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SLOW TRANSIENT OVERPOWER TESTS - C04, C05 AND L03

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SLOW TRANSIENT OVERPOWER TESTS - C04, C05 AND L03*

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Among the low probability LMFBR accident scenarios addressed by the collaborative US/UK transient testing program[1] is the slow transient overpower ramp resulting from the hypothetical event of a control rod runaway with failure to trip. This has been simulated in US's TREAT facility with three tests on irradiated driver fuel from the UK's Prototype Fast Reactor. Tests C04 and C05 were single pin experiments designed as a pair to study the effect of burnup on the time, location, and mechanisms of cladding failure and initial fuel escape. They were conducted on individual fuel pins of different burnup and power history; the C04 fuel had an axial peak burnup of ~4% while C05 fuel had reached a maximum burn-up close to 9%. Test L03, reported in detail previously[2], studied post-failure fuel dispersal in a bundle of seven pins like the C04 fuel.

The test vehicle used for C04 and C05 included a MK III flowing sodium loop and a test train designed by Westinghouse Hanford Company in collaboration with the UKAEA to accommodate the bottom plenum test fuel in simulated grid supports in a flow tube with prototypic flow area. Instrumentation was provided to measure flows, temperatures, pressures, and fuel motion.

The power transient was designed to be as slow as practicable within the overall TREAT energy limitations while still assuring that cladding failure could be reached. This resulted in a power period of 15 seconds for the test,

* Work performed under the auspices of the U. S. Department of Energy.

which was judged on the basis of calculations to produce similar phenomena to those expected in the 50 second period reference case.

The power transients for C04 and C05 are shown in Figure 1, together with records of the inlet flow, and selected flow tube temperatures. The results from these two tests (Table 1) are qualitatively very similar except for the C04 temperature oscillations caused by thermally induced mechanical oscillations of the flow tube. In both tests, inlet flow reversed sharply upon cladding failure, generating a signal which initiated a TREAT reactor scram thereby preserving the just-failed fuel pins for post-test examination.

The fast neutron hodoscope was used to monitor fuel motion. Prior to cladding failure, the hodoscope recorded lateral oscillation of the fuel column in C04, and an axial expansion of the fuel column in C05. First observed fuel escape coincided with the cladding-failure induced flow excursions showing that cladding failure and fuel escape were simultaneous. The failures occurred at ~3 x nominal power and were in the top 50 mm of the fuelled length for both tests. A decrease in fuel worth followed due to relocation of molten fuel from inside the pins to locations above the top of the fuel. This trend is considered representative until the flow tubes breached in C04 and C05 and is confirmed by L03 which, in a more representative 7 pin bundle envirionment, led to a post failure worth decrease of ~15% from upward sweepout from a failure ~0.18 m below the top of the fuel, thus corroborating the single pin results.

Post test analyses of C04 and C05 with the UK codes PINEX-AR and TRAFIC show that when allowance is made for the C04 temperature oscillations, both tests are modelled well by existing codes. Cladding failure was caused by increasing fission gas pressure as the fuel melted. The small difference in timing of the two failures results from the cumulative effects of the different power histories of the two test pins in their irradiation in PFR.

The conclusions reached from these tests are that: as predicted, there are no phenomenological differences in failure behavior between the two burn-ups tested; and that a slow overpower accident in an LMFBR will result in fuel pin failures near the top of the fuel column, followed immediately by rapid upward fuel dispersal and a large reduction in reactivity.

References

1. The PFR/TREAT Programme: Objectives, Progress and Future Work, C. B. Cowking (UKAEA), et al., Proceedings of the L.M.F.B.R. Safety Topical Meeting, July - 23 1982 - Lyon - Ecully France, Vol. II pp 103-112.

2. Results from the PFR/TREAT Test L03, R. J. Page, et al., Trans. Am. Nucl. Soc., Vol. 45 p 407 (1983).

Event Description	TREAT Clock Time (s) C04	C05
• TREAT clock and computer control start. Reactor power increases on 0.21 s period.	0.00	0.00
• Transient simulation begins. Reactor power begins increasing on 15 s period.	3.32	3.22
• Flow tube temperature oscillations. (C04 only)	9.5 - 18.0	----
• Hodoscope data indicates cladding breach and initial fuel expulsion.	18.80	20.06
• Flow sensors indicate coolant explusion.	18.80	20.08
• Scram signal generated by computer	18.81	20.09
• Flow tube breached and sodium begins filling test train adiabatic region.	18.86	20.10

Table 1. Key events observed in PFR/TREAT C04 and C05 tests.

