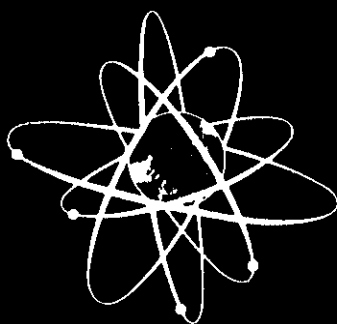


OECD NUCLEAR ENERGY AGENCY

AN OVERVIEW OF SMORN V – MUNICH

A summary of the fifth Symposium on Reactor Noise (SMORN V)
Munich, Federal Republic of Germany, 12th - 16th October 1987



NUCLEAR ENERGY AGENCY

OECD/OCDE
PARIS, 1988

94030001

AN OVERVIEW OF SMORN V-MUNICH*

compiled by

R. C. Kryter, LaWanda E. Klobe, and Shirley P. Hendrix
Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA

from

Summaries provided by Symposium Session Chairmen

March 11, 1988

*Symposium on Reactor Noise, held 12-16 October 1987 at the European Patent Office, Munich, Federal Republic of Germany, and organized by Gesellschaft für Reaktorsicherheit (GRS) with the collaboration of the International Atomic Energy Agency (I.A.E.A.).

The NEA Committee on the Safety of Nuclear Installations (CSNI) is an international committee made up of scientists and engineers who have responsibilities for nuclear safety research and nuclear licensing. The Committee was set up in 1973 to develop and co-ordinate the Nuclear Energy Agency's work in nuclear safety matters, replacing the former Committee on Reactor Safety Technology (CREST) with its more limited scope.

The Committee's purpose is to foster international co-operation in nuclear safety amongst the OECD Member countries. This is done essentially by:

- (i) exchanging information about progress in safety research and regulatory matters in the different countries, and maintaining banks of specific data; these arrangements are of immediate benefit to the countries concerned;
- (ii) setting up working groups or task forces and arranging specialist meetings, in order to implement co-operation on specific subjects, and establishing international projects; the output of the study groups and meetings goes to enrich the data base available to national regulatory authorities and to the scientific community at large. If it reveals substantial gaps in knowledge or differences between national practices, the Committee may recommend that a unified approach be adopted to the problems involved. The aim here is to minimise differences and to achieve an international consensus wherever possible.

The technical areas at present covered by these activities are as follows: particular aspects of safety research relative to water reactors, fast reactors and high-temperature gas-cooled reactors; probabilistic assessment and reliability analysis, especially with regard to rare events; siting research as concerns protection against external impacts; fuel cycle safety research; the safety of nuclear ships; various safety aspects of steel components in nuclear installations; licensing of nuclear installations and a number of specific exchanges of information.

The Committee has set up a sub-Committee on licensing which examines a variety of nuclear regulatory problems, provides a forum for the free discussion of licensing questions and reviews the regulatory impacts of the conclusions reached by CSNI.

The Nuclear Energy Agency Committee on Reactor Physics (NEACRP) is a committee of individually designated experts, with representation - either directly or through regional arrangements - from all interested NEA countries and from the Commission of the European Communities. The IAEA is normally represented at plenary NEACRP meetings by a qualified observer.

The overall task of the Committee is to "review the existing state of knowledge in selected areas of reactor physics of general interest to the nuclear energy programmes of the countries concerned, identify discrepancies and gaps in this knowledge and promote the initiation and coordination of programmes of research to fill the gaps". This task is approached principally through plenary meetings, which are normally held at laboratories where relevant work is carried out, and through specialist meetings on subjects of particular importance.

LEGAL NOTICE

The Organisation for Economic Co-operation and Development assumes no liability concerning information published in this publication.

Copies of this publication are available from:

OECD NUCLEAR ENERGY AGENCY
38 Boulevard Suchet
75016 Paris, France



94030005

Page 10000

Contents

1 INTRODUCTION	7
2 OPERATIONAL EXPERIENCE	8
3 VIBRATION	11
4 SYSTEMS	13
5 MECHANICAL AND PROCESS MODELING	15
6 MEASUREMENT METHODS	17
7 THERMOHYDRAULICS	18
8 LOOSE PARTS	19
9 FLOW MEASUREMENTS AND BOILING	20
10 SAFETY-RELATED APPLICATIONS	21
11 FOURIER TRANSFORMATION AND PATTERN RECOGNITION	23
12 SIGNAL MODELING	25
13 BENCHMARK EXERCISE	27
14 CONCLUDING PANEL DISCUSSION	30
A List of papers presented at SMORN-V	33

Contents

1 INTRODUCTION	7
2 OPERATIONAL EXPERIENCE	8
3 VIBRATION	11
4 SYSTEMS	13
5 MECHANICAL AND PROCESS MODELING	15
6 MEASUREMENT METHODS	17
7 THERMOHYDRAULICS	18
8 LOOSE PARTS	19
9 FLOW MEASUREMENTS AND BOILING	20
10 SAFETY-RELATED APPLICATIONS	21
11 FOURIER TRANSFORMATION AND PATTERN RECOGNITION	23
12 SIGNAL MODELING	25
13 BENCHMARK EXERCISE	27
14 CONCLUDING PANEL DISCUSSION	30
A List of papers presented at SMORN-V	33

1 INTRODUCTION

At the recent fifth Symposium on Reactor Noise (SMORN V), over half the participants represented power utilities, and thirteen out of ninety papers covered practical experience of plant monitoring by noise analysis.

In 1986 the Nuclear Energy Agency published a "State of the Art Report on Reactor Noise Analysis"¹ providing an assessment of the applicability of noise techniques to power reactor operations, which was drawn up by a working group of the NEA Committee on Reactor Physics in the aftermath of the 1984 SMORN IV symposium in Dijon². Since that time, the practical applications of noise analysis techniques to plant surveillance have become more widespread, in particular in the areas of loose part detection and vibration monitoring. Theoretical understanding of the methods has continued to improve. These advances were presented at the SMORN V symposium, held in Munich from 12th – 16th October 1987.

The meeting also recommended that the 1986 State of the Art report should be updated, and the present overview is intended, like its predecessor, for a wide audience including national safety authorities and managers in the nuclear industry. The full Proceedings of the symposium, to be published in 1988 by Pergamon Press, will include all the papers presented at the meeting.

This document was assembled and edited at Oak Ridge National Laboratory from the summaries of each session provided by the session chairmen. Topics which were divided into multiple sessions for the purpose of the conference have been regrouped into single chapters.

A complete list of the papers presented at the conference is included in the appendix.

¹State of the Art on Reactor Noise Analysis, P. Bernard, D. Fry, D. Stegemann and H. van Dam, OECD Nuclear Energy Agency, Paris, 1986.

²Progress in Nuclear Energy: Reactor Noise – SMORN IV, Vol. 15, Pergamon Press, Oxford, England, 1985.

2 OPERATIONAL EXPERIENCE

Summarized by D. Fry (USA), E. Türkcan (Netherlands), and R. Baeyens (Belgium)

In this session operational experiences from five countries were described, showing that the benefits of noise analysis can be expected to exceed the costs both now and in the future. In due course, advances in electronics and microprocessors (including special signal-processing capabilities) will lead to deployment of monitoring systems that provide early indication of impending failure, thus benefitting the electric power utilities.

Baeyens described the noise monitoring programs at seven PWRs in Belgium. Emphasis has been on loose-part monitoring, neutron noise diagnostics, and vibration monitoring of turbogenerators. The Belgian utilities realize that noise monitoring can help plant operations, and they are therefore cooperating with scientists to develop practical applications of noise methods. In this regard, current development is directed toward automated techniques, including artificial intelligence systems, reducing false alarms in loose-part monitoring systems, and improving monitoring methods for turbogenerators.

