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TEMPERATURE, FLOW AND ACOUSTIC NOISES IN A LOCALLY BLOCKED 37-PIN BUNDLE

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ABSTRACT

Temperature, flow and acoustic noises were measured in a locally blocked 37-pin bundle.

Comparison of sodium temperature noise obtained in the blocked and unblocked experiments led to the fact that the blockage formation increased the measured root-mean-square (RMS) value by approximately three times in the low frequency ranges (0.1∿10 Hz).

Noncondensable gas (argon) entrainment caused a considerable increase in the outlet flow noise measured by an eddy-current type flowmeter.

The boiling caused a considerable increase in acoustic noise intensity at all frequencies, particularly in the high frequency ranges (5∿100 kHz).

INTRODUCTION

Local faults such as local flow blockages in an LMFBR fuel subassembly must be early detected since the blockages cause fission gas release and/or sodium boiling, which may lead to fuel failure propagation and finally total core disruption. Among the various methods proposed for the detection of local faults, the measurement of temperature, flow and acoustic noise signals with the local faults appears to be promising.

In the earlier seven-pin experiments it was revealed that the blockage formation increased the RMS value of the outlet temperature fluctuations (noises) by a factor of two to three in the low frequency ranges (<10Hz).(1)(2) Examination of the RMS value of outlet flow fluctuation indicated the possibility of local sodium boiling detection.(3) The boiling caused a considerable increase in acoustic noise intensity at all frequencies,(3)(4)(5) and the frequency spectra of boiling acoustic noise were different from those of the experimental system resonance in the high frequency ranges (10∿100kHz).(6)

The present experiments have been conducted to investigate temperature, flow and acoustic noises in a locally blocked 37-pin bundle. This paper gives the experimental results of outlet temperature fluctuation under single-phase liquid conditions, outlet flow fluctuation under two-phase argon-sodium conditions and acoustic noise under boiling conditions.

EXPERIMENTAL EQUIPMENT AND OPERATING PROCEDURES

Test Section

A series of experiments were carried out in the Sodium Boiling and Fuel Failure Propagation Test Loops, SIENA at PNC's O-arai Engineering Center.

Figure 1 shows a sketch of the locally blocked 37-pin bundle test section and the positions of the instruments. In order to simulate an LMFBR fuel subassembly, a 37-pin bundle was centered in a hexagonal tube, 50.4 mm flat-to-flat distance inside. The bundle consisted of a central gas-injector pin, 18 electrically heated pins and other dummy pins. The diameter of each pin was 6.5 mm and the distance between pin centers (i.e. pin pitch) was 7.9 mm. At the distance of 304 mm from the start of the heated section a centrally located blockage of 5 mm thick stainless steel plate was welded on the upstream of a grid spacer. The blockage covered 27.3 % of the total flow area.

Argon, simulating fission gas, was injected into sodium through a small nozzle (0.3∿0.8 mm in diameter) of the gas-injector pin in the direction shown in the figure.

To keep heat losses to a minimum, the outer wall of the hexagonal tube was insulated by a compensating heater and thermal insulater.

The pin surface temperatures were measured by many chromel-alumel thermocouples of 0.3 mm in diameter, which were embedded in the outer surface of each pin. Most of their hot junctions were located at the axial locations downstream from the blockage. The inlet and outlet temperatures were measured by the thermocouples T-113 and T-114, respectively. Thermocouples T-4 and T-10 were provided at the outlet to measure the local coolant temperatures.

Potential-tap type void meters (VoT-1, through VoT-14) were used for measuring vapor or gas bubbles' behavior.

The sodium velocities at the inlet and outlet were measured by the electromagnetic flowmeters F-106 and F-107, respectively. A compact eddy-current type flowmeter FEC-1 also was used for measuring the outlet flow velocity.

Two types of pressure transducers were used in order to measure the pressure changes caused by boiling or gas injection. The first were strain-gauge type pressure transducers P-106 and P-107. The second were high temperature eddy-current type pressure transducers P-108 and P-109.

Three types of acoustic transducers were used in order to measure the boiling acoustic noises. The first were quartz accelerometers Ac-101 and Ac-102. Secondly lead zirconate-titanate microphones M-103 and M-104 were mounted onto waveguides placed to the expansion tank and the inlet of the test section, respectively. The third were high-temperature lithium niobate microphones BD-101, BD-102 and BD-103.