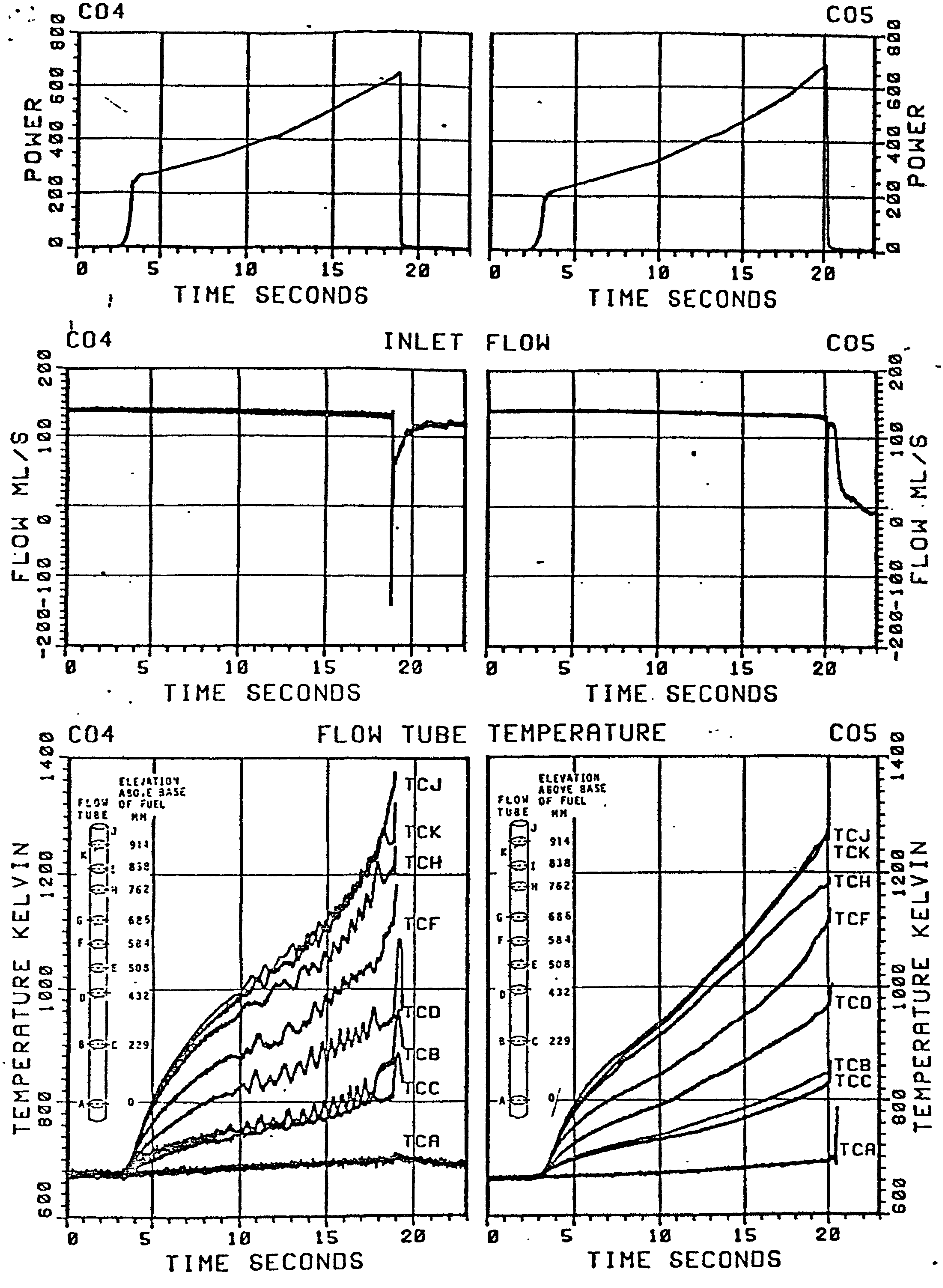

FIGURE 1. C04 AND C05 RESULTS.

SLOW TRANSIENT OVERPOWER TESTS

C04, C05 AND L03

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SLOW RAMP TOP TEST OBJECTIVES

SCENARIO

- Reference accident is the runaway of a control rod with failure to scram.
- Simulate reactor conditions occurring during an unprotected slow transient overpower accident up to and beyond cladding failure.

C04 AND C05 - SINGLE PIN TESTS, TO FAILURE.

- Determine the time, location, and mechanism of cladding failure.
- Determine the effect of test fuel burn-up on the above parameters.
- Study fuel motion within the test pins prior to cladding breach.

L03 - SEVEN PIN TEST, RUN BEYOND FAILURE.

- Observe the fuel motion both before and after cladding failure.

