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〒311-13　茨城県東茨城郡大洗町成田町4002
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ACOUSTIC NOISES WITH LOSS-OF-FLOW SODIUM BOILING EXPERIMENT IN A 19-PIN BUNDLE

Y. OZAKI[a)], K. HAGA[b)], Y. KIKUCHI[b)*], T. MORIKAWA[a)], M. HORI[b)]

a) Central Research Laboratory, Mitsubishi Electric Corporation, Japan

b) O-arai Engineering Center, Power Reactor and Nuclear Fuel Development Corporation, Japan

ABSTRACT

This paper deals with the measurement of acoustic noises with sodium boiling in an electrically heated 19-pin bundle which simulated an LMFBR fuel subassembly.

The intensity of boiling acoustic noises measured with the waveguide method was much higher than the background noises such as mechanical and flow noises.

A distinct peak, which was observed at approximately 10 kHz, may be attributed to the peculiarity of sodium boiling phenomena because this peak could easily be distinguished from the resonance peaks of the experimental system.

The waveform of the boiling acoustic noises was similar to the burst type acoustic emission (AE).

The propagation speed of acoustic noises agreed well with a prediction by the theory based on the assumption that the measured acoustic signals were transmitted on the pipe as surface waves (Rayleich waves) or Lamb waves.

INTRODUCTION

Since sodium boiling due to local flow blockage could cause the fuel pin failure propagation, finally leading to a subassembly failure, sodium boiling should be detected in the early stage of accidents in LMFBRs. Among the various methods proposed for the sodium boiling detection, the method of measuring acoustic noise signals with sodium boiling appears to be most promising.

In the earlier experiments of sodium boiling, the boiling was observed to make a considerable increase in acoustic noise intensity at all frequencies,(1)(2)(3) and the power spectrum density of boiling acoustic noise was different from the resonance peaks of the experimental system in high frequency ranges (10∿100 kHz).(4)(5)

An experiment was carried out to investigate sodium boiling

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* Present address; Kyoto University

phenomena in a 19-pin bundle (6). This paper gives the results of acoustic noise observation made in that experiment.

EXPERIMENTAL EQUIPMENT AND OPERATING PROCEDURE

Loop

A series of experiments have been carried out in the Sodium Boiling and Fuel Failure Propagation Test Loops SIENA at O-arai Engineering Center, PNC. The details of the SIENA loops are described in reference(7).

The SIENA loops have three test sections; T-1, T-2, and T-3. T-3 test section was utilized for this 19-pin sodium boiling experiment.

Test section

Figure 1 shows a schematic diagram of the 19-pin bundle test section.(6) In order to simulate an LMFBR fuel subassembly, an electrically heated 19-pin bundle was centered in a hexagonal tube, 36.7mm flat-to-flat distance inside. The heater pins were 6.5mm in diameter and approximately half as long as the fuel pins of the Japanese prototype LMFBR, MONJU. The heater pins had an effective heating length of 465mm and could be operated at the maximum heat flux of 300 W/cm^2 in the flowing sodium of 900°C. Each pin was wrapped with a 1.3 mm diameter wire clockwise in the flow direction at a 264.8 mm pitch and assembled together into a tight bundle. The distance between pin centers (i.e. pin pitch) was 7.9mm and the pitch-to-diameter ratio (P/D) was 1.22.

A compensating heater and a thermal insulator were equipped on the outer wall of the hexagonal tube to minimize the heat loss from the outer wall. The by-passes of the test section simulated other subassembly channels adjacent to the boiling subassembly.

Three types of acoustic transducers were used in order to measure the boiling acoustic noises. The first were quartz accelerometers A-101 and A-102. Secondary lead zirconate-titanate (PZT) microphones AC-103 and AC-104 were mounted onto waveguides placed to the expansion tank and the inlet of test section, respectively. The third were high-temperature lithium niobate microphones BD-101, BD-102 and BD-103. Among the results obtained from these transducers, this paper deals with the acoustic noises recorded by the PZT type sensors. The frequency response of the PZT transducers was flat in the range between 1kHz and 100kHz. Figure 2 shows a bird's-eye view of the 19-pin test section and the expansion tank. The distance of AC-103 and AC-104 was about 9.2m.

All the signals from these transducers were recorded with an analog data recorder and were analyzed with a data processing system. Figure 3 shows a instrumentation system for sodium boiling acoustic noises.