All the signals from these instruments were recorded by analog data recorders as well as by a digital data acquisition system. The data were analyzed by a data processing system.

Operating Procedure

In the first series of experiments, where temperature fluctuations were measured at the outlet under single-phase liquid conditions, the sodium flow rate was set and the heater pins were adjusted to a fixed power level. Sufficient time was allowed for the test section to reach steady-state conditions prior to experiments. The single-phase liquid experiments were conducted under the following conditions:

Flow velocity	0.51 ∿ 4.17 m/s
Inlet temperature	260.3 ∿ 293.5 °C
Heat flux	2.4 ∿ 58.5 W/cm^2

In the second series of experiments, where outlet flow fluctuations were measured under two-phase argon-sodium conditions, argon was injected transiently or continuously through a nozzle of the gas-injector pin into sodium behind the blockage. The gas injection experiments were conducted under following conditions:

Flow velocity	0.47 ∿ 4.28 m/s
Inlet temperature	256 ∿ 352 °C
Heat flux	4.8 ∿ 44.2 W/cm
Gas plenum pressure	7 ∿ 63 bar

In the third series of experiments, where boiling acoustic noises were measured, the inlet temperature and flow rate were held constant and the heat flux was gradually increased up to boiling inception. After boiling inception had thus set in, the heat flux was further increased step by step. The boiling experiments were conducted under following conditions:

Flow velocity	0.63 ∿ 3.51 m/s
Inlet temperature	444 ∿ 514 °C
Heat flux	68.1 ∿ 237.3 W/cm^2

RESULTS AND DISCUSSIONS

Temperature Fluctuation

Figure 2 shows the effect of heat flux on the RMS value of outlet sodium temperature fluctuation in the low frequency ranges (0.1∿10 Hz). In this figure are also shown the unblocked 19-pin experiments. It is seen that the temperature fluctuation increased with increasing heat fluxes. The measured fluctuation intensity was higher by approximately three times in the blocked experiments than in the unblocked experiments.

Figure 3 shows the effect of flow velocity on the temperature fluctuation intensity. In this figure are also shown the experimental results obtained by Fry.(7) In order to compare the present experimental results with Fry's data all the results were extrapolated to the heat flux of 71 W/cm^2. It is seen that the fluctuation intensity decreased with increasing the flow velocity. The RMS value of the fluctuation obtained in the present experiments agreed fairly well with Fry's value.

Flow Fluctuation

Figure 4 represents typical patterns of gas plenum pressure, outlet temperature and outlet flow velocity during a transient gas injection run GL-1. In this figure is also shown the outlet temperature fluctuation. The experimental conditions were : flow velocity, 3.59 m/s ; heat flux, 29.5 W/cm^2; inlet temperature, 272.3 °C; and initial gas plenum pressure, 61 bar. The gas plenum pressure decreased after gas started to be injected into sodium at 0 s. The eddy-current type outlet flowmeter FEC-1 registered an abrupt change upon gas injection followed by oscillations. These oscillations indicated that the two-phase argon-sodium flow passed the position of the flowmeter.

On the other hand the outlet temperature fluctuation T-4A decreased rapidly after gas injection since the outlet flow was accelerated upon gas injection. But the bulk outlet temperature T-4 could not detect gas injection.

Figure 5 shows the effect of quality on the RMS value of outlet flow velocity fluctuation measured in the continuous gas injection experiments. The fluctuation intensity first increased with the increase in the quality, and after attaining a maximum, remained more or less constant. The fluctuation was little influenced by heat flux and inlet flow velocity.

Acoustic Noise

Figure 6 shows the effect of changes in heat flux q on the acoustic noise intensity ratio I/Io measured by the lead zirconate-titanate microphone M-104 during a typical boiling run 37(12)LB-129, where I was the noise intensity at a given heat flux q, and Io the noise intensity in the absence of boiling. The experimental conditions were : flow velocity, 0.98 m/s ; inlet temperature, 469°C ; and cover gas pressure, 1.05 bar. Each curve represents the acoustic noise intensity, as registered after passage through the particular band-pass filter that is indicated in the figure. It is seen that the acoustic noise intensity increased sharply upon boiling inception, as the heat flux was gradually raised. This particularity was accentuated as the band-pass frequency of the filter was made higher.