Kunze presented experience with a computer-aided noise monitoring system installed at the Greifswald WWER-440 nuclear power station. Emphasis is currently placed on development of an integrated automation concept that creates noise diagnostics databases and relieves power station personnel of the routine work associated with noise measurement and analysis. The automation distinguishes between normal and abnormal noise spectra by selecting proper noise spectra features, applying learning principles during baseline spectra acquisition, establishing patterns for baseline and trend data, establishing tolerance ranges for normal and abnormal plant conditions, and establishing error probabilities to assure an acceptable number of false alarms (less than one per month). The system and its diagnostic database should provide an efficient means for collecting and retrieving information regarding changes in vibration characteristics due to aging and wear in the Greifswald plant.

Umeda described an on-line noise surveillance system installed at the Onagawa-1 BWR-4 plant to record data from plant initial startup through the third fuel cycle. Several anomalies were detected during the 5-year project including (1) detection of inferior electronic parts in a recirculation pump speed adjuster, (2) incorrectly constructed control devices in a motor generator, (3) incorrect adjustments of a feedwater control system, (4) drift in a feedwater control valve signal due to valve wear, and (5) misadjustment of a pressure control valve position sensor. Thus, the usefulness of an on-line system for improvement of plant reliability was demonstrated, resulting in the installation of a noise analysis-based "Plant Diagnosis Supporting System" in September 1987.

Diagnostic systems installed on Czechoslovak nuclear power stations were described in a paper by **Kott**. The objectives of these systems are to provide information to plant operators to aid them in optimizing operation and to guide maintenance workers planning and preparing for repair of equipment. The surveillance system is made up of five subsystems for vibration monitoring, loose-part monitoring, coolant leakage monitoring, acoustic monitoring in free space, and residual life monitoring for steam generators and the pressurizer. The system has proved useful in providing information with which to diagnose impaired quality of glands in main coolant circulating pumps. This diagnosis provided guidance for inspection during scheduled plant shutdowns, thus ensuring reliable operation of the pump during the subsequent operating period.

Messainguiral-Bruynooghe presented the results of in-vessel and under-vessel neutron noise measurements made at the Superphenix 1200-MWe LMFBR at power

problems. This outlook was underlined in a paper by **Guillon** showing the tremendous effort being made in France to develop new tools for use directly by the operators. The long, positive experience of the French with noise monitoring is evidenced by their plans to incorporate noise analysis into expert systems that will be installed in French nuclear power plants.

Finally, **Zigler** presented a paper describing efforts in the United States to standardize terminology, equipment, application practices, and data reduction procedures used in reactor noise work.

3 VIBRATION

Summarized by D. Wach (FRG)

Epstein presented the results of theoretical and experimental investigations aimed at the determination of the vibrational behavior of reactor vessel internal structures of French PWRs. Of particular interest were the investigation of fractures of one or more flexures (supports) connecting the cylindrical thermal shield with the core barrel and the investigation of effects of changes in the compression force provided by hold-down springs at the reactor flange. Computations were based on a hydroelastic model, using subroutines of the CASTEM program system, and experimental simulations were performed with the SAFRAN loop, a 1:8 scaled hydroelastic mock-up. Computational and experimental results were in good agreement. Using these results, shell mode vibrations of the reactor thermal shield, as extracted from the ex-vessel neutron noise, can be better monitored and evaluated.

Wehling described a new microprocessor-based vibration monitoring system installed in the newest KWU "Convoy" plants in the Federal Republic of Germany. Frequency and amplitude at resonance frequencies are monitored with respect to deviations from reference spectra. A quotient spectrum formed from the current and reference vibration and noise spectra is calculated and compared to thresholds to determine abnormal deviations. Up to 48 dynamic signals are evaluated simultaneously. Further developments are directed toward expert systems providing the user with immediate access to expert knowledge.

Liewers discussed a new method for measuring core barrel motions of the WWER-440-DWRs in the German Democratic Republic. Ex-core neutron noise signals are correlated with the envelope of at least one acoustic signal measured at the outer surface of the reactor vessel. This acoustic signal is generated by leakage cross flow from the coolant inlet directly to the outlet. Significant coherence between the neutron noise and the acoustic signal was found as long as the direction of the core barrel vibration was not orthogonal to the acoustic sensor position.

Trenty presented results of acoustic and in-core neutron noise investigations at the French 1300- and 900-MWe reactors. These studies were performed in order to characterize the phenomena of thimble vibrations and shocks of the in-core instrumentation against their guides, which produce wear and possibly leakage. Studies of the statistical distributions of burst amplitudes, impulse rates of shocks, etc., were performed. Clear correlations were found between shocks and neutron noise fluctuations, thereby enabling the estimation of the thimble mode shape in the instrumentation tube of the assemblies. In new plants, all in-core guide tubes have been equipped with an accelerometer and an on-line monitoring system that transmits the main shock parameters to the central analysis center of EDF.

Akerhielm reported on in-core neutron noise measurements in a Swedish BWR. The analysis gave indications that instrument tube vibrations occurred in several cases. A phenomenological model for the in-core spectra was developed by including a global resonance-like term and its first harmonic into the noise sources representing the detector vibration. Comparisons of model results with measurements showed good qualitative agreement.

Quinn presented two papers dealing with thermal shield problems in several Combustion Engineering reactors. On behalf of his colleague Dr. Lubin, he presented results of reanalyses of the internals' vibration and loose-part monitoring systems data acquired

over the operating lifetime of the St. Lucie plant. After the fifth fuel cycle the thermal shield was found to be damaged. Dynamic analysis of the core barrel/thermal shield system was utilized in the interpretation of ex-core neutron noise and accelerometer signals. In his second paper, Quinn described a surveillance program (developed in conjunction with the utility) for the thermal shield support structure at the Fort Calhoun nuclear station. Neutron noise analyses of ex-vessel detectors were performed near zero reactor power to determine the first shell mode frequency of the core barrel/thermal system. Since the identified frequency was stable in later measurements, the new support structure was judged to be effective.

4 SYSTEMS

Summarized by K. Dach (CSSR) and N. Suda (Japan)

The common feature of all reports presented in this session was a desire to automate the surveillance procedure through introduction of artificial intelligence into systems in a step-by-step fashion and thereby eliminate the necessity of results evaluation by humans.

A microprocessor-based system presented by **Jax and Ruthrof** was shown to be very effective for detecting, classifying, and evaluating acoustic signals. The knowledge base of the system incorporates actual know-how of experts so that the need for assistance from external experts is restricted to infrequently encountered instances of anomalous noises.

Valko discussed in depth the problems connected with integrating noise analysis into reactor monitoring systems. An integrated noise analysis system was proposed which would combine two basically different approaches to noise measurements interpretation: (1) pattern recognition methods, which excel at detecting occurrences but give little or no insight into the physical or technical nature of the phenomena, and (2) analytical methods, which use physical models to mimic the measured noise characteristics. An important part of such a system would be a signal validation procedure and means for its incorporation into automatic operation of the system.

van Niekerk and Sunder introduced an on-line condition monitoring system (COMOS) which was developed both for application to main coolant pump shafts and for general vibration monitoring of passive primary components. A high degree of automation and information extraction and a user-friendly representation of measurement results allow utility personnel to apply methods for detecting impending failures without a need for continual expert assistance. Modular hardware and software make possible future integration of noise rules to increase the diagnostic capabilities of the system.

Thie proposed a solution for the problem of how to cull from large masses of data stored on hard disk very specific types of information in answer to narrow, precisely formulated questions. It was recognized that computing efficiencies would be achieved by storing in the databases spectral features rather than numerous spectral points. Additional suggestions were offered: (1) user-friendly programs with numerous and powerful commands should be used; (2) users should be alert to the possibility of extensive information in the individual data points and not always restrict analysis to just a few features; (3) close contact with the data should be maintained by visual examination of samples.