Operating procedure

The experiments were performed in following manner. The oxygen concentration in sodium was controlled less than 10 ppm with the purification system.

In the each run of experiments, where transient boiling phenomena were investigated under loss-of-flow conditions, the sodium flow rates of the test section and by-passes were controlled by adjusting the pump power and throtting valve opening. The heat flux was maintained constant by adjusting the power supply to the heater pins. Thereafter, the flow was reduced or stopped according to the pump coastdown, or sudden pump stop.

The inception of boiling was anticipated from the hottest thermocouple reading and the actual onset of boiling was detected by the signals from the acoustic transducers, pressure sensors, flowmeters and void meters.

The boiling experiments were conducted under the following conditions;

Flow velocity at boiling inception : 0∿1.21 m/s
Inlet temperature : 354∿397 °C
Heat flux : 58∿186 W/cm^2
Cover gas pressure : 1.04∿1.06 bar

RESULTS AND DISCUSSIONS

Spectrum of acoustic noises

Figure 4 shows the record of waveform and power spectrum density of acoustic noises with sodium boiling by the AC-104 transducer settled at the inlet of test section. The experimental conditions were flow velocity at boiling inception 0.5 m/s, inlet temperature 371 °C and heat flux 143 W/cm^2. The experiment was made by sudden pump stop method. In this figure, it is seen that the waveform of acoustic noises is similar to a burst type AE which can be observed when a crack occures in materials, and so energy of sodium boiling is much higher than that of mechanical and flow noises. A distinct peak, which was observed at approximately 10 kHz in the power spectrum density, can be distinguished easily from the lower frequency peaks (1∿5 kHz) due to the resonance of experimental apparatus, such as the test section and the expansion tank. This characteristic is similar to the previous 7-pin and 37-pin experiments.(4)(5)

Figure 5 shows a comparison of power spectrum density of acoustic noises with boiling measured at the expansion tank (AC-103) and the inlet of test section (AC-104). The experimental conditions were flow velocity at boiling inception 1.21 m/s, inlet temperature 377°C and heat flux 168 W/cm^2 (only 15 pins were heated). The experiment was conducted by pump coastdown method. In this figure, several peaks in power spectrum at the expansion tank can be seen at 1∿2 kHz and 6∿9 kHz. The peak at about 10 kHz however, is lower than the peaks in the low frequency range in several orders. On the other hand, the power spectrum measured at the inlet of test section shows the distinct peaks at 1.5∿3 kHz and 8∿15 kHz. From the comparison of these two power spectra, it can be considered that the lower peaks in the kilohertz range are not peculiar to the boiling acoustic noise, but related to the characteristics of the resonance of the experimental apparatus. The higher peaks at approximately 10 kHz may be peculiar to the boiling, because among peaks in 8∿15 kHz range at the inlet of test section, the components above 10 kHz are reduced in propagating process from the test section to the expansion tank. The peaks in 8∿15 kHz range were observed also in the earlier 7-pin boiling experiment.(4)

Propagation speed of acoustic noise

Figure 6 shows waveforms of acoustic noises with sodium boiling measured at the expansion tank and at the inlet of test section. This figure shows that the acoustic noises arrive at AC-104 5∿6 ms faster than at AC-103. The transducer at the expansion tank is about 12 m apart from that at the inlet of test section. The propagation speed of acoustic noise can be evaluated from the arrival time difference of two transducers. The obtained propagation speed agreed well with a prediction by a theory based on the assumption that the measured acoustic noises are transmitted on the pipe as surface waves (Rayleich waves) or Lamb waves, and the propagation speed of these waves is 2540 m/s in the case of stainless steel. This indicates that the waveguide method in which the acoustic noises with boiling can be detected as surface waves is a useful method for sodium boiling detection, since surface waves transmit with smaller reduction rate in intensity and/or energy than longitudinal waves.

Intensity of acoustic noises

Figure 7 shows the effect of cut-off frequency of band-pass filter on intensity of acoustic noises with sodium boiling, where I is the noise intensity after inception of boiling, and Io is the noise intensity in non-boiling state. In this figure, it is seen that the acoustic noise intensity increases sharply upon boiling inception, and the intensity ratio (I/Io) in the case of band pass filter of about 5 kHz or 10 kHz is several times higher than that of under 5 kHz. For the boiling detection in LMFBRs, it will be also useful to measure the acoustic noises above 5 kHz rather than under 5 kHz because background mechanical and flow noises exist mainly at kilohertz range (<5 kHz).

