«Detection and localization of leak of pipelines of RBMK reactor. Methods of processing of acoustic noise»

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Introduction

Absence of reactor protection cap and the one-circuit type of a reactor cooling makes especially important to increase of operation safety of the equipment by the duly leak detecting of pipelines and exception of their instant destruction.

For realization of leak detection of input pipelines and output pipelines of RBMK reactor the method, based on detection and control of acoustic leak signals, was designed.

In this report the review of methods of processing and analysis of acoustic noise is submitted. These methods were included in the software of the leak detection system and are used for the decision of the following problems:

- leak detection by method of sound pressure level in conditions of powerful background noise and strong attenuation of a signal;
- detection of a small leak in early stage by high-sensitivity correlation method;
- determination of a point of a sound source in conditions of strong reflection of a signal by a correlation method and sound pressure method;
- evaluation of leak size by the analysis of a sound level and point of a sound source;

The work of considered techniques is illustrated on an example of test results of a fragment of the leak detection system. This test was executed on a Leningrad NPP, operated at power levels of 460, 700, 890 and 1000 MWe.

State of Problem

For the inspection of the RBMK reactor input pipelines (low water lines, pressure and distributing headers) and output pipelines (steam-water lines, drum separator and sections of downcomer piping) a method based on the detection and monitoring of acoustic signals of a leak propagating in the air atmosphere has been suggested.

The system operation is based on the principle of recording acoustic noise emitted by a leak, using the acoustic sensors.

The leak detection system, used this acoustic method makes an uninterrupted automatic monitoring of the reactor piping leak and has to solve the following problems:

- leak detection with sensitivity of about 230 l/h in the course of 1 hour;
- leak localization with an accuracy of approximately 1 m;
- quantitative evaluation of the coolant draining away;
- generation of warning signals to the power unit operator and alarm signals on reaching the threshold leak size.

The tests of a fragment of the leak detection system are carried out on a Leningrad NPP.

Object of inspection

Part of the RBMK cooling circuit piping located in rooms 033 and 505 within the reactor leak-tight area and not having thermal protection coatings is subject of inspection. The cooling circuit consists of two symmetric loops, controlled equipment within one loop contains the following components (Fig. 1):

a) Input pipelines of the reactor (room 033):

- pressure header (1 piece);
- group distributing headers (22 pcs.);
- low water line piping sections (846 pcs.);

b) Output pipelines of the reactor (room 505);

- steam water line piping sections (846 pcs.);
- steam drum separators (2 pcs.);
- downcomer piping sections (24 pcs.).

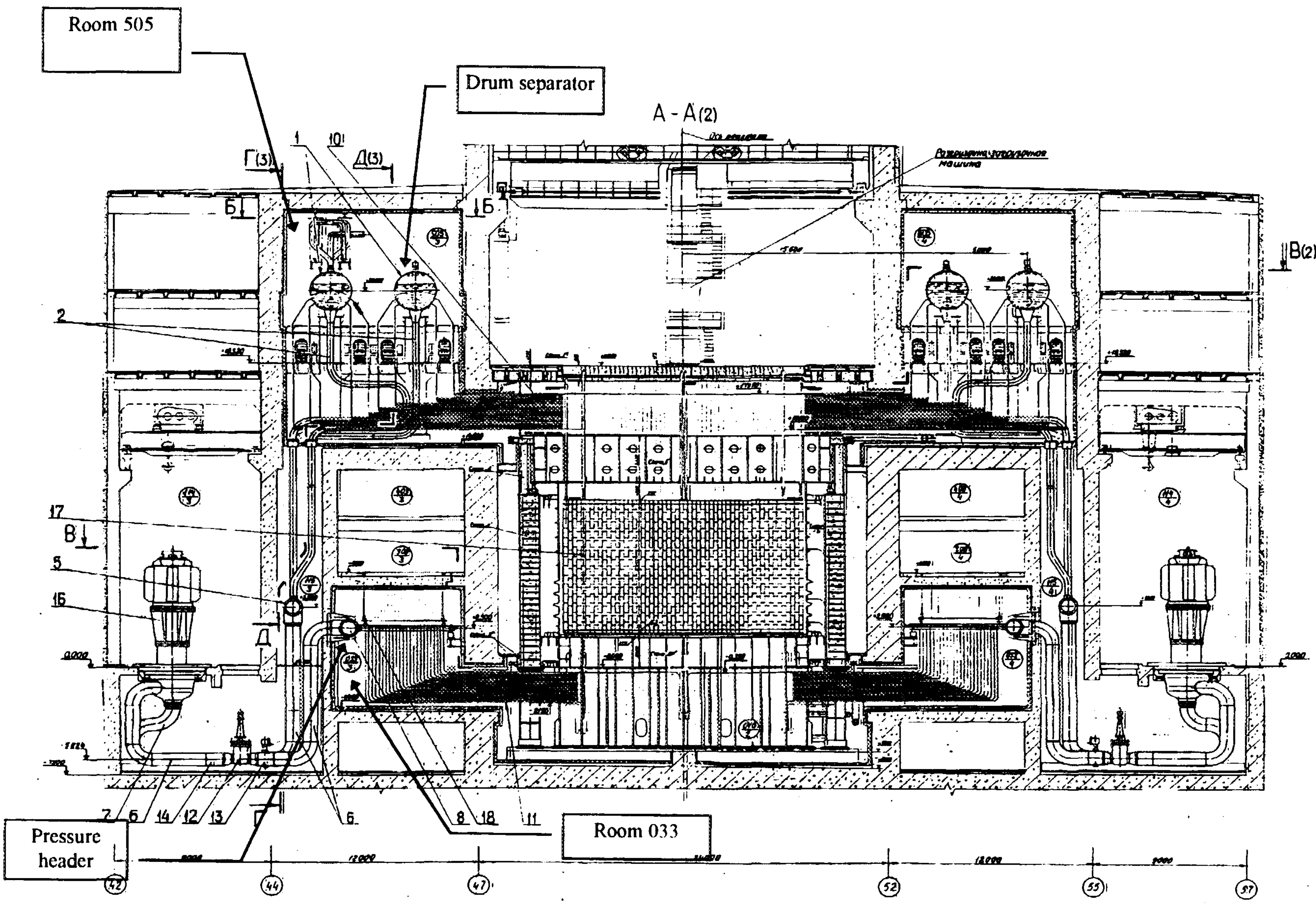


Fig. 1 The Unit 1 of Leningrad NPP with RBMK reactor

3. Methods of analysis

The algorithm of inspection comprises the following basic procedures (Fig. 2):

- «fast» detection of a leak;
- «early» detection of a leak;
- definition of location of a leak (localization);
- estimation of a leak flow rate.