TEST VEHICLES AND FUEL

LOOPS

C04, C05 & L03 - ANL MK III loops

TEST TRAINS

C04 and C05 - HEDL Single Pin Test Trains

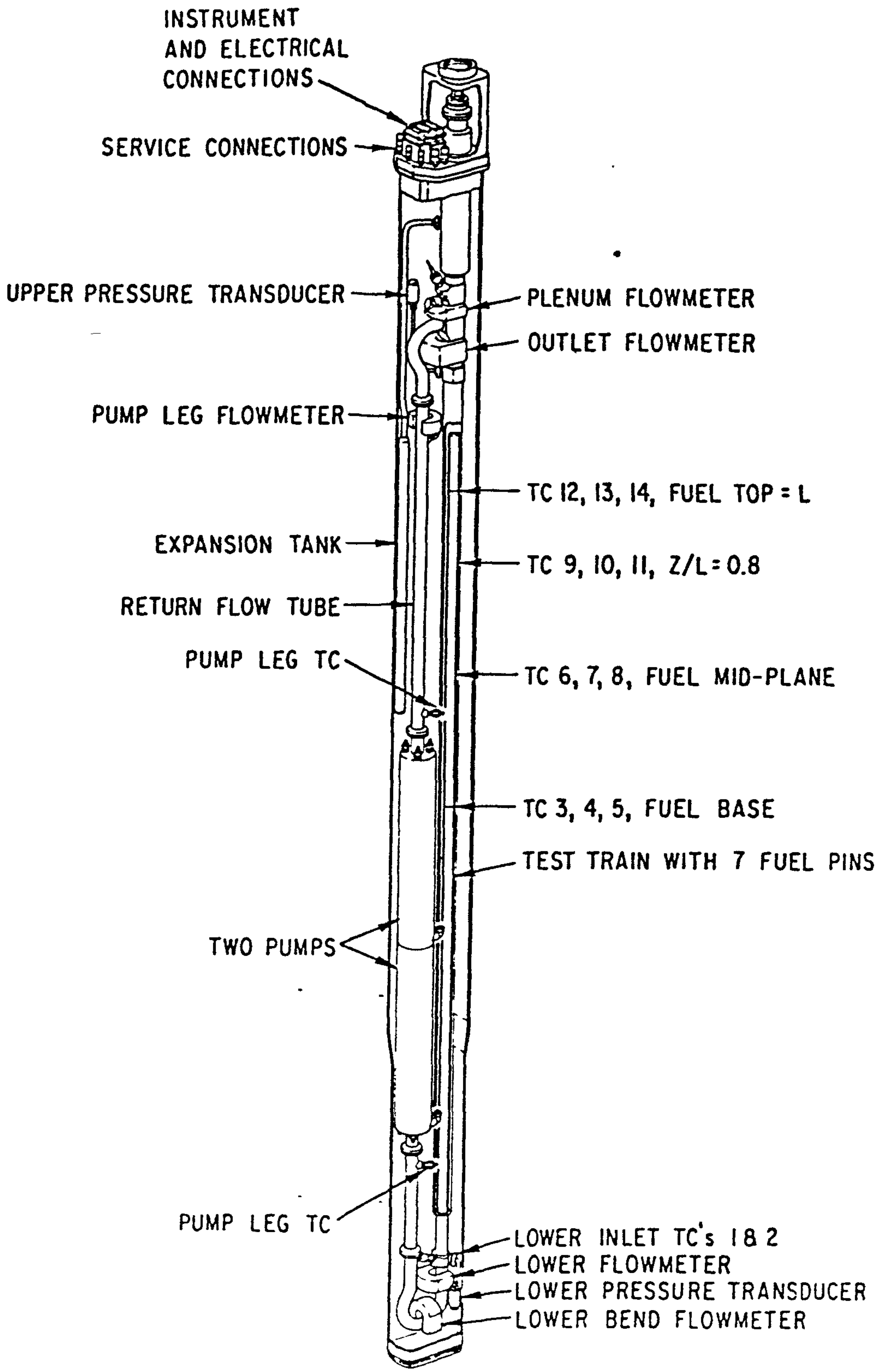
L03 - ANL 7 pin test train

TEST FUEL: PFR irradiated driver fuel

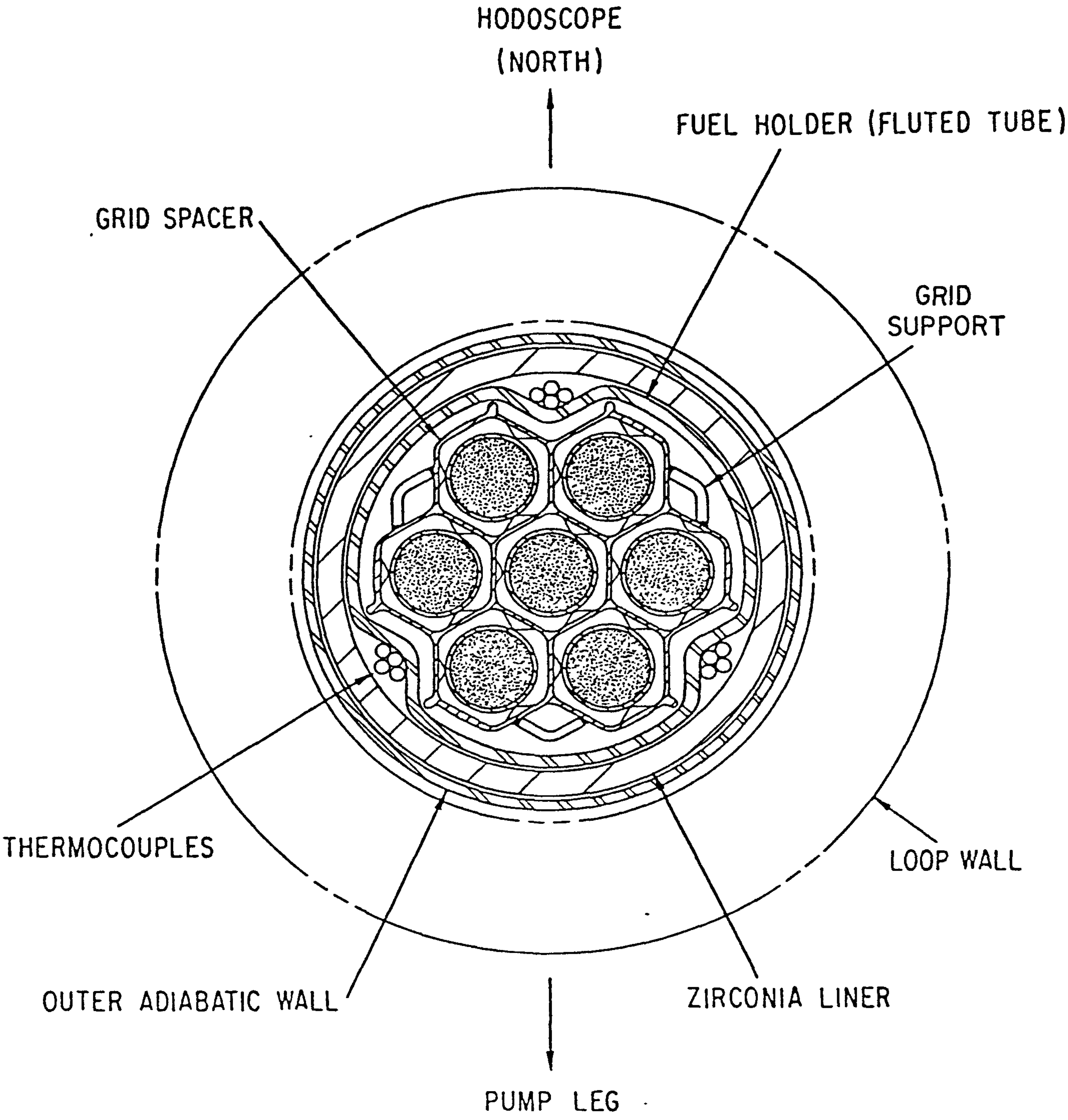
C04 and L03 - 4% peak burn-up

C05 - 9% peak burn-up

SLIDE 4


INSTRUMENT AND ELECTRICAL CONNECTIONS
SERVICE CONNECTIONS
UPPER PRESSURE TRANSDUCER
PLENUM FLOWMETER
