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AN OVERVIEW OF SMORN VI-GATLINBURG

A summary of the sixth Symposium on Reactor Noise (SMORN VI)
Gatlinburg, United States, 19-24 May 1991

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AN OVERVIEW OF SMORN VI-GATLINBURG*

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from

Summaries provided by Symposium Session Chairmen

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*Symposium on Nuclear Reactor Surveillance and Diagnostics, held 19-24 May 1991 in Gatlinburg, Tennessee, U.S.A.

Pursuant to article 1 of the Convention signed in Paris on 14th December, 1960, and which came into force on 30th September, 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

- to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;

- to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and

- to contribute to the expansion of world trade on a multilateral, non- discriminatory basis in accordance with international obligations.

The Signatories of the Convention on the OECD are Austria, Belgium, Canada, Denmark, France, the Federal Republic of Germany, Greece, Iceland, Ireland, Italy, Luxemburg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries acceded subsequently to this Convention (the dates are those on which the instruments of accession were deposited): Japan (29th April, 1964), Finland (28th January, 1969), Australia (7th June, 1971) and New Zealand (29th May, 1972).
The Socialist Federal Republic of Yugoslavia takes part in certain work of the OECD (agreement of 28th October, 1961).

The OECD Nuclear Energy Agency (NEA) was established on 20th April, 1972, replacing OECD's European Nuclear Energy Agency (ENEA) on the adhesion of Japan as a full Member.
NEA now groups all the European Member countries of OECD and Australia, Canada, Japan and the United States. The Commission of the European Communities takes part in the work of the Agency.
The primary objectives of NEA are to promote co-operation between its Member governments on the safety and regulatory aspects of nuclear development, and on assessing the future role of nuclear energy as a contributor to economic progreess.
This is achieved by:

- *encouraging harmonisation of governments' regulatory policies and practices in the nuclear field, with particular reference to the safety of nuclear installations, protection of man against ionising radiation and preservation of the environment, radioactive waste management, and nuclear third party liability and insurance;*

- *keeping under review the technical and economic characteristics of nuclear power growth and of the nuclear fuel cycle, and assessing demand and supply for the different phases of the nuclear fuel cycle and the potential future contribution of nuclear power to overall energy demand;*

- *developing exchanges of scientific and technical information on nuclear energy, particularly through participation in common services;*

- *setting up international research and development programmes and undertakings jointly organised and operated by OECD countries.*

In these and related tasks, NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has concluded a Co-operation Agreement, as well as with other international organisations in the nuclear field.

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 whenever 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 aned 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 tasks 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 co-ordination 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.

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SESSION 1:

OPERATIONAL EXPERIENCE WITH SURVEILLANCE AND DIAGNOSTIC SYSTEMS

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In a session entitled operational experience, understandably a considerable variety of experiences were presented. It is possible to see from these the directions in which surveillance and diagnostics (S&D) are going.

Many fundamental methods and analysis approaches have been in existence for some time. Their potential had been envisioned in previous years. But now these are being used on larger scales and given opportunities to prove their potential. The following examples of S&D power are selected as representative from the papers of this session.

- Primary system vibration and anomaly monitoring by signal analyses — extending over many reactor fuel cycles and sites (*Türkcan, Sunder, Por*).
- On-line monitoring with varieties of algorithms at work stations remote from the plant (*Türkcan*).
- Exceptionally thorough understandings of the intricacies of measured PWR spectra in terms of underlying physical phenomena (*Sunder*).
- Low thresholds of detection capabilities, for purposes of giving warnings well in advance of traditional operator monitoring methods (*Mullens, Kanemoto, Sunder, Por*)
- Special algorithms providing immediate alerts of changed conditions for whatever reason (*Mullens, Kanemoto, Por*).
- On-line comparisons of detailed fundamental principles models with plant behaviors— to give alarms and then even diagnostic information (*Poujol, Kanemoto*).
- Signal validation and sensor checking by a variety of methods (Mullens, Por).
- Sensor response time measurement (*Türkcan, Por*).
- Database management system for retrievability of staggering amounts and varieties of S&D signal analysis data (*Kanemoto, Türkcan*).

- Human-factored and ingenious colorful displays for both operations and diagnostic specialists (*Mullens, Kanemoto, Sunder, Por*).

- Practical utilization of tools of artificial intelligence, including pattern recognition and expert systems assistance in diagnostics (*Poujol, Kanemoto, Türkcan*).