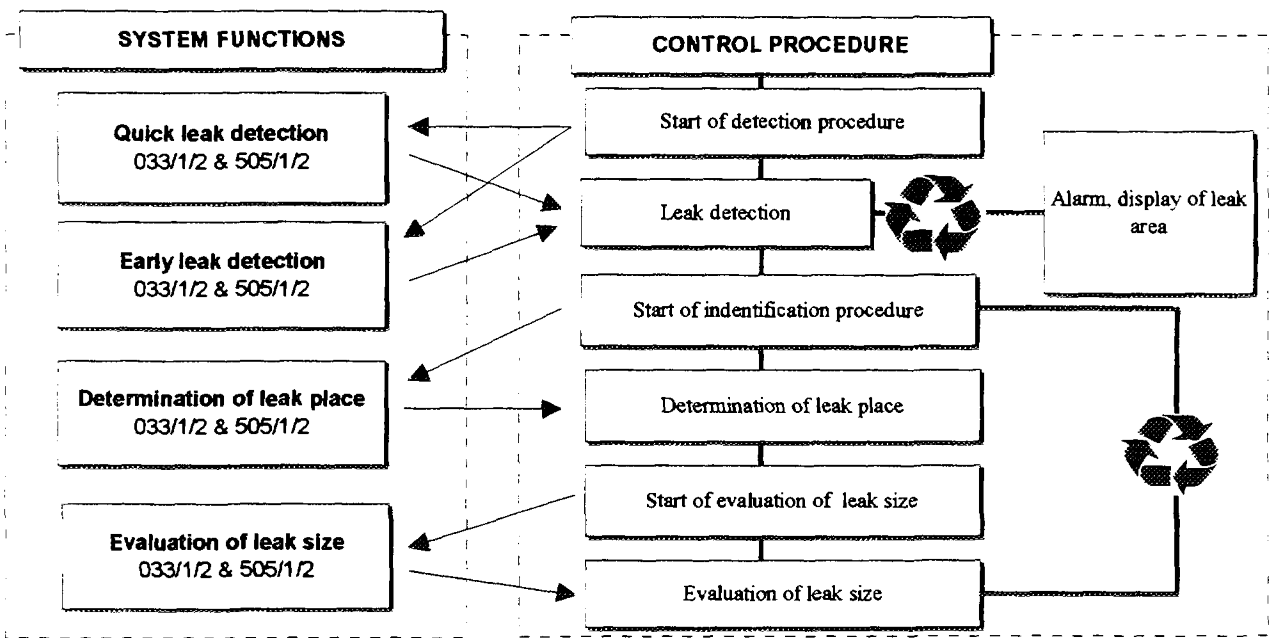


Fig. 2 The basic procedures of inspection algorithm

3.1. «Fast» detection of a leak by sound pressure method

The algorithm is based on comparison of sound pressure level in a preset frequency band with a threshold specified (the sampling cycle is about 2 min) and provides the inspection at signal/noise ratio ≥ 1.

So as to reduce the probability of «signal missing» and «false response» of the system the comparison is made for a preset time interval using three methods:

- excess of the absolute threshold for each microphone;
- excess of a relative threshold for each microphone;
- excess of a relative threshold, when comparing readings of different microphones.

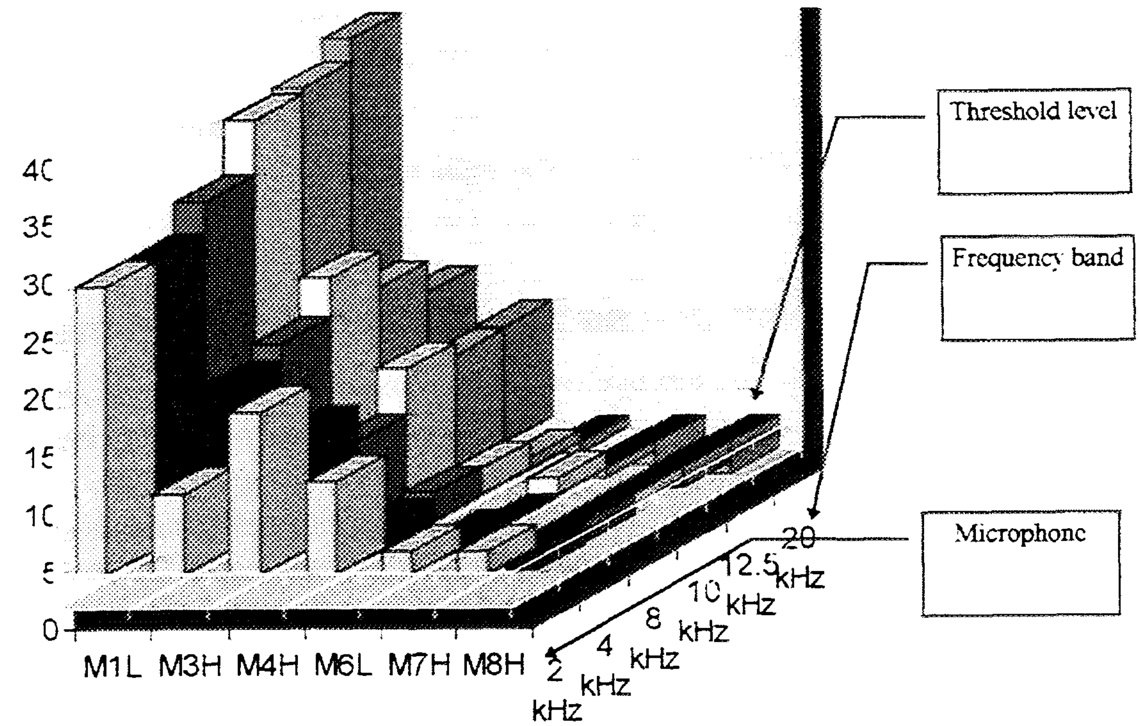


Fig. 3 Signal/Noise ratio (dB) of microphone signals of the leak: 800 l/h

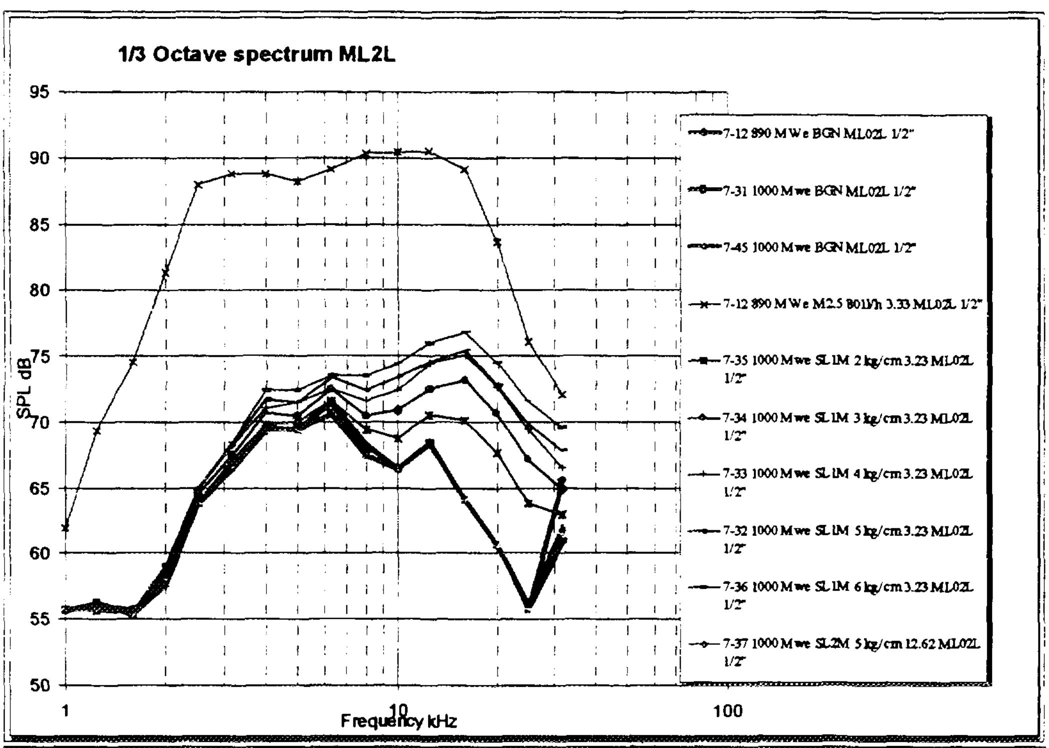


Fig. 4 The 1/3 Octave spectrum of microphone signals (SPL dB) for imitation of different leaks

