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CHARACTERIZATION STUDIES OF BWR-4 NEUTRON NOISE ANALYSIS SPECTRA^a

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ABSTRACT

Neutron noise analysis measurements were made in three BWR-4 reactors under full-power conditions to determine the noise characterization spectra of the reactors with two different instrument-tube cooling configurations. Both configurations were designed to prevent flow-induced vibration of the instrument tubes and subsequent damage of fuel channel boxes caused by impacts of the tubes with the boxes. Noise spectra from these three reactors were compared with spectra previously obtained prior to changing the instrument-tube cooling configuration, and no evidence of impacting was found.

INTRODUCTION

Neutron noise analysis measurements were made in three BWR-4 reactors to determine the noise characterization spectra of the reactors with their bypass flow altered and with the reactors operating at 100% flow and power. In two of the reactors, all designed bypass coolant holes in the core support plate had been plugged (allowing only leakage bypass flow) to prevent flow-induced vibration of the instrument tubes and subsequent damage of fuel channel boxes, which previously had been caused by impacts of vibrating tubes with the boxes. In the third reactor, all bypass coolant holes in the core support plate also had been plugged, after which two 9/16-in.-diam holes were drilled in the lower tie plate of each fuel assembly to provide alternative cooling for the instrument tubes.

BACKGROUND

In late 1974, significant changes were observed in the characteristics of the readings from traversing in-core probe (TIP) instrumentation in a foreign BWR-4 plant (1). Subsequent examination of the Zircaloy channel boxes of the fuel bundles in this plant revealed significant wear on the corners of the channel boxes adjacent to instrument and source tubes. This wear led to cracking and holes in the channel boxes adjacent to the instrument tubes that had displayed the anomalous readings. Subsequent studies (2) showed that this wear was caused by vibration and subsequent impacting of stainless steel instrument and source tubes against the Zircaloy channel boxes. As illustrated by Fig. 1, this vibration was induced by high velocity coolant flow through the 1-in.-diam bypass holes in the core support plate. The potential consequences of the cracking and holes in the channel boxes are addressed in the following excerpt from the U. S. Nuclear Regulatory Commission Annual Report for 1975 (1):

Operation of a plant for extended periods with high wear rates could lead to penetrations of the channel wall, allowing too much of the reactor coolant to bypass certain fuel rods and thereby to reduce thermal safety margins. Loose channel-box fragments could also cause local coolant flow blockage and possible overheating of some of the fuel rods. The margin of safety was assured in all cases by reducing the local power generation and permissible thermal-hydraulic operating limits and by reducing the reactor coolant flow to decrease instrument tube vibration (reactor power was reduced to 50-60% of rated power) from plants that exhibited excessive noise on their traversing in-core probe (TIP) system.