Sophisticated signal-processing usages are making substantial inroads into commercial power plants. It can be expected that, over a period of time, specific concrete safety and economic advantages of S&D methods of this conference will accrue. The authors in this session made no attempt at compiling all the particular advantages arising within their own experiences. But a few payoff examples they give may be taken to be representative:

- A main coolant pump shaft crack detected in on-line spectra several months before detection by conventional broad-band amplitude surveillance (*Sunder*).

- Detailed spectral trending accepted as a substitute for a planned inspection of a secondary core support structure (*Sunder*).

- Reduction in minimum noise levels from a neutron detector fault while shut down (*Mullens*).

Beyond these there are implicit safety and economic benefits realized in many items on the longer applications list cited above.

Finally, an observation might be made on the outlook for S&D methods of this conference. There seems to be an underlying force, usually taken for granted, in helping to make possible the advances in research and applications reported: the ever-growing computer hardware and software advances at one's disposal. It might be projected, due to intensive use of such tools in signal analyses and interpretations, that continued computer technological expansion will be a synergistic effect with growing plant S&D needs— leading to a paralleled expansion somewhat in S&D signal analysis applications.

SESSION 2:

BWR STABILITY MONITORING: THEORY AND PRACTICE

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Stability problems of BWRs are as old as BWRs themselves. It was recognized from the beginning that a BWR could become unstable when operating at low pressure. This effect is due to the coupling of reactor kinetics and thermal hydraulics via the reactivity feedback of the void production. The stability problem ceased with increase of the vessel pressure. Nonetheless, a renewed interest in BWR stability arose a few years ago after some incidents and further research at several BWRs in which large power oscillations occurred (known as limit cycles) when the circulation flow through the core was reduced. As a result, a certain region of the power-flow map, which is determined experimentally in some power plants, has to be avoided or the stability of the reactor has to be monitored when operating in this region. During instability the amplitude of the power oscillation grows but is finally limited by the strongly nonlinear behavior of the reactor system. The occurrence of such oscillations is, of course, of direct importance to reactor safety. The growing interest in this subject was also reflected in the Workshop on BWR Stability held in Holtsville, N.Y., in October 1990. An accurate description of this phenomenon, especially the exact circumstances leading to such an unstable situation and the role of reactor noise as a driving force, turns out to be very complicated. A so-called reduced-order model proposed by *March-Leuba* and consisting of five partially nonlinear differential equations is capable of describing the phenomenon of limit cycle oscillations and is used by several authors for further investigation. However, it cannot describe the noise features of the signals.

Blázquez used this model to connect the parameters from an ARMA model of the appropriate order of the measured APRM signal to physical parameters, which can be monitored to detect changes in the stability of the reactor. The parameters are obtained using the Dynamic Data System technique, which calculates the poles of the reactivity-to-power transfer function. From these also the decay ratio (DR) of the impulse response is calculated, which is a widely accepted parameter for stability monitoring. Using the prompt jump approximation, the author introduces further reduction of the theoretical model and, accordingly, the ARMA model order.

Konno took a more fundamental theoretical starting point to describe the processes in a BWR by considering a nonlinear stochastic theory for reactor dynamics. Features like self-excitation and multiple-mode oscillations are demonstrated for a mathematical model of two coupled, nonlinear oscillators with slightly different resonance frequencies. Space-dependence is introduced by considering a one-dimensional time-dependent diffusion equation with nonlinear feedback and assuming a stochastic reactivity noise source. With this model the noise suppression noted in Japanese BWRs can be illustrated. A further extension of the theoretical model to 2-D diffusion theory with point temperature feedback results in spatial modes that can be related to observations in different BWRs. Finally, a model based on the nonlinear Van der Pol oscillator is suggested to derive parameters like the decay ratio, which can also be used in case of limit cycle oscillations.

From Eurosim, Sweden, two papers were presented. *Åkerhielm* discussed the analysis of measurements on different Swedish BWRs. Univariate and multivariate AR analyses are applied to APRM and LPRM signals. Limit-cycle oscillations were observed at the Forsmark-1 NPP, showing a resonance peak at 0.5 Hz and a growing peak at double frequency during the growth of the oscillation amplitude. Decomposition techniques were applied, leading to the conclusion that the poor stability is a core resonance phenomenon. However, from a general model such as AR no basic physical causes can be identified. From different measurements it was noted that the fuel type (8x8 or 9x9) as well as burnup and the axial power distribution all influence stability. Furthermore, clear space-dependent effects were noticed, showing phase changes with position. The use of LPRMs instead of APRMs is therefore to be recommended for better monitoring of the core stability, since the oscillations in the APRM signal will be partially damped due to phase differences among the various LPRMs.