CONCLUSIONS

Experimental studies of acoustic noises with sodium boiling were carried out using a 19-pin bundle which simulated an LMFBR fuel subassembly, under loss-of-flow conditions.

Analysis of the results yielded the following conclusions.

(1) Sound energy and/or intensity with sodium boiling is much higher than that with mechanical and flow noises.
(2) Distinct peaks at approximately 10 kHz in power spectrum density of acoustic noise with sodium boiling may be attributed to the peculiarity of sodium boiling itself.
(3) Acoustic noise signal with sodium boiling can be detected as surface waves using waveguides which are set on the equipment system.
(4) It is more useful for detection of sodium boiling to measure the sound intensity above 5 kHz or 10 kHz.

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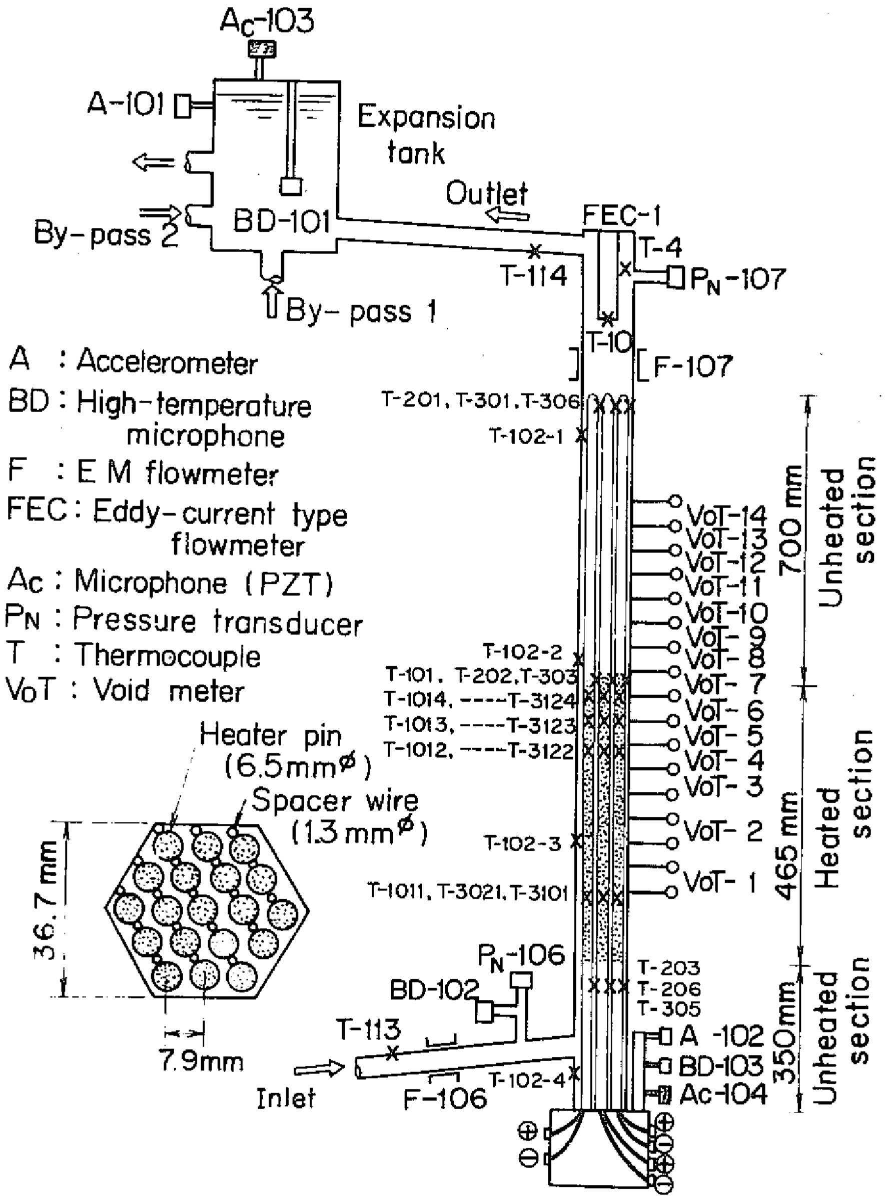