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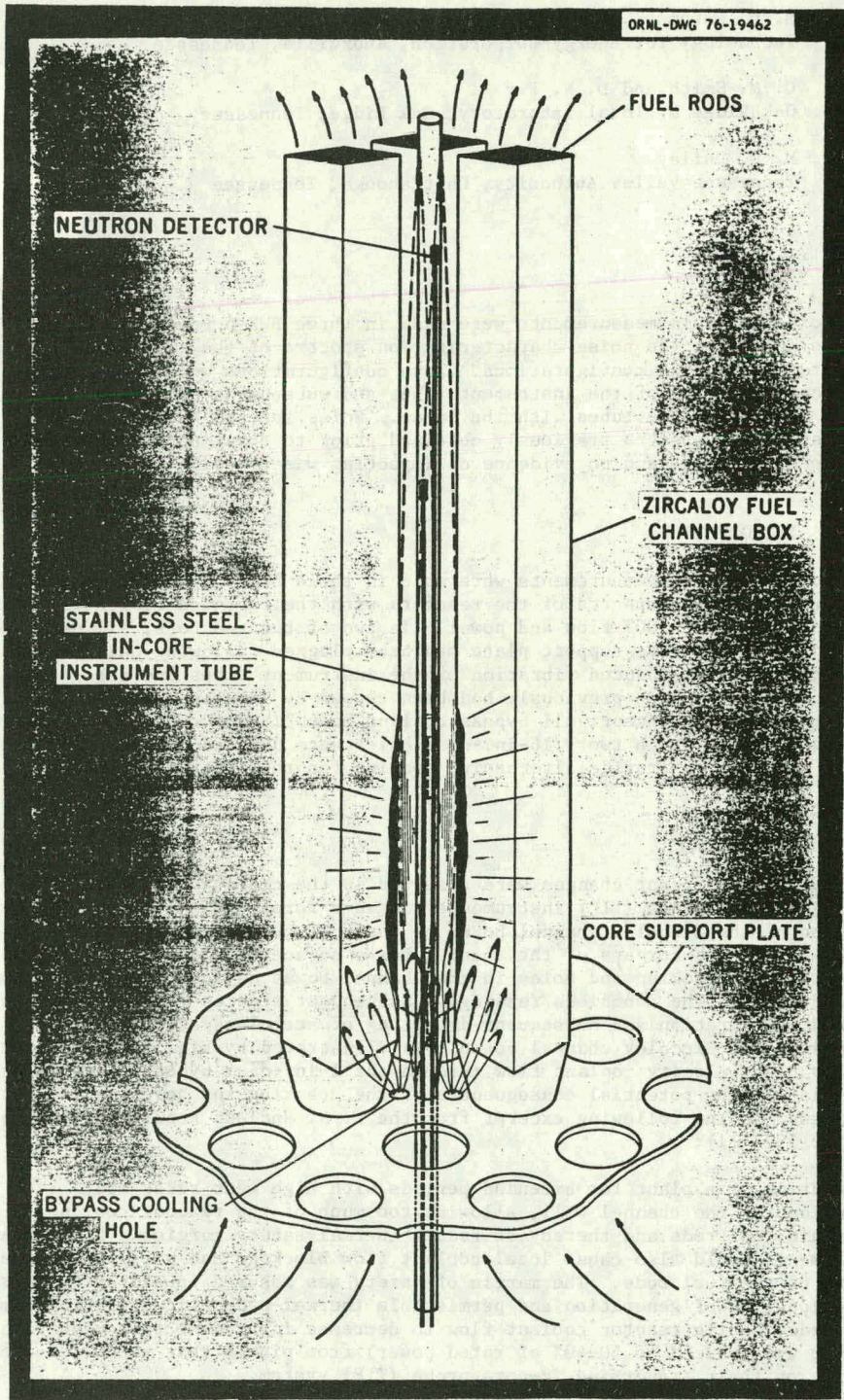


Fig. 1. BWR-4 instrument tube bypass cooling configuration prior to modification to prevent vibration and subsequent impacting.

The diagnosis and confirmation of the instrument tube vibrations were performed by using noise analysis of the signals from in-core neutron detectors--TIP and local power range monitors (LPRMS)--and by using impact analysis of the signals from accelerometers mounted on the extensions of the instrument tubes below the reactor vessels (2-5). From these diagnoses, an interim operational strategy for BWR-4 plants in the United States was initiated: no further significant channel box impacting would occur because coolant flows would be reduced to a rate at which neutron noise and accelerometer impact signals indicated no impacting. The BWR-4 plants were continued in operation under this strategy until mechanical alterations could be completed to eliminate the flow-induced vibrations.

All of the BWR-4 plants have been altered by either plugging the bypass holes in the core support plate (allowing only leakage bypass flow) or by plugging the bypass holes in the core support plate and drilling two 9/16-in.-diam holes in the lower tie plate of some or all fuel bundles to allow alternate cooling for the instrument tubes. We performed neutron noise measurements to confirm that these modifications have reduced impacting (5-6). The balance of this paper presents measurement results from operational BWR-4 plants that confirm that the mechanical fix did reduce, if not totally eliminate, the impacting problem.

LPRM MEASUREMENTS

Neutron noise analysis signals were recorded and analyzed on line from all operable LPRM strings in each of the three reactors. Data were recorded simultaneously from all four neutron detectors (Fig. 2) in each LPRM string while on-line noise analysis was performed on the detectors at the C and D levels. Previous experience (3,5-6) had shown that the normalized cross-power spectral density (NCPSD) between these two detectors was a very reliable indicator of whether impacting was occurring. Front panel switch settings at the appropriate LPRM or average power range monitor instruments (APRM) allowed selection of applicable LPRM string and associated detectors for particular test runs.

Instrumentation and Signal Conditioning

For the purposes of these measurements, several specially designed instruments and accessories were fabricated to route and condition the signals from the LPRMs and APRMs. A special startup test panel had been installed and left in place at all three reactors by the reactor vendor. Cables carrying signals from the LPRMs and APRMs were made available at these panels and were connected to the ORNL instrumentation and signal conditioning equipment.