As the evaluation results of the NPP test, the following results were obtained:

- the system sensitivity makes up to 0.067 m^3/h (at a distance up to 3.56 m from the source of sound) in rooms of low water pipelines;
- and up to 0.024 m^3/h (at a distance up to 4.36 m from the source of sound) in rooms of steam-water pipelines and drum separator;.

The threshold of detection was 3 dB.

3.2. «Early» detection of a small leak by correlation method

The algorithm is based on comparing cross-correlation characteristics of signals generated by a microphone pair with a preset threshold in the frequency band selected (the polling cycle is about 40 min) and it provides inspection at signal/noise ratio ≤ 1 (Fig. 5, 7, 8). To increase fast response of the method the polling is realized for the microphone pairs chosen in advance and for preset polling path.

(1) Analysis of coherence function

The coherence function is used for choice of an optimum frequencie band of the analysis and for detection of a local sound source.

To get diagnostic parameters, coherence function is smoothed out by the «moving averaging» method.

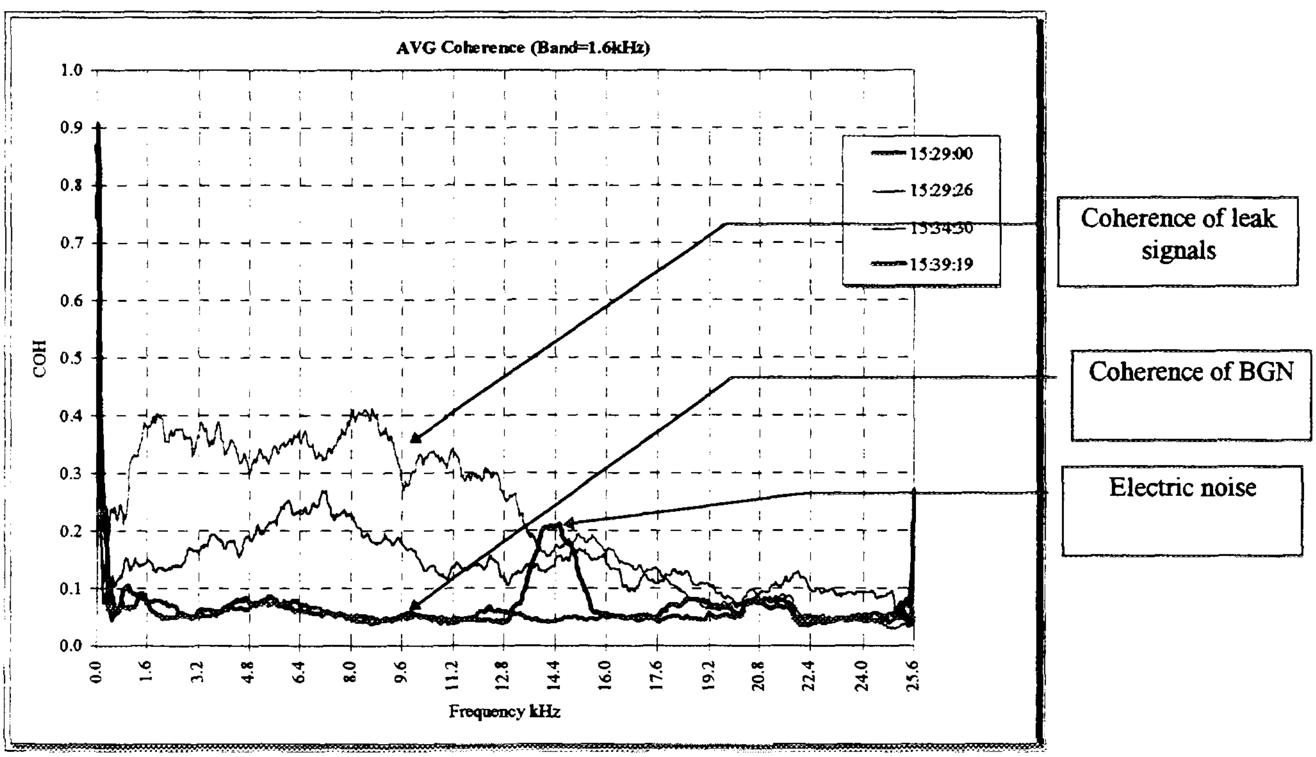


Fig. 5 Comparison of coherence functions, made before and after leak occurence

(2) Analysis of correlation function

The cross-correlation function is calculated by ZOOM method (frequency band is about 1.6 kHz) according to the following algorithm:

