HEDL-SA-862

HEDL EXPERIMENTAL TRANSIENT OVERPOWER PROGRAM

CONF-761001--38

By

T. Hikido and G. E. Culley

Fuels Safety
Fuels and Controls

March 16, 1976

For presentation to the International Meeting on Reactor Safety and Related Physics to be held in Chicago, Illinois, October 5-8, 1976.

HANFORD ENGINEERING DEVELOPMENT LABORATORY
Richland, Washington
operated by
WESTINGHOUSE HANFORD COMPANY
A SUBSIDIARY OF Westinghouse Electric Corporation
for the
UNITED STATES ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
UNDER CONTRACT E(45-1)-2170

ABSTRACT

HEDL is conducting a series of experiments to evaluate the performance of Fast Flux Test Facility (FFTF) prototypic fuel pins up to the point of cladding breach. A primary objective of the program is to demonstrate the adequacy of fuel pin and Plant Protective System (PPS) designs for terminated transients. Transient tests of prototypic FFTF fuel pins previously irradiated in the Experimental Breeder Reactor-II (EBR-II) have demonstrated the adequacy of the PPS and fuel pin designs and indicate that a very substantial margin exists between PPS-terminated transients and that required to produce fuel pin cladding failure. Additional experiments are planned to extend the data base to high burnup, high fluence fuel pin specimens.

HEDL EXPERIMENTAL TRANSIENT OVERPOWER PROGRAM

T. Hikido and G. E. Culley

HEDL is conducting an experimental transient testing program to evaluate the performance of Fast Flux Test Facility (FFTF) prototypic fuel pins up to the point of cladding breach. Primary objectives of the program are to:

- Demonstrate adequacy of fuel pin and Plant Protective System (PPS) designs for terminated transients,
- Determine fuel pin cladding failure thresholds,
- Define fuel pin cladding failure mechanisms, conditions and characteristics,
- Develop analytic models for fuel pin transient performance prediction.

This paper summarizes results of the HEDL/Fuels Engineering Proof Test (HOP) and the transient overpower test (HUT) experiments conducted to date. A related paper by C. W. Hunter and G. D. Johnson describes cladding failure characteristics observed in recent Fuel Cladding Transient Tester (FCTT) Laboratory Experiments.[1]

HOP Series

Transient tests of prototypic FFTF fuel pins previously irradiated in the Experimental Breeder Reactor-II (EBR-II) are being conducted to evaluate fuel pin performance during postulated FFTF accident transients terminated by the PPS.

The design criteria for extremely unlikely faults (i.e., extremely low probability conditions that are not expected during the plant lifetime) is that in-place coolable geometry be maintained. A hypothetical 3$/sec reactivity insertion was defined as the limiting excursion for which the PPS must maintain the coolable geometry.

The fuel pins used in these tests operated at ∿11 kW/ft peak power to burnups ranging from 7,000 to 42,000 MWd/MTM in the EBR-II. The fuel pins were subjected to shaped transients designed to obtain the thermal equivalent of a PPS terminated FFTF hypothetical 3$/sec transient in the Transient Reactor Test (TREAT) facility. Experiment results are summarized in Table 1. Data analyses showed the energy input to the fuel pins was within ∿5% of desired for HOP 3-1A and 3-3B and ∿25% greater than required for HOP 3-2A and 3-2B.

TABLE 1

SUMMARY OF HOP TEST RESULTS

Experiment	Design Peak Temp. at Midplane		Actual Peak Temp. at Midplane		Peak Cladding Incremental
	Fuel V. Av.	Cladding Mid.	Fuel V. A.	Cladding Mid.	strain, %
HOP 3-3B	1750°C	550°C	1740°C	540°C	0
3-1A	1990	550	1980	590	0
3-2A	1950	650	2370	800	0.4
3-2B	1830	630	2070	720	0.4

* Temperature difference between the peak transient overpower temperature and that experienced during steady-state operation in the EBR-II

Fuel pin cladding did not breach even under the more severe HOP 3-2A and 3-2B test conditions. A comparison of pretransient and post-transient diameter measurements showed no detectable incremental cladding deformation of the HOP 3-1A and 3-3B pins and only 0.4% diameter increase for the HOP 3-2A and 3-2B pins. Figure 1 compares fuel microstructure at the axial midplane for the sibling (non-transient tested) pin and transient tested fuel pin for the HOP 3-3B test which is typical of the results obtained; i.e., effects of the transient on the fuel microstructure were not discernible.