Figure 3 is a diagram of the signal conditioning instrumentation and analysis systems utilized for these measurements. Signals from the reactor startup test panel were connected to an ORNL designed and fabricated multichannel signal distribution panel. This panel allowed multiple selection and distribution of signals to one or more of the 12 signal-conditioning amplifiers mounted in a NIM instrumentation chassis.

Each of the differential input (ac or dc coupled) signal-conditioning amplifiers was a special low-noise design with ≥ 70 dB common mode rejection. Each amplifier had a capability for high (0.001-10 Hz) and low (10-30 kHz) band-pass filtering with variable gains of 0.1 to 10,000. Each amplifier drove an appropriate channel of a Bell and Howell model CPR-4010, 14-channel FM tape recorder. Likewise, the outputs from two of the amplifiers were routed to the input of the minicomputer-based spectral analysis system. To enable later data retrieval and analysis, both ac- and dc-coupled signals from the LPRMs and APRMs were recorded on magnetic tape. All channels were available for selection and viewing on a test oscilloscope.

Data Acquisition and Processing

The minicomputer-based spectral analysis system (Fig. 3) consisted of a portable Digital Equipment Corp. (DEC), PDP-11/20 disk operated system (RT-11) with 32K words of fast memory and bulk storage on two disks. Inputs for the system were provided to two channels of a 16-channel DEC AR-11, 10-bit analog-to-digital converter (ADC) via a Rockland, model 852 band-pass filter; this gives -48 dB/octave signal attenuation to aliasing frequencies. Special assembly language software (a fast Fourier transform (FFT) algorithm) was prepared to perform spectral analysis on the two channels of data. The analysis yielded power spectral densities normalized by the square of the dc signal (NPSD), normalized cross-power spectral density (NCPSD) magnitudes, and phases, coherence functions, and transfer functions.

On-line analysis of neutron noise was conducted over a 10-min period, using 60 blocks of data (512 data points/block), with a sampling rate of ≈ 51 Hz. These results covered the frequency range of 0.2 to 20 Hz, with a resolution of 0.1 Hz. The first frequency analysis

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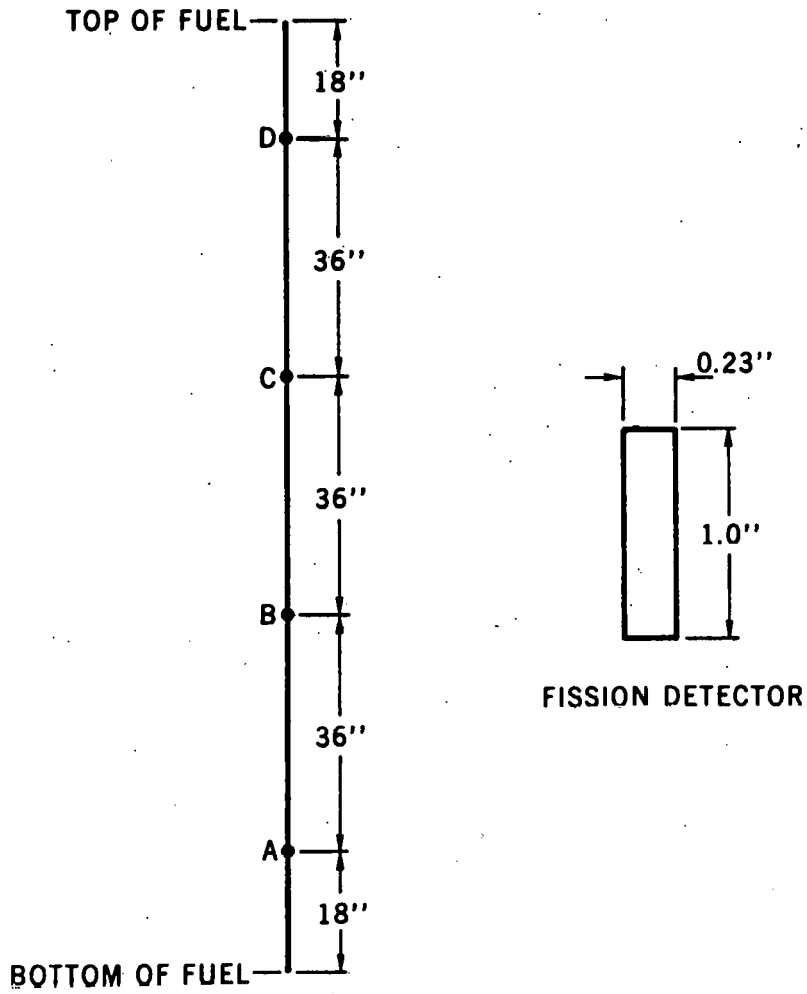


Fig. 2. Axial positions of in-core detectors in an LPRM string.

