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NATURAL CONVECTION BOILING OF SODIUM IN A SIMULATED FBR FUEL ASSEMBLY SUBCHANNEL*

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ABSTRACT

A series of single channel sodium boiling experiments were conducted in the Sodium Boiling Test (SBT) Facility at the Oak Ridge National Laboratory. The objective of these tests was to determine the maximum power that can be transferred to the coolant in a fuel assembly subchannel when the flow is driven by natural convection. Stable boiling was achieved for test times approaching one hour in duration for powers below the critical level. The power corresponding to dryout in these tests compares well with predictions from an earlier water simulation of fuel assembly voiding behavior.

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SUMMARY

Griffith[1] suggested in early 1975 that the augmentation of coolant flow, produced by the differential head between boiling and non-boiling subassemblies, could significantly delay dryout and fuel failure for certain categories of LMFBR accidents. A single channel, low pressure water test was conducted by Hinkle[2] to investigate this effect. The results of this test, extrapolated to Fast Flux Test Facility (FFTF) conditions, indicated that stable, two-phase cooling could be maintained under natural circulation conditions for coolant power densities below 214. watts/cm^3. The development of the Sodium Boiling Test (SBT) Facility, a sodium analog of the water test loop was begun at Oak Ridge National Laboratory following completion of this test program. The thermal hydraulic characteristics of the SBT Facility were selected to simulate the FFTF reactor subchannel geometry. The design is sufficiently close to that used in the water tests to permit a direct comparison between sodium and low pressure (1 atm) water boiling behavior for conditions representative of hypothetical LMFBR accidents.

The primary objective of this test was to determine the maximum power that can be transferred by a simulated LMFBR coolant subchannel when the coolant flow is driven by natural convection. Secondary objectives include the use of the data obtained from these tests; (1) to evaluate the ability of the water simulation to predict sodium behavior, (2) to evaluate the accuracy of natural convection and boiling stability computer models currently under development, and

(3) to develop guidelines for boiling stability tests in the multi-pin Thermal-Hydraulic Out-of-Reactor Safety (THORS) test facility.

Facility Description

The SBT loop is illustrated in Fig. 1. The test section is a 3.0 m (118 in.) Hastelloy X tube with a 3.25 mm (0.128 in.) ID and a 2.90 mm (0.114 in.) wall. The inside diameter of the test section was selected to correspond to the mean hydraulic diameter of an FFTF fuel subassembly.[3] A coil, located at the test section inlet, simulates subassembly inlet hydraulic resistance and accommodates the thermal growth of the test section. A 16. kW quad-elliptical radiant furnace simulates core heat loads to a 0.97 m (38 in.) zone of the test section. The furnace reflector is water cooled. The power input to the test section is computed based on measurements of the electrical power supplied to the furnace and the enthalpy rise of the furnace coolant. The test section downstream of the furnace is guard heated to simulate the fission gas plenum region of the subassembly. Tanks at the top and bottom of the test section simulate the inlet and outlet plenums of the reactor. The cover gas in the upper tank is argon. The 51. mm (2.0 in.) ID return line is sized to minimize the influence of the downcomer on the test section flow dynamics. An ac electromagnetic pump in the return leg of the loop is available for forced flow operation, if required. Oxide control is accomplished by a zirconium trap located in the facility dump tank.

Fast-response pressure transducers (Sensotec and Kaman) are located at the inlet of the heated zone. Permanent magnetic flowmeters are provided at each end of the test section and upstream of the EM pump. Plenum pressures are monitored by Taylor pressure transducers with NaK filled sense lines. Approximately 100 Chromel-Alumel (Type K) thermocouples are installed throughout the loop. Test section thermocouples are attached to the outer wall of the tube. The sodium void detection system consists of a series of voltage taps distributed along the length of the test section. Voiding patterns are detected by local changes in the electrical conductivity of the parallel test section and sodium paths. An acoustic monitor is located at the inlet of the heated section. Level sensors are provided in both the sodium dump tank and the upper plenum.