The paper of **March-Leuba and King** described the characteristics of a portable real-time system for performing nonperturbing measurements of stability in boiling water reactors. The algorithm used in this system estimates the closed-loop asymptotic decay ratio using only the naturally occurring neutron noise; it is based on univariate autoregressive methodology. Experimental evidence has shown that open-loop decay ratios can be as much as 50% smaller than closed-loop decay ratios and therefore are nonconservative estimates of reactor stability.

This session concluded with several papers emphasizing pattern recognition and artificial intelligence (expert systems in particular). The studies, using sophisticated selection and combination of various branches of signal processing technology, were aimed at developing intelligent systems for vibration monitoring and diagnostics. From the computer application point of view, symbolic or logical manipulation (in addition to ordinary numerical computation) plays a key role in most of the studies.

Sädtler described a diagnostic system based on a combination of feature extraction and classification. The feature vector is composed of specific functions of auto-power spectral density values at discrete frequencies. The classification is basically a hypothesis test: assuming that the feature vector is related to a stochastic process described by a Markov model, a maximum likelihood model, called the maximum-a-posteriori (MAP) estimator, is obtained. The hardware is a modular system composed of 16-bit microprocessors. A sample plot of a simulated decision process was shown.

Dach discussed the development of an expert system for diagnostics of reactor internal behavior. Knowledge concerning measured noises, such as deviation of frequency and amplitude of fluctuating power, is augmented by knowledge derived from a mathematical model of mechanical behavior of the reactor. The knowledge base is a set of production rules thus obtained. To identify the origin of the anomaly, use is made of decision matrices, which relate alterations of the noise descriptor values to the occurrence of transients in reactor operations.

Kitamura described a knowledge base suitable for supporting reactor noise analysis. To extract appropriate information from the reactor noise, expertise in signal processing technology is needed at every stage of analysis, namely, a priori tests of statistical properties of the noise, modeling, and noise signature evaluation and a priori tests of the results. The frame representation of knowledge specific to procedures of analysis is combined with a set of production rules related to situations encountered in the analysis. Several examples demonstrating the usefulness of the proposed method were shown.

Bokor reviewed the functional structure of a noise diagnostic system composed of subsystems for signal-processing, pattern recognition, knowledge-based signal processing supervision, diagnostic expert system, and so forth. The author then described in more detail the signal processing supervisor, the objective of which is similar to that of the system developed by Kitamura.

Kemeny stated his views on pattern recognition and artificial intelligence and described some of his experiences.

5 MECHANICAL AND PROCESS MODELING

Summarized by G. Hughes (U.K.)

Bauernfeind reported a frequency-domain model of a four-loop PWR primary circuit that provides estimates of vibrational power spectral densities. The model was used to calculate the influence of mechanical degradation and damage on the signals analyzed by a vibration monitoring system. Good agreement between model and measurement was demonstrated.

Shinaishin presented calculations of neutron flux perturbation due to control rod vibration using a two-energy-group diffusion model. The model was applied to a PWR control rod element to demonstrate that malfunction detection and location can be achieved using ex-core detectors. The work was confirmed by experimental observations.

Upadhyaya described a detailed theoretical analysis of the cross-power spectral density phase relationships between fluctuations of in-core flux and core exit temperature. Modeling applied to the LOFT reactor showed a linear change in phase over a frequency range of 0.1 to 2 Hz. The influence of the moderator temperature coefficient of reactivity was discussed. The analysis further showed that coolant flow rate fluctuations are the primary driving force for LOFT, a conclusion confirmed by independent studies. The author suggested that phase behavior is a good way to monitor the moderator temperature coefficient.

Antonopoulos-Domis explained the structure of neutron noise coherences at low frequencies in BWRs, drawing attention to the rise in coherence at very low frequency. A one-dimensional, two-region (fuel/coolant) reactor model is used to demonstrate that pressure feedback could be one reason for the rise in coherences, which are observed experimentally. Other experimental evidence of a different feedback mechanism is satisfactorily modeled by the use of space-dependent feedback.

Messaingirai-Bruynooghe demonstrated how in-core neutron detectors can be used to identify and locate vibration phenomena—including fuel, control rod, and thimble movements—in 900- and 1300-MWe PWRs. Fluctuations caused by local boiling are also considered. Despite the restricted spatial sensitivity of the detectors, it is possible to detect remote perturbations in the frequency range established by the plateau region of the reactor transfer function and thus obtain reasonable spatial location. By comparing theoretical predictions with measured values, it is possible to ascertain the nature of the anomaly.

Reddy reported on transport theory predictions of the transmission of neutron noise through nonmultiplying media, with the objective of estimating the performance of ex-core detectors of fast reactors. Both infinite and finite media cases were considered, the later providing a more realistic estimate of the upper break frequency, which was calculated to be about 10 Hz for transmission through graphite and 100 Hz through borated concrete.

Nomura presented a method for monitoring reactor systems by a state space trajectory pattern. The method has been applied to one- and two-dimensional equations and to reactor systems with temperature and void feedback using a computer simulation. The trajectory patterns permit direct treatment of new data and can cope with nonlinear systems. It is proposed to utilize pattern recognition methods in n-dimensional space to detect anomalies automatically.

Kozma outlined his study of a space-dependent, coupled neutronic/thermohydraulic noise model. The eigenvalues were shown to be useful in understanding feedback effects. Critical combinations of coolant velocity and heat transfer coefficient were explored for a PWR core, resulting in the appearance of low-frequency resonances (0.15 to 0.4 Hz) which are an inherent feature of light-water reactors.

6 MEASUREMENT METHODS

Summarized by R. Albrecht (USA)

Of the eight papers presented in this session, four dealt with noise analysis methods applied to the understanding of fuel performance, and the others described a variety of other applications. The latter included estimation of control rod effectiveness during xenon transients, early detection of local boiling, investigation of two-phase flow properties by X-ray tomography, and observance of space-dependent stochastic fluctuations in a large graphite reactor.

Oguma et al. reported on a recursive identification technique based on an adaptive lattice filter. Results were shown for the estimation of the thermal time constant of reactor fuel and the fuel's mechanical response (elongation) under steady and transient conditions. The recursive identification technique appears to be useful for studying fuel behavior during slowly varying state changes.

The three remaining papers on fuel performance all dealt with evaluating LMFBR fuel. **Girard et al.** reported on the analysis of good quality temperature noise signals obtained during the commissioning phase of Superphenix I. The signals from 448 instrumented subassemblies were analyzed for root-mean-square level and other statistical parameters. The data came from a combination composite thermocouple and intrinsic thermocouple and allowed the determination of the k -value (normalized rms temperature), which was shown to remain very nearly constant as reactor power and mass flow were varied.

The paper by **Edelmann et al.** was based on the same data from Superphenix I; however, the analysis here concentrated on the frequency range 0.001 to 1.0 Hz. The result was relatively pessimistic for noise analysis: the major part of the temperature noise measured above the Superphenix subassembly outlets appeared to be unrelated to fluctuations of reactor or subassembly power.

Morishima and Türkcan presented a simple index with which to express control rod effectiveness: the ratio of covariance to variance. This ratio is easily estimated and has a clear physical meaning. However, care must be taken to remove the almost deterministic component (trend) attributable to slow feedback effects.

A paper by **Hummel and Wesser** showed spatial distributions of various moments of data obtained from an air/water two-phase flow loop. Spatially dependent spectra were also presented. The results showed considerable promise; however, it is clear that much more refined analyses are required if these X-ray tomography techniques are to make a significant contribution to the fundamental understanding of two-phase flow phenomena.