TABLE 2

SUMMARY OF HUT TEST RESULTS

Test	Steady State Pin Power kW/ft	Ramp Rate	T_{Clad}^{Max}	Incremental Cladding Strain, % Ave	Max	Pin Failed?	Transient Gas Release, %	Areal Fuel Melt, Fraction %
HUT 5-3A	8.8	50¢/sec	1515	--	--	Yes	30	47*
HUT 5-5A	5.6	50¢/sec	1400	0.1	0.24	No	15	31
HUT 5-1A	12.4	50¢/sec	1550	0.22	0.55	No	4	55
HUT 3-3A	8.9	3$/sec	1450	0.5	0.56	No	9	50
HUT 3-5A	6.1	3$/sec	1575	0.5	0.6	No	5	0
HUT 5-5B	5.7	50¢/sec	1715	--	--	Yes	8	49*
HUT 3-1A	12.2	3$/sec	1525	--	--	Yes	25	73*
HUT 3-5B	12.2	3$/sec	1635	0.4	--	Yes	15	61*
HUT 5-1B	5.8	50¢/sec	1680	--	--	Yes	30	65*

*Calculated; at failure.

Analyses of these experiments show that the PPS will not only maintain a coolable geometry as required for this limiting event but will prevent loss of cladding integrity. Adequacy of the PPS and fuel pin designs was thereby demonstrated to confine fuel pin transient overpower damage within the design criteria envelope.(2)

HUT Series

The regime of fuel behavior between PPS-terminated transients and cladding failure is relevant to characterization of failure thresholds and failure mechanisms and is extremely important to the development and correlation of suitable analytic models to be used in reactor Safety Analysis. It is this area to which the HUT series tests are focused. The initial tests used fuel pins previously irradiated in the EBR-II at three power levels to evaluate the effect of steady state power (i.e., fuel microstructure) on fuel pin cladding failure thresholds.(3)

The fuel pins used in these tests operated at individual peak power levels from ≈6 kW/ft to ≈12 kW/ft to a burnup of ≈50 MWd/kg. The fuel pins were subjected to shaped transients designed to obtain the thermal equivalent of FFTF hypothetical 50¢/sec and 3$/sec transients not terminated by the PPS. The TREAT transients were terminated at the estimated time of fuel pin cladding failure. Five of the nine fuel pins achieved cladding failure. Results (calculated and observed) are summarized in Table 2.

Of particular interest is the transient performance of the fuel pins irradiated at low power in the EBR-II, specifically HUT 5-5A and HUT 3-5A. A peak incremental cladding strain of ≈0.22%, and a fuel areal melt fraction of ≈30% were observed in the HUT 5-5A experiment, but the fuel pin cladding did not fail. An incremental cladding strain of ≈0.6% was observed for the HUT 3-5A experiment and the fuel pin cladding did not fail. A comparison of fuel microstructures at the axial midplane for the HUT 5-5A and HUT 3-5A fuel pins and their sibling pin are given in Figures 2 and 3. Results were contrary to what was expected of low power, "gassy"*, fuel

*"gassy" fuel refers to the relatively hign retained fission gas content of low power fuel as compared to high power fuel.