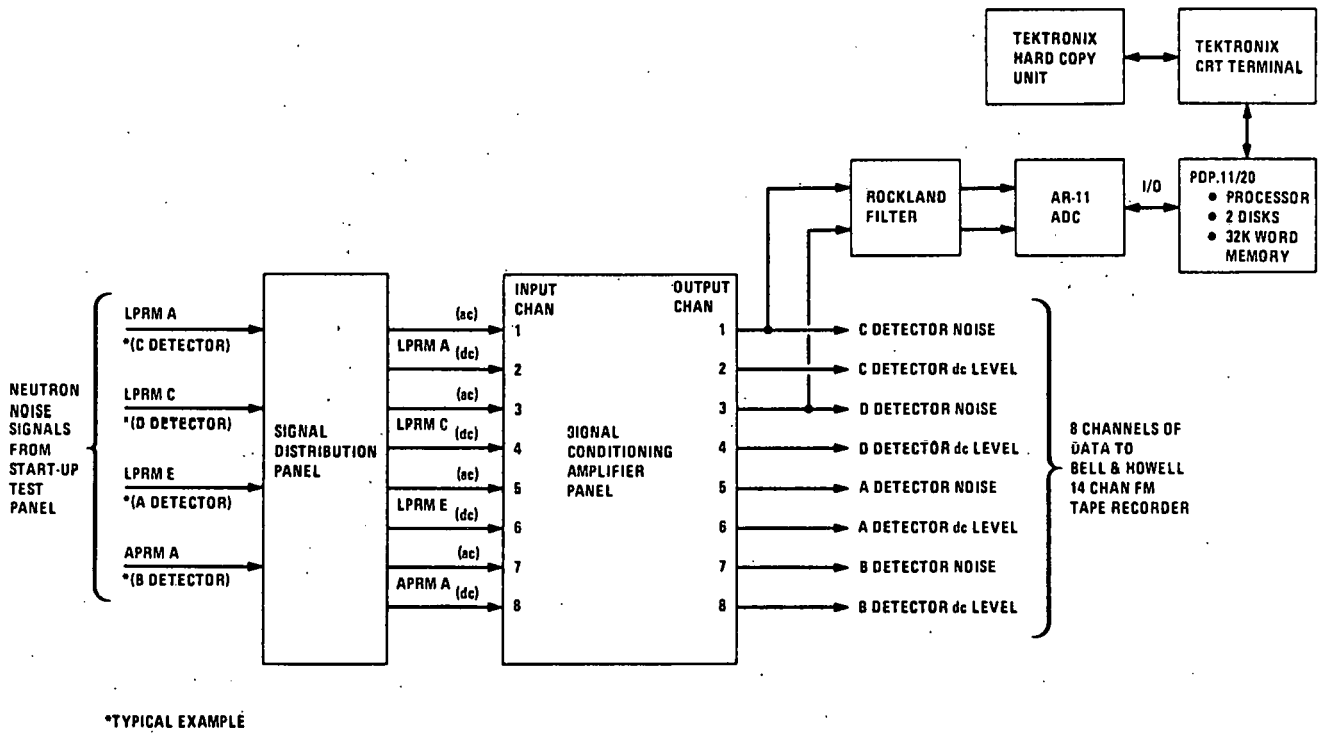


Fig. 3. Signal conditioning and spectral analysis instrumentation functional diagram.

point was not used because a Hanning window filter was used on the processed data. The anti-aliasing filter cut-off frequency was normally set to 80% of the maximum analysis frequency.

The results of the analysis were plotted on a Tektronix 4010 CRT terminal as graphs of the selected analysis function versus frequency, and a permanent copy was obtained from a Tektronix 4631 hard copy unit. The analysis data were permanently stored on a data disk through the use of a DEC RK05 disk drive.