Decreton and Bouneder showed the results of an experimental investigation of the detection of the onset of localized boiling in water on a heated fuel pin. Accelerometers placed on the pin and on surrounding structures at appreciable distances from the boiling position were used. The technique proved to be very sensitive because of the transmission of mechanical energy from the boiling to the mechanical environment.

Crowe et al. reported on new measurements made in a large graphite reactor. Low-frequency phase shifts between axially displaced neutron detectors were observed and rationalized by a comparison to calculation. At higher frequencies, the behavior of phases between various detectors was not supported by computations. Also, a small but unexplained 1.4-Hz resonance was observed in this reactor. The results showed that future measurements with a fully deployed array of in-core sensors in the Hanford "N" reactor would be needed to obtain a more complete and comprehensive understanding of such large systems.

7 THERMOHYDRAULICS

Summarized by P. Liewers (GDR)

In this session four papers were presented on the use of low-frequency fluctuations for surveillance and parameter estimation in PWRs.

Puyal described the monitoring of internal structures of the French 900-MWe and 1300-MWe PWRs using ex-core neutron detectors and accelerometers. Comprehensive statistical data are available. He also presented the results of investigations of thermo-hydraulic phenomena such as temperature fluctuations in the reactor hot legs (caused by the use of gadolinium in the core) and pressure fluctuations (caused by pressurizer/loop interaction).

Kostic and Katona presented two papers dealing with the problem of information extraction from the low-frequency fluctuations of in-core neutron and core-exit thermocouple signals. Comprehensive experimental data from the Grohnde plant were presented, together with some theoretical interpretation. Experimental results from different plants were compared with one another and with results from theoretical models. Thereby it was shown that the usual theoretical approach, based on an assumption of propagating voids, leads to some inconsistencies. Both papers concluded that thermo-hydraulic parameters can be determined by analyzing low-frequency fluctuations. In the ensuing discussion, Wach expressed the opinion that mechanical vibrations must also be taken into account, even at low frequencies.

Glöckler presented a multivariate noise analysis method which shows promise for plant diagnosis because it allows the separation of process and sensor anomalies and can be automated. The method was applied to experimental data from the LOFT reactor and showed convincingly the feasibility of identifying noise sources and signal transmission paths.

8 LOOSE PARTS

Summarized by F. Akerhielm (Sweden)

Three of the five papers in this session dealt with loose-part monitoring and the remaining two with leak detection.

A paper by Mayo et al. showed results of a research project to establish an analytical basis for loose-part monitoring system performance using metal impact theory, plate wave transmission theory, and experimental data. The results can be used to design or evaluate loose-part monitoring system detection and diagnostic capability. They also provide a basis for using impacts of either known energy or measured force to calibrate system response over the range of potential impact signals. The findings of this work have been translated into guidelines for American utilities to use in defining, evaluating, and improving loose-part monitoring system performance.

Castanie et al. reported on recent experiences in loose-part monitoring of LWRs. The examples given demonstrated a whole spectrum of applications and advantages of the loose-part monitoring system presently installed in all LWRs in the FRG. A new burst analysis method of sound mode separation permits the localization of all anomalous sound sources with only a few (in principle, even one) accelerometer signals.

Olma described advanced burst processing methods for use in loose-part monitoring. Examples were given which showed, from a view of early failure detection, that this method of acoustic monitoring covers important kinds of mechanical contacts within the primary coolant systems of both PWRs and BWRs. Increasing plant age and more extensive use of digital analysis systems can be expected to intensify the trend to condition monitoring of actual components. Access to a specialized knowledge base is expected to improve the ability to interpret the bursts.

A paper by Brunet et al. described an acoustic method for detecting leaks in the steam generator of Superphenix. Fast detection of a rapidly growing leak is necessary to prevent rupture of neighboring tubes. Simulation of water leaks in the steam generator using argon injections has shown promising results at 50% rated power. The observed decrease in signal-to-noise ratio with increasing source/sensor separation is expected to give information on the axial location of leaks.

A follow-up paper by Berjon et al. reported on the success of acoustic location of a sodium leak in the "bartillet" of Superphenix in March 1987. Both conventional and acoustic methods were used in determining the location of the leak. The methods gave consistent results both for the altitude and the azimuth of the leak.

The papers presented in this session showed that loose-part monitoring has now reached a state of maturity, from both theoretical and application points of view. It is clear that the monitoring equipment installed on most plants can be used efficiently and contributes substantially to plant availability. The cost/benefit ratio has proved to be favorable. The papers on leak detection in Superphenix also showed how theory and experience can be combined successfully for special needs.

9 FLOW MEASUREMENTS AND BOILING

Summarized by A. Federico (Italy)

The four papers presented in this session, evenly divided between in-core applications and out-of-pile simulations, were directed towards detecting subcooled boiling in PWRs and characterizing two-phase flow patterns in BWR coolant channels.

Defloor reported on an anomaly that occurred at Doel 2 (a PWR) in 1986. Unusually large values of the axial offset and anomalous readings from two thermocouples were observed, possibly indicating the onset of nucleate boiling—presumably due to crud deposits induced by oxidized cladding—at a few fuel pins. Analysis of the power spectra of repositioned fission chambers revealed a signature typical of nucleate boiling in the upper region of the suspected pins. Even though some aspects of the phenomena are not fully understood, it was emphasized that neutron noise analysis supplied a convincing assessment of the anomaly, one that is quantitatively supported by complementary calculations and measurements of reactivity effects in the core.

Por described analytical and experimental efforts at Paks 2 (a PWR) aimed at detecting the presence of voids—and not just their propagation velocities—by studying and understanding the significance of the shape of the CPSD phase between signals from axially displaced neutron detectors. In fact, detailed interpretation of Paks 2 experiments and the supporting calculations confirmed that a linear dependence of CPSD phase on frequency was a reliable indicator of the presence of hot spots on fuel pins and, therefore, of the possibility of localized boiling. In particular, such linear dependence was found to be strongly correlated to the power generation of the pins involved and to overheating of their surfaces; thus, its puzzling disappearances and reappearances can be attributed to normal changes in the power form factor during the course of the fuel cycle.

van der Hagen described an experimental campaign, carried out in an air/water loop simulating a BWR channel, aimed at measuring two-phase flow velocities in a variety of flow regimes via noise correlation techniques. The simulation was done with attention to detail, the velocities were accurately measured in the loop, and significant conclusions were reached by comparing simulated and calculated values for both bubbly and slug flows. Such analysis, however, is precluded in real BWR channels, where indispensable information about the steam distribution cannot be obtained experimentally.

Iida's paper related to the problem of detecting local boiling in situations where temperature fluctuations are very small, as in PWRs and LMFBRs. The author described a refined and simplified version of a double thermocouple instrument he announced at SMORN IV. A single, automatically compensated thermocouple is used in the present setup, and temperature fluctuations are derived from changes in the PSD of the optimally high- and low-pass-filtered signal. Despite the lower sensitivity exhibited by the single thermocouple setup in mock-up tests, it seems to have greater prospective usefulness than the previous double thermocouple system.

10 SAFETY-RELATED APPLICATIONS

Summarized by P. Bernard (France) and J. Valko (Hungary)

Three of the eight papers presented in this session dealt with the assessment of on-site measurement system characteristics and with monitoring and signal validation. Two of the remaining papers dealt with signal processing techniques for sodium boiling detection in LMFBRs, and the other three dealt with BWR stability.

Hashemian et al. described the results of applying autoregressive (AR) methods to the evaluation of response time of temperature and pressure sensors. Laboratory and in-plant tests showed that the apparent response time was greater than the value measured directly. This was presumably due to non-white noise characteristics of the input noise. Modeling of sensing line characteristics for monitoring was also presented.

Oguma et al. presented results from tests performed at the Ringhals Station, where time series analysis was applied to the estimation of temperature sensors and control system time constants. The authors concluded that control system filter characteristics and temperature sensor response times can be estimated with good accuracy using this technique.