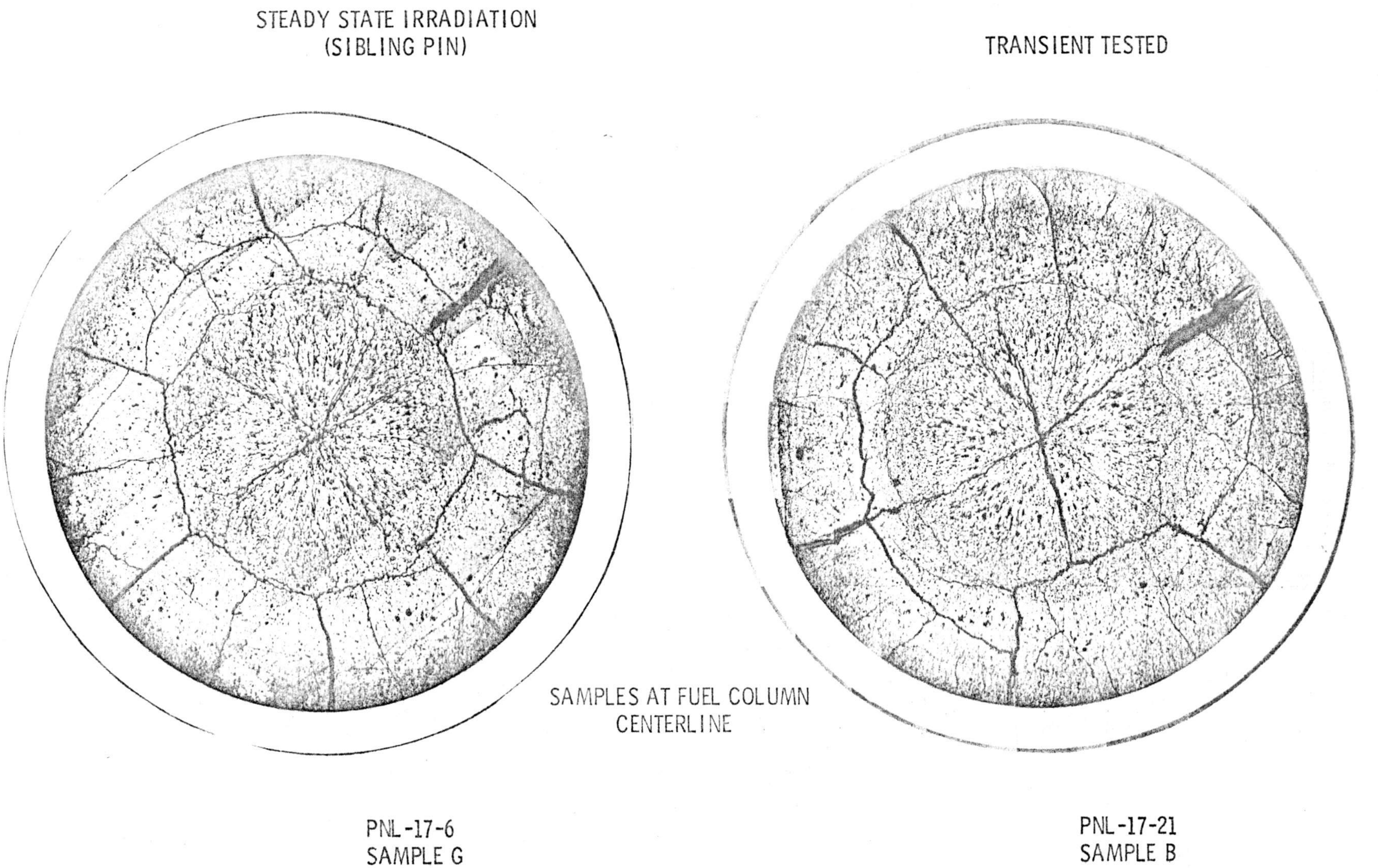

FIGURE 1. Comparison of Fuel Microstructure at the Axial Midplane for the Sibling and Transient Tested Fuel Pins (HOP 3-3B).