PRESENTATION OF DATA

Data presented in the figures in this section are from all of the LPRM strings that were operable in the reactors. The multiple plotting technique used allows observation and characterization of trends in the spectra for the different functions analyzed. Only data that indicates significance between the two modified core-cooling configurations will be shown or discussed.

Normalized Power Spectral Densities

Composite NPSD data from the two reactors with plugged bypass coolant holes in the core support plate (allowing only leakage bypass flow) show that the PSD in the 3.5- to 6-Hz frequency interval is about 10^{-6} Hz^{-1} for the C (lower) detector. The magnitude of the PSD from the D (upper) detector in the same string is 4 to 10 times higher. Consequently, the resulting coherence function in the same frequency interval is quite low (≤ 0.2).

The composite NPSD data from the reactor with alternative cooling for the instrument tubes show the PSD to be about $2 \times 10^{-6} \text{ Hz}^{-1}$ for both the C and D detectors. Consequently, the coherence function in the same frequency interval is much higher (~ 0.5).

Normalized Cross-Power Spectral Densities

Figure 4 shows the composite NCPD data from the reactor with two 9/16-in.-diam holes drilled in the lower tie plate of each fuel assembly. The NCPD in the frequency interval from 3.5 to 6 Hz is essentially below the $2 \times 10^{-6} \text{ Hz}^{-1}$ (with no pronounced peaks) level established to detect impacting (3,5-6).

Composite NCPD data from the two reactors with plugged bypass coolant holes (allowing only leakage flow) were essentially identical to data from other reactors with the same modification (magnitude $\leq 2 \times 10^{-6} \text{ Hz}^{-1}$ between 3.5 and 6 Hz), indicating that impacting had ceased.

Coherence

Figure 5 shows composite coherence data from one of the two reactors with plugged bypass coolant holes. In the frequency interval from 3.5 to 6 Hz, the coherence is below 0.2, as should be expected from two different detectors whose NPSD magnitudes are factors of 4 to 10 apart.

Composite coherence data (Fig. 6) from the reactor with 9/16-in.-diam holes drilled in the lower tie plate of each fuel assembly show that for a majority of the strings in the core the coherence is ≥ 0.4 in the frequency interval from 3.5 to 6 Hz. This indicates that the NPSD values for the C and D detectors in that particular string are almost equal. However, some LPRM strings near the outer edge of the core have lower coherence values (≤ 0.3) in the same frequency interval.

This difference in coherence between center-of-core and edge LPRM strings was also noted by Sides (7); it is being investigated further by ORNL.

SUMMARY OF FINDINGS

1. In the case of the two core modifications discussed in this paper (plugged bypass coolant holes, and plugged and drilled alternate holes), each modification in itself reduced the magnitude of the NCPD between the C and D detectors below the level which had previously been determined to indicate impacting (3,5-6).