Fig. 1 19-pin bundle test section

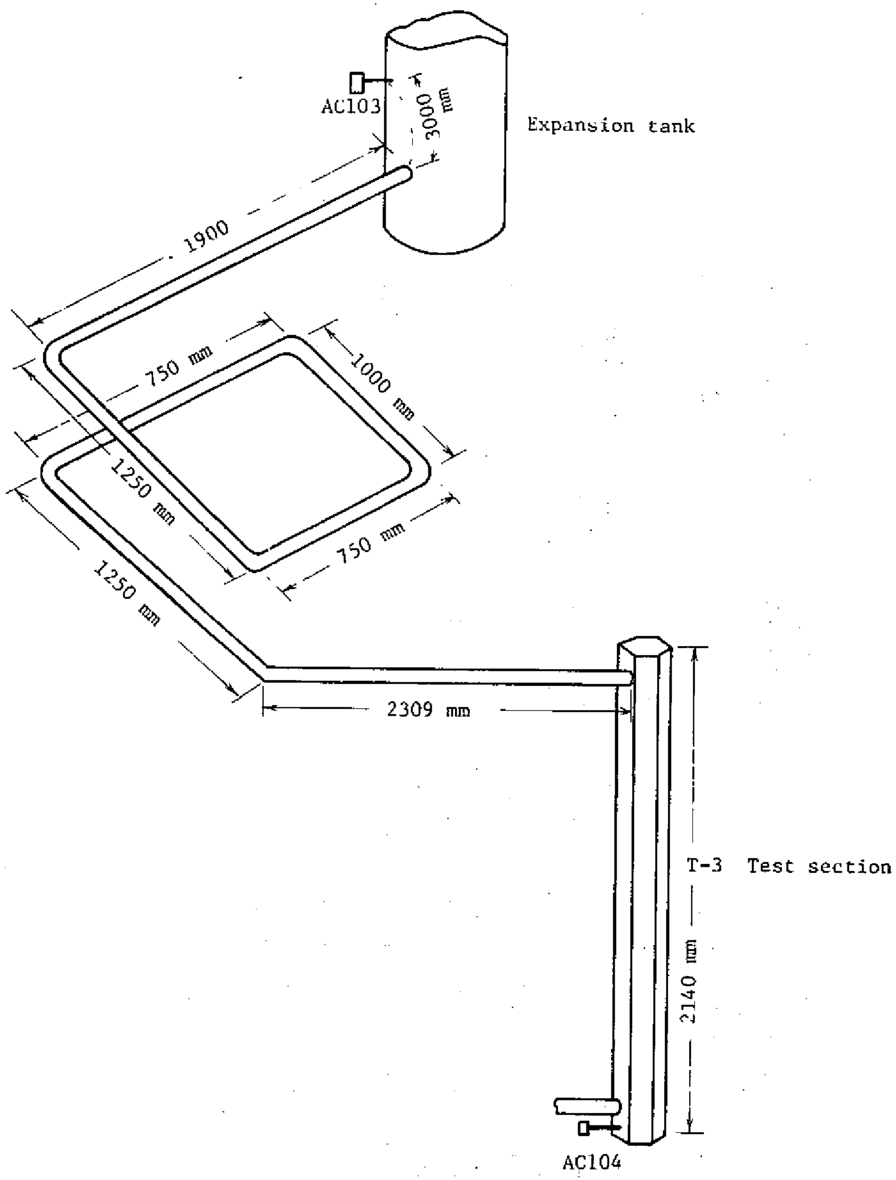

Fig. 2 Bird's-eye view of 19-pin test section and expansion tank

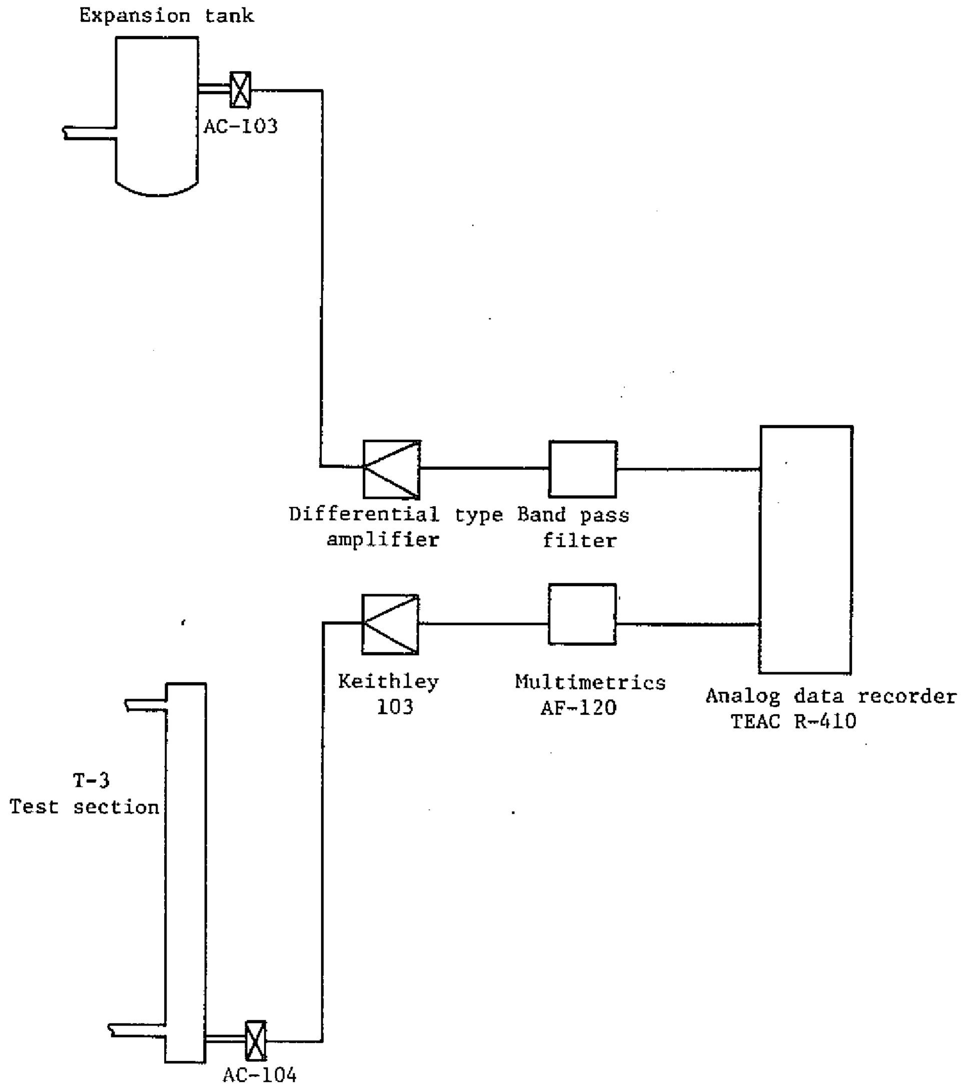