The SBT Facility utilizes the THORS Facility data acquisition system. This system consists of a PDP-8E computer, a DATUM multiplexer, two magnetic tape storage units, a CRT display, a Tektronix 4006 console and hardcopy unit, a teletype and a character printer. Data is recorded on a 7-track magnetic tape at a rate of 10,000 samples per second for post-test processing. Real time data is displayed on the aforementioned ouput devices. Facility protection is provided by the computer during operation.

Test Results

A series of steady state, natural convectin tests were run in which data were taken at a series of test section powers up to and including the film dryout condition. These runs were made with an upper plenum pressure of 97.2 kPa (14.1 psia). Test section inlet temperature and upper plenum temperature were maintained at 420°C (790°F) and 590°C (1100°F), respectively.

Large flow oscillations, characteristic of low pressure boiling, were observed during all the boiling runs. This was particularly true for the low power boiling runs, an example of which is given in Fig. 2. The flow measurements were made at the inlet of the heated section and downstream of the riser. The fast response transducer (PE-2B) and the Taylor transducer (PT-7) pressure measurements were made upstream of the heated section and in the upper plenum, respectively. The temperature measurements were taken at axial stations in the heated section (TE 117-TE 120) and in the riser (TE 121-TE 127). The void detector data presented were taken at stations near the exit of the heated section. The test section power for this run was 1.3 kW. Large oscillations in the flow downstream of the heated section and in the response of the void detectors in this region suggest a slug flow regime. Boiling was highly unstable at these conditions and the system reverted to single phase flow at approximately 70 sec into this run. Wall temperatures typically increased following such an event until incipient superheat requirements were met, thus triggering a second boiling cylcle, or until the loop scram limit of 1010°C (1850°F) was exceeded. Wall temperature is measured at the outer surface of the thick wall (2.9 mm) test section and is not representative of the sodium temperature.

At a higher test section power the flow became more stable with sustained boiling for periods as long as one hour. Figure 3 is representative of this behavior. This run was made at a test section power of 1.4 kW. The frequency of liquid slugs, appearing downstream of the heated section, in this run was reduced; transition to an annular flow pattern is suggested.

At a test section power of approximately 1.7 kW intermittent dryout conditions were encountered. An example of this behavior is given in Fig. 4. The outlet flowmeter indicates annular flow and/or film dryout at approximately 30 sec into this run. This is substantiated by the void detector signals downstream of the heated section and by the inlet flow which continues to oscillate. Contrast this behavior to the low power data presented in Fig. 2. The wall temperature in Fig. 4 increases in response to the dryout condition but this increase is checked by the rewetting of the wall associated with reestablishment of the pre-dryout flow pattern. A second dryout cycle begins at approximately 90 sec. This cycle was terminated a few seconds after the end of the data file by the high temperature scram command. No evidence of recovery from this final temperature excursion was apparent prior to the shutdown by the loop protection system.

A preliminary assessment of these test results indicates the following: (1) Low pressure sodium boiling under natural circulation conditions is characterized by large amplitude flow oscillations. Effective cooling was achieved, however, for channel powers as high as 1.6 kW or 200. $watts/cm^3$. (2) Intermittent dryout was indicated at a power of 1.7 kW or 212. $watts/cm^3$ which is in excellent agreement with the results of Hinkle's[2] water simulation.

References

1. P. Griffith, 'An Overview of LMFBR Voiding," unpublished paper prepared for ERDA LMFBR Loss-of-Pipe Integrity Working Group, March 1975.

2. W. D. Hinkle, Water Tests for Determining Post Voiding Behavior in the LMFBR, HNL-Sub-4450-1, (MIT-EL 760-005), June 1976.

3. E. H. Novendstern, "Turbulent Flow Pressure Drop Model for Fuel Rod Assemblies Utilizing a Helical Wire-Wrap Spacer System," Nuclear Engineering and Design, 22 (1972), 19-27.