Lorenzen showed results obtained with a PC-based on-line stability monitor system called SIMON. This system calculates the value of the decay ratio as a function of time. It is intended for routine use in NPPs, and therefore much effort was spent to improve the accuracy of the estimated DR and its robustness against different reactor operating conditions and power transients. These features were demonstrated for benchmark tests with simulated signals, which include step changes in the signal characteristics determining the DR. Its response time to step changes in DR is well below 1 min. Moreover, it has prognostic capabilities for limit cycle behavior 20 to 30 s before onset. Operational experience is now being gathered at the Oskarshamm NPP.

The last presentation in this session, by *Kitamura*, had a wider scope and described a methodology for signal analysis that improves diagnostic and prognostic capabilities. For system identification the MAR method is used with a special form of signal path transmission (SPT) analysis. To separate disturbances from the stationary part of the signals, a nonlinear filter is introduced which calculates the median value over a number of samples. This filter responds faster to sudden changes. The difference signal satisfies the stationarity requirement for the STP analysis of the noise. A next improvement is in the causal identification of the system, using *a priori* knowledge of the system dynamics and considering different plausible causal structures by systematically including and excluding signals in a multivariate analysis. By combined use of the model and the trend diagram of the noise signatures, predictive information can be obtained (power spectra, coherences, etc.). The method was demonstrated with simulated signals, focusing on monitoring the performance of the feedwater control system. It was remarked that such frequency-domain STP analysis should be accompanied by time-domain analysis, since certain anomalies are more effectively detected though time-domain analysis.

Putting the papers of this session into perspective, there appears to be a wide gap between theory and practice. Progress has been made on both sides. Practioners can very well determine important parameters (like the decay ratio) for stability monitoring from general signal modeling techniques, sometimes supported by a simple physical model. Such methods can be made robust for routine application in power plants and can alert the operator if reactor operation is evolving to a less stable situation. However, limits to parameters that are monitored must be set in advance on a rather arbitrary basis. No generally accepted rules are available for determining those limits for a specific reactor. Nor can it be predicted under which precise circumstances instability will occur. Operational experience will ultimately show whether such systems will really be accepted in the control room as an aid to achieving safe operation of a reactor. From the theoretical side there is progress in exploring models with which to explain basic phenomena observed in BWRs. However, dealing with such models becomes mathematically more and more complex. In this respect, I may also refer to the Workshop on Noise and Nonlinear Phenomena in Nuclear Systems, held in Valencia, Spain, in 1988. Further work on nonlinear stochastics – including space dependence – will be necessary to arrive eventually at an applicable description of the essential processes describing stability-related phenomena in a BWR. Much work in this field is originating in Japan. However, it will probably be a long road before details like axial power distribution, fuel burnup, and fuel type can be adequately incorporated. Nonetheless, the gap between theory and practice must be bridged. On the one hand, we can include more physics in the signal analysis methods, of which several authors in this session already showed examples. On the other hand, we can make more fundamental but very complex theoretical models better understandable for practioners.

SESSION 3:

LEAK AND BOILING DETECTION IN FAST REACTORS

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This was the only session that addressed the subject of early diagnosis of anomalies specific to LMFBRs, such as in-sodium small water leaks in steam generators and sodium boiling within fuel subassemblies.

The presentations recalled that passive acoustic detection is the reference technique for both types of anomaly, so that to some extent the problems are also similar. One problem is that, in general, only the acoustic signature in non-upset operating conditions can be taken for the core and for full-size steam generators, which means that the modeling of the diagnostic process must pretty much rely on small-scale experiments, on measurements in different media and geometries, or on numerical simulations. Another major problem is the high environmental acoustic background existing in fast reactor power plants, which means that it is necessary to use advanced signal processing techniques to improve the likelihood of detecting anomalies in situations where the rms signal-to-noise ratio is very low.

The paper by *Voss et al.* on leak detection outlines the four-year R&D program jointly defined by AEA Technologies, CEA, and Interatom to support the design of a high-performance, safety-related ALD system for the European Fast Reactor (EFR) project. This comprehensive program includes a large number of passive acoustic measurements in power plants, mock-up loops, and laboratory rigs; furthermore, the potential of active acoustic transmission, a method that has given encouraging results in preliminary tests, will be investigated. By pursuing the combined development of the two techniques, the participating organizations aim at the stringent requirement targets that have been set for the system performance in terms of leak rate sensitivity ($\geq$1 g/s), detection time ($\approx$1 s), unavailability ($<10^{-3}$), and spurious trip rate (<1/reactor-year).