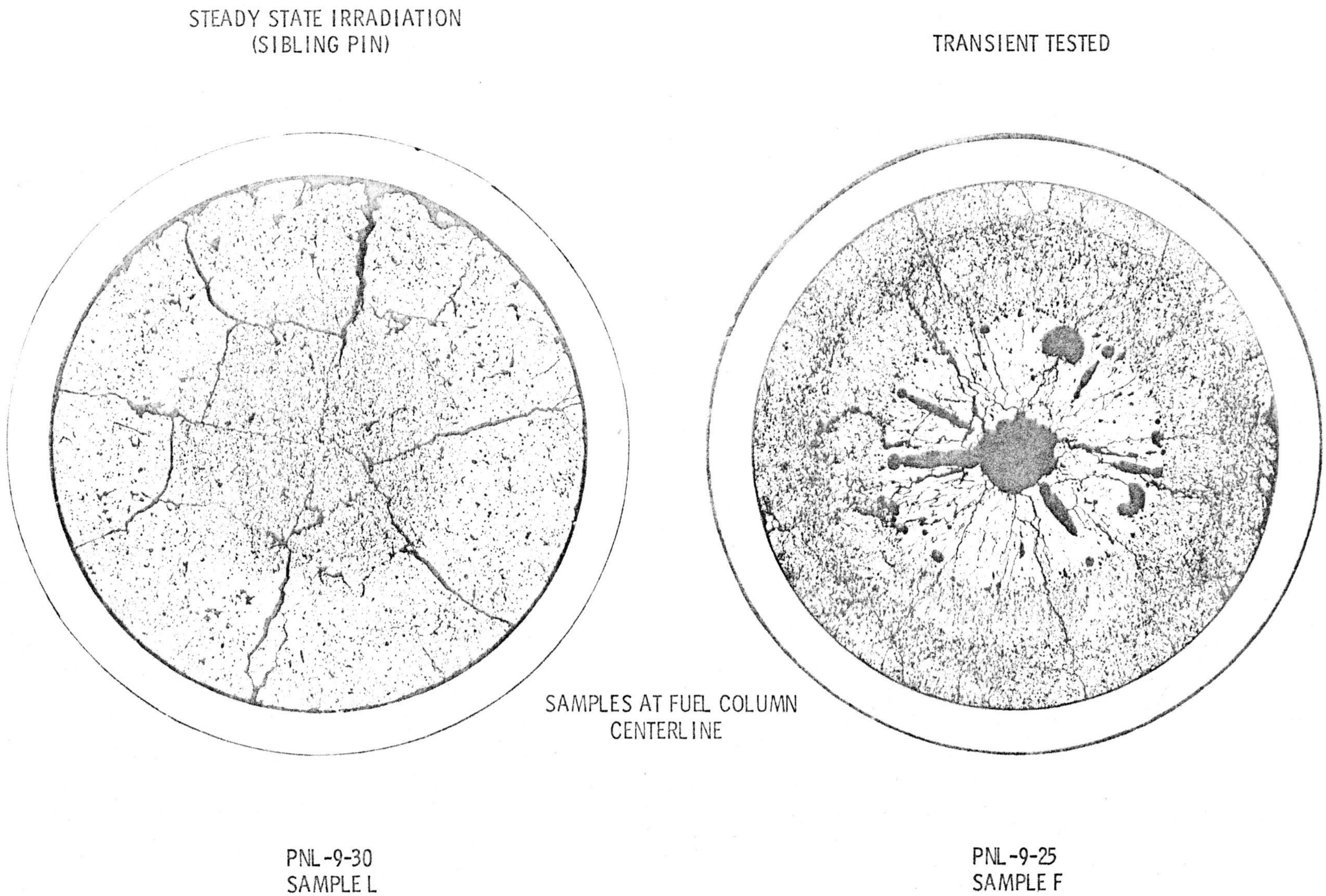

FIGURE 2. Comparison of Fuel Microstructure at the Axial Midplane for the Sibling and Transient Tested Fuel Pins (HUT 5-5A).