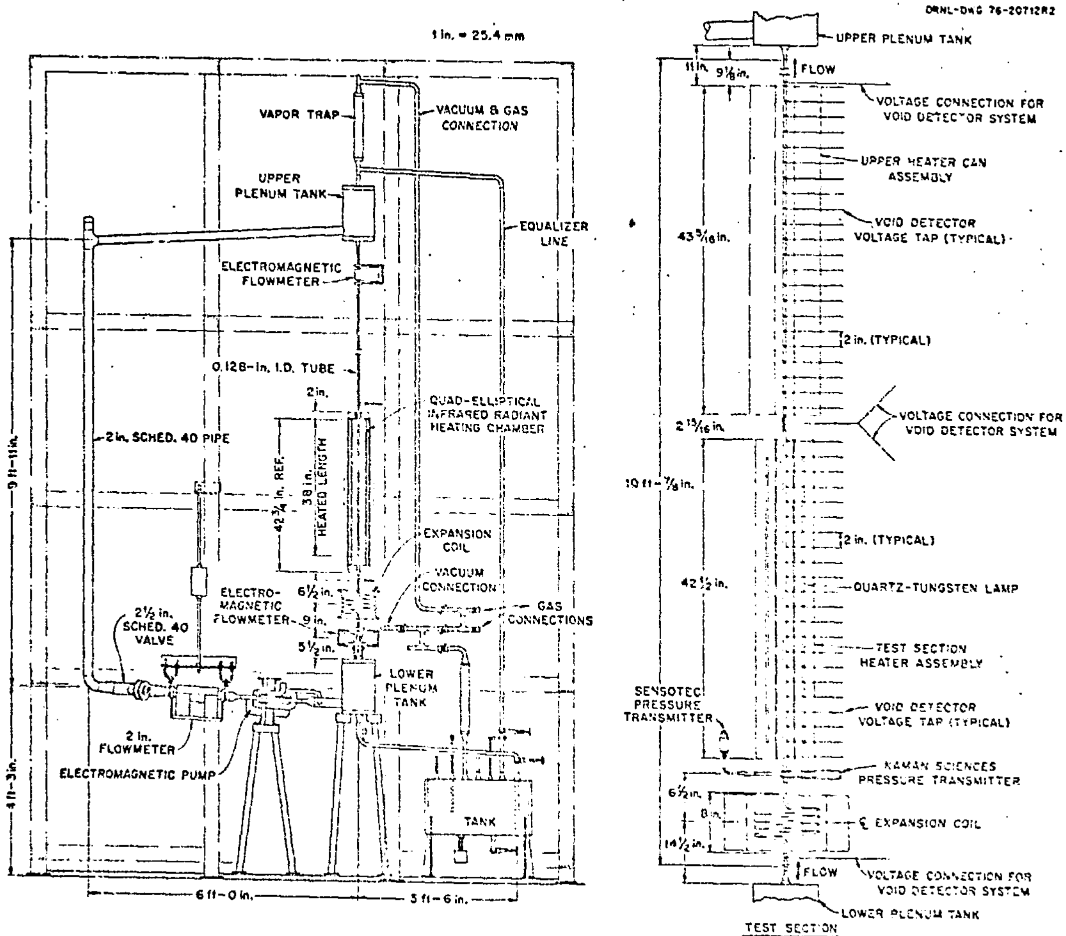
Figure Captions

1. Sodium Boiling Test (SBT) Facility.

2. SBT Natural Convection Boiling Test 130 Run 1, Test Section Power = 1.3 kW.

3. SBT Natural Convection Boiling Test 121 Run 1, Test Section Power = 1.4 kW.

4. SBT Natural Convection Boiling Test 124 Run 1, Test Section Power = 1.7 kW.