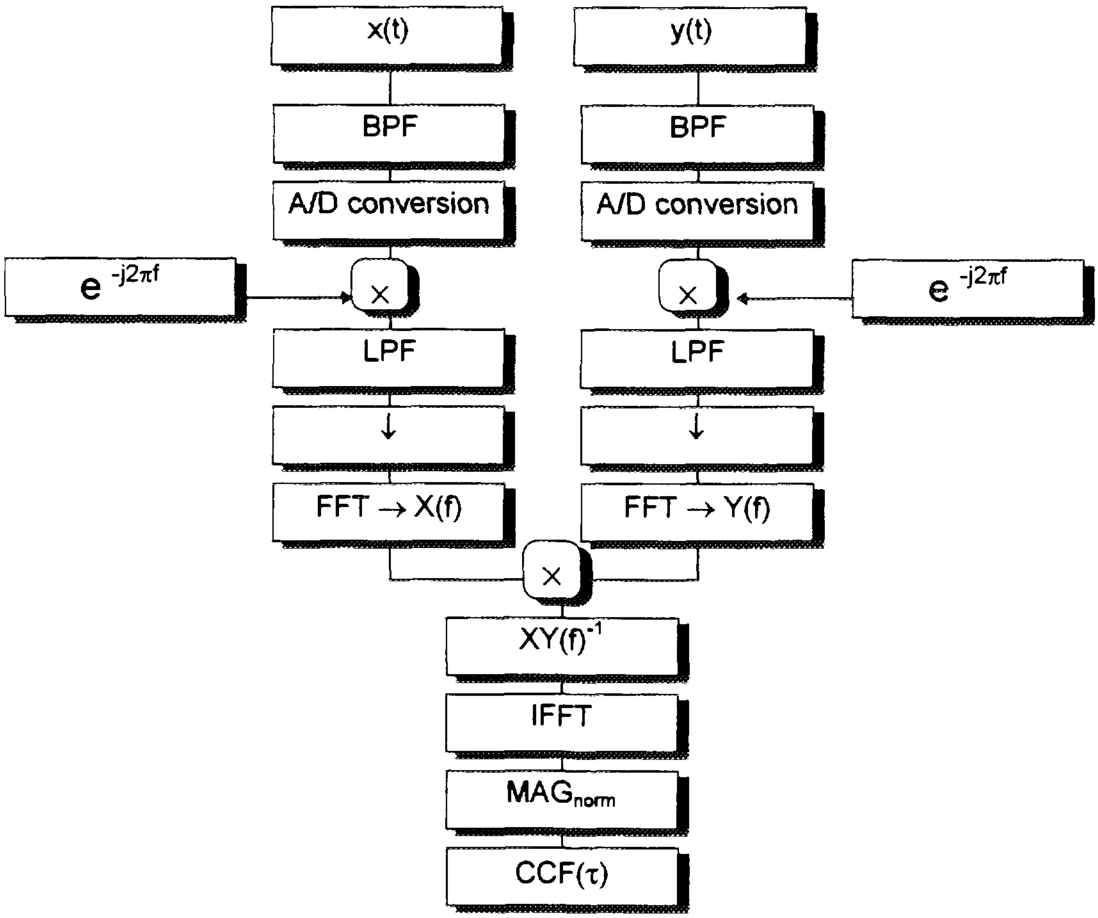


Fig. 6 The algorithm of calculation of cross-correlation function

The following diagnostic parameters of leak signal was used:

- maximum value of the normalized correlation function: Max[CCF]
- form factor of correlation function: Q[CCF]

The example is shown on Fig. 7, 8.

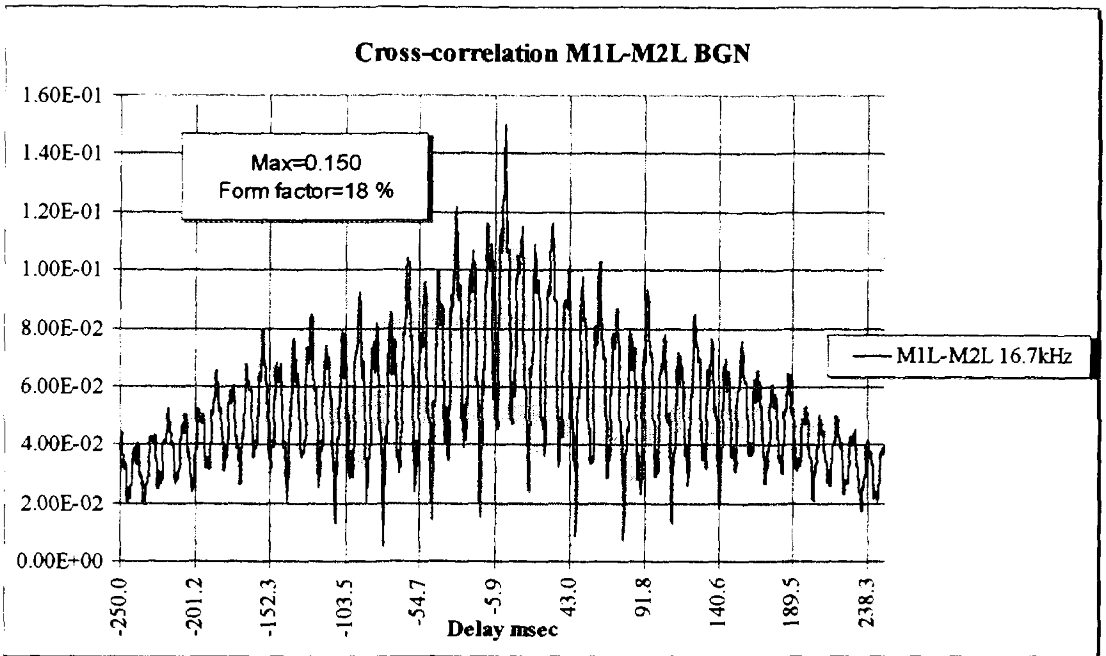


Fig.7 The cross-correlation function, made before leak occurence

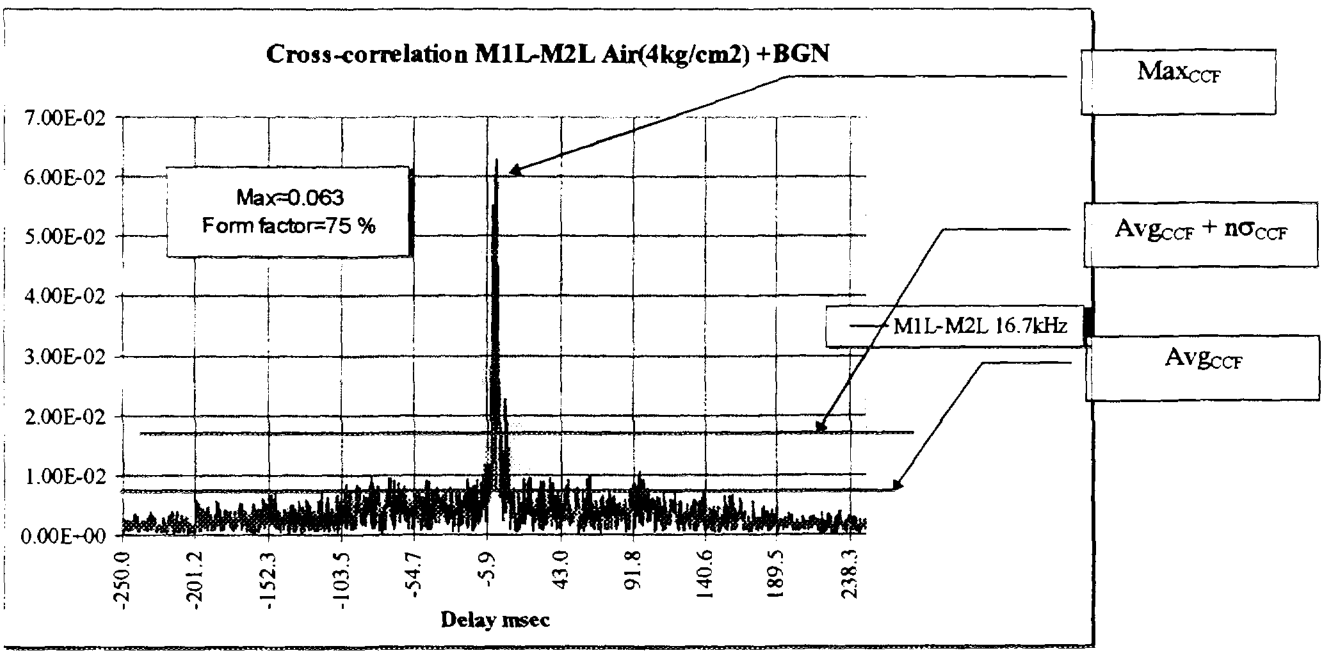


Fig.8 The cross-correlation function, made after leak occurence

As the evaluation results of the NPP test, the following results were obtained:

- it takes approximately 40 min to detect a leak by the correlation method;

- leak detection by form factor of cross-correlation function obtained by ZOOM method proved possible in the range of frequencies from 5 to 20kHz in the case, when: $(S+N)/N \cong 1$ and less;

3.3. Definition of location of a leak (localization)

The location of a leak is ascertained by the hyperbolic method (fig. 14) on the basis of the result of cross-correlation analysis of signals from a group of microphones (the sampling cycle is about 40 min, the error being about 1 m), as well as by the sound pressure method (fig. 10, when the signal/noise ratio ≥ 1). A group of microphones is defined when analyzing the sound level in the course of «fast» detection of a leak.