Fig. 3 Instrumentation system for sodium boiling acoustic noise signal

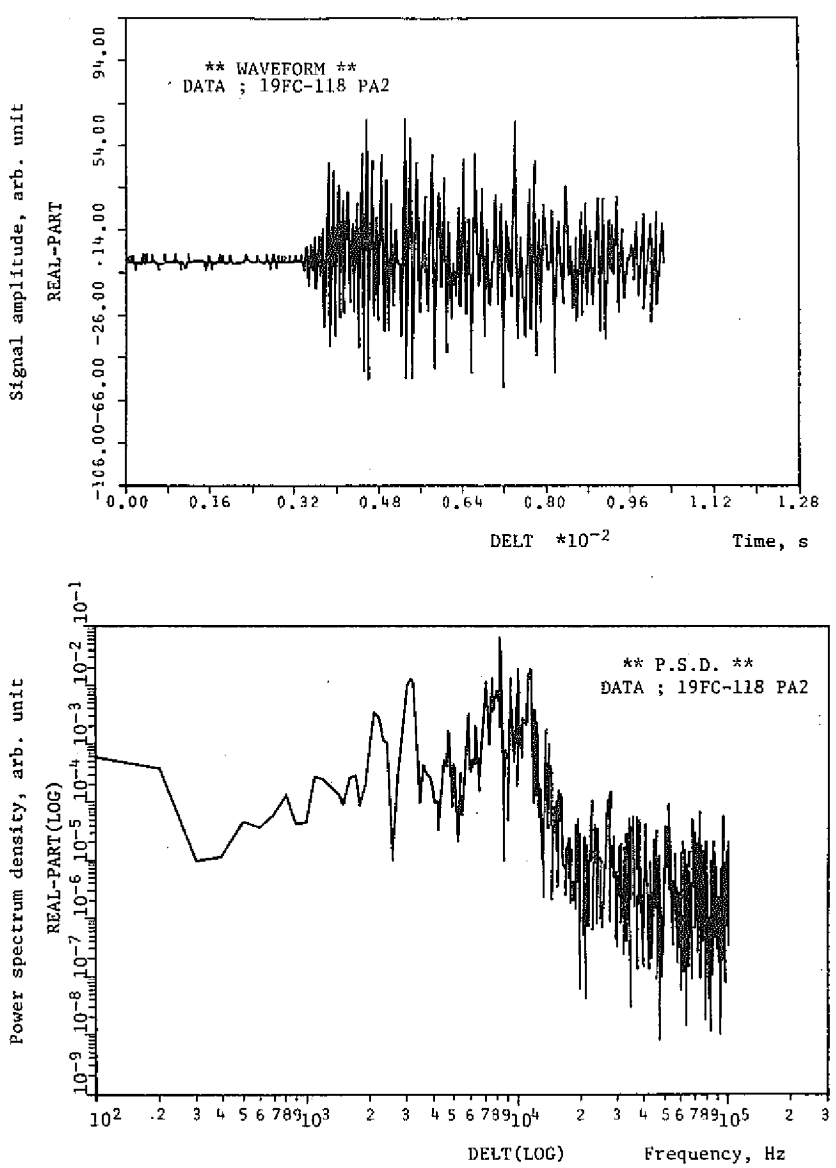

Fig. 4 Waveform and power spectrum density of acoustic noise signal with sodium boiling in 19-pin bundle (run No. 19FC-118)

