ANL/ET/CP-94022
CONF-971125--

DART MODEL FOR IRRADIATION-INDUCED SWELLING OF DISPERSION FUEL ELEMENTS INCLUDING ALUMINUM-FUEL INTERACTION*

J. Rest and G. L. Hofman
Argonne National Laboratory
Argonne, IL 60439

June 1997

Submitted to the ANS 1997 Winter Meeting, Albuquerque, NM, Nov. 16-20, 1997.

*Work supported by the U.S. Department of Energy, Office of Arms Control and Nonproliferation, under Contract W-31-109-Eng-38.

DISCLAIMER

DISCLAIMER

DART MODEL FOR IRRADIATION - INDUCED SWELLING OF DISPERSION FUEL ELEMENTS INCLUDING ALUMINUM-FUEL INTERACTION

J. Rest and G. L. Hofman
Argonne National Laboratory
Argonne, Illinois USA

Summary

The Dispersion Analysis Research Tool, DART (1), contains models for fission-gas induced fuel swelling, interaction of fuel with the matrix aluminum, for the resultant reaction-product swelling, and for the calculation of the stress gradient within the fuel particle. The effects of an aluminide shell on fuel particle swelling are evaluated. Validation of the model is demonstrated by a comparison of DART calculations of fuel swelling of U_3SiAl-Al and U_3Si_2-Al for various dispersion fuel element designs with the data.

Figure 1 shows DART results compared with data for fuel swelling of U_3SiAl-Al in plate, tube, and rod configurations [2] as a function of fission density. The plate and tube calculations were performed at a constant fuel temperature of 373 K, and 518 K, respectively. An irradiation temperature of 518 K results in a calculated aluminide layer thickness for the Russian tube that is in the center of the measured range (16 μm) [3]. The rod calculations were performed with a temperature gradient across the rod characterized by surface and central temperatures of 373 K and 423 K, respectively. The effective yield stress of irradiated Al matrix material and the aluminide was determined by comparing the results of DART calculations with postirradiation immersion volume measurement of U_3SiAl plates (shown by the closed circles in Fig. 1). These values for the effective yield stress were then used in all subsequent simulations.

The lower calculated fuel swelling in the rod-type element is due to an assumed biaxial stress state as compared with an assumed uniaxial stress state for the plate and thin-walled tube geometry. Fuel swelling in plates results in plate thickness increase only, while plate width and length remain virtually unchanged. Likewise, in tubes, only the wall thickness increases and the overall diameter remains unchanged. Irradiation experiments have shown that plate-type dispersion fuel elements can develop blisters or pillows at high ^{235}U burnup when fuel compounds exhibiting breakaway swelling, such as U_3SiAl and U_3Si, are used at moderate-to-high fuel volume fractions. The U_3SiAl plate data shown in Fig. 1 exhibits this behavior at fission densities above about ~5 x 10^{27} m^{-3}.

Submitted to the ANS 1997 Winter Meeting, Albuquerque, NM, Nov. 16-20, 1997

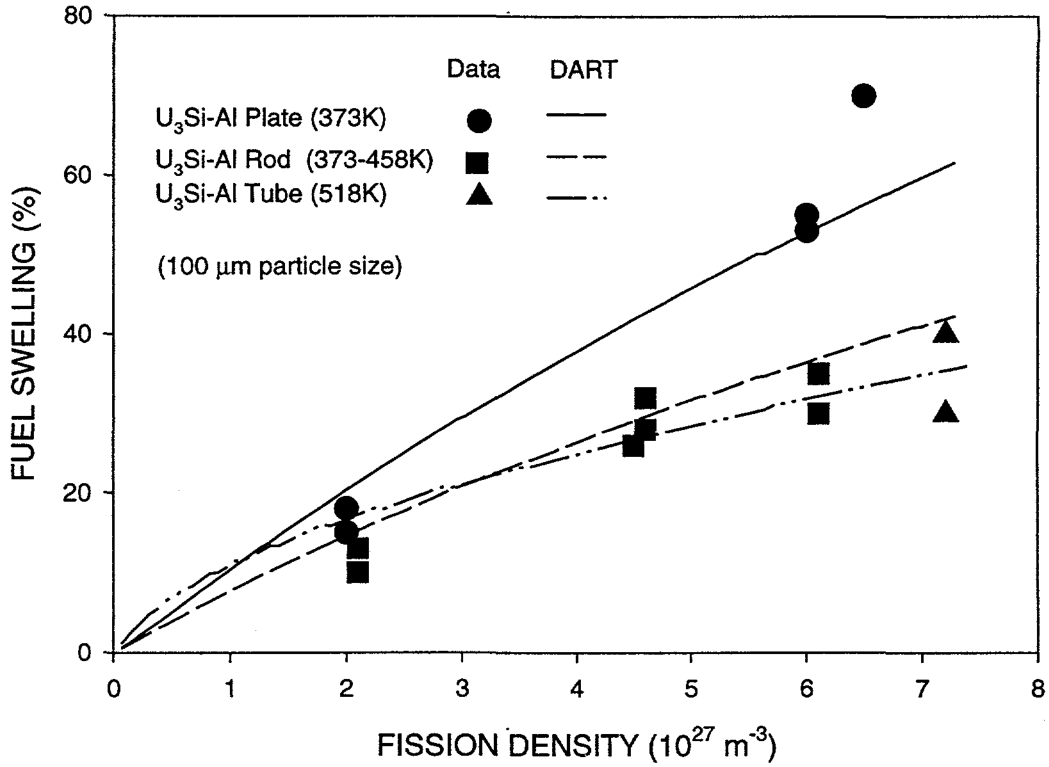

Fig. 1 DART results for swelling of U_3SiAl-Al in plate, tube, and rod configurations as a function of fission density compared with data