LMFBR Program—Sodium Boiling Test Facility

FIG 1

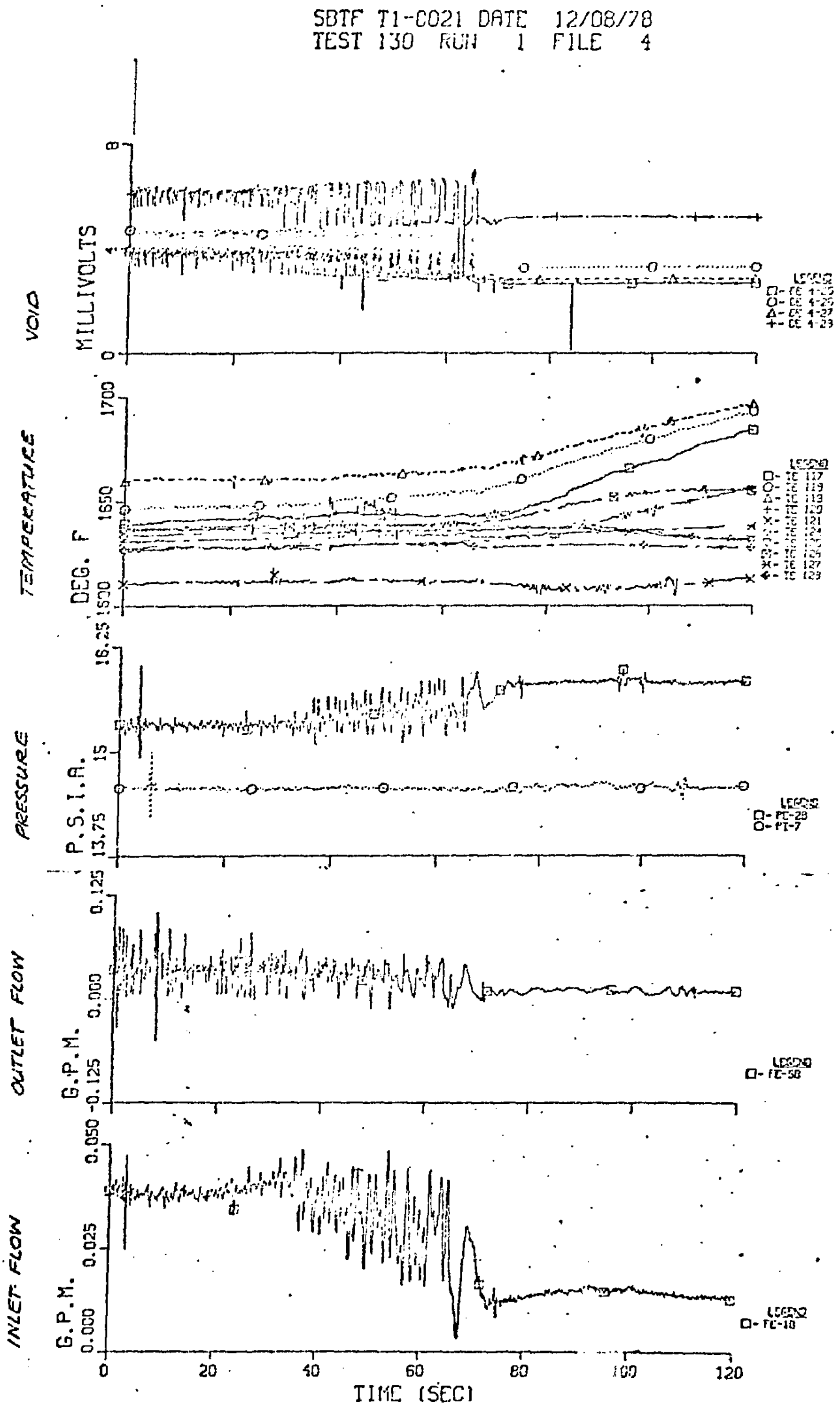

SBTF T1-C021 DATE 12/08/78
TEST 130 RUN 1 FILE 4
VOID
MILLIVOLTS
0
4
8
TEMPERATURE
DEG. F
1600
1650
1700
PRESSURE
P.S.I.A.
13.75
15
16.25
LEGEND
OUTLET FLOW
G.P.M.
-0.125
0.000
0.125
LEGEND
INLET FLOW
G.P.M.
0.000
0.025
0.050
LEGEND
0
20
40
60
80
100
120
TIME (SEC)

