# APPLICATION OF NOISE ANALYSIS TO SAFETY-RELATED ASSESSMENTS AND REACTOR DIAGNOSTICS

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## ABSTRACT

Noise analysis methods were used to assess anomalous in-core temperature fluctuations at the Fort St. Vrain gas-cooled reactor and postaccident reactor conditions at Three Mile Island, Unit 2. In addition to these applications of noise analysis, we continued to develop the underlying technology, our principal activity areas being (1) analytical methods for predicting noise signatures under postulated anomalous conditions, (2) techniques for on-line monitoring of boiling water reactor stability, (3) new methods for locating and characterizing loose or drifting metallic objects in reactor coolant systems, and (4) acquisition of baseline noise signatures for commercial pressurized water reactors. We also demonstrated, through temporary installation at a research reactor, the capability of an automated, on-line surveillance system to provide early indication of anomalous plant conditions or approaching component or sensor failures.

## INTRODUCTION

Noise analysis methods have been studied, developed, and successfully applied to a wide variety of reactor measurement and diagnostic problems by Oak Ridge National Laboratory (ORNL) Instrumentation and Controls Division technical staff and their consultants over a period of more than 15 years. Since long-range development and demonstration programs directed toward the advancement of the state of the art in instrumentation and diagnostic systems are customarily not the province of reactor manufacturers and electrical utilities, we believe that continuing programs at the national laboratories constitute an effective means of ensuring that up-to-date data and techniques will be available when required to satisfy future regulatory needs related to safety, reliability, and plant operating efficiency.

The body of this paper highlights seven major subject areas in which we have ongoing research programs or consultative participation. The referenced publications provide additional details.

## FORT St. VRAIN (FSV)

We recently used noise analysis methods to aid the U.S. Nuclear Regulatory Commission (NRC) in determining the nature of in-core temperature fluctuations at the Fort St. Vrain gas-cooled reactor. All available data indicated that small movements of the columnar stacks of graphite core blocks (essentially unrestrained at their upper ends) altered the size and position of gaps between the stacks, thereby redistributing the flow of helium coolant and creating the unanticipated temperature fluctuations observed. By comparing properly phased ex-core neutron noise signals and reactor vessel displacement probe signals on a common time base, we were able to infer the predominant direction of these movements. Noise techniques were also used to confirm that the movements of individual stacks were more or less random in nature (i.e., that the core did not move as an aggregate body) and that such movements did not result in significant total core reactivity changes.

Oscillation-inhibiting core restraint devices were installed at the upper ends of the graphite columns in November 1979, but their effectiveness remains untested since FSV has not resumed power operation as of this writing.

## THREE MILE ISLAND (TMI-2)

ORNL personnel ard their consultants from Science Applications, Inc., and Technology for Energy Corp. used noise analysis methodologies[1] at TMI-2 to provide: (1) assessment of the size of a bubble of noncondensible gas in the primary system and assessment of the structural integrity of the reactor vessel internals by using the plant's loose-parts monitoring system; (2) monitoring for incipient failure of critical postaccident instrumentation (especially the pressurizer level indicators) and for bulk coolant boiling in the reactor core; and (3) confirmation of degasification of the primary system prior to the establishment of natural circulation cooling. Since the first two items are treated in other papers[2,3] presented at this topical meeting, attention is restricted here to primary system degasification.

A large amount of hydrogen gas was produced in the TMI primary circuit as a result of the Zircaloy-steam reaction that accompanied core dryout, and much of it was subsequently absorbed by the primary coolant water. The presence of this dissolved gas, which would be released from solution if primary system pressure were lowered, was viewed as a threat to the achievement of safe shutdown, since coalescence of a quantity of gas in some portions of the system might either reexpose the already damaged core or terminate convective circulation cooling processes. To remove the unwanted gas, operations personnel planned to first lower the system pressure slightly, thereby bringing some gas out of solution, collect this gas in the pressurizer tank, and finally vent the primary circuit to containment, thereby permitting the released gas to escape. This system degasification required careful control, but there was no plant instrumentation to indicate directly the amount of gas remaining in solution. However, during a trial depressurization/venting exercise it was observed from a strip chart recorder that the noise on the primary pressure signal decreased abruptly as soon as the reduction in pressure took place and then consistently increased again during the venting phase. We postulated that these observations were explainable by gas first leaving solution (thereby producing a "soft" or "spongy" system); then, as venting proceeded, the system would be relieved of gas and would return to its former "hard" state and the pressure noise would consequently reappear. This reasoning, confirmed by additional tests, led to the use of pressure noise monitoring as an aid to the TMI operators for determining residual system gas content during the repeated "spray-and-vent" operations by which they eventually succeeded in degasifying the primary circuit. A representative strip chart trace of the pressure noise signal, as observed during one step of the degasification program, is shown in Fig. 1.

It is our opinion that noise analysis, through on-site monitoring and diagnostic measurements, played a helpful role in achieving a final safe shutdown condition at TMI-2.