OUTLET FLOWMETER
PUMP LEG FLOWMETER
TC 12, 13, 14, FUEL TOP = L
EXPANSION TANK
TC 9, 10, 11, Z/L = 0.8
RETURN FLOW TUBE
PUMP LEG TC
TC 6, 7, 8, FUEL MID-PLANE
TC 3, 4, 5, FUEL BASE
TEST TRAIN WITH 7 FUEL PINS
TWO PUMPS
PUMP LEG TC
LOWER INLET TC's 1 & 2
LOWER FLOWMETER
LOWER PRESSURE TRANSDUCER
LOWER BEND FLOWMETER

SLIDE 5



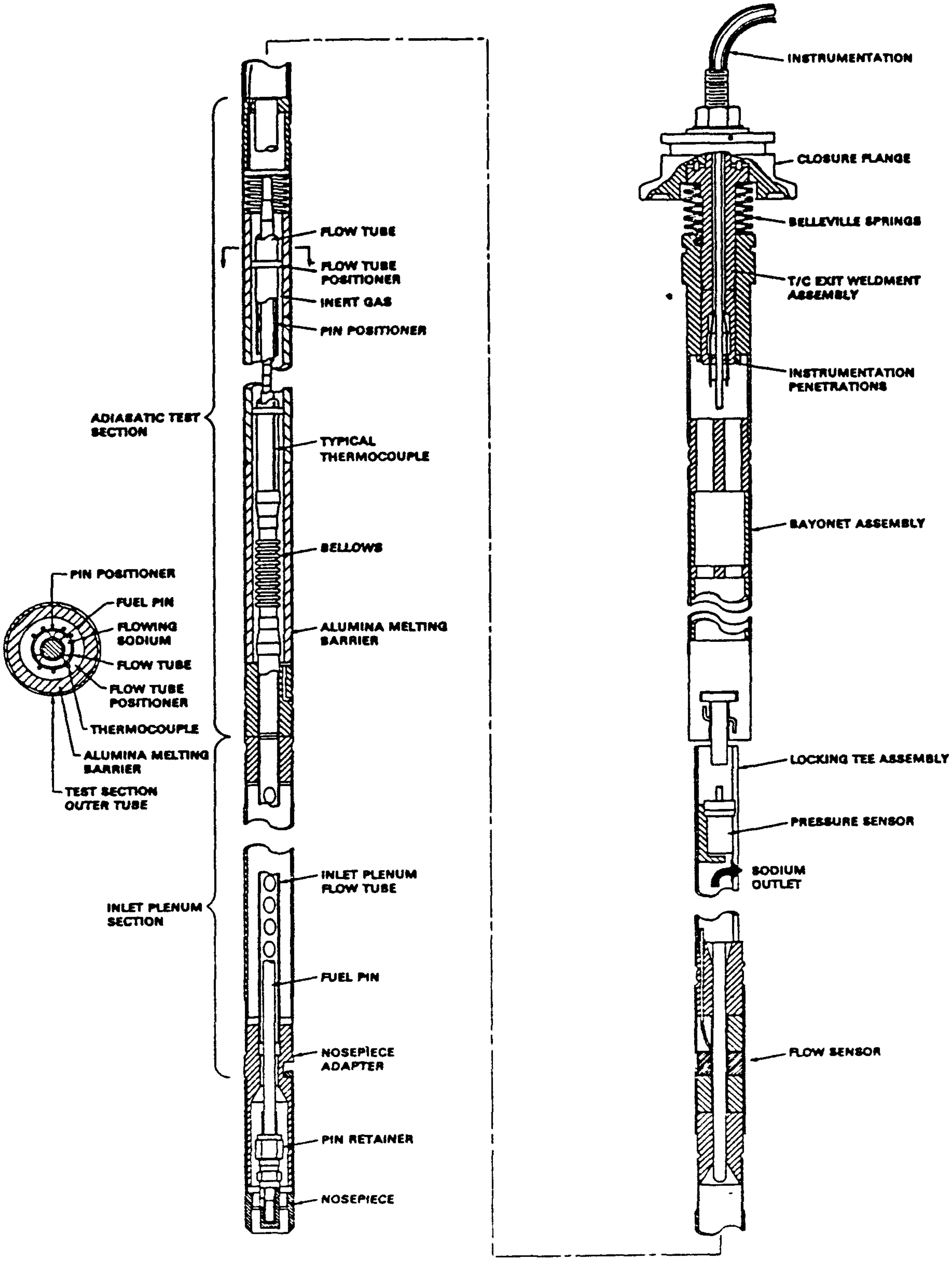
Cross-sectional view of the LO3 fuel bundle - looking down.