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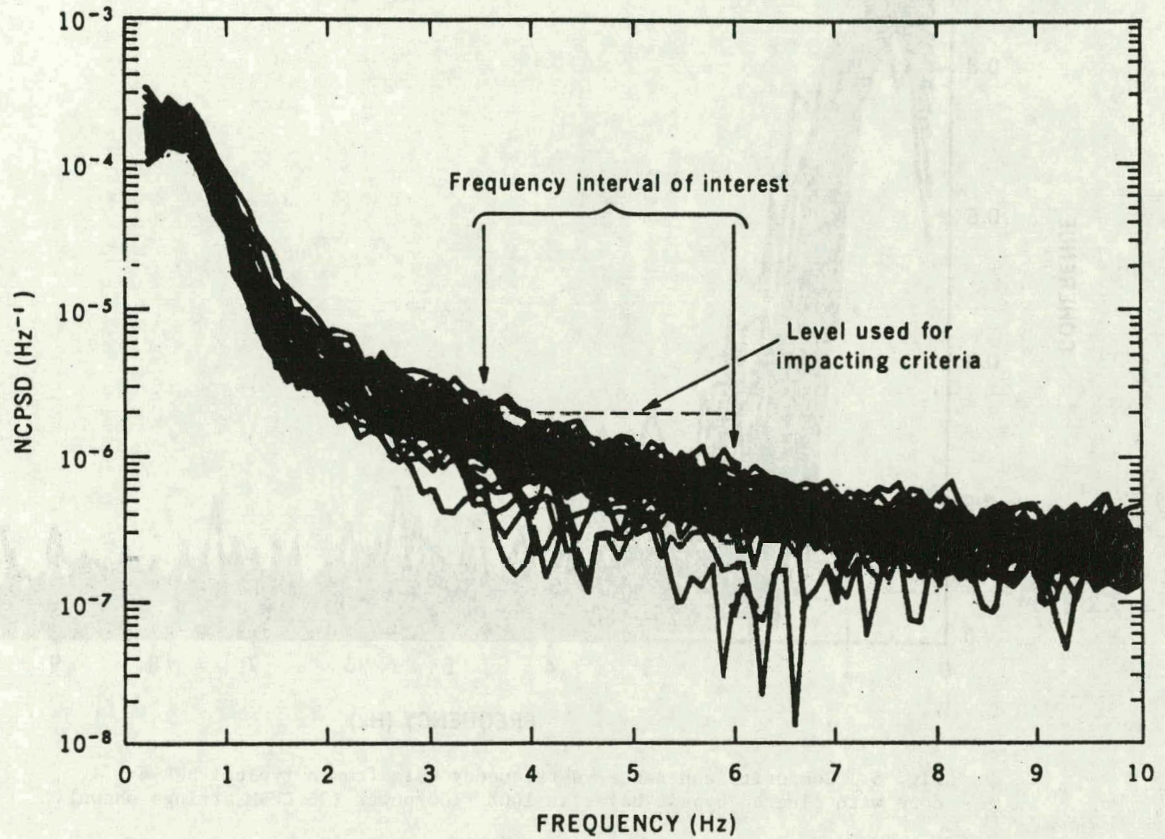


Fig. 4. Composite normalized cross-power spectral densities (NCPSD) from a BWR-4 at full power and a drilled lower tie plate modification (39 LPRM strings shown).

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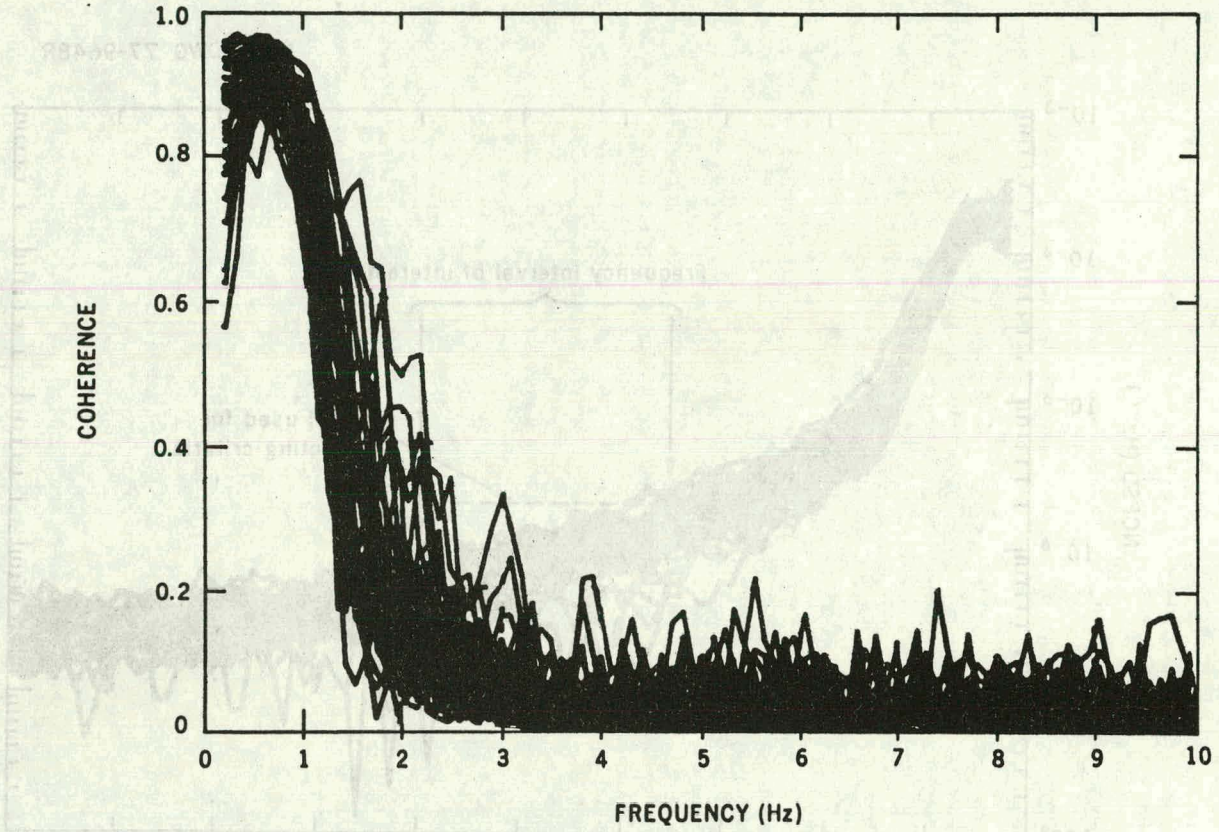