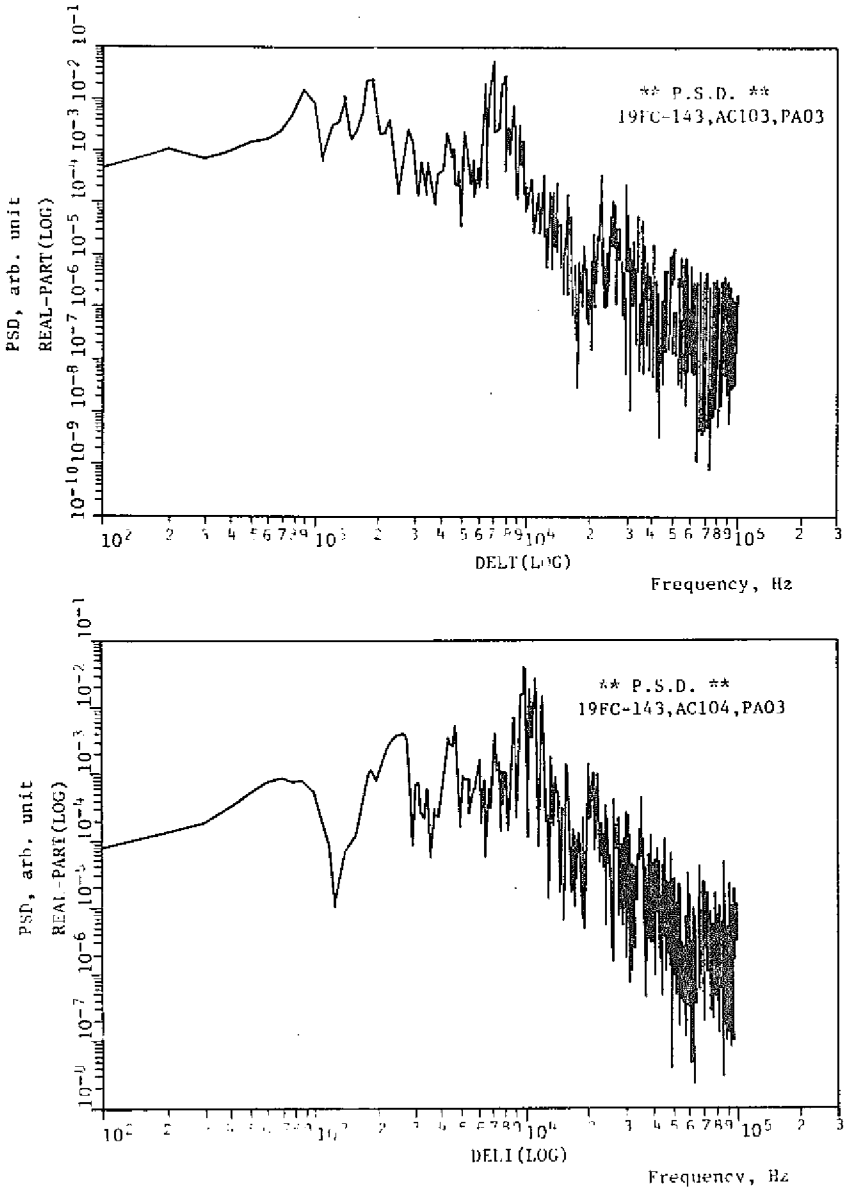

Fig. 5 Comparison of power spectrum density of acoustic noise signals with sodium boiling measured at expansion tank and inlet of test section (run No. 19(15)FC-143, pulse No.P-03)