SLIDE 6

NOMINAL PRE-IRRADIATION PARAMETERS FOR PFR FUEL PINS

FUEL:-	
MATERIAL	UO_2-PuO_2
COMPOSITION, PU/PU+U	0.32
PELLET DIAMETER	4.93 MM
PELLET GEOMETRY	ANNULAR, FLAT END
PELLET ANNULAR HOLE DIAMETER	1.52 MM
COLUMN LENGTH	914 MM
BREEDER:-	
MATERIAL	UO_2
PELLET GEOMETRY - LOWER	ANNULAR, FLAT END
PELLET GEOMETRY - UPPER	SOLID
PELLET DIAMETER	4.93 MM
ANNULAR HOLE DIAMETER	1.52 MM
LENGTH OF BREEDER COLUMN - LOWER	497 MM
LENGTH OF BREEDER COLUMN - UPPER	94 MM
CLADDING:-	
MATERIAL	316 SS
CONDITION	20% COLD WORK
DIMENSIONS	5.84 MM OD x 0.381 MM WALL

SLIDE 7



HEDL ~~FIGURE 3.3.~~ Single Pin Test Train.

SLIDE 8

TRANSIENT DESIGN

- Reference transient period is 50 seconds.
- Treat reactor energy limit means 15 second period is the slowest achievable; L03 requires "jump-in".
- C04 and C05 designed to give identical energy input to facilitate study of differences due to burn-up.
- C04 and C05 included provision to terminate on signals generated by cladding failure to preserve the just-burst fuel pins for post test examination.

RESULTS

EVENT	C04	C05	L03
Axial expansion of fuel prior to cladding breach	masked by flow tube oscillations	observed: 11 + 5mm	masked by flux tilt effect
First fuel escape seen by hodoscope.	18.80 sec.	20.06 sec	13.583 sec
Relative axial location of first fuel escape (top = 1.0)	0.95 - 1.0	0.95 - 0.97	~ 0.84
Cladding breach and fuel escape - inferred from loop and test train instruments.	18.80 sec.	20.08 sec	13.585 sec
Fraction of cladding in fuel zone intact after the test	0.98	0.99	0

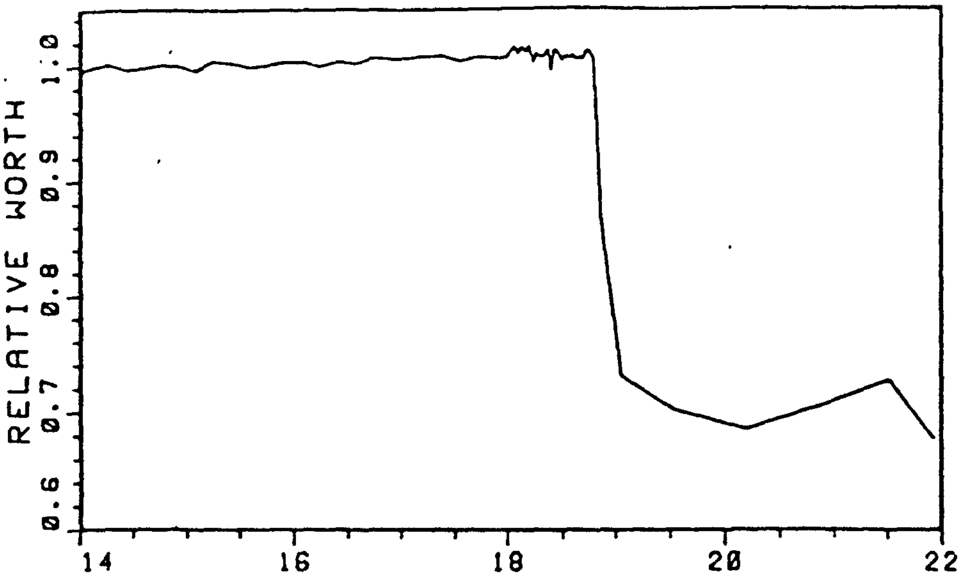
SLIDE 10 IS WORTH CURVES - DRAFT ENCLOSED

SLIDE 11 IS POST TEST PHOTOGRAPHS OF CO4 AND CO5 PINS
ONLY FAXED COPIES AVAILABLE AT THIS STAGE
QUALITY PRINTS WILL BE MOUNTED AND REPHOTOGRAPHED
FOR PRESENTATION. 1 COPY CO4 PHOTO ENCLOSED TO SHOW
DETAIL OF FINAL MATERIAL.

