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FUEL-PIN CLADDING TRANSIENT FAILURE STRAIN CRITERION

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A criterion for cladding failure based on accumulated strain was developed for mixed uranium-plutonium oxide fuel pins and used to interpret the calculated strain results from failed transient fuel pin experiments conducted in the Transient Reactor Test (TREAT) facility. The new STRAIN criterion replaced a stress-based criterion that depends on the DORN parameter(1,2) and that incorrectly predicted fuel pin failure for transient tested fuel pins. This paper describes the STRAIN criterion and compares its prediction with those of the stress-based criterion.

The STRAIN criterion for cladding failure depends on cladding fluence, rate of temperature change and temperature and was based on postirradiated fuel cladding transient tests (FCTT)(1) results on fuel column cladding. The cladding STRAIN criterion is composed of five parts, which are defined as the unirradiated uniform failure strain (ε_{UNI}), the irradiated strain (ε_{IRR}), the minimum strain (ε_{MIN}), the failure strain (ε_{FAIL}), and the strain life fraction (SLF). The unirradiated failure strain correlation was based on unirradiated 20% CW 316 SS cladding tests at 5.6 K/s and 111 K/s temperature ramp rates. Post-test ductility measurements were taken at 0° and 90° orientations along the entire uniformly-heated section of the specimen, disregarding the gross deformation closest to the breach location. These measurements were termed the "uniform failure strain." The unirradiated strain (ε_{UNI}) equation depends on failure temperature and temperature ramp rate only and is presented in Figure 1. Predicted and measured failure strains are shown in Figure 1 for unirradiated 20% CW type 316 SS cladding at 5.6 K/s ramp rate. The strain irradiation fluence dependence was determined by multiplying the unirradiated correlation (ε_{IRR}) by a factor to account for the loss of ductility due to irradiation. The minimum strain to failure at all temperature and fluence conditions (ε_{MIN}), is introduced to account for the