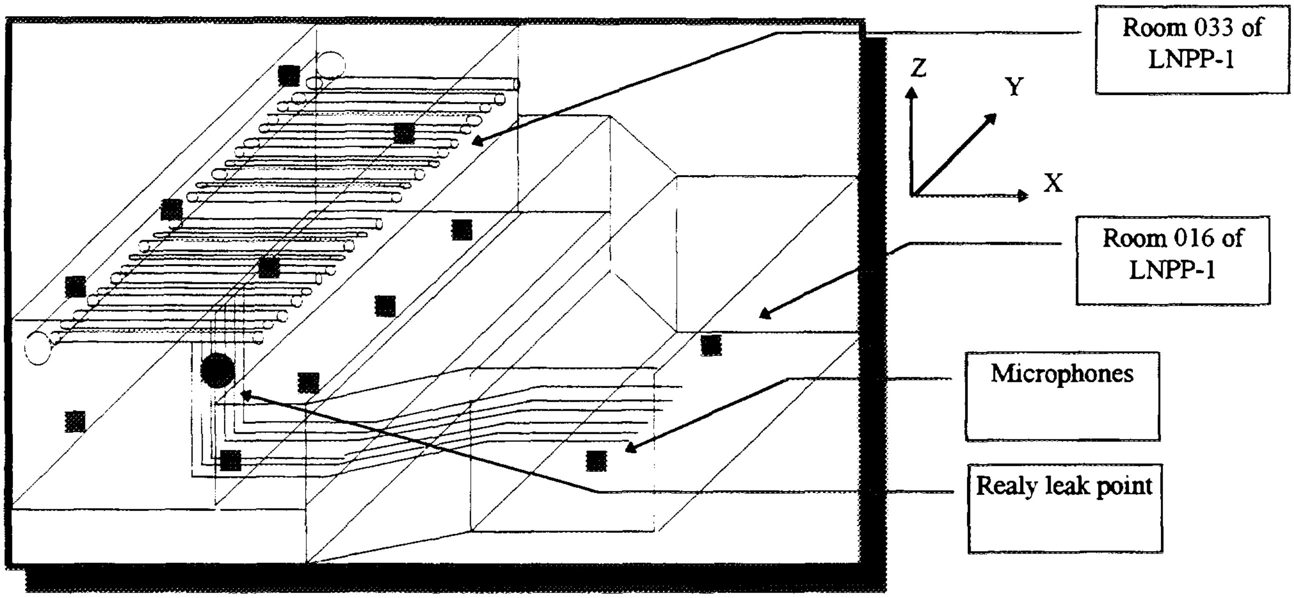
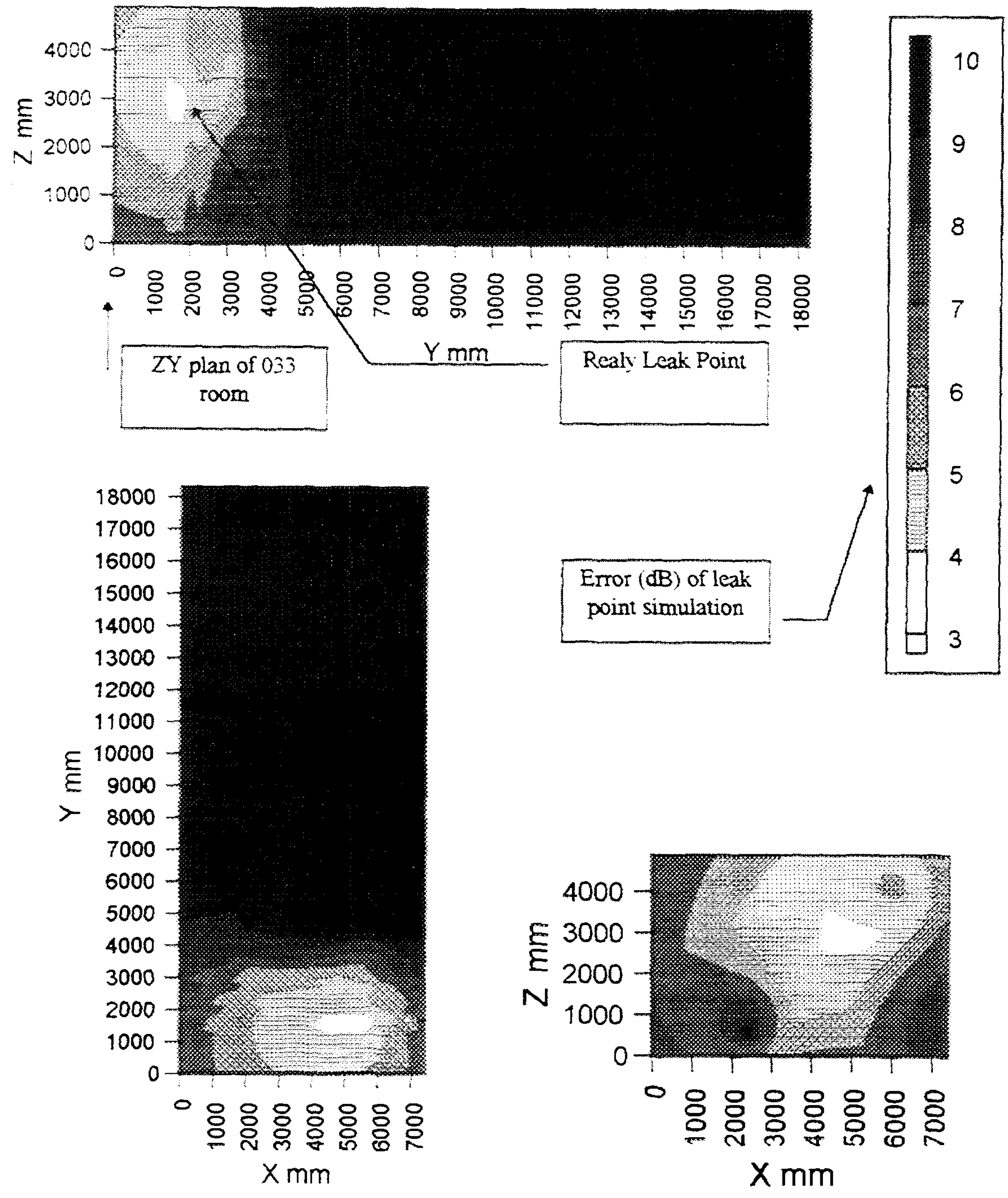


Fig. 9 The positions of microphones and leak imitator in NPP rooms

(1) Localization by sound pressure method

The definition of space location of a leak is made on the basis of analyzing sound pressure levels recorded by microphones after leak occurrence, making allowance for sound attenuation in the room.