Figure 7 shows the frequency spectra of acoustic noise measured by the microphone M-104 during the same boiling run 37(12)LB-129. It is seen that the boiling caused a considerable increase in intensity at all frequencies. Distinct broad peaks were also observed at approximately 3 kHz and 10 kHz when boiling had set in. The first peak observed at 3 kHz could well be related to the characteristics of the resonances of the experimental system. The second peak at 10 kHz, however, was possibly attributed to the sodium vapor collapse phenomenon. These experimental results are consistent well with the earlier seven-pin experiments.[5][6]

CONCLUSIONS

Experimental studies were carried out on temperature, flow and acoustic noises in a locally blocked 37-pin bundle under single- and two-phase flow conditions. In the first series of experiments sodium temperature fluctuations were measured at the outlet of the bundle under single-phase liquid conditions. In the second series of experiments outlet flow fluctuations were measured by the eddy-current flowmeter under two-phase argon-sodium conditions. In the third series of experiments acoustic noises were measured under boiling conditions.

Analyses of the results obtained permit the following conclusions to be drawn.

(1) The blockage formation increases the RMS value of outlet sodium temperature fluctuations by approximately three times in the low frequency ranges (0.1∿10Hz).

(2) Noncondensable gas entrainment causes a considerable increase in outlet flow fluctuation.

(3) The boiling causes a considerable increase in acoustic noise in intensity at all frequencies, particularly in the high frequency

ranges (5∿100 kHz). The broad peak observed at approximately 10 kHz is possibly attributed to the sodium vapor collapse phenomenon.

The above observations indicate that the measurement of temperature, flow and acoustic noise signals is promising for early detection of local faults in LMFBR fuel subassemblies.

Larger-scaled experiments in a 61-pin bundle are scheduled for next year.

ACKNOWLEDGMENTS

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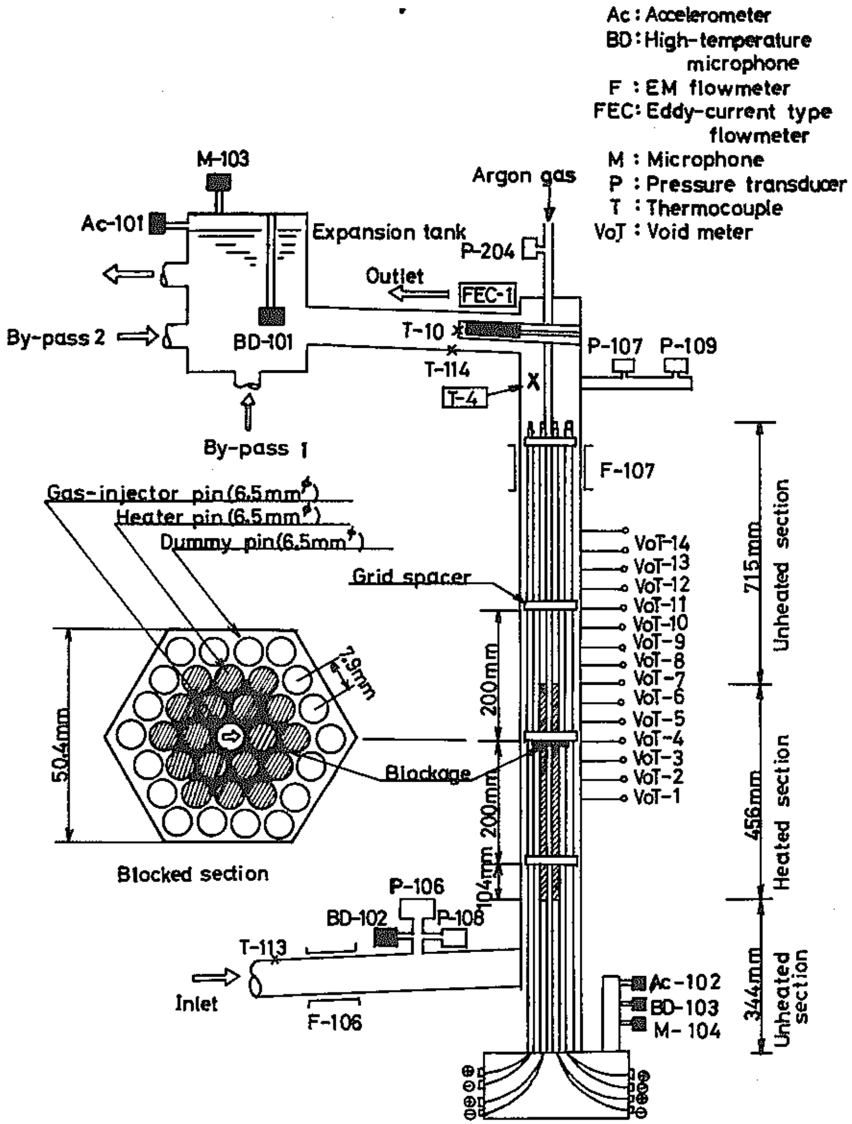