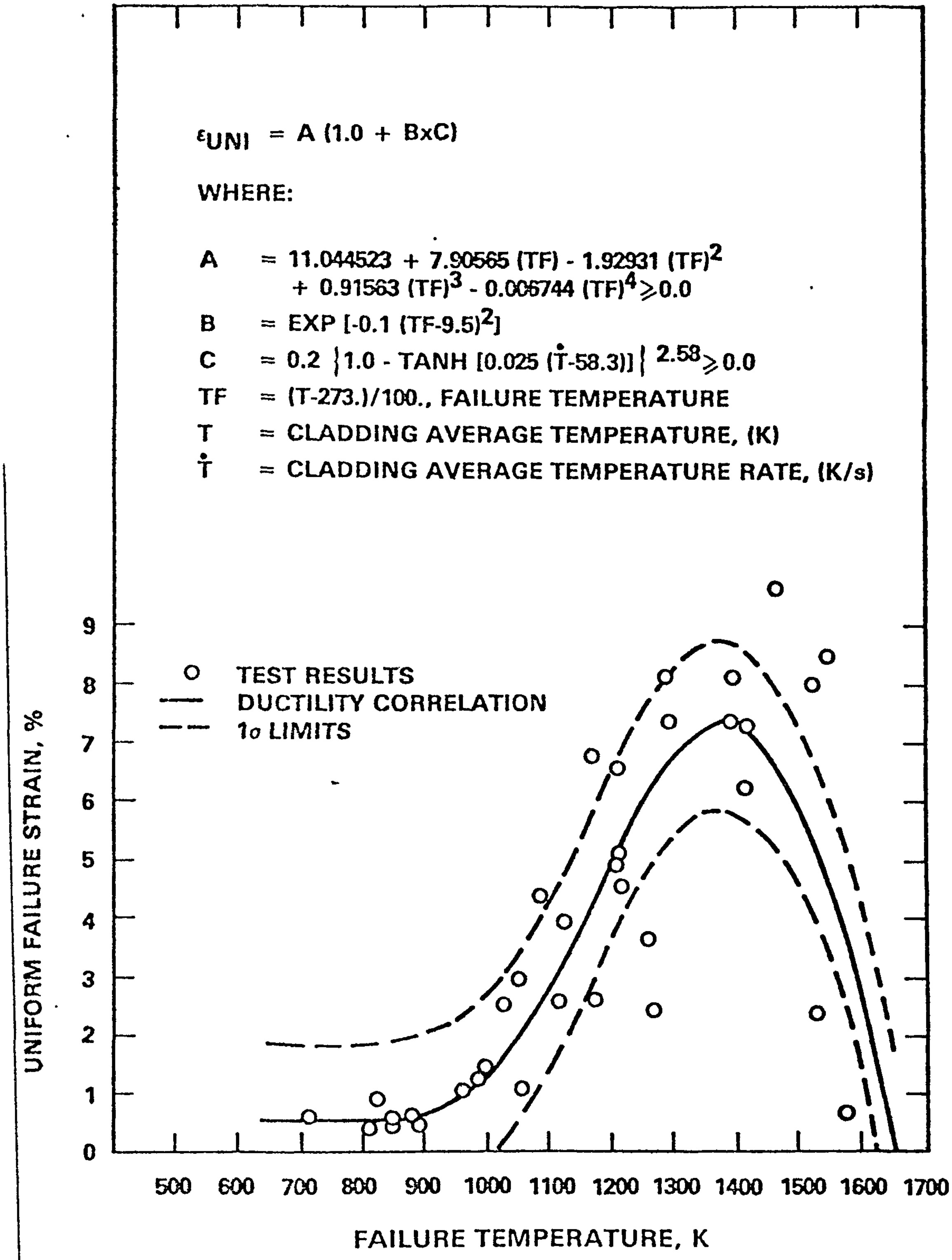

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FIGURE 1. Transient Burst Ductility of Unirradiated 20% CW 316 SS Cladding at 5.6 K/s Ramp Rate.

difference between fuel cladding mechanical interaction loading and the gas pressure FCTT results, as shown by the mandrel loading tests,(3) and was defined as a function of the maximum temperature ramp rate during the transient event; both the minimum strain and fluence dependence are incorporated in the curves presented in Figure 2. The failure strain is determined by taking the greater of the irradiated strain and the minimum strain, i.e., $\varepsilon_{FAIL} = \text{AMAX1}\ (\varepsilon_{IRR}, \varepsilon_{MIN})$ where AMAX1 represents the maximum value. Figure 2 shows the failure strain correlation as function of fluence and temperature at a heating rate of 5.6 K/s. The last part of the STRAIN criterion is the strain life fraction part, which is the summation of calculated plastic strain increments ($\Delta\varepsilon_p$) divided by the corresponding failure strain, i.e., $SLF = \sum (\Delta\varepsilon_p/\varepsilon_{FAIL})$.

The above STRAIN correlation is suitable for cumulative damage calculations. It was programmed into the Westinghouse Hanford version of the LAFM(4) fuel pin transient performance code and was used to analyze TREAT tests HUT 1-6A and HOP 1-6A.(5) Both tests used high burnup (110 WWd/kg) EBR-II irradiated WSA-3 pins and were performed in MARK-IIC sodium loops in the TREAT reactor. The three fuel pins in the HUT 1-6A experiment underwent an undercooling condition without failure in which cladding loading occurred only by the plenum fission gas pressure of 4.8 MPa with no additional fuel-cladding mechanical interaction (FCMI). The hottest pin, W-3-14, reached a maximum midwall cladding temperature of 975°C. The standard stress-based criterion utilizing the DORN parameter(1,5) predicted failure for all three unfailed fuel pins, while the STRAIN criterion did not predict failure for these pins. Two consecutive slow 3¢/s overpower events terminated at 25% overpower were applied to the three fuel pins in the HOP 1-6A experiment. Maximum cladding temperatures were 563°C during the first power ramp and 545°C during the second power ramp. Both criteria predicted failure in the high power fuel pin and no failure in the other two fuel pins. However, the DORN based criterion predicted failure at an axial relative position (X/L) of 0.7, whereas the STRAIN criterion correctly predicted the failure site (X/L = 0.5). This comparison demonstrates the applicability of the STRAIN