## BASELINE SIGNATURES

In addition to the preceding applications of noise analysis to current safety-related problems, we are continuing to broaden our noise analysis capabilities by acquiring baseline noise signatures for normal plant operating conditions and by evaluating new methods for understanding and applying noise signals for safety assessment. Our experience over the years with the application of noise analysis for diagnosing abnormal plant behavior has shown a continuing need for baseline, or reference, signatures for normal plant behavior against which to compare abnormal signatures. This need was again emphasized at TMI-2, where we were asked to assess vessel internal conditions with the reactor in an unusual state, namely, at hot shutdown with only one (or no) primary coolant pump in operation. Noise analysts could have performed this task much better if baseline signatures for pressure, temperature, and acoustic signals at these special conditions had been available.

Recognizing this need, the NRC had asked ORNL even before the TMI-2 accident to acquire limited neutron noise baseline data from a few pressurized-water reactors (PWRs). However, based on subsequent TMI-2 experience, we are strongly recommending an expansion of our baseline signature acquisition program to include signals other than neutron noise and measurements at conditions other than full power.

In connection with these studies, we plan to install a continuous monitoring system in a plant to acquire, catalog, and establish statistical bounds for noise signatures from a number of selected signals. The monitoring system is programmed to detect automatically any statistically significant deviations from baseline conditions that may appear. The system will eventually be capable of performing some specific diagnostic tasks, such as detecting PWR core boiling, a loose core barrel, or abnormal fuel element vibration.

## ANALYTICAL PREDICTION OF NOISE SIGNATURES

We have also developed and performed an initial evaluation of a stochastic modeling methodology[4] that promises to be a great asset in reactor noise analysis. Stochastic modeling has already proved extremely helpful in understanding the nature of and the relationships between the so-called global and local components of the signal from a neutron detector in a BWR.[5,6] A second intended use for this methodology is the prediction of the sensitivity of noise techniques for detecting various postulated anomalous conditions[7] that cannot be readily obtained experimentally. We also plan to use this approach to calculate the minimum amount of in-core coolant boiling that can be detected with ex-core neutron detectors in a PWR.

## LOOSE PARTS MONITORING

In another effort, we examined performance experience and current practice in the U.S. commercial power reactor industry[8] regarding the detection, location, and size determination of possible primary coolant system loose parts. We extended the methodology already in use through fundamental research[9] and measurements, including studies utilizing a full-scale reactor pressure vessel at ORNL. Important outcomes of these tests have been (1) recommended procedures for mounting loose-part system sensors, and (2) a method for locating loose parts that is based on signal amplitude ratios rather than on signal time-of-arrival differences which, because of high acoustic background levels, are often difficult to measure accurately while the monitored plant is in operation.

In connection with this second outcome, Fig. 2 shows a projected view of the path taken by an automated, iterative search procedure based on relative signal amplitudes in arriving at the most probable location (designated F) of an impact that actually occurred at position I on the lower hemispherical head of the reactor vessel. The locational accuracy depicted in Fig. 2 is typical of the results obtained with the amplitude-based method on the reactor vessel (of unusual construction) available for our tests and, while less than remarkable, it represents an improvement on similar results obtained by the arrival-time-difference method.

## BOILING-WATER REACTOR STABILITY MONITORING

Over the past several years an international effort to better understand the nature of neutron noise in boiling-water reactors (BWRs) has been under way. Potential applications of noise analysis for safety assessment in BWRs include on-line measurement of bundle void fraction[10] and bypass region coolant boiling,[11] detection of in-core component vibration and impacting,[12] and monitoring of core power stability on a continuous, on-line basis. Results in this last area indicate that changes in stability measures (such as the decay ratio) can be detected by performing time-series analysis of neutron noise signals from the conventional power-range monitor instrumentation.[13,14] We have recommended to NRC that the practicability of this methodology for continuous monitoring of stability be demonstrated using real plant data, and this work is in progress.

## AUTOMATED SURVEILLANCE SYSTEM DEMONSTRATION

ORNL noise analysts have developed an advanced-concept surveillance system[15] that can monitor nuclear plant signals for changes in their statistical properties that may be indicative of anomalous conditions or an approaching component failure. The system employs pattern recognition techniques and is designed to operate on-line and continuously, with only infrequent need for human attention. Internal consistency checks are used to maintain a low false alarm rate.

This system was demonstrated[16] recently at the High Flux Isotope Reactor by monitoring two neutron signals through four consecutive 22-d reactor fuel cycles from April through July 1979. This demonstration, though somewhat limited in scope, was quite successful—only minor difficulties relating to the monitoring system design were uncovered, and these were easily corrected with changes to the software. Most significantly, an acceptably low false alarm rate was demonstrated. A longer-term demonstration, employing upgraded equipment installed at a commercial power plant, is being planned for 1980-81.