Fig. 1 Locally blocked 37-pin bundle test section

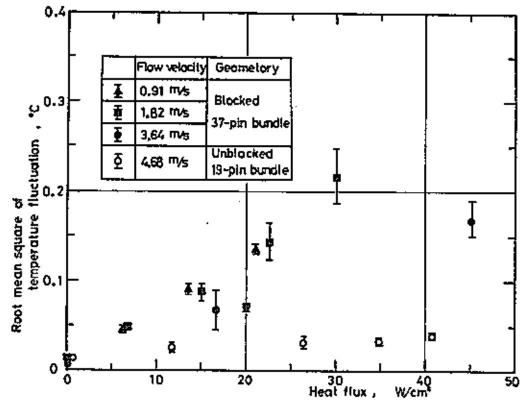

Fig. 2 Effect of heat flux on root mean square of outlet temperature fluctuation

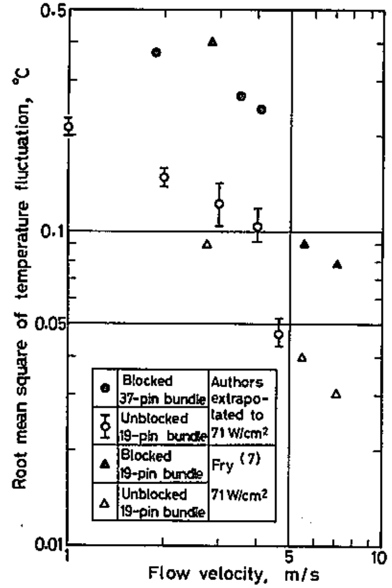

Fig. 3 Effect of flow velocity on root mean square of outlet temperature fluctuation