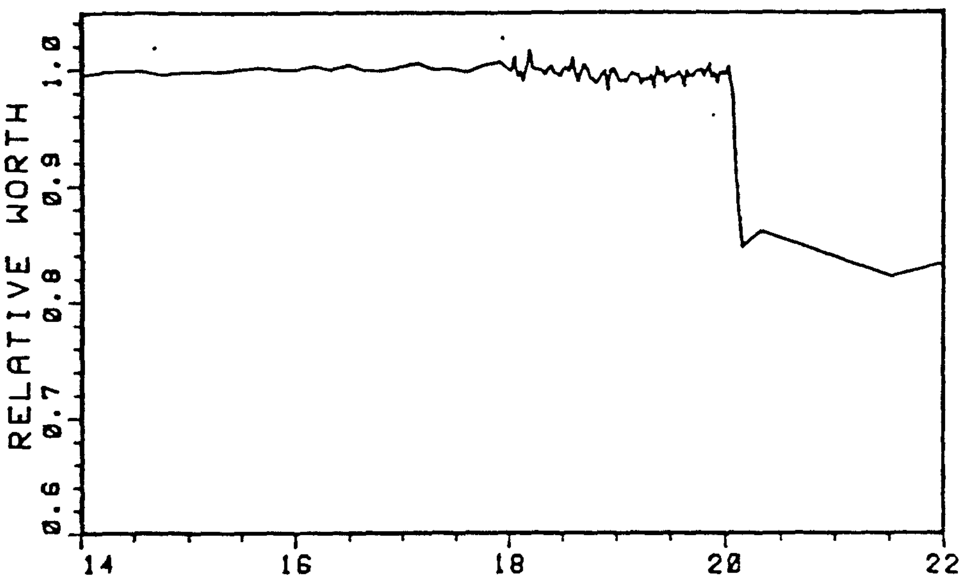
SLIDE 12 IS CLADDING STRAIN FROM CO4 & CO5 - DRAFT ENCLOSED

SLIDE 13 IS 6 MACRO SECTIONS FROM LO3.
ONLY PHOTOCOPIES AVAILABLE AT THIS STAGE
QUALITY PRINTS WILL BE MOUNTED AND REPHOTOGRAPHED
FOR PRESENTATION.