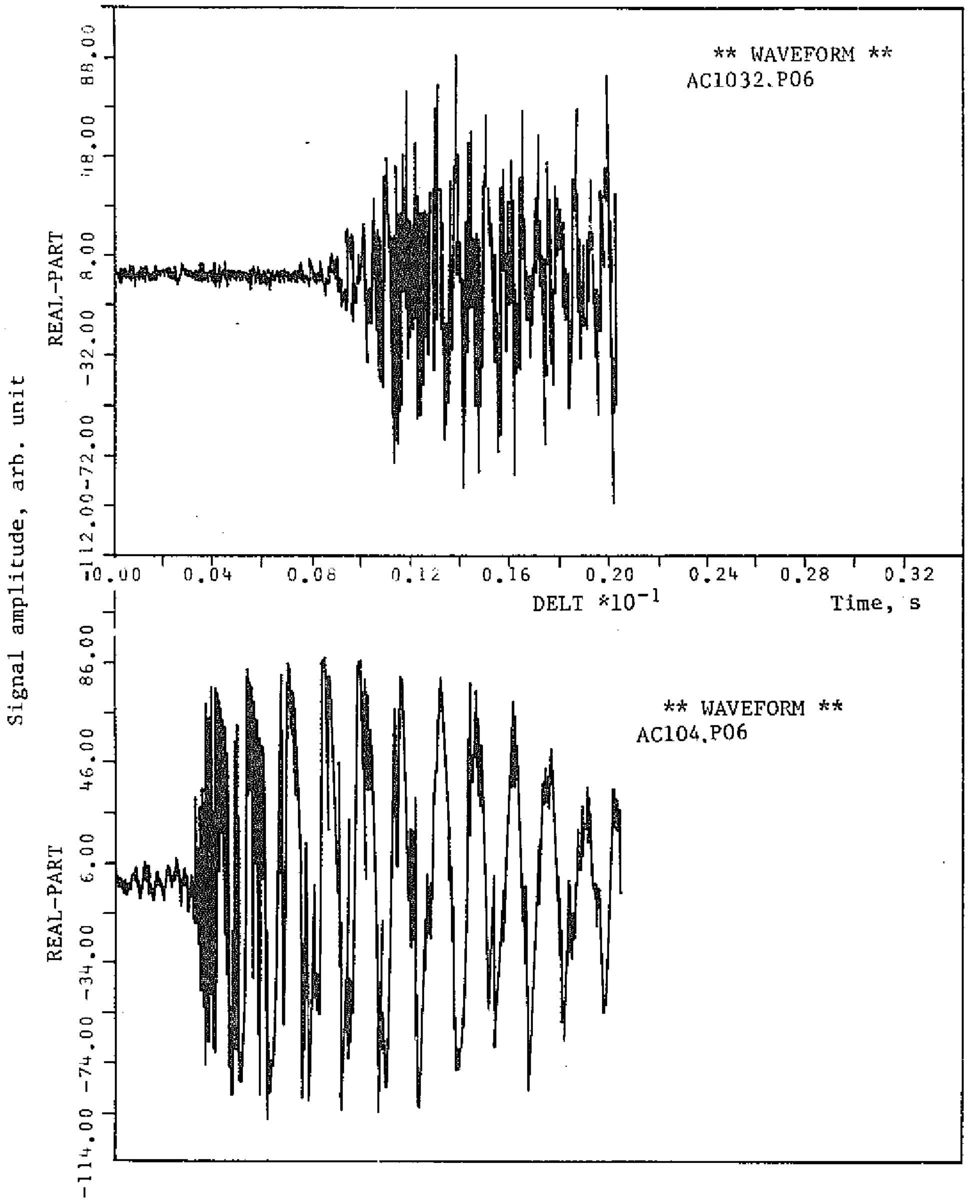

Fig. 6 Record of arrival time difference of boiling acoustic noise signals measured at expansion tank and at inlet of test section (run No. 19(15)FC-143, pulse No.P-06)