The paper on boiling detection by *Thomas et al.* outlines the acoustic monitoring system installed on the Dounreay PFR and illustrates some results obtained from measurements performed to characterize the acoustic signature of the PFR core. These results show the presence of a randomly occurring impulsive activity in the core background noise, a finding that greatly complicates the task of reliably discriminating the pulses due to hypothetical sodium boiling events. However, the paper also shows how the application of pattern recognition and source location techniques in the signal analysis enabled the authors to isolate and identify virtually all the impulsive components of the background. In this context, it is worth noting that the enhancement of sodium boiling pulse discrimination capability, apparently obtainable by using selected statistical features in the pattern recognition analysis of benchmark data, is also the subject of a paper by *Singh et al.* (not presented orally at the conference).

The picture of acoustic detections in FBRs emerging from this session is that of an area showing great progress, where the research and development aspects still predominate over the pressure for industrial applications. This is consistent with the large amount of R&D work that seems necessary to translate today's performance targets into equipment specifications at the quality level required for safety-related systems suitable for installation in commercial LMFBR plants.

SESSION 4:

MODELING AND MONITORING THE MOTION OF PWR AND BWR STRUCTURES

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This session and the conference as a whole have clearly demonstrated that vibration monitoring of mechanical structures in nuclear power plants based on vibration, neutron noise, and dynamic pressure signals has reached a well-developed state with respect to understanding the physical phenomena used for feature monitoring as well as signal analysis methods and monitoring systems installed in the plants. Vibration monitoring of reactor internals and primary circuit components has become— next to loose parts and acoustic monitoring— the most widely applied method for early fault/degradation monitoring in PWRs.

In Session 4, seven outstanding papers from Argentina, Czechoslovakia, U.S.A., Hungary, and France have been presented (and at least seven additional papers in other sessions), in which modeling and monitoring of structural motions were described for quite different nuclear power plant types such as: PHWR-320 MW, WWER-440 (and 1000) MW, Westinghouse 1200-MW PWR, Framatome 900- and 1300-MW 3- and 4-loop PWRs with and without thermal shields, and (outside this session) 2-loop PWR Borsselle, Siemens/KWU 900- and 1300-MW PWRs, Koeberg 900-MW PWRs and Chinese PWRs.

The variety of plants proves that vibration monitoring is a generally applicable surveillance technique and is well established in PWRs. It is surprising that for BWRs no vibration monitoring programs have been realized: there was just one poster presentation reporting on flow-induced vibration of in-core instrumentation tubes in a German BWR similar to earlier findings in the U.S. BWRs in the seventies.

Rather than going through the particular papers and repeating the various abstracts, I should like to summarize the main points of the session in a more generalized form. However, before doing that, I want to remind you of the particular speakers by mentioning the highlights of their presentations.

Laggiard (Argentina) reported on a neutron noise monitoring program at the PHWR Atucha I, established as required by the plant management and the licensing authority when a fuel assembly rupture led to strong neutron flux fluctuations.

Vavrin (Czechoslovakia) discussed the results of a single-degree-of-freedom structural model for core barrel impact oscillations in a WWER-440 as a basis for coolant pressure and steam generator vibration spectra interpretation.

Presnell (U.S.A.) reported on an ex-core neutron noise analysis program at the two units of the McGuire NPP. Classical as well as "unusual" coherence and phase behavior have been detected during different fuel cycles. The influence of a higher mode of fuel assembly vibration is supposed to be an essential signal source with changing intensity.

Wood (U.S.A.) presented a model and analysis results for PWR ex-core neutron noise signals: a thermal-hydraulic model for the lower frequencies (below 1 Hz), and a mechanical motion model for the higher frequencies. Discriminant monitoring was applied to available stored data.

Kozlosky (U.S.A.) presented a new vibration monitoring system for reactor internals designed to address the standards and guidelines provided by EPRI and ASME/ANSI.

Hollo (Hungary) reported on a model development for the loop component vibrations at the PAKS NPP and described an advanced vibration monitoring system.

Trenty (France) described the system SINBAD used in France as a data base for handling and interpreting neutron noise and vibration spectra in 54 plants. Detailed interpretation of spectral components and several long-term feature trends were discussed.

In all of the papers, interpretation of the different peaks in the frequency spectra played an important role. Peak identification has been performed by means of more or less comprehensive model developments and investigations (at least by means of the results of pre-operational in-core vibration analyses). A reliable spectral interpretation is seen as an important prerequisite for the establishment of a vibration monitoring program and practice-oriented fault diagnoses.