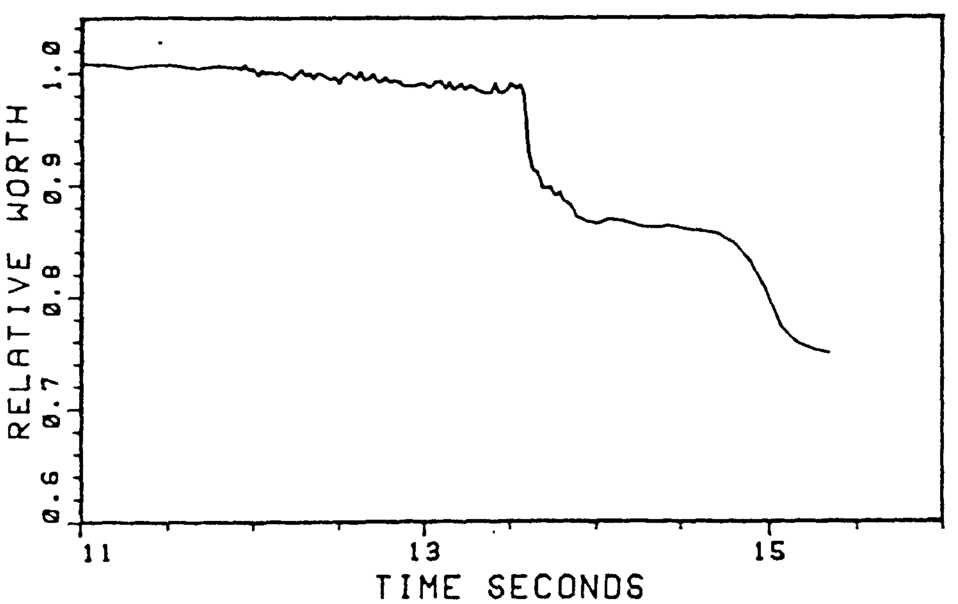
SLIDE 10



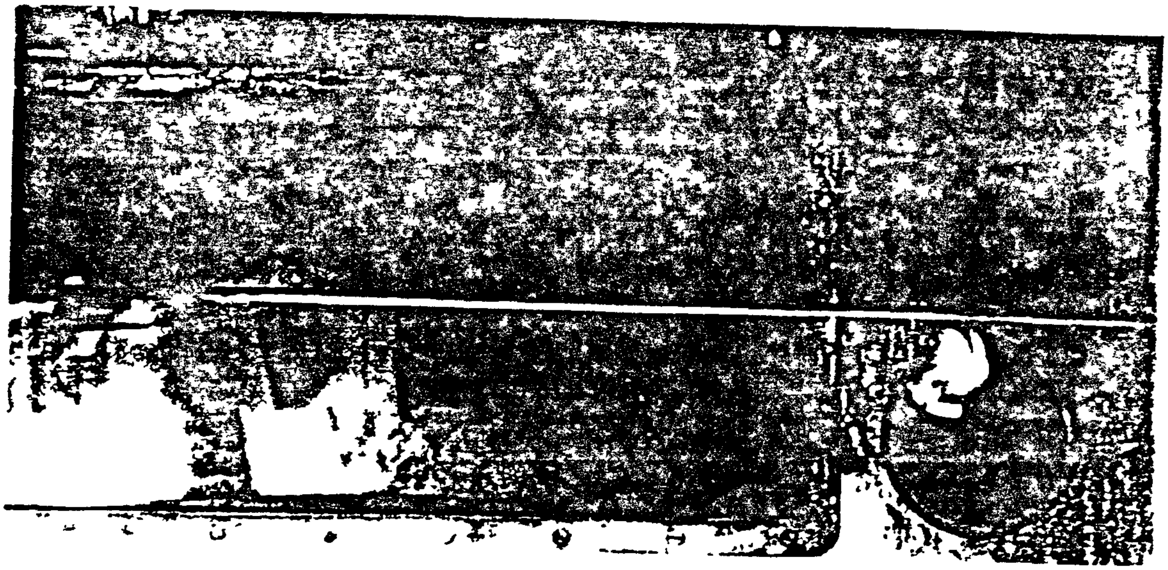
C05 WORTH CURVE

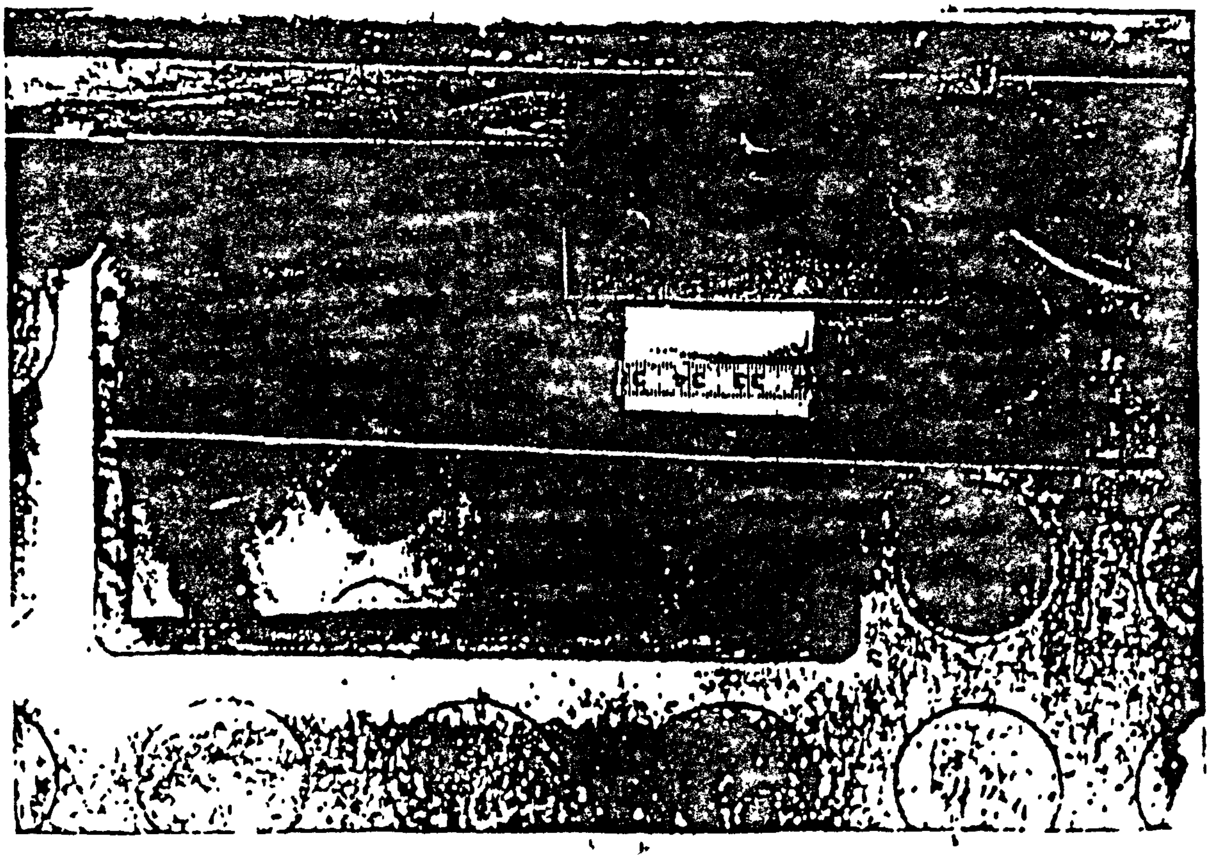


L03 WORTH CURVE

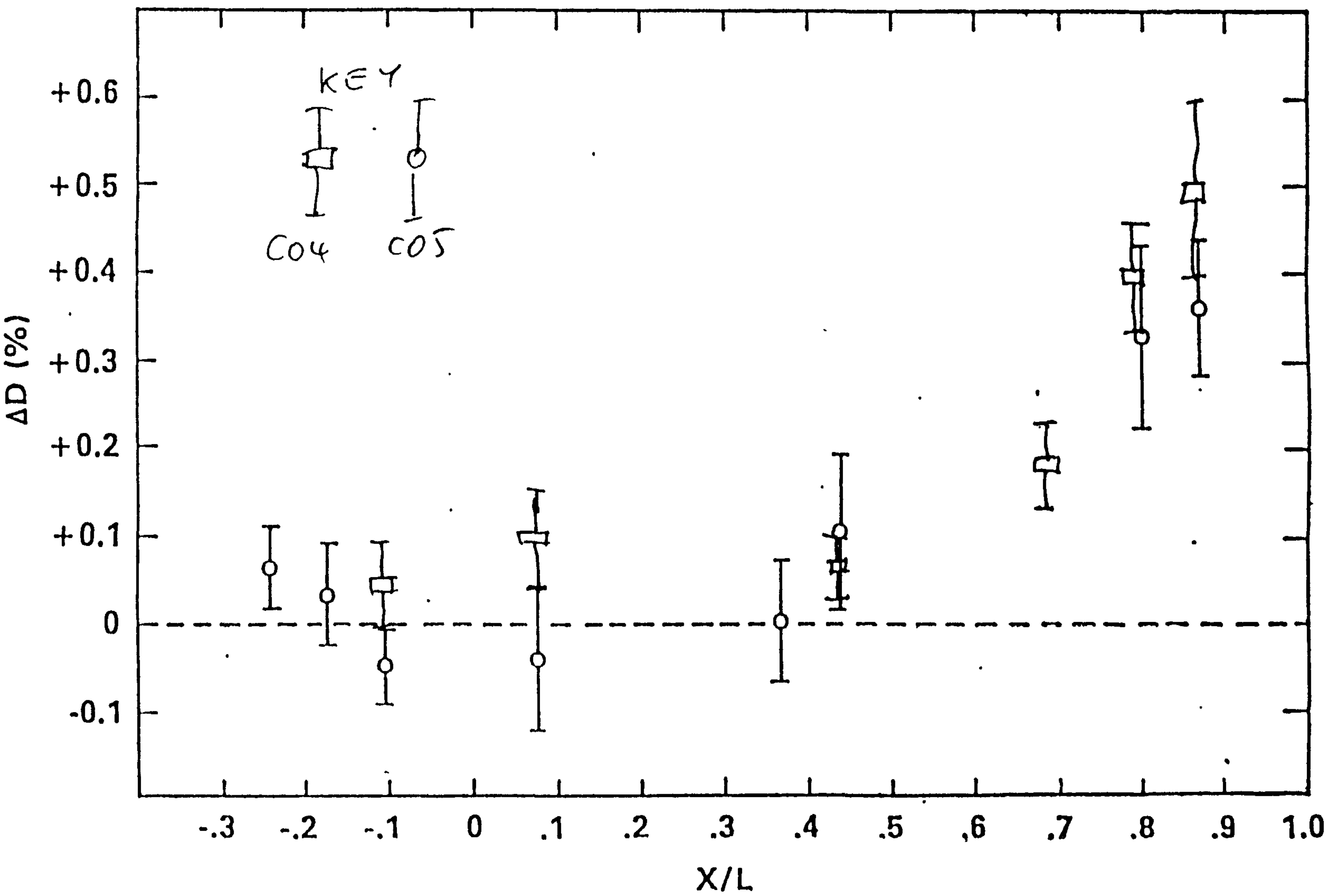


DRAFT. SLIDE 11





C04 AND C05 CLADDING STRAIN POST-TEST.



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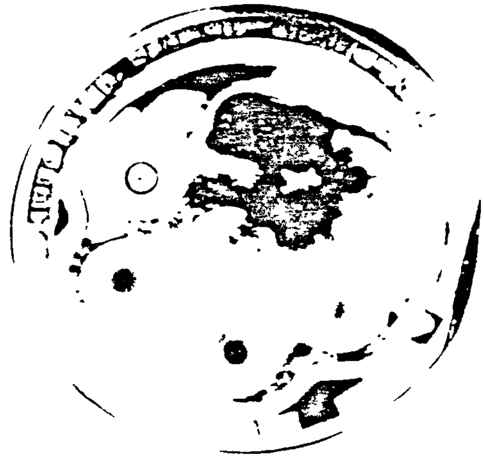
+530 mm

−276 mm

−301 mm

−402 mm

−428 mm



−482 mm

L03 MACRO SECTIONS.

0mm = FUEL MID PLANE

POST-TEST ANALYSES

CODES -	UK	COBRA SABRE	L03 Flow and temperature distribution
		PINEX-AR TRAFIC	Thermal and mechanical modelling of fuel pins.
	US	COBRA FPIN-BOIL FSTATE	Thermal hydraulic and fuel pin modelling in L03.
		TEMECH	Thermal hydraulics and fuel pin modelling in C04 and C05.

RESULTS - C04 and C05:-

- Generally good agreement between measured and calculated temperatures.
- Good agreement between calculated and observed failure times if allowance is made for temperature oscillations in C04.

RESULTS - L03:-

- Satisfactory agreement between observed and calculated failure time and location. Some inconsistancies in thermal results.
- Post failure analysis with SAS3-D in progress

SLIDE 15

which a hypothetically not terminated by the PPS)

CONCLUSIONS

- In irradiated fuel subject to a slow transient overpower ramp cladding failure occurs at or near the top of the fuel column.
- Molten fuel escapes immediately and the subsequent fuel motion is strongly dispersive producing a large reduction in fuel worth.
- Hence "unprotected" slow transient overpower excursions appear to be self terminating.
- Single and seven pin slow transient tests appear to be equivalent for determining fuel dispersal in the immediate post failure time frame.
- Further tests required to evaluate fresh fuel and more representative goal burn-up fuel under slow transient overpower conditions.

(clarify?