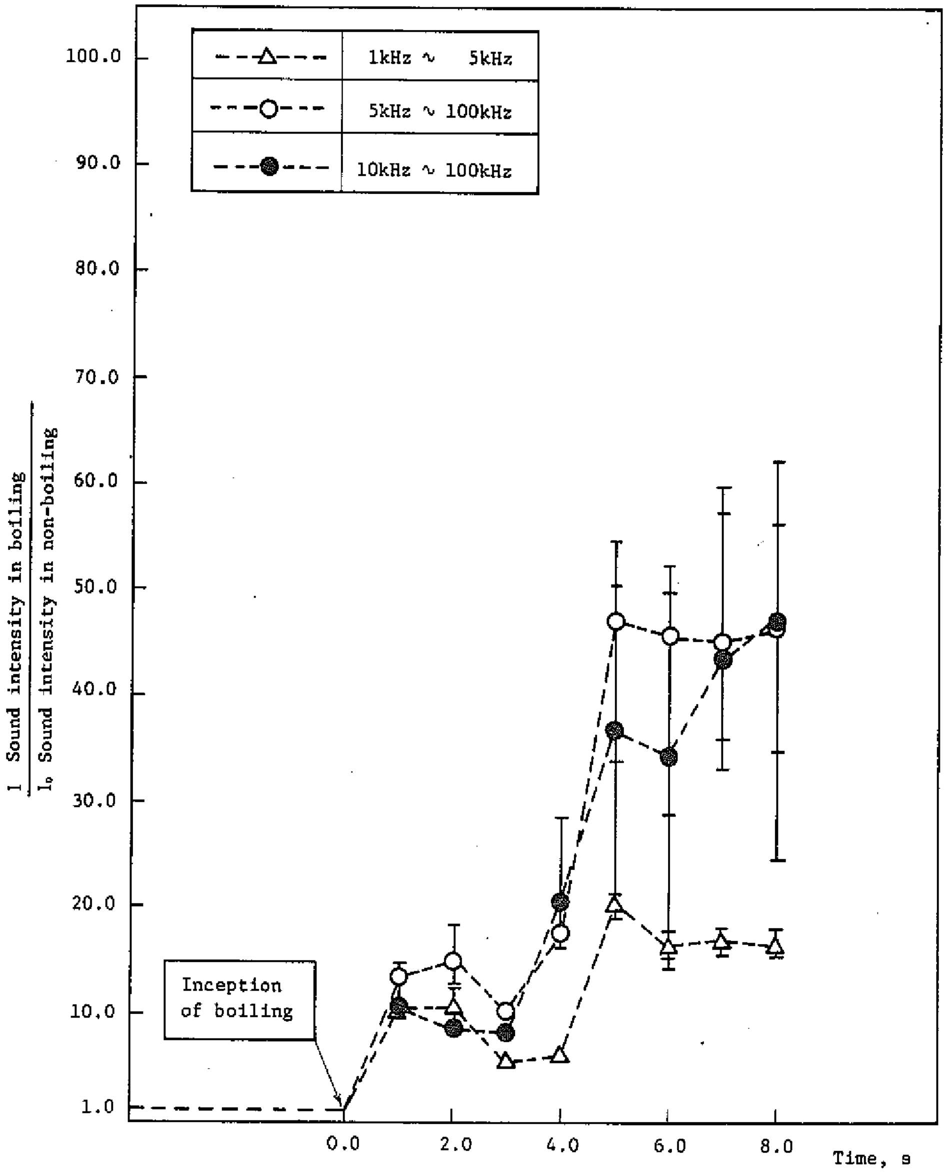

Fig. 7 Effect of cut-off frequency of band-pass filter on intensity of acoustic noise signal with sodium boiling in 19-pin bundle (run No.19(15)FC-143)