FIG 2

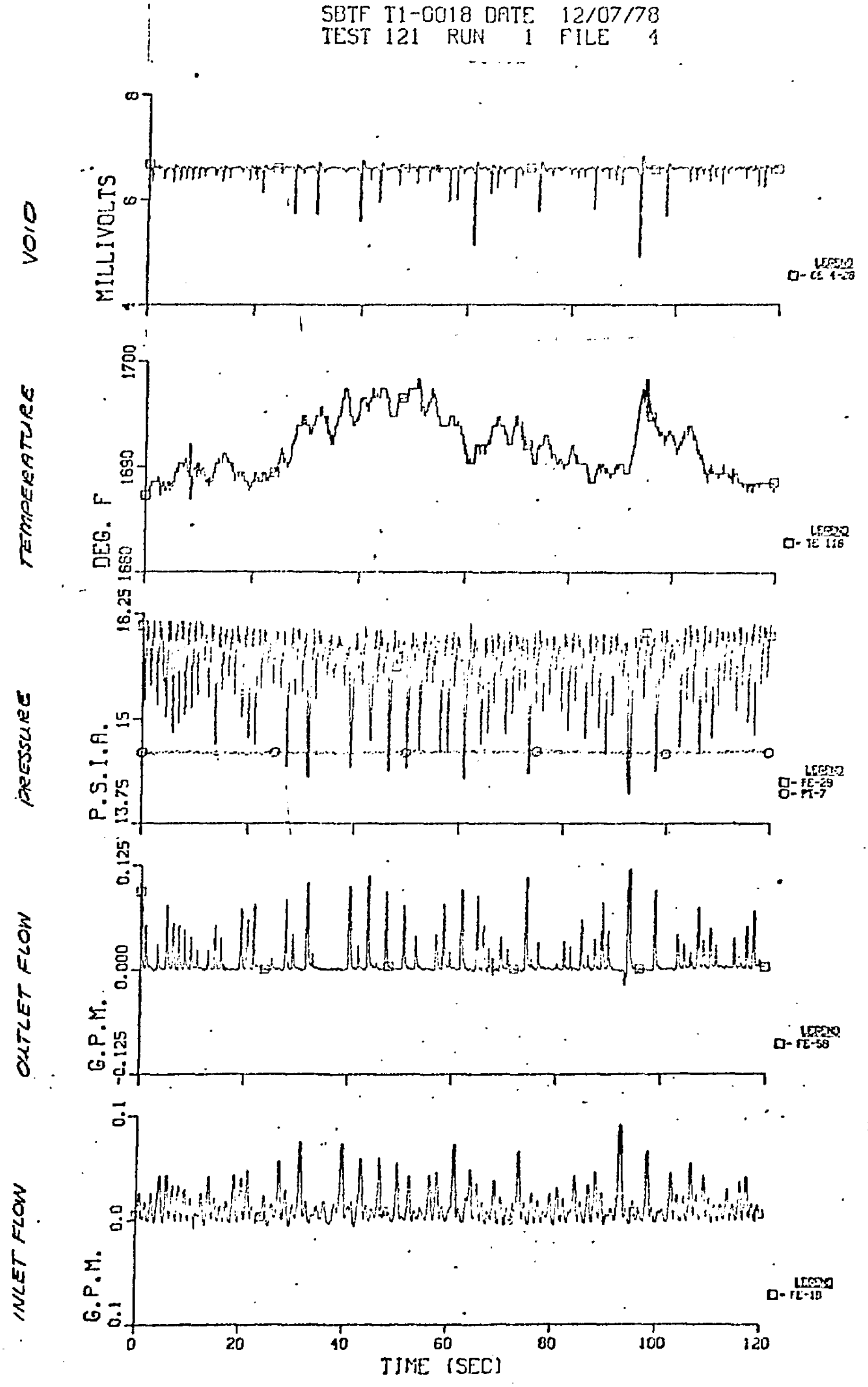

SBTF T1-0018 DATE 12/07/78
TEST 121 RUN 1 FILE 4
VOID
MILLIVOLTS
8
6
4
TEMPERATURE
DEG. F
1700
1690
1680
PRESSURE
P.S.I.A.
16.25
15
13.75
FE-29
PT-7
OUTLET FLOW
G.P.M.
0.125
0.000
-0.125
FE-58
INLET FLOW
G.P.M.
0.1
0.0
0.1
0
20
40
60
80
100
120
TIME (SEC)