The formation of the aluminide reaction-product layer results in decreased fuel-particle swelling rates due to increased stresses provided by the "stronger" aluminide shell. The calculated swelling of the Russian tube "looks" like the calculated rod swelling due to additional restraint provided by an increased reaction-layer thickness resulting from the irradiation at a substantially higher temperature than the plate irradiations. Again, the fuel rods exhibit lower values of swelling than the plates because of the greater restraint imposed by the rod configuration.

Results of DART calculations for low-enriched (LEU) U_3Si_2-Al fuel plates as a function of fission density are compared with irradiation data in Fig. 2.

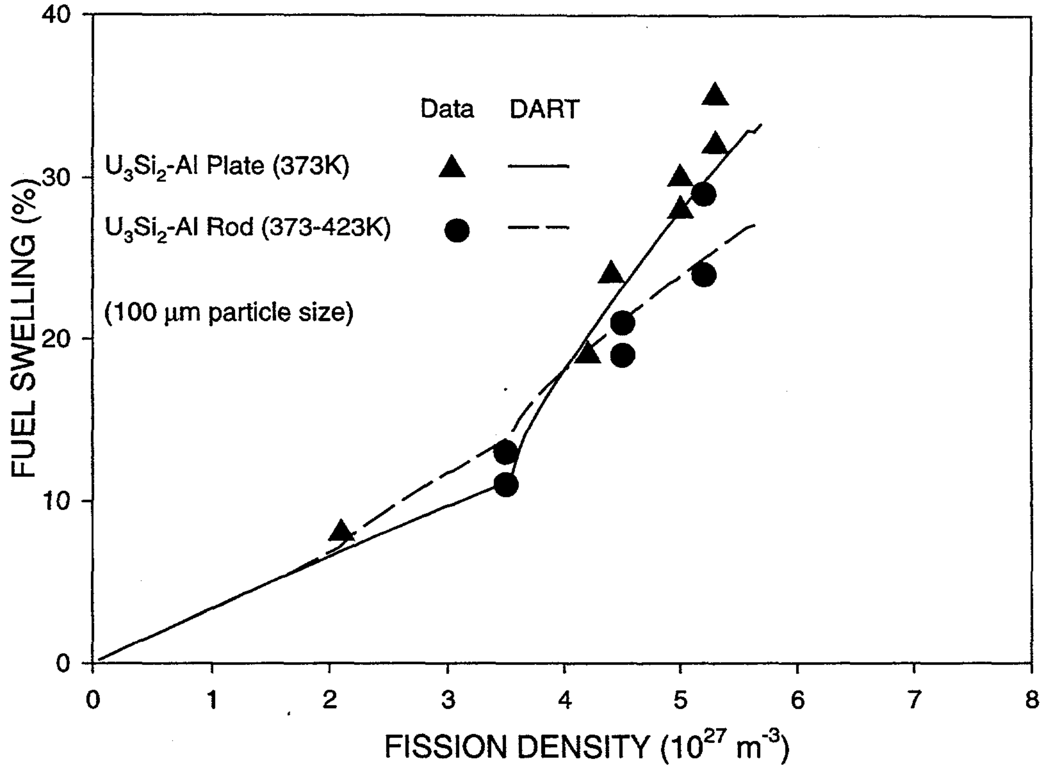

Fig. 2 DART-calculated results for fuel particle swelling of low-enriched U_3Si_2-Al fuel plates and rods as a function of fission density

The calculated values shown in Fig. 2 indicate that irradiation-induced recrystallization occurred at ~3.5 x 10^{27} m^{-3}. After recrystallization occurs, the gas-atom diffusion to the grain boundaries, bubble nucleation, and accelerated growth (relative to that of bubbles in the bulk material) result in an increased swelling rate, as shown in Fig. 2. Again, the fuel rods exhibit lower values of swelling than the plates because of the greater restraint imposed by the rod configuration.

The DART-calculated interaction layer thickness and fuel swelling for the U3Si-Al plates, rods, and tubes, and for the U3Si2-Al plates and rods follow the trends of the observations

REFERENCES

1. J. Rest, "The DART Dispersion Analysis Research Tool: A Mechanistic Model for Predicting Fission-Product-Induced Swelling of Aluminum Dispersion Fuels," ANL-95/36, Argonne National Laboratory (August, 1995).

2. D. F. Sears, "The Development and Irradiation Testing of Al-U_3Si_2 fuel at Chalk River," Proceedings of the 14th International Meeting on Reduced Enrichment for Research and Test Reactors, Jakarta, Indonesia, November 4-7, 1991, pp. 175-186 (1995).

3. A. V. Vatulin, "Behavior Analysis of U_3Si - Al fuel in MR type fuel elements under irradiation," Presented at the 1996 International Meeting on Reduced Enrichment for Research and Test Reactors, October 7-10, 1996, Seoul, South Korea.