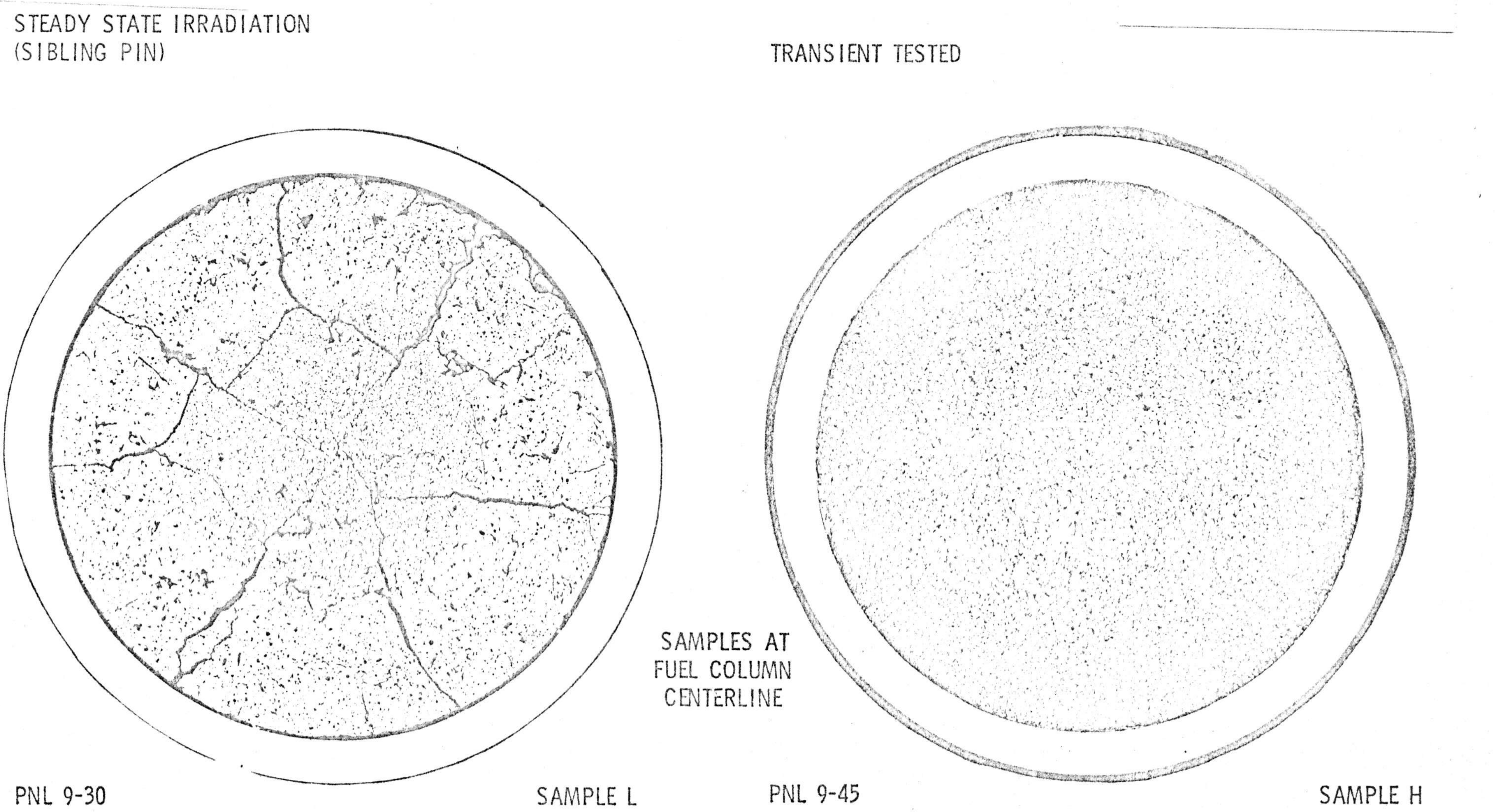

FIGURE 3. Comparison of Fuel Microstructure at the Axial Midplane for the Sibling and Transient Tested Fuel Pins (HUT 3-5A).