A paper by **Upadhyaya et al.** dealt with the combination of a generalized consistency check and a sequential probability ratio test for on-line detection of sensor failure. Application to an aluminum rolling mill was described.

General remarks concerning the above papers are as follows:

- On-line, continuous monitoring permits detection of malfunctions while reducing the period of tests and manpower.
- The performance of the entire measurement system can be monitored (to obvious advantage).
- A continuous check of signal validity will increase confidence in the information extracted from the signal.
- There is merit in using both the deterministic and random information content of the signals in combination so as to yield a coherent approach to on-line diagnosis.

In the second portion of the session, **Singh et al.** presented a new approach in signal processing techniques for sodium boiling noise detection, and **MacLeod et al.** presented the results of specialized signal processing techniques applied to data recordings from KNS experiments and from the BOR 60 reactor.

General remarks from these papers are:

- Acoustic detection appears to be a promising technique for on-line detection of boiling at an incipient level of progression.
- The acoustic signal from boiling is highly impulsive in character, and the detection technique must take this characteristic into account.
- The methods proposed allow rapid computations, as necessary for practical on-line applications.

In the third portion of the session, several methods of stability monitoring were examined by the authors, and their respective merits and drawbacks were analyzed. Two papers described microcomputer-based stability monitoring systems applicable to BWR control rooms.

Ando presented the work of several colleagues in which various methods for estimating reactor stability from process noise signals (such as neutron flux and core flow rate) were compared. All methods were based on univariate or multivariate autoregression combined with various techniques for estimating the decay ratio and have been checked against simulated data and also with real power plant data. A BWR stability monitoring system was constructed, and its capabilities were tested in a power plant.

A paper presented by **van der Hagen** examined the stability of the natural-circulation-cooled Dodewaard BWR in six different experimental conditions. The methods and criteria used for assessing the stability of the BWR core were compared. In all cases, perturbations were introduced through control rod movement or steam valve operation. A method based on peaking factors (ratios of rms noise in given frequency ranges) is suggested as a reliable yet simple technique for estimating stability.

Tricoli presented a paper, similar to those of previous speakers, comparing different methods and algorithms. The method chosen for demonstration in a stability monitoring system was based on univariate autoregression, and the decay ratio was extracted. Prior to the analysis of experimental data from the Caorso nuclear power plant, artificial data were first used to analyze the capabilities of the method.

General remarks from these papers are:

- BWR core (channel) stability monitoring is an important topic to reactor safety. Using continuous monitoring, reactor operators can operate closer to stability limits, and reduced margins can be permitted. This strategy helps in load following and in other cases when the reactor is not running at nominal conditions. The decay ratio is the basic quantity used to characterize BWR stability.
- Microprocessor-based on-line systems that monitor global and local stability and provide easy-to-read operator displays are being used successfully at several reactors.

11 FOURIER TRANSFORMATION AND PATTERN RECOGNITION

Summarized by K. Behringer (Switzerland)

The five poster papers of this session were concerned more with basic problems in noise analysis methods than with new applications. The paper of **Pineyro and Behringer** dealt with a problem in the field of noise data qualification. A new method based on Fourier transform techniques was presented which allows one, within certain limitations, to distinguish between sinusoidal components and narrowband random noise contributions in otherwise random noise data. For this analysis a special fourth-order spectral function was introduced. The paper gave the theoretical background of the analysis procedure, proposed a validation criterion for the type identification of the peaks in the PSD, and showed results from experimental examples. The method is believed to be suitable for semiautomatic routine applications.

Reddy and Murthy proposed a new method for the on-line detection of a malfunction. The method uses noise data segmentation and requires the selection of a statistical feature variable that must show well separated amplitude distributions under normal conditions and in the presence of a specific malfunction, so that a threshold can be defined. By summing instantaneous feature values relative to the threshold from succeeding segments, a random walk is obtained that runs either to a left-hand boundary or to a right-hand boundary, indicating thereby either the normal or the anomalous state. After the walker has crossed one of the boundaries, it is reset and restarted. The method and the theoretical considerations given to the problem of spurious decisions have been tested on sodium boiling noise.

Dailey and Albrecht modeled the vibrations of the core internals in an operating PWR (as sensed by the fluctuations of the in-core and ex-core neutron detector signals) and developed a set of parameters for establishing a discriminant that allows monitoring of the state of vibrating internals. In the first part of the paper a modeling procedure was described which was a continuation of work published at SMORN IV. The model is a linear combination of four types of independent noise sources: lateral motions of the fuel assemblies, lateral motion of the core support barrel, background noise, and spatially localized assembly-specific information. In the second part of the paper a state vector was constructed. A statistical (frequency-dependent) discriminant was proposed, which indicates the normalized squared deviation of the observed state from a baseline state. The methodology provides a means of establishing a baseline state and evaluating the deviation of the present state from the established baseline and suggests a way of setting a threshold.

The paper of **Konno** was concerned with modeling the category of hump and burst phenomena appearing in randomly excited nonlinear mechanical vibration systems. The appearance of an anomaly may be associated with a nonlinear random process which affects non-Gaussian contributions to the noise signal. For the characterization of non-Gaussian noise, higher-order correlation functions or their corresponding Fourier transforms (e.g., the triple correlation function or the bispectrum, respectively) must be considered. The authors focused on system identification, using bispectral techniques in addition to the amplitude distribution function. The given Langevin equation is based on a one-dimensional vibrational model and contains, as special cases, the equations that are shown to describe either the hump or the burst phenomena.

The paper of **Avila and Oliveira** analyzed core barrel vibrations in PWRs. The method of "identifying functions" was applied to ex-core neutron noise data from the Borssele reactor (SMORN III benchmark data) and from three French PWRs. This method was recently proposed by the authors and consists of the definition of four pairs of functions of frequency which are based on the phase relationships of the CPSDs between four ex-core neutron detectors located in different quadrants of the same plane. Each pairing of these functions enhances the appearances of different noise sources. In particular, the application of this method to the Borssele PWR resulted in the observation of shell-mode core barrel vibrations that had not been reported earlier.

12 SIGNAL MODELING

Summarized by M. Antonopoulos-Domis (Greece)

All presentations in this session dealt with time series linear model analyses (namely, univariate AR, MAR and ARMA models), reflecting the increasing interest over the last decade in using such methods for reactor surveillance, malfunction detection, and diagnosis. Two of the papers presented AR applications to nonstationary data, while the rest of the presentations dealt with stationary data.

Kishida presented separation rules for AR poles which can distinguish between system and ring poles, using properties of geometrical pole location in AR models. The application of these rules to artificial JPDR data from the benchmark test of SMORN III and to Borssele reactor noise data was presented and discussed.

Ciftcioglu presented a study treating optimum choice of MAR modeling parameters in which it was shown that the finite sampling interval may cause false correlations between the noise sources, which were assumed to be independent. By application of MAR analysis to data from a digital simulator of a point reactor with simplified thermohydraulic feedback, the authors found that the covariance matrix became increasingly nondiagonal as the sampling frequency decreased. However, they found it difficult to estimate the precise role of sampling frequency, due to interdependence of the model parameters. Despite the dependence of parameters on the particular application, they concluded that memory time and sample-length time criteria are applicable to each individual case in common for the establishment of optimality.

The objective of the work presented by Hayashi was to test MAR model fitting for system identification, using analog-computer-simulated data representing a two-dimensional feedback system. This study of the effect of sampling conditions showed dependence of the results on sampling frequency. It was also found that, although MAR gives correct estimates of power spectra, it does not necessarily give correct estimates of transfer functions. An example of the application of system identification using MAR modeling of noise data from a pulsed reactor was presented.