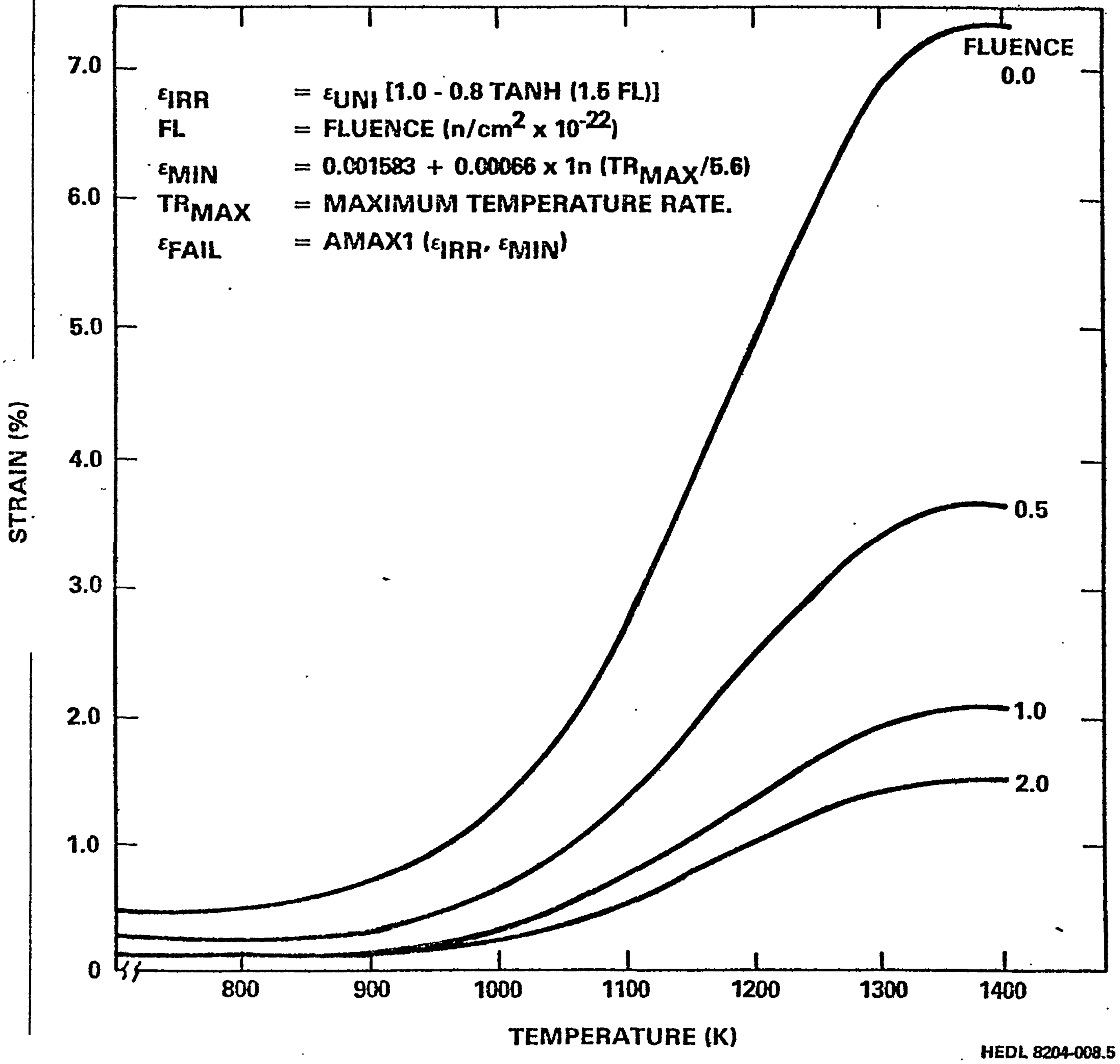

FIGURE 2. Failure Strain Correlation as Function of Fluence and Temperature at 5.6 K/s.

criterion for prediction of in-reactor fuel pin cladding response during both undercooling and overpower events. The temperature, heating rate and fluence dependence, determined in FCTT tests, provided a solid basis for the criterion in predicting failure in TREAT tested fuel pins.

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