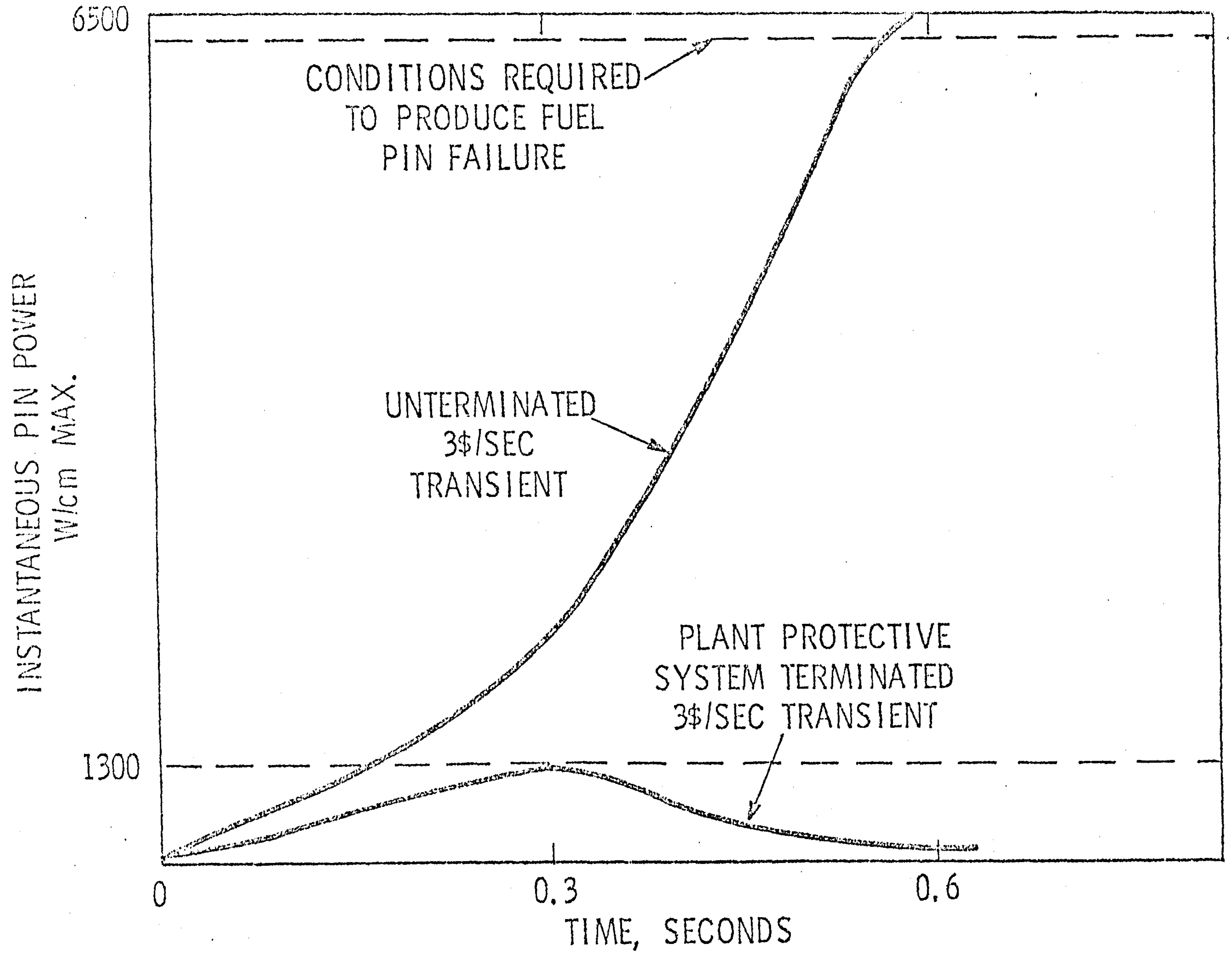

FIGURE 4. Margin between PPS-Terminated Transients and Fuel Pin Cladding Failure.

pin transient performance and indicate that low power fuel pins may not be as susceptible to failure as previously thought. Further studies are being conducted (i.e., analysis of other low power pin tests) to verify the observed responses of low power fuel pins and establish their failure mechanisms.

Evaluation of the HUT test results and preliminary analyses indicate that a very substantial margin exists between PPS-terminated transients and that required to produce fuel pin cladding failure. This is illustrated in Figure 3, and provides additional confirmation for the adequacy of fuel pin and PPS designs for terminated transients.

The results of the HUT test series were incorporated into a revised version of the empirical fuel pin failure threshold correlation model developed by Baars, et al,[3] which will be discussed in a subsequent paper by R. E. Baars.[4] This fuel pin failure correlation has been incorporated into the MELT-III[5] accident analysis code and its influence upon accident analysis will be discussed in a subsequent paper by N. P. Wilburn, et al.[6]

REFERENCES

1. G. D. Johnson and C. W. Hunter, "Fuel Cladding Mechanical Properties for Transient Analysis," to be presented at the ANS Fast Reactor Safety Topical Meeting, October 1976.

2. C. M. Cox et al, "FFTF Fuel Pin Design Bases and Performance," Trans. Am. Nucl. Soc., 20, 313 (April 1975).

3. J. H. Scott, et al, Microstructural Dependence of Failure Threshold in Mixed Oxide LMFBR Fuel Pins, HEDL-TME 75-9, October 1974.

4. R. E. Baars, "HEDL Empirical Correlation of Fuel Pin TOP Failure Thresholds--Status 1975," to be presented at the ANS Fast Reactor Safety Topical Meeting, October 1976.

5. A. E. Waltar, et al, "MELT-III--A Neutronics, Thermal-Hydraulics Computer Program for Fast Reactor Safety Analysis, HEDL-TME 74-47, December, 1974.

6. N. P. Wilburn, L. D. O'Dell, A. E. Waltar, "Sensitivity of LMFBR Hypothetical Accident Analysis to Variations in an Empirical Fuel Pin Failure Criterion," To be presented at the ANS Fast Reactor Safety Topical Meeting, October, 1976.