Fig 3

SBTF T1-0019 DATE 12/[illegible]/78
TEST 124 RUN 1 FILE 1

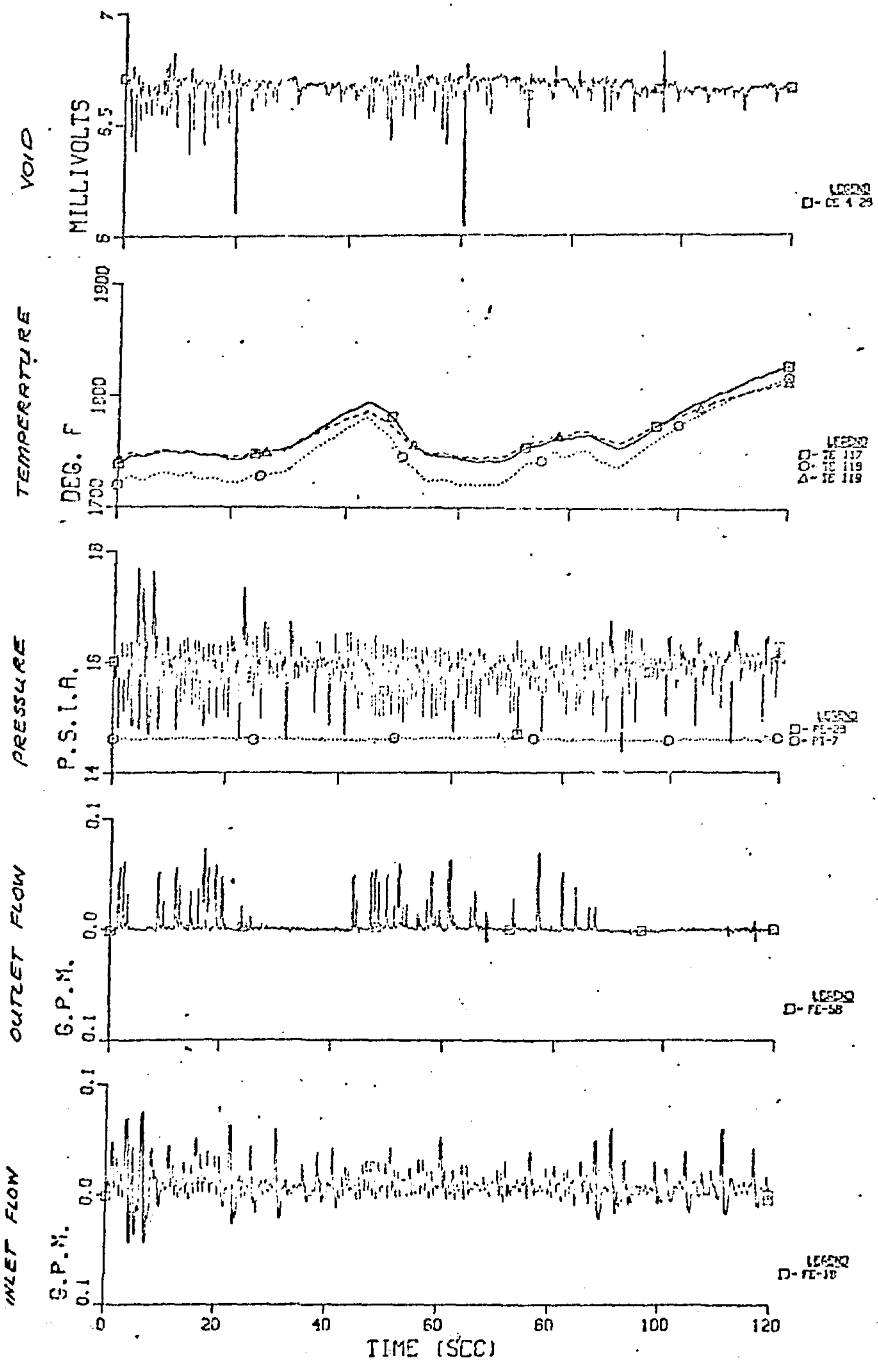


Fig 4