Shinohara et al. presented tests and applications of univariate AR analysis to nonstationary data, the advantage of AR over normal FFT being its ability to process small sample sizes. By application of AR analysis to data from analog system simulation and from reactor noise acquired during shutdown, the authors calculated local and instantaneous spectra. They found that instantaneous AR spectra can be used to analyze nonstationary data, but only if the data span used for each instantaneous spectrum is short in comparison to the time constant of the transient.

Kuroda presented a study of Bayesian AR modeling applied to nonstationary data, with special attention given to the fine structure of reactor noise. Both instantaneous and local spectra were computed from univariate models of neutron and pressure noise signals from the Borssele reactor and temperature noise signals from the Phenix reactor. The local structure of these signals was thus identified.

Nagy described the signal processing hardware used in a noise surveillance system installed at Paks nuclear power station and the methodology and experience in applying parametric signal processing and spectral analysis. The methods included MAR and ARMA modeling. A method for decomposing PSDs was also applied, so as to study the effect of common source noises in multivariate situations.

Bokor presented a study of the relationships among three analysis methods (namely, signal transmission path analysis, Dynamic Data System analysis, and linear dependence and feedback analysis), all of which are linear models of the system, similar to MAR or ARMA models. Extending these methods, the authors proposed "signal effect analysis," defining two new concepts for studying the effect of source noises on variables and interactions between variables. They illustrated this by analyzing reactor pressure and in-core neutron fluctuation processes.

In summary, the session demonstrated some of the advantages of AR modeling, namely, capability to analyze cause and effect, applicability to feedback systems, and ability to use smaller data samples than classical FFT techniques. Limitations and unresolved issues were also demonstrated, namely, dependence of results on the signals selected and difficulty with optimum selection of the interdependent model parameters. The dependence of these parameters on the nature of the signals and on system dynamics appears to be stronger than that of conventional FFT analysis. It seems, therefore, that a prerequisite for the acceptance of these methods for practical application by the user is the existence of clear and reliable selection rules for the model order and parameterization. It is also clear that some understanding of the physical system being modeled is necessary; a strictly black-box approach does not seem to be feasible. A combination of physical and black-box modeling is perhaps a reasonable compromise.

13 BENCHMARK EXERCISE

Summarized by H. van Dam (Netherlands)

The benchmark exercise was the third in a series undertaken at three consecutive SMORN meetings. At SMORN III a computational benchmark was organized to compare methods for calculating characteristic noise functions. This was followed by physical benchmarks (SMORN IV) which focused on the extraction of physical parameters from noise signals. The SMORN V benchmarks were an extension of the previous ones, in the sense that they required the estimation of physical parameters but were also intended to demonstrate a capability for anomaly detection.

Two benchmark problems were offered, both produced by groups in the Netherlands:

- Artificial noise data, prepared by a group from the Interfaculty Reactor Institute of Delft University of Technology, and
- Actual noise data from the Borssele nuclear power plant, prepared by the Energy Research Foundation at Petten.

The first benchmark was analyzed by seven groups from five different countries, whereas nine groups from seven countries participated in the second benchmark.

The first (artificial) benchmark was focused on system identification, preferably through application of MAR methods. Embedded in the data, however, were two consecutively occurring anomalies. The main advantage of computer-simulated noise signals is that all relevant parameters of the system are known exactly, thus furnishing a firm basis for evaluating the analysis methods applied.

The results from the participants' analyses provided the following conclusions:

- The choice of appropriate sampling interval and model order in AR analysis remains an important issue. A nonoptimal choice leads to pseudocorrelation between residual noise sources. It is also apparent that the effective strength of these sources depends on the sampling interval.
- Problems were encountered with regard to normalization of signals and conversion to physical units, but the exact cause is not clear.
- The identification of physical parameters of a multiparameter system, even if this system is relatively simple, is still a problem, and the accuracy of the results is in many cases rather limited.
- The results of the anomaly detection portion of the benchmark are very interesting but need a more detailed assessment. The anomalies simulated in the first benchmark had a realistic character (a vibrating control rod and a gradually deteriorating system stability) but were not of such magnitude as to be conspicuous. Most participants were successful in detecting the anomalies, but further analysis of the characteristics of the different detection methods would be useful, particularly in regard to the inevitable compromise between false alarm rate and probability of missed alarms.

The second (Borssele) benchmark contained a real anomaly in the form of a rather drastic operational transient initiated by a sudden electrical load change. The jump in the generator power signal was quite pronounced and formed a well defined time point for the start of the anomalous event. This rapid change in output requirement caused heavy oscillations at the generator input, propagating via the steam turbine into the entire secondary system and through the steam generator to the primary coolant system. During this propagation the signal deviations caused by this anomaly were gradually attenuated. The benchmark tape contained eight signals ranging from generator power to core coolant temperature.

Tentative conclusions from this second benchmark exercise are:

- All participants detected the initiating event successfully; also, the propagation of the disturbances back through the system was clearly identified.
- There was, however, a considerable spread in the timing of the starting point as given by the participants, which may indicate deficiencies in the copying of the signals or ambiguities in definitions. The total duration of the anomaly was correctly identified, which supports the conclusion that the anomaly was correctly detected. Further analysis of the reported results may reveal the cause of the starting time discrepancies.
- A wide range of anomaly detection methods was applied successfully by the participants, such as moments of amplitude distributions, various forms of correlation functions, power spectral densities, noise power in particular frequency intervals, pattern recognition, and so on.

As a general conclusion, it can be stated that the benchmark tests are useful. Additional benefit could be obtained, however, if more participants engaged in the exercise and if group experience were fed back to the participants for reevaluation of their own results. It is therefore the intention to proceed with these benchmarks in future SMORN meetings. Continuance also provides an opportunity to solve some of the noted problems with tape recording quality and the lack of accompanying information to participants. It is recommended that these benchmark materials be included in the files of the Nuclear Energy Agency Data Bank as reference material for future users. The benchmarks should include the original tape-recorded signals and also intermediate results of analysis (such as sampled data from the analog signals, correlations functions, AR coefficients, noise contribution ratios, transfer functions) as well as time constants and similar results obtained from fitting procedures. It should be stressed that the basic starting point is the set of analog signals recorded on tape, but if a user has no sampling equipment at his disposal, he may start from material of the next level, that is, sampled data (preferably obtained with a short sampling time interval).

Finally, it was concluded that there is no need for an additional physical benchmark involving process signals—merely full exploitation of the existing ones. It is, however, recommended that the present set of benchmarks be completed with a loose-parts benchmark, in keeping with the original intent of SMORN V.

14 CONCLUDING PANEL DISCUSSION

Summarized by W. Bastl (FRG)

Technical Issues

We believe that "aging" is an issue to which we noise people can contribute substantially with our monitoring methods. As plants become older and older, aging provides an increasing challenge for us. In addition, longer fuel cycles (a tendency nowadays because of economic reasons) and load-following operation make aging considerations more important. There are certainly other areas where we can contribute with our methods. It was also observed that we should think more about combining mean value measurements with noise analysis measurements to extract thereby even more useful information. We also noted that noise analysis is enjoying increasing popularity with end users, that is, the plant operators. In fact, SMORN V could be considered a breakthrough because of the substantial participation by utilities. Then there is the question of standards. Certainly, some national standards have been developed already, but we have much left to do in this area. I would like to mention that the International Electrical Commission (IEC) is producing a standard on loose-parts monitoring and also one on vibration. In connection with the benchmark testing, we discovered that some of the methods need further validation, while others need further development. We know that there are many new ideas for more sophisticated analysis methods, and these need to be validated against practical cases to be sure that they work correctly in industrial application. In my opinion, this was the main outcome of our technical discussion.

Of course it is impossible to treat all the problems within a symposium like this. It is often overlooked that noise analysis—though it seems to be a very narrow specialist field—has a wide range of useful applications. Because of time constraints we have been forced to focus on some major topics and could not really draw conclusions that covered all aspects.

