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HIGH DENSITY DISPERSION FUEL

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A fuel development campaign that results in an aluminum plate-type fuel of unlimited LEU burnup capability with an uranium loading of 9 grams per cm^3 of meat (while at the same time meeting required homogeneity and formability criteria) should be considered an unqualified success. To put this goal in perspective, our current worldwide approved and accepted highest loading is 4.8 g cm^{-3} with U_3Si_2 as fuel. This fuel compound has excellent radiation performance to full ^{235}U burnup, but its modest density limits application for very high loadings.

The 4.8 g cm^{-3} loading corresponds to approximately 43 vol % U_3Si_2 in the meat which is, with conventional rolling techniques, an upper limit for commercial fabrication.

Recently several fabricators have reported satisfactory yields with up to 53 vol % U_3Si_2 achieved through optimized fabrication procedures. Assuming that these new processes prove commercially viable, we have now an upper limit of 6 g cm^{-3} with a proven fuel compound. Or in other words we are a factor of 1.5 short of our 9 g cm^{-3} goal. We can not expect to increase the fuel volume fraction significantly, if at all, beyond 53%. Thus our only hope lies in finding a much-higher-density fuel than U_3Si_2 with, however, similar characteristics such as fabricability, compatibility with aluminum, and stable irradiation behavior.

High-density uranium compounds are listed in Table 1 with, for comparison, U_3Si_2 and an older stable fuel, UAl_2. Many of these compounds offer no real density advantage over U_3Si_2 and have less desirable fabrication and performance characteristics as well. Of the higher-density compounds, U_3Si has approximately a 30% higher uranium density but the density of the U_6X compounds would yield the factor 1.5 needed to achieve 9 g cm^{-3} uranium loading.

Unfortunately, irradiation tests proved these peritectic compounds as a group to have poor swelling behavior, as shown in Fig. 1. The high swelling rate of these compounds is associated with fission-induced amorphization, and, unless we can find a way to stabilize these compounds without reducing their density, it must be concluded that intermetallic compounds are not going to get us to our 9 g cm^{-3} goal. It is for this reason that we are turning to uranium alloys. The obvious question is, why not use pure uranium, for this would clearly result in the highest possible loading. The reason pure uranium was not seriously considered as a dispersion fuel is mainly due to its high rate of growth and swelling at low temperatures. This problem was solved at least for relatively low burnup application in non-dispersion fuel elements with small (a few hundred ppm) additions of Si, Fe, and Al. This so called adjusted uranium has nearly the same density as pure α-uranium and it seems prudent to reconsider this

alloy as a dispersant.

Further modifications of uranium metal to achieve higher burnup swelling stability involve stabilization of the cubic γ phase at low temperatures where normally α phase exists. Several low neutron capture cross section elements such as Zr, Nb, Ti and Mo accomplish this in various degrees. As shown in Fig. 2, combinations of Nb-Zr and Mo by itself appear most effective. The density of some of these alloys are given in Table II showing that U-5Mo is equivalent in density with the aforementioned U_6X compounds. Alloys around this composition, as well as the lower U-NbZr alloys, would meet our high loading requirements. The challenge is to produce a suitable form of fuel powder and develop a plate fabrication procedure, as well as obtain high burnup capability through irradiation testing.

In summary, as in the case of any new fuel development effort, there is no guarantee that we will reach our goal but we have enough promising options to hope for a high probability of success.

Table I. Nominal Density, Uranium Content and Melting Point of Uranium Compounds

Compound	Density, g cm^{-3}	U-Density g cm^{-3}	Melting Point, °C
UO_2	10.9	9.7	2750
U_4O_9	11.2	9.7	a
UC	13.6	13.0	2400
UN	14.3	13.5	2650
UAl_2	8.1	6.6	1590
U_3Si_2	12.2	11.3	1650
U_3Si	15.4	14.8	930[b]
U_6Ni	17.6	16.9	790[c]
U_6Fe	17.7	17.0	815[c]
U_6Mn	17.8	17.0	725[c]

a. Transforms to UO_2 at high temperatures
b. Peritectoid temperature
c. Peritectic temperature

Table II. Density, Uranium Content and Melting Point Of γ Stabilized Uranium Alloys