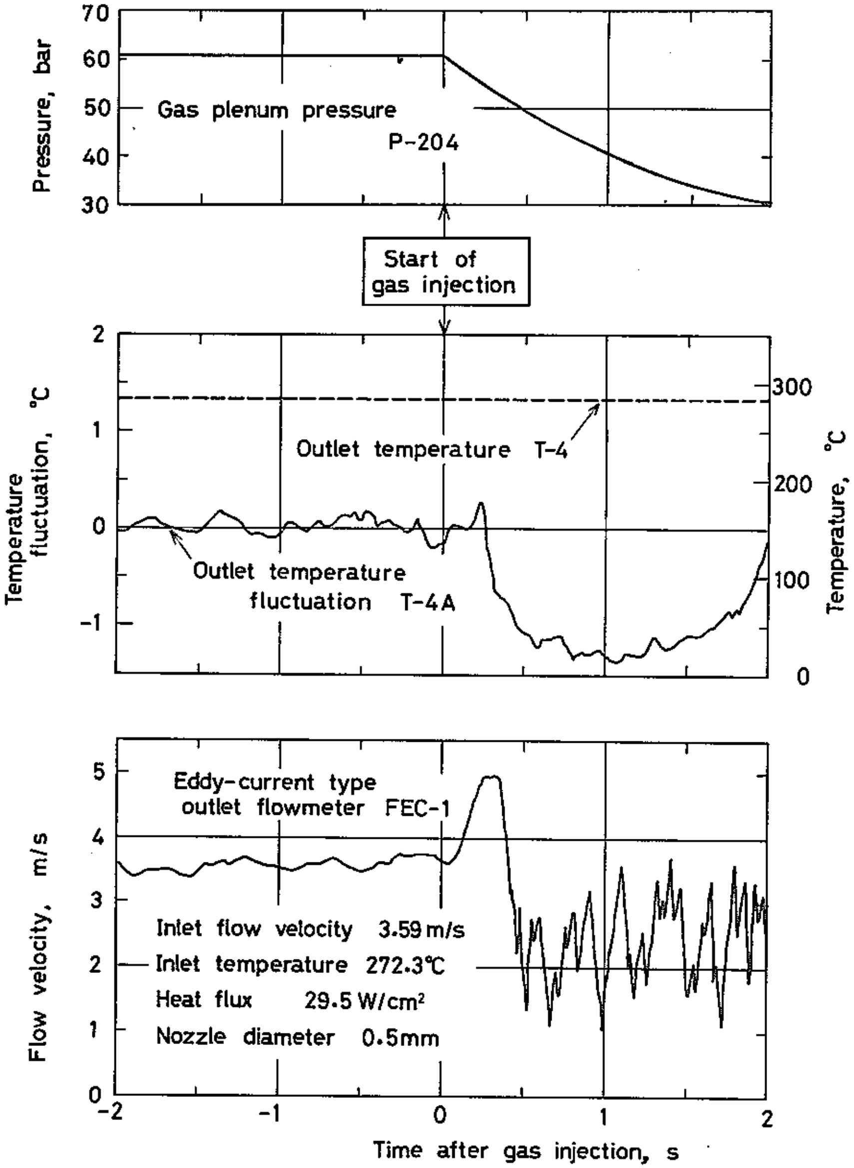

Fig. 4 Typical signals from pressure transducer, thermocouple and flowmeter during transient gas-injection run GL-1

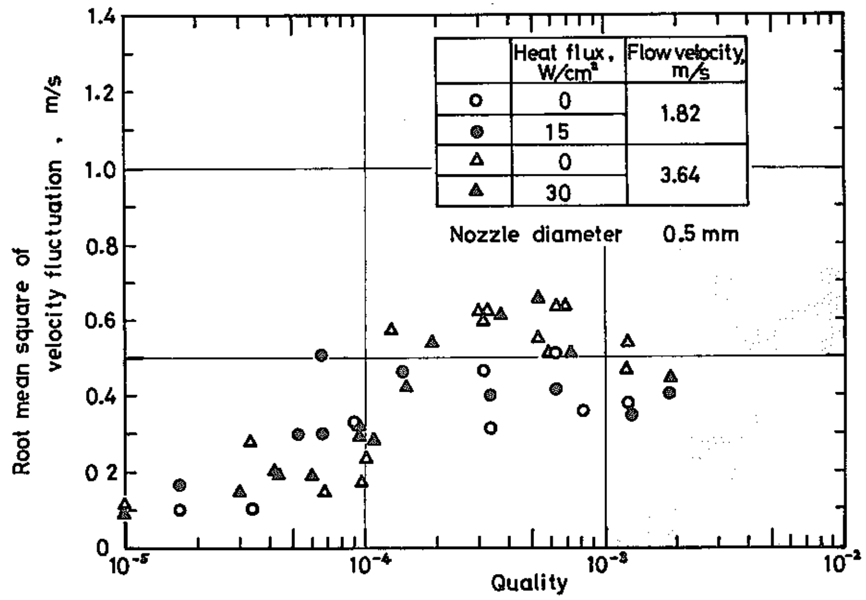

Fig. 5 Effect of quality on root mean square of outlet flow velocity fluctuation with continuous gas injection into sodium

