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FUEL-MOTION DIAGNOSTICS FOR PFR/TREAT EXPERIMENTS*

by

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In all the transients in the PFR/TREAT series, fuel motion has been monitored by the fast-neutron hodoscope.[1,2] This paper treats the enhancements in hodoscope operation and data analysis since the start of the PFR/TREAT tests. As fuel-motion data from the series are reported elsewhere in this session, we concentrate on results and considerations that are not specific to individual experiments.

The hodoscope has a maximum viewing height of 1.2 m. Data collection intervals for the series have been in the order of 1 ms, depending on the duration of the transient. Mass-displacement resolutions of about 0.1 g are achievable for the single-pin tests and 1 g for 7-pin tests. The hodoscope system can accommodate the full dynamic range of power.

As the PFR/TREAT series progressed, several changes in technology and operations were introduced. A second hodoscope detector bank[3] came on line, enabling better transient response, higher sensitivity, and independent corroboration of systematic effects. A new disk recording system[4] was installed to record the additional data and to give an extra element of redundancy. Commencing with L03, the fuel stack was lowered 0.075 m below the centerline, partly to let the hodoscope view fuel displacement 0.2 m above the top of the PFR pins. In L07 there was a power "shelf" at the end of the transient to permit adequate hodoscope sensitivity to fuel motion after failure. For some experiments, accelerated data processing and preliminary analysis were carried through to meet special program requirements. With the cooperation of the experimenters and the reactor-operations staff, considerably more trial transient and heat balance data have been collected and used in analysis of fuel motion.

In addition to routine processing and analysis,[1] certain special, approximate corrections are being studied or have been applied to reduce systematic discrepancies. These include, where significant, shaping-collar depressions, self-shielding effects, and axial flux tilts.[5]

Before an experiment, the fuel assembly is scanned at low power by the hodoscope for alignment and for a useful radiographic image of the fuel. In one of these routine scans, a small discrepancy of about 1 g of fuel in one of 7 pins stood out clearly. It was subsequently confirmed that two effects, neither of consequence to the experiment, caused the disparity: a particular pin had one less pellet, and its pellet stack had been pushed up higher than the other pins. This confirms the sensitivity of the hodoscope and enhances confidence that fuel configurations in the other tests were as expected.

Both the hodoscope and the internal loop instrumentation monitor the time and location of failure of fuel pins during TREAT tests. Enough data has been accumulated in recent years to establish a pattern of validation and to derive some useful conclusions regarding the nature of fuel failure itself. Table 1 contains a comparison of results, according to type of test -- either prototypical (1 or 7 pin) or phenomenological -- including for completeness recent experiments not part of the PFR/TREAT series. The EBT and F series were conducted with short pins in stagnant capsules, C01, C02, C03 were full-length pins in stagnant capsules, and all the others were with full-length fuel-section pins in flowing sodium loops. The photographic system in the F-series phenomenological tests recorded images of cladding rupture, thus constituting direct verification of the hodoscope data. Fundamental differences in the phenomena lead to different detectable effects. The hodoscope fast-neutron arrays are sensitive to fuel motion, and thus the signature measured is an abrupt, local change in radial and/or axial fuel distribution that is characteristic of escape of fuel from the cladding. The flow, pressure, and temperature sensors typically in loops are more likely to detect prior effects

-- those of cladding failure, such as gas escape or molten clad in contact with thermocouples.

The hodoscope has the capability for 1-ms fuel escape resolution and can also measure the approximate rate of escape. Full capability is not always achieved because of several factors: number of test pins, power coupling, peak power, power level at failure, and rate of fuel emergence.

From Table 1 it is clear that there are precise and accurate means to determine time and location of cladding failure or fuel escape during the PFR/TREAT transients. Moreover, the degree of agreement between the independent measures of fuel escape and clad failure definitely suggest that fuel emerges immediately after failure.

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Table 1

FAILURE TIME AND LOCATION
COMPARISON OF INSTRUMENT RESULTS

Type of Test	Test ID	Time, s			Loc., cm from center	
		Fuel Escape	Failure		Fuel Escape	Failure
		Hodoscope	Loop Instru.	Loop Sensor	Hodoscope	Loop Instru.
1 pin	C01	8.295±0.010	8.30	TC	~0	
	C02	8.372±0.001	8.37	TC	+20±1	
	C03	7.590±0.007	7.575±0.020		-20±2	~-23
	C04	18.795±0.008	18.80	FM	+41.0	
	C05	20.057±0.004	20.08		+42.5±1.0	
	C06R	13.828±0.004			+26.2 ±3.4	
	TS-1	32.200±0.006	32.20	FM, TC	+31±2	+29±2
	TS-2	33.82 ±0.02	*		+18±8	*
	EBT-1	12.736±0.010	12.74	TC	+3.5±3.5	+8±5
	EBT-2	12.625±0.006	12.635	TC	-1±2	-3±3
	EBTB	23.58±0.03	*		+14±3	*
7 pin	L01	<8.66	8.64	PT, FM	0	
	L02	9.405±0.002	9.53	PT, FM	~+7	
	L03	13.583±.002	13.585	TC, FM	~+32	+28±10
	L04	9.52±0.03	9.30	PT, FM	~+12	
	L05	9.87±0.04	10.1	FM	~0	
	L06	9.394±0.004	9.35±0.05	TC, FM		
	L07	9.063±0.007			+1.5±1.5	
Phenom.	F3	5.180±0.010	5.200±0.006	PH		
	F4	4.115±0.006	4.123±0.006	PH		

* not available

TC = thermocouple
FM = flow meter
PT = pressure transducer
PH = photocamera