Next Symposium

Turning to the question of continuing our symposium series, I think so many problems are still to be solved in our field that there can be only one answer: "Yes." Looking from the outside into noise analysis, one might get the impression that after working so long a time in so narrow a field the methods are mature and the R&D work finished. However, we do not feel that this is the case; a lot of work still remains to be done, since the full potential of our methodologies has not yet been realized. This judgment is not intended to minimize the considerable progress made in the field since SMORN IV. I can't help recalling statements made at the end of SMORN IV, when we were concerned that there would not be sufficient progress to warrant a conference in the near future. I guess we were all surprised about the new work done during the last three years. I am confident this progress will continue because we have just entered some new application areas which will call for new solutions.

Summary of the Symposium

I will now make some personal observations and conclusions about the symposium. In thinking back a bit about the series of SMORN meetings, I note we started off with basic research work. Then, more and more, practical applications began to be realized, including monitoring for loose parts, vibration, and fluid leakage.

It seems to me that there are two main branches of application in our field: structural or mechanical monitoring on the one hand and process monitoring on the other. I would say that up to now we have advanced primarily the structural part, but I see a high potential in the process branch as well, and in this context I mention the excellent work being done by our Japanese colleagues. Since SMORN IV we have had sessions devoted to safety applications. This was not only because the Committee on the Safety of Nuclear Installations is a co-organizer of our meetings, but because early on it was recognized that noise analysis methods can play an important role in resolving safety issues. Nowadays our symposium provides a good interplay between application issues and R&D work, and, I would like to stress, this is not the case because of organizational constraints but because it reflects the true present situation of the nuclear industry.

Let me now express my opinion of where noise analysis stands at present. In the area of methodologies, I feel that a lot of work needs to be done with respect to higher-order correlation methods, pattern recognition, and the analysis of multiple input/output systems, more specifically, autoregressive modeling. The capability of AR to analyze cause/effect relationships and feedback systems is extremely important, but as we have heard, there are still many problems to be solved (e.g., the problem of optimal selection of independent model parameters) before we can enter confidently into the realm of practical applications.

Turning again to the applications, I find we have several excellent examples in the form of systems for monitoring structural parts in our plants. These are not really on-line systems, but rather on-site systems. In the future we must think more about the ability of our methods to be employed in on-line systems and, moreover, to perform on-line process analysis. In the framework of nuclear power plant instrumentation and control, I feel we have in our hands the means with which to contribute substantially to a progression from simple monitoring to diagnostic (and even prognostic) systems. This is not as futuristic as it may first appear, considering that a revolution in I&C techniques as a whole is now just beginning. I am referring here to the very advanced electronic systems we already have or soon will have; to use a direct translation from the German, we say "Processorized I&C." This means the hardware will be there to run all the programs useful in noise analysis, even complicated ones. If we are able to industrialize, to customize, and to validate our software—and this is a different situation from former days—there is basically no limitation to the application of all our methods in the I&C systems of the future. So it seems to me that our main thrust should be directed towards on-line diagnostics, making this the up-and-coming methodology to be applied in future I&C systems.

Closing

In officially closing the Symposium, I would like to thank—on behalf of OECD, IAEA, and the Organizing Committee—our session chairmen for their excellent work and also the benchmark group, which did a tremendous job. I would not want to forget the excellent interpreters; it is not easy to translate our specialized noise terminology. Also, I thank our technical officers and acknowledge all the support provided by the technical staff of the patent office. Please let us not forget to thank the courteous attendants at the conference desk and all the administrative staff who planned and oversaw the social events. Special thanks go to my colleagues in the Organizing Committee for their stimulating ideas and cooperation.

We at GRS are especially grateful to the OECD for giving us the opportunity to organize SMORN V and to the IAEA for their assistance in encouraging non-OECD member states to send delegates to this meeting. We are quite pleased with the increased participation of the non-OECD countries and hope that this trend will continue. Last but probably the most important, I should not forget the major ingredients for a successful conference, namely, the quality and quantity of papers submitted. Quality, of course, is not something the organizers can control. All the contributors deserve our thanks for the consistently high quality of their presentations.

I wish the people participating in the technical tours of facilities next week a nice weekend here in Munich followed by an interesting visit. Please have a safe trip home, and I hope to see you in three years at SMORN VI in the United States. Thank you very much for coming to Munich. SMORN V is now officially closed.

A List of papers presented at SMORN-V

- M. Antonopoulos-Domis, V. Chatziathanasiou
Investigation of boiling and pressure feedback on neutron noise
- R. Baeyens, G. Boon, G. d'Ans
Belgian experience in noise monitoring of nuclear power plants
- V. Bauernfeind
Vibration monitoring of a four-loop PWR: Model-investigations of the sensitivity of the monitored signals on mechanical failures
- B.-G. Bergdahl, R. Oguma
Health test of components in nuclear reactor instrument systems using process identification
- A. Berjon, P. Garnaud, R. Demarais, C. Acket
Acoustic location of the sodium leak in the "Barillet" of Super Phenix
- J. Blomstrand, A. Spencer
Noise analysis of core coolant channel flow signals, recorded in Swedish and Finnish BWRs
- M. Brunet, P. Garnaud, D. Ghaleb, N. Kong
Water leak detection in steam generator of Super Phenix
- J.C. Carré, A. Epstein, C. Puyal, M. Castello, P. Dumortier
Malfunction tests and vibration analysis of PWR internal structures
- G. Castanie, K. Krien, M. Lehmann
Recent experiences in loose parts monitoring of light water reactors
- Ö. Ciftcioglu, J.E. Hoogenboom, H. van Dam
Studies on multivariate autoregressive analysis using synthesized reactor noise-like data for optimal modelling
- R.D. Crowe, H. Toffer, R.W. Albrecht
Incore neutronic fluctuation measurements in a large graphite moderated power reactor
- K. Dach, V. Krett, J. Vavřín, L. Pečinka
Developing a knowledge base for noise diagnostic expert system of reactor internal behaviour
- D.J. Dailey, R.W. Albrecht
Parameterization of in-core PWR signals for use with pattern recognition techniques
- M. Decréton, M. Bouneder
Early detection of localized onset of boiling
- J. Defloor, R. Baeyens
Nucleate boiling detected by neutron noise monitoring at DOEL 2
- M. Edelmann, J.P. Girard, H. Massier
Experimental investigations of correlations between neutron power and fuel element outlet temperatures of Super Phenix-1
- H. Eitschberger, D. Burns, U. Siegfried
Power oscillations at the Leibstadt nuclear plant
- J. Eklund, S. Kuismanen, A. Lucander, L.-E. Häll
Early fault detection and diagnosis in Finnish nuclear power plants
- A.G. Federico, R. Ragona, C. Tricoli
Dynamic characterization of the BWR core/channel for the Caorso nuclear power plant with applications to stability patterns evaluation from operating data
- D.N. Fry
Summary of the fourth informal conference on US utility experience in reactor noise analysis