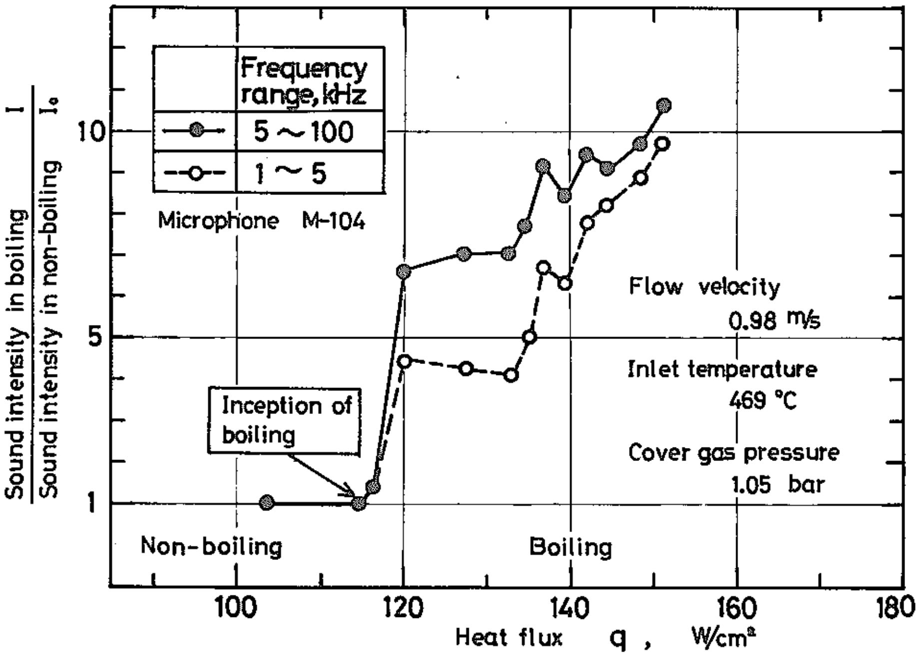

Fig. 6 Effect of heat flux on intensity of acoustic noise with boiling ; run No. 37(12)LB-129

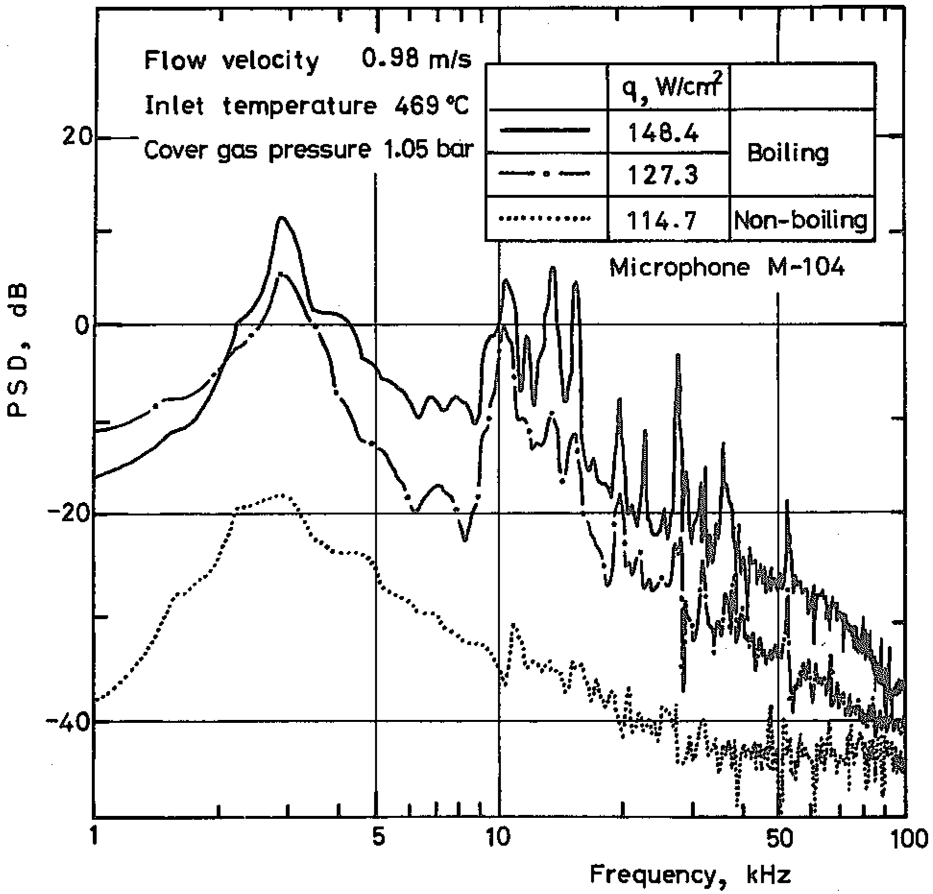

Fig. 7 Frequency spectra of acoustic noise with boiling ; run No. 37(12)LB-129