The calculation method takes into consideration the presence of direct sound propagation areas and the effect of sound reflection, the characteristic of the microphones directivity and the influence of the background noise in the rooms.



Freq.= 8kHz, Mic. M1L, 2L, 3H, 4H, 6L, 7H, 12H
Real position: Xs= 4400, Ys= 1870, Zs= 2770
Estimated position: Xs= 5100, Ys= 1700, Zs= 3000, ERROR= 756

Fig. 10 Localization by sound pressure method

(2) Localization by correlation method

The location of a leak is made by the hyperbolic method on the basis of a times difference of arrival of signals on various pairs of microphones. The definition of time delay of signals is made by cross-correlation functions.

The cross-correlation functions is calculated in optimum frequency band, chosen by coherence function:

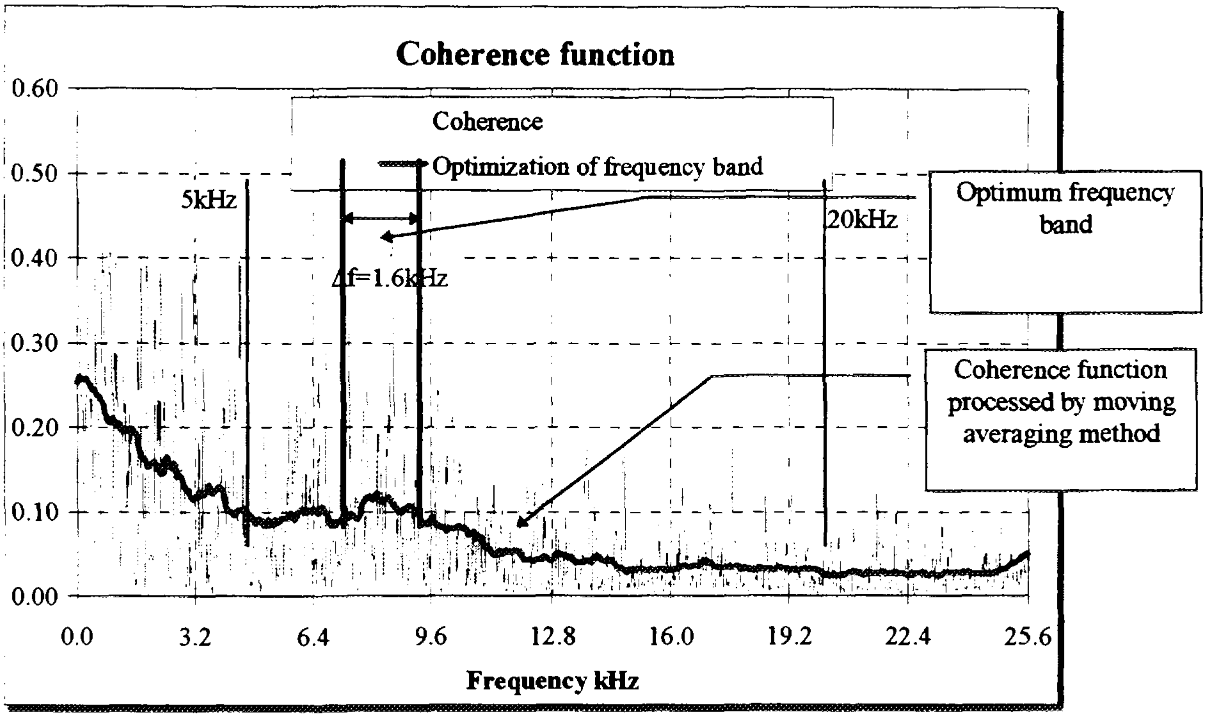


Fig. 11 The definition of optimum frequency band by coherence function

To increase the reliability of definition of signal delay, a several cross-correlation functions are processed in nearby frequency bands:

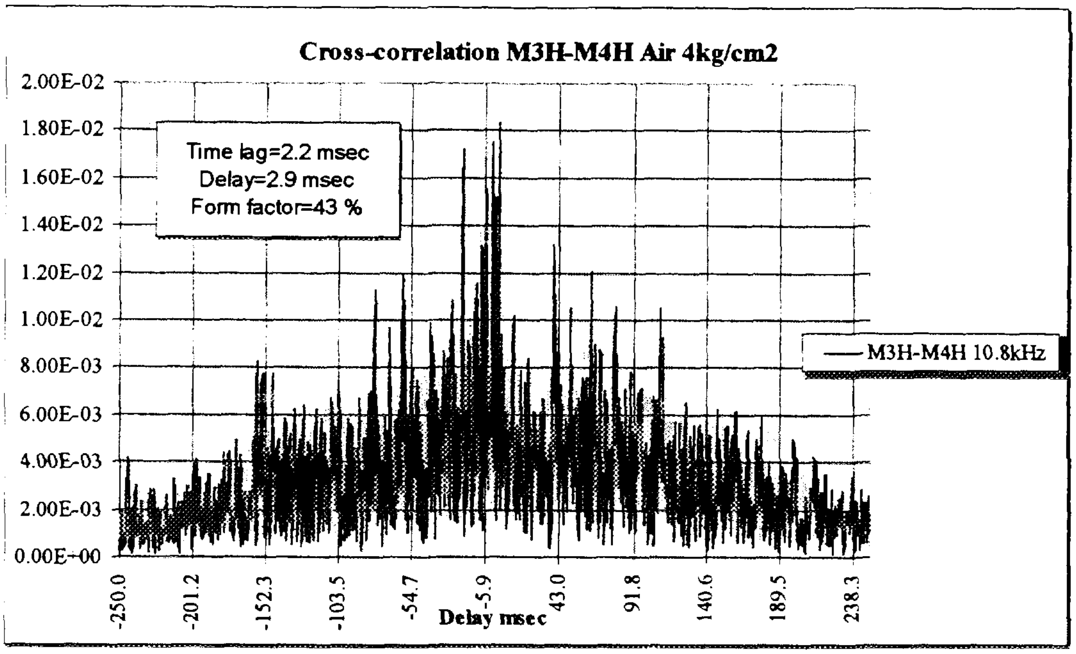


Fig. 12 The cross-correlation function is calculated before processing

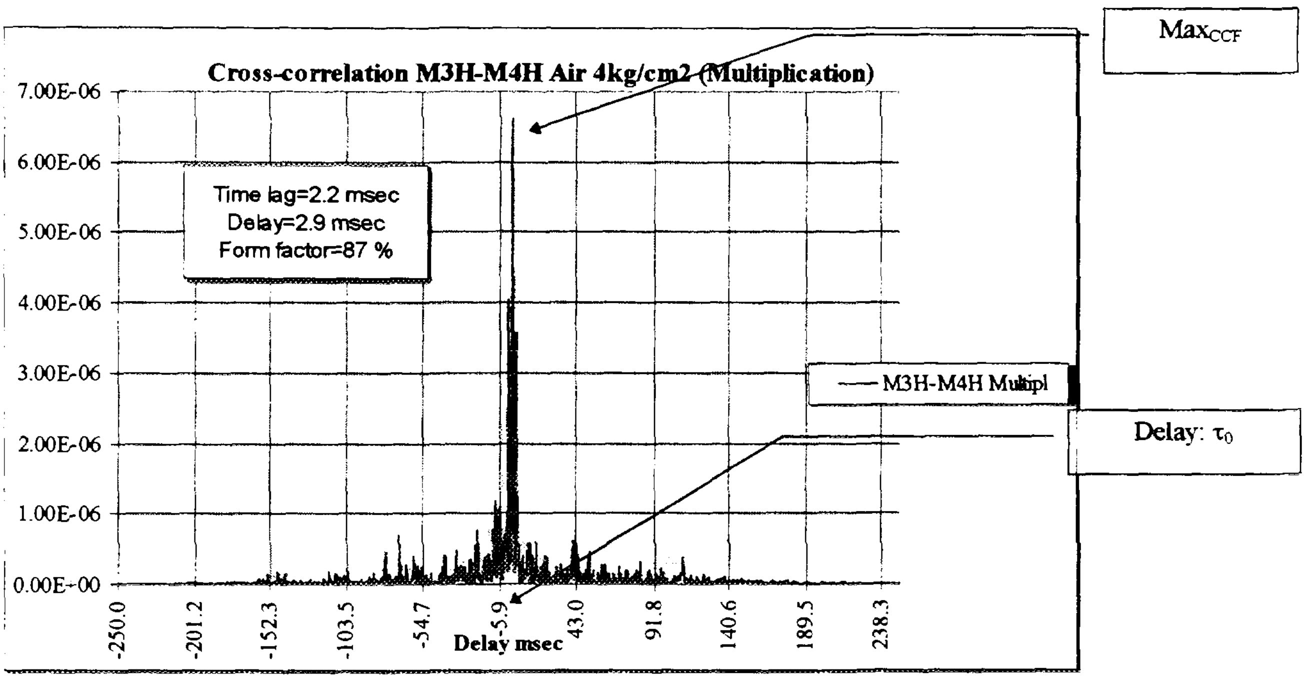
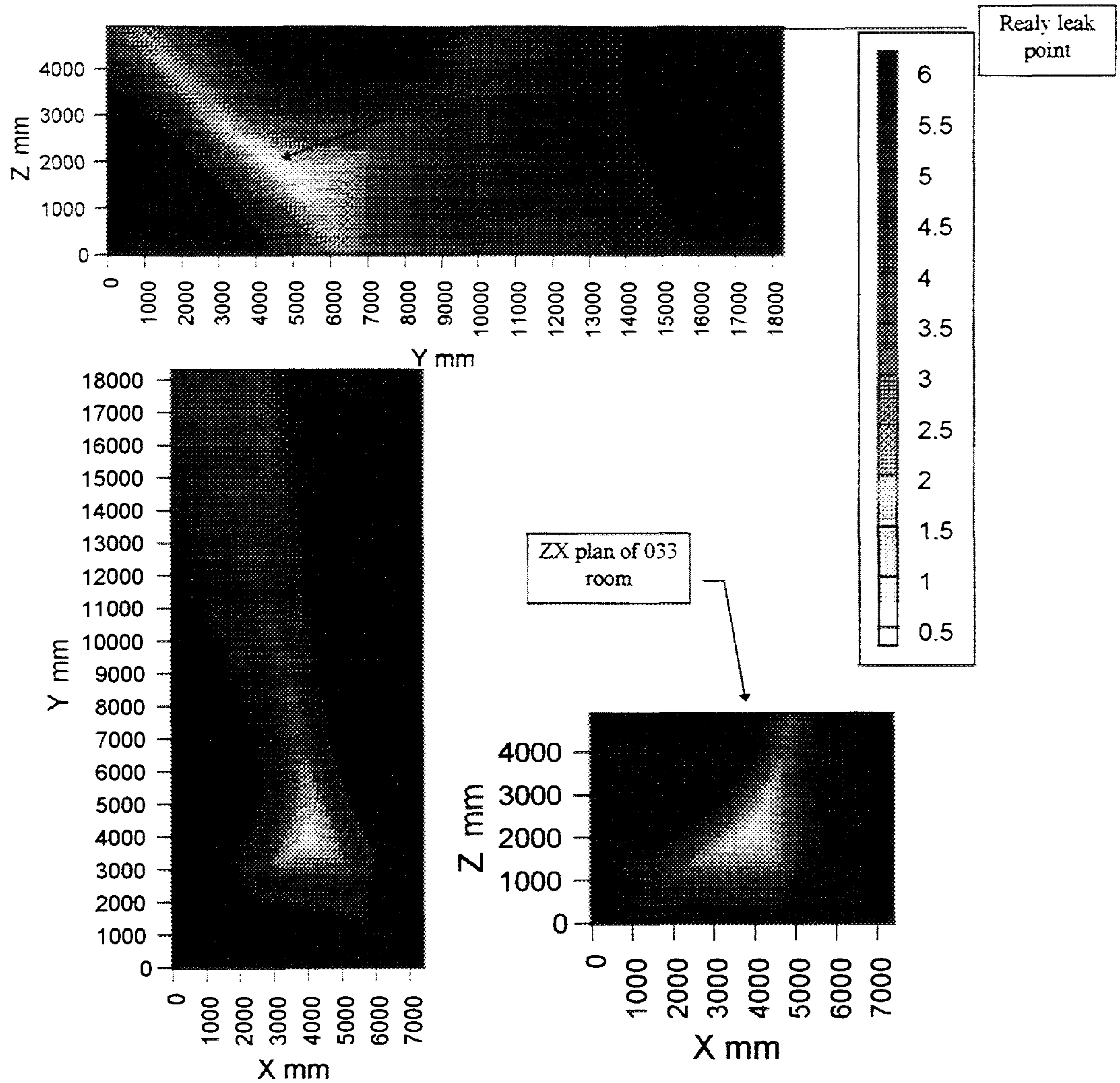


Fig. 13 The cross-correlation function is calculated after processing

The spatial location of a leak is made by the hyperbolic method (fig. 14) on the basis of a times difference of arrival of signals on various pairs of microphones:



Mic. M1L-M2L,M1L-M3H,M2L-M3H,M3H-M4H
Real position: Xs= 4450, Ys= 3100, Zs= 3000
Estimated position: Xs= 3700, Ys= 4400, Zs= 2400, ERROR= 1616

Fig. 14 The spatial location of a leak by the hyperbolic method

As the evaluation results of the NPP test, the following results were obtained:

- the accuracy of leak localization amounted to approximately 1.3 m using the correlation method
- and from 1 to 0.4 m using the sound pressure method

3.4 Leak location by the beam microphone technology

Beam microphone testing has been conducted in room 033/2 of LNPP-1 in the course of «cold» one-channel tests in case of turned on circulation pumps.