- J.-P. Girard, H. Recroix, M.J. Beesley, G. Weinkötz, L. Krebs, R.S. Overton, L. Hughes
Detection of coolant temperature noise in SPX1 using intrinsic high frequency thermocouples
- O. Glöckler, B.R. Upadhyaya
Results and interpretation of multivariate autoregressive analysis applied to the LOFT reactor process noise data
- J. Guitton, C. Puyal
New trends in vibration and acoustic monitoring in nuclear components in EDF
- H.M. Hashemian, J.A. Thie, B.R. Upadhyaya, K.E. Holbert
Sensor response time monitoring using noise analysis
- K. Hayashi, Y. Shinohara, K. Nabeshima
Study on the goodness of system identification using multivariate AR modeling
- K. Hayashi, Y. Shinohara, E. Türkcan
A method of nonstationary noise analysis using instantaneous AR spectrum and its application to Borssele reactor noise analysis
- J.E. Hoogenboom, Ö. Ciftcioglu, H. van Dam
Summary of benchmark test on the artificial anomaly noise data.
- R. Hummel, U. Wesser
Determination of density noise in a two-phase-flow by X-ray computer tomography
- S. Iida
Instrumentation method and analysis of small temperature fluctuation in incore coolant
- P. Jax, K. Ruthrof
Advanced techniques for the surveillance of light water reactors using microprocessor-based systems
- A.K. Jena, O.P. Singh
On the neutron noise transmission studies for non-multiplying media using transport theory
- S. Kanemoto, M. Enomoto, Y. Ando, H. Namba, S. Ebata, A. Takagi, T. Hattori, N. Kitamura, A. Yoshizawa
Development of an on-line reactor stability monitoring system in a boiling water reactor
- T. Katona, R. Kosma
Problems of estimation of the thermohydraulic parameters using neutron and temperature noise signals in PWR's
- L.G. Kemeny
Operating experience with an on-line computer based nuclear plant surveillance and anomaly detection system based on pattern recognition and artificial intelligence
- L. Keviczky, J. Bokor, I. Nagy, S. Veres
An expert system approach to the development of noise diagnostic system in NPP Paks
- K. Kishida, S. Yamada
Poles and their weights in AR type model
- M. Kitamura, M. Takahashi, T. Washio, K. Sugiyama
Synthesis of heuristic knowledge base for supporting development of goal-oriented reactor noise analysis programs
- H. Konno
Characterization of chaotic, nonstationary time series and its application to early detection of anomalies in nuclear reactors
- L. Kostić, J. Runkel, D. Stegemann
Thermohydraulics surveillance of pressurized water reactors by experimental and theoretical investigations of the low frequency noise field

- J. Kott, L. Haniger, Z. Hubáček, J. Chládek
Systems of operational diagnostics on Czechoslovak nuclear power stations
- R. Kozma
Application of reactor noise models for the analysis of thermohydraulic feedback
- U. Kunze
Method and experience of computer-aided spectra control in the Greifswald nuclear power station
- Y. Kuroda, H. Suzuki
Some aspects of reactor noise analysis from the Bayesian viewpoint
- P. Liewers, W. Schmitt, P. Schumann, F.-P. Weiss
Detection of core barrel motion at WWER-440-type reactors
- B.T. Lubin, R. Longo, T. Hammel
Analysis of internals vibration monitoring and loose part monitoring systems data related to the St. Lucie 1 thermal shield failure
- I.D. MacLeod et al.
Signal processing techniques for the acoustic detection of boiling in LMFBR's. Preliminary results of an IAEA collaborative research programme
- J. March-Leuba, W.T. King
A real-time BWR stability measurement system
- Ch.W. Mayo, H.G. Shugars
Loose part monitoring system improvements
- Ch. Messainguirial-Bruynooghe, G. Lagarde
Spatial sensitivity of a 900 MWe PWR incore detector signal to void fraction, fuel and control rod displacement
- Ch. Messainguirial-Bruynooghe, G. Le Guillou, J.C. Collognes, J.L. Artaud
Results of neutron noise measurements on the Super-Phenix 1200 MWe LMFBR, from start-up to nominal power
- B. Michel, C. Puyal
Operational and economical experience with vibration and loose parts monitoring systems on primary circuits of PWR's
- J. Molina Avila, J. Costa Oliveira
Application of the identifying functions method to the ex-core neutron noise analysis of PWR's
- N. Morishima, E. Türkcan
Application of noise analysis for estimation of control rod effectiveness in the HFR Petten and the Borssele PWR during the xenon transient
- I. Nagy, J. Bokor, S. Veres, M. Tanyi, P. Gáspár
Experiences of reactor noise diagnostics applying parametric spectral analysis methods
- T. Nomura, T. Tsunoda, S. Kanemoto
Method of monitoring reactor system by state space trajectory pattern
- R. Oguma, B.-G. Bergdahl, D. Shrire
Application of a recursive identification technique to noise analysis for fuel performance study
- B.J. Olma, B. Schütz
Advanced burst processing methods in loose parts monitoring
- I. Pazsit, F. Åkerhielm, B.-G. Bergdahl, R. Oguma
BWR instrument tube vibrations: theory of in-core detector spectra and interpretation of measurements
- J. Piñeyro, K. Behringer
Displaced spectra techniques as a tool for peak identification in PSD-analysis

- G. Por, O. Glöckler, U. Rindelhardt
Boiling detection in PWR's by noise measurement
- C. Puyal, C. Vincent, C. Meuwisse, A. Trenty
Use of low frequency fluctuations for the surveillance of structures, sensors and thermohydraulic phenomena on the 900 MW and 1300 MW reactors
- J. Quinn, C. Sterba, J. Stevens
The use of excore neutron noise at near zero reactor power to monitor thermal shield support system integrity
- C.P. Reddy, K.P.N. Murthy
A random walk technique to analyse noise and detect malfunction in a reactor
- E. Saedtler
A modular multi-microcomputer system for on-line vibration diagnostics
- A. Schütte, D. Sommer, J. Weingarten, D. Wach
Utility experience in reactor noise analysis in German LWR's
- M.A. Shinaishin, M. Soubhi
Three dimensional reactor noise analysis for prediction of a control rod potential failure
- O.P. Singh, C.P. Reddy, G.S. Srinivasan, R. Prabhakar, R.K. Vyjayanthi
New approaches in signal processing technique for sodium boiling noise detection
- J.A. Thie
Fast flux test facility noise data management
- A. Trenty, C. Puyal, C. Vincent, M.H. Inchauspe, R. Baeyens, C. Messainguirial-Bruynooghe, G. Lagarde
Thimble vibration analysis and monitoring on 1300 and 900 MW reactors using accelerometers and in-core neutron noise
- L. Turi, P. Siklóssy, S. Rátkai
Practical experience with primary circuit vibration noise analysis at Paks nuclear power plant
- E. Türkcan, G. Tsotridis, R.L. Moss
Noise analysis for thermal studies of LMFBR fuel pins
- E. Türkcan
Summary of benchmark test on the actual anomaly noise data
- T. Umeda, K. Chiba, S. Ebata, Y. Ando, H. Sakamoto
Experience of on-line surveillance at Onagawa-1 BWR plant
- B.R. Upadhyaya, O. Glöckler, F.P. Wolvaard
An integrated approach for signal validation in dynamic systems
- B.R. Upadhyaya, D.J. Shieh, F.J. Sweeney, O. Glöckler
Analysis of in-core dynamics in pressurized water reactors with application to parameter monitoring
- J. Valko
Integrating noise analysis into reactor monitoring systems
- T.H.J.J. van der Hagen, W.H.M. Nissen, W.J. Oosterkamp, H. van Dam, J.E. Hoogenboom
Application of noise analyses to stability determination of a natural circulation cooled BWR
- T.H.J.J. van der Hagen, J. van der Voet
Interpretation of velocities determined by noise analysis for various void fractions and flow regimes in two-phase flow
- F. van Niekerk, R. Sunder
COMOS - an online system for problem-oriented vibration monitoring

S. Veres, I. Nagy, J. Bokor

Signal effect analysis for noise diagnostics of a nuclear power plant

H.-J. Wehling, R. Warnemünde

Vibration monitoring of light water reactors with advanced methods and the new microprocessor-based SÜS-86 system

G.L. Zigler

Reactor noise standards in the USA

PUBLICATIONS DE L'OCDE, 2, rue André-Pascal, 75775 PARIS CEDEX 16 - N° 71776 1988
IMPRIMÉ EN FRANCE

94030038