Further adaptations of the basic surveillance system design may be directed toward such tasks as the detection of boiling in PWRs, malfunctions in rotating machinery, and flow anomalies in BWRs.

## SUMMARY

Noise analysis methods have repeatedly proved helpful in achieving a better understanding of safety-related problems in nuclear plants of diverse design. Recent experience with a number of new—and seemingly powerful—noise diagnostic techniques, some of which have already progressed from the development stage to a point of initial application, suggests that the future achievements of this field may well surpass those already recorded.

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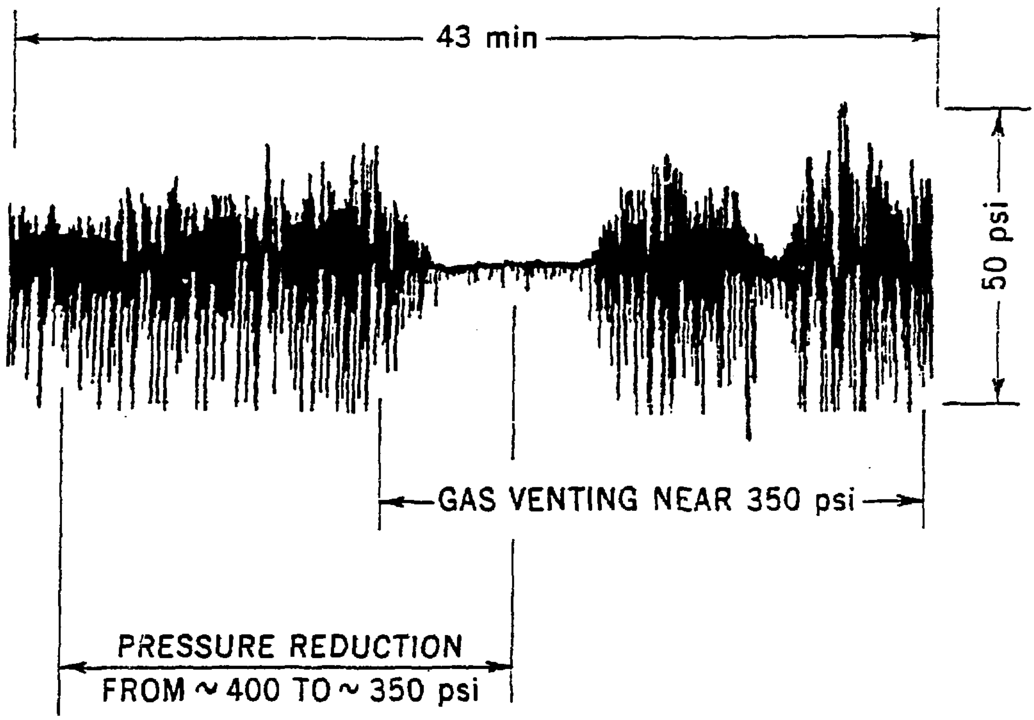


Fig. 1. Pressure noise in loop "B" during pressure reduction (~400 to ~350 psi) and gas venting (at ~350 psi). The average (DC) value of the pressure signal has been removed.

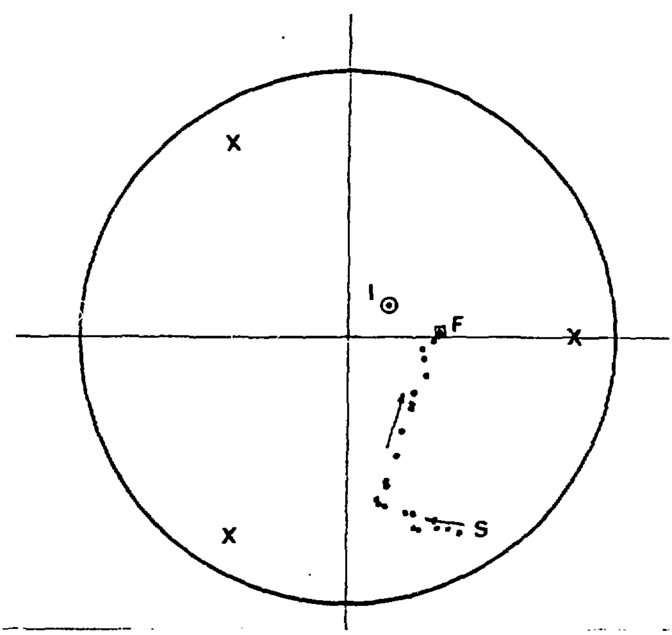


Fig. 2. Impact location on the hemispherical reactor vessel lower head using an iterative convergence scheme. The acoustic signal from a single impact at position I was detected by three accelerometers positioned symmetrically at locations X. Starting at an initial (arbitrarily selected) location S, successive position estimates produced by the locational scheme advanced in the direction indicated until a most probable impact location F was reached. The error in final location (separation of I and F on the hemispherical surface) is ~72 cm; for comparison, the reactor vessel diameter is ~610 cm.