The measurements were made according to pitch-by-pitch change in the microphone position in a horizontal plane (horizontal angle) and in a vertical plane (helix angle - elevation).

The operation of main circulation pumps results in powerful background noise. The noise level decreases with the frequency growth, while major part of acoustic energy is concentrated in the range of frequencies up to 8 kHz.

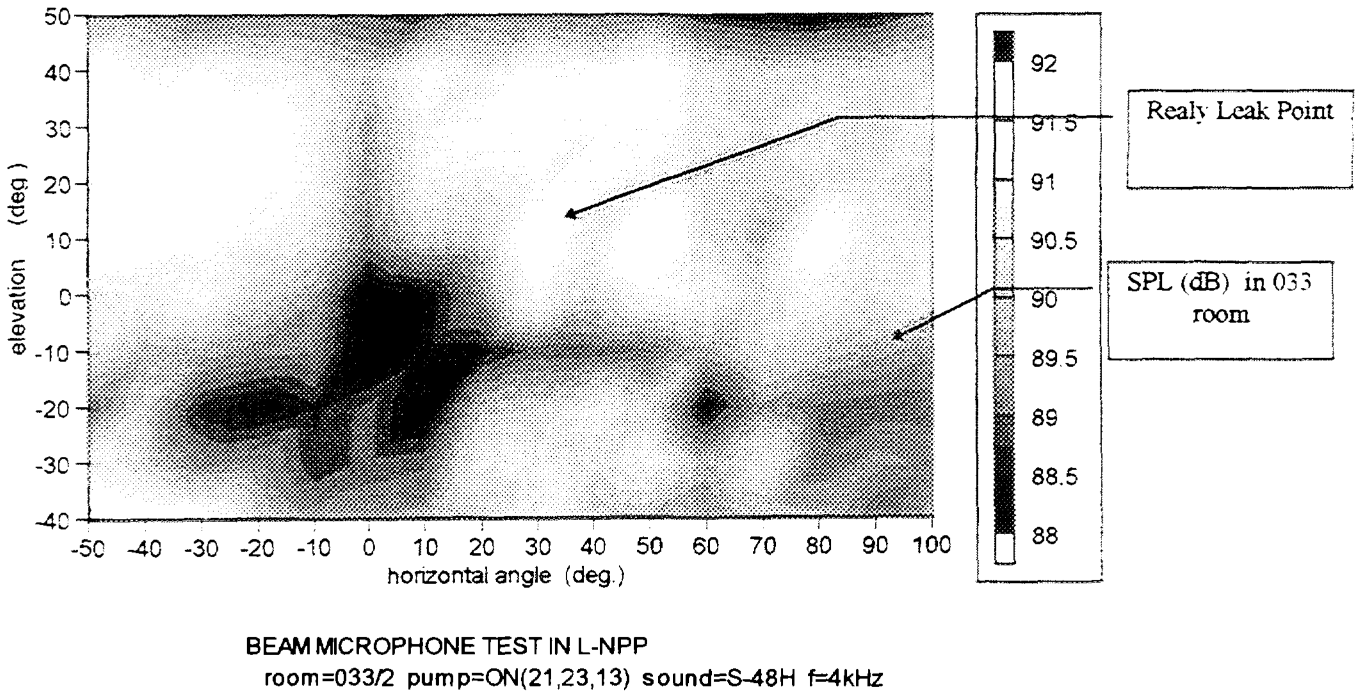
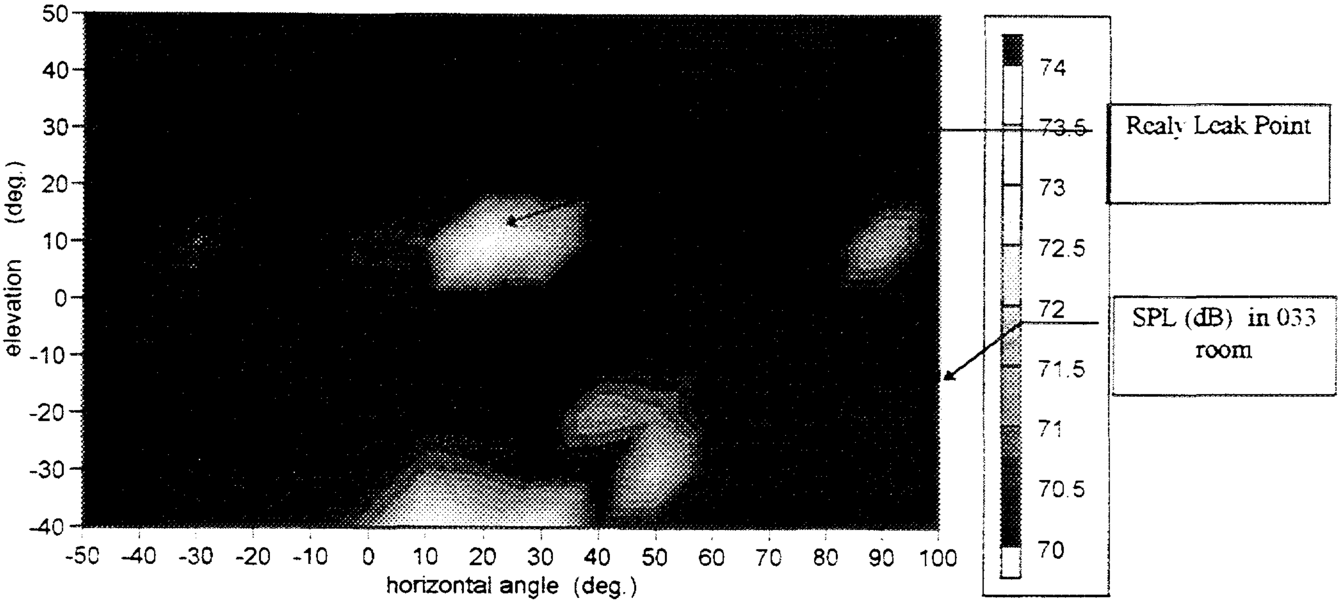


Fig. 15 Sound pressure, recorded on 4kHz

With an increase in the analysis frequency the influence of the background noise starts decreasing. Specifically, starting from the frequency of 8 kHz, the detection and localization of a leak is feasible. And at the frequency of 25 and 31.5 kHz the error in defining the leak angular coordinates does not exceed 50 (fig. 16):



BEAM MICROPHONE TEST IN L-NPP
room=033/2 pump=ON(21,23,13) sound=S-48H f=31.5kHz

Fig. 16 Sound pressure, recorded on 31.5 kHz.

It should be borne in mind that detection and localization of a leak in the process of the tests were performed at a distance of 8.5 m from the source of sound. At this distance the value of 5^0 brings about an error in the spatial localization of about 0.7 m.

4. Conclusion

As the evaluation results of the NPP test, the following results were obtained:

- the reviewed methods are suitable for the detection and localization of leak in RBMK reactor even in the environment of high background noise level;
- and acoustic leak detection system can be successfully used on Leningrad NPP.