Although there are many different plant-specific signatures found in the various plants, in principle, however, very often quite similar phenomena could be identified -- such as core barrel beam mode motion, fuel assembly eigenfrequencies (first and higher modes) with clamped or flexible support conditions, core barrel shell mode vibrations, and reactor vessel vertical vibrations.

Many plants show characteristic time-variant signatures over the fuel cycle or in the long term. Very often, relaxation of spacer grids in the fuel assemblies has been found as the cause for the changes; however, the signature changes are not fully understood in all cases. Feature trending (for instance, peak trending of relevant features) seems to be a useful tool for monitoring and cause identification. Though not a new observation, it became evident during this symposium that there is a strong desire to introduce more and more computerized systems on site to facilitate data handling, feature monitoring, and automated signal analysis. Advanced systems from France, Hungary, and the U.S.A. have been reported in this session, and in other sessions, systems from Germany, South Africa, and the Netherlands.

Vibration monitoring programs are in some cases required by the licensing authorities, especially if mechanical problems of internals or fuel assemblies have been detected. An example was given in the paper of Argentina. Other examples could be baffle jetting due to gaps in the core liner caused by bolt cracks, shaft cracks in the main reactor coolant pumps, and thermal shield degradation.

In most cases, however, it is the intention of the utilities to use vibration/neutron noise monitoring on their own accord as a predictive maintenance tool. Collection of data to detect aging phenomena and to provide a data base for structural integrity assessment is another important aspect of the overall motivation for applying vibration monitoring systems to NPPs.

During the conference we were informed that in the U.S.A. standards and guidelines are either available or are in preparation. I can add that this also holds for Germany.

In this context I should also like to address one aspect that I believe is very important for future development: vibration monitoring is a useful tool for integrity assessment, but we should never forget that it provides an *early warning* of developing faults. The users of such systems (namely, the plant operators) should never be forced to treat the detection of the beginning of an abnormal behavior as if it were a safety issue (i.e., be forced to give an immediate report to the licensing authorities). Such a requirement would inevitably lead to a negative attitude on the part of the utilities and would hinder further and broader application of vibration monitoring. As long as the information provided by vibration monitoring systems can be used for the optimization of plant operation, it serves in the best way also to enhance the safety of the plant. Early fault diagnostic methods will be used more generally also for other monitoring tasks in equipment or components, and in this way will contribute materially to further improvement of the operational safety of nuclear power plants.

SESSION 5:

SURVEILLANCE AND DIAGNOSTIC ISSUES/VIEWPOINTS - OPEN FORUM

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Session 5 consisted of two parts: Session 5A, Surveillance and Diagnostic Issues/Viewpoints, at which four formal papers were presented, and Session 5B, an Open Forum, where five individuals gave extemporaneous presentations on topics that were pertinent to the theme of the conference.

Session 5A: SURVEILLANCE AND DIAGNOSTIC ISSUES/VIEWPOINTS

The first paper, entitled "IAEA Activities on Nuclear Reactor Diagnostics" by *P. Dastidar, A. Kossilov, V. Arkhipov,* and *L. Ianko* described how IAEA activities in nuclear power technology promote technical information exchange between member states having major development programs, offer assistance to member states having an interest in exploratory or research programs, and publish reports that are available to all member states interested in the current status of development. The activities planned by the groups include technical information exchange meetings of several kinds, such as specialist meetings on selected developmental areas and technical committee meetings and symposia open for general participation. Such meetings provide opportunities for users, regulators, developers, and designers to become more aware of worldwide developments, and they enable other nations with an interest in using nuclear power in the future to learn about and gain a better understanding of the new directions being taken.

Nuclear reactor surveillance and safety-related applications are major IAEA activities. Such topics are dealt with in meetings of the International Working Groups on "Nuclear Power Plant Control and Instrumentation," "Reliability of Reactor Pressure Components," and "Fast Reactors." The first research program on "Signal Processing for Boiling Noise Detection" has led to development of a number of advanced processing techniques which were shown to perform satisfactorily in terms of sensitivity and low rate of spurious trips in tests on data from the BOR-60 reactor. The goal is now to apply this technique to related problems of acoustic detection of leaks in steam generators.

For most nuclear power plant components, there is a need to understand and quantify degradation processes of reactor structures, systems, and components and to manage these processes. In 1989, a report on "Aging Mechanisms of Reactor Key Components and Its Monitoring" was prepared covering current studies, aging mechanisms, monitoring methods, and assessment of specific components.

The second paper was "ASME Reactor Standards Using Noise Techniques" by *Gilbert Zigler*. It described the emphasis placed on the operation and maintenance aspects of nuclear power plants in recent years and the activities of the Operations and Maintenance (O&M) Committee of the ASME in identifying