Fig. 5. Composite coherence vs frequency data from a typical BWR-4 core with plugged bypass holes at 100% flow/power (36 LPRM strings shown).

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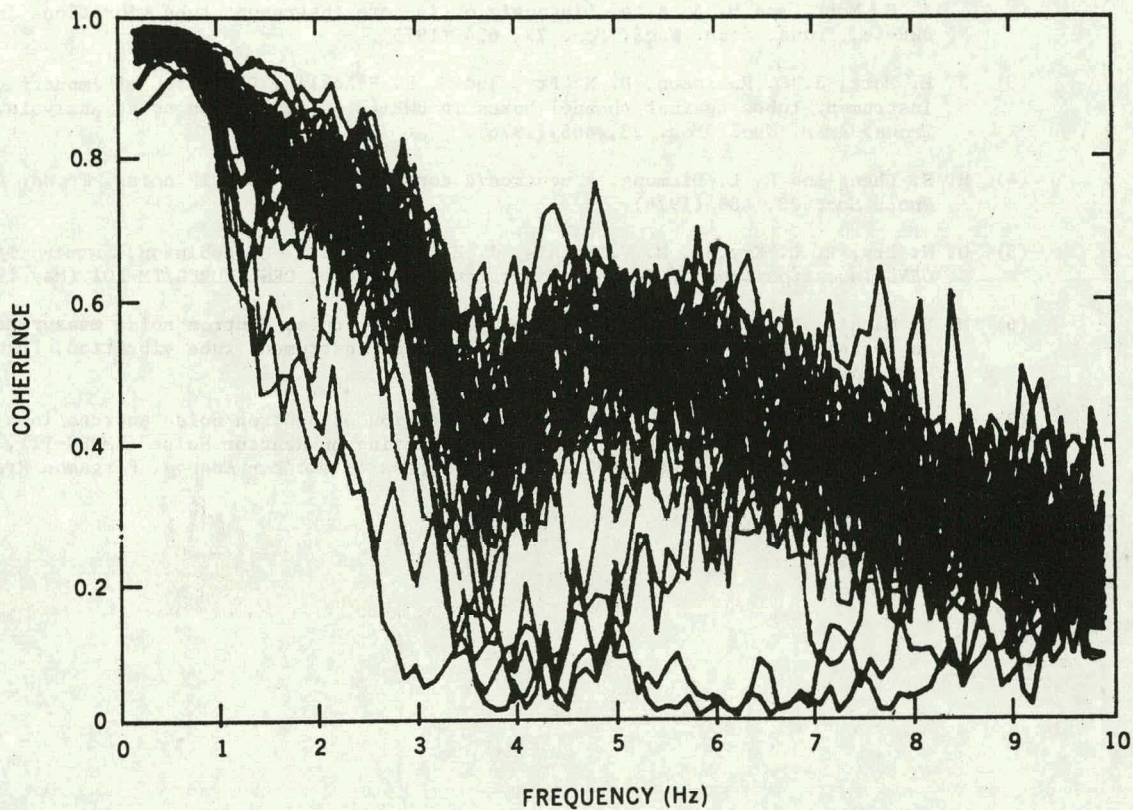


Fig. 6. Composite coherence vs frequency data from a BWR-4 core with the drilled fuel assembly lower tie plate modification at 100% flow/power (39 LPRM strings shown).

2. There is a significant difference in the coherence between the plugged cores and the core with alternate coolant holes drilled in the lower tie plate of each fuel assembly. This difference in coherence should be investigated further to determine the exact cause of the coherence change.

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