DATA	-
U6%Mo	6.30	F	-
U7%Mo	FEW DATA	F	-
U9%Mo	NO DATA	NO DATA	-
U10%Mo	6.18	F	-
U3%Zr9%Nb	NO DATA	NO DATA	-
UN (100% TD)	NO DATA	NO DATA	-
U2Mo	NO DATA	NO DATA	-
UN (90% TD)	NO DATA	NO DATA	-
U3Si2	7.00	9.6	1.00

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OVERALL ESTIMATOR (GEOMETRIC MEAN) FOR SMALL FD SCENARIO

FUEL	Relative CL	Relative Tt	Relative swelling slope	Overall estimator
U5%Mo	1.00	0.50	-	-
U4%Zr2%Nb	0.97	-	-	-
U6%Mo	0.95	0.52	0.748	0.717
U7%Mo	0.90	0.53	-	-
U9%Mo	0.81	0.57	-	-
U10%Mo	0.76	0.60	0.803	0.716
U3%Zr9%Nb	0.74	-	-	-
UN (100% TD)	0.59	0.97	-	-
U2Mo	0.57	-	-	-
UN (90% TD)	0.45	0.97	-	-
U3Si2	0.45	1	1.00	0.767

OVERALL ESTIMATOR FOR HIGH FR AND LARGE FD SCENARIO

FUEL	Relative CL	Relative Tt	Relative swelling slope	Overall estimator
U5%Mo	1.00	0.50	-	-
U4%Zr2%Nb	0.97	-	-	-
U6%Mo	0.95	0.52	-	-
U7%Mo	0.90	0.53	-	-
U9%Mo	0.81	0.57	-	-
U10%Mo	0.76	0.60	-	-
U3%Zr9%Nb	0.74	-	-	-
UN (100% TD)	0.59	0.97	-	-
U2Mo	0.57	-	-	-
UN (90% TD)	0.45	0.97	-	-
U3Si2	0.45	1	1.00	0.767

CONCLUSIONS

- An overall estimator, comprising and quantifying several critical properties, was proposed.
- The poor amount of data reflects the lack of alternatives for fuel candidates, specially for high FR large FD scenario.
- Standard roll bonding technology applied to U-Mo fuel with standard matrix seems to fail to provide VHD solutions for most important scenarios.
- The RERTR program should consider the development of alternative fallback options.