Alloy W. %	Density, g cm	U-Density, g cm^{-3}	Melting Point, °C
U	19.0	19.0	1135
U-2Mo	18.5	18.1	1135
U-5Mo	17.9	17.0	1135
U-6.5Mo	17.5	16.4	1135
U-8Mo	17.3	15.9	1135
U-9Mo	17.0	15.5	1160
U-4Zr-2Nb	17.3	16.2	1160
U-6Zr-41Nb	16.4	15.8	1160
U-7Nb	17.0	15.0	1160
U-10Zr	16.0	14.4	1160

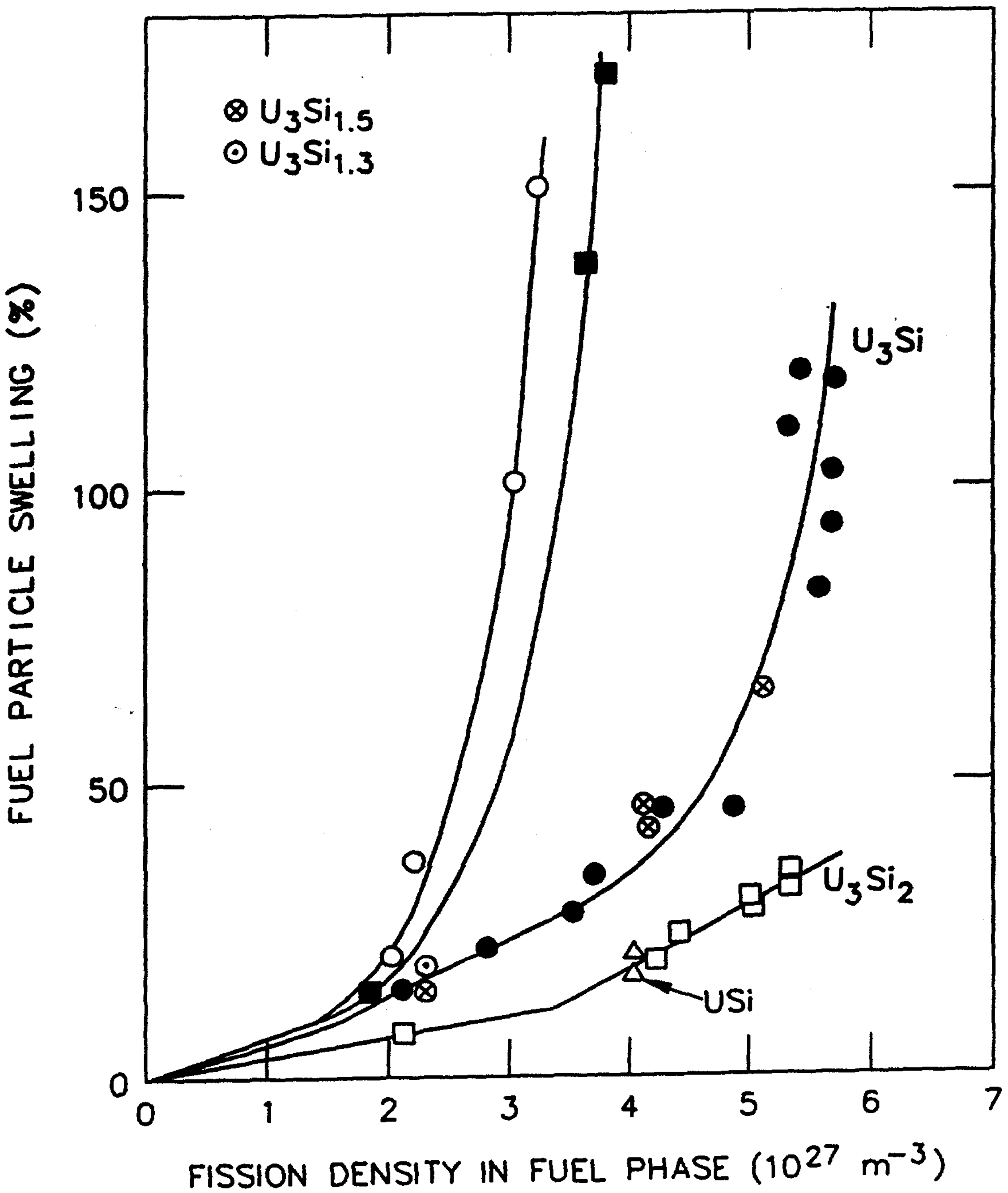

Fig. 1. Swelling of LEU fuel particles in experimental aluminum dispersion fuel plates irradiated in the ORR.

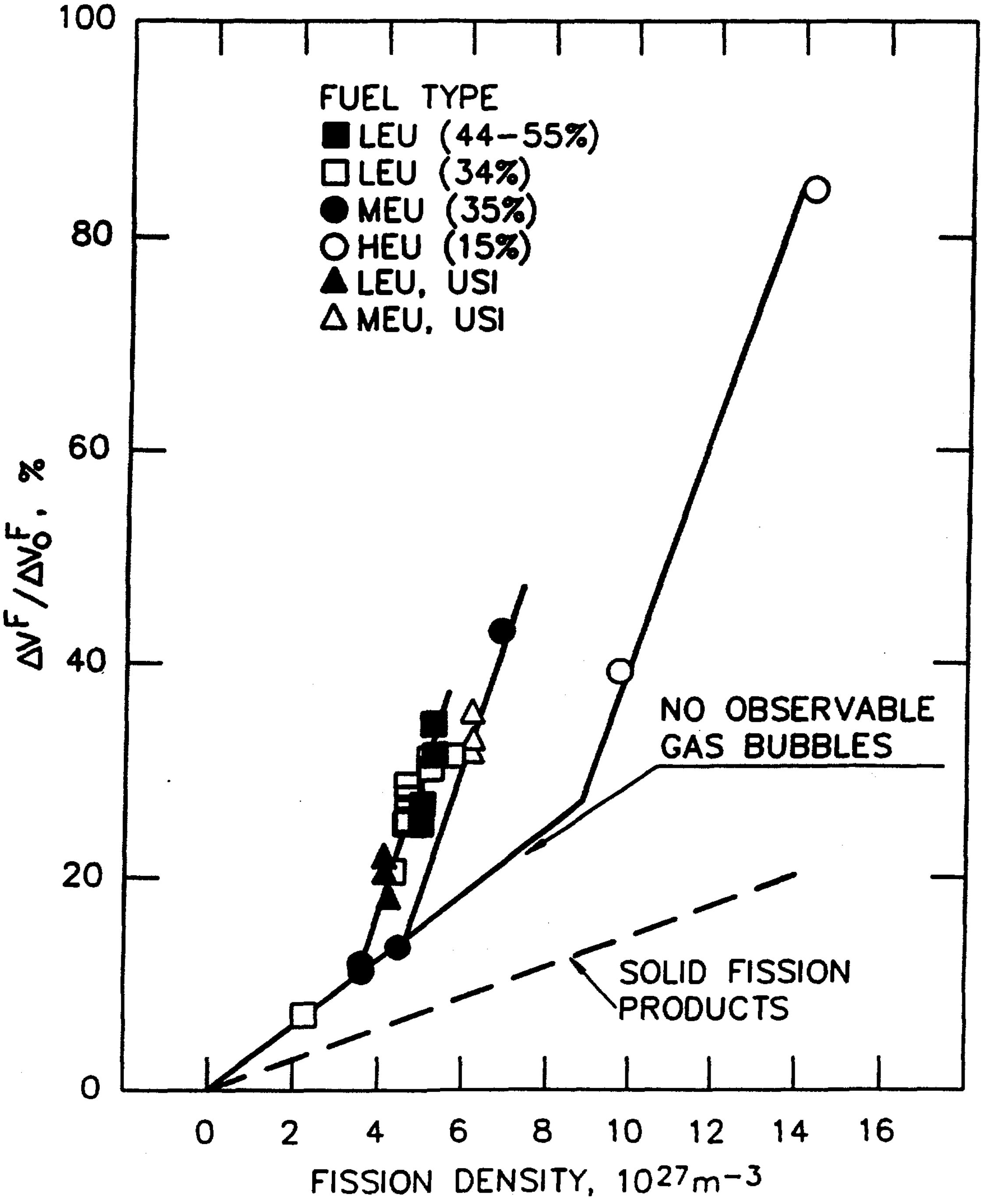

Fig. 2. Swelling of U_3Si_2 of various enrichment and fuel dispersion loadings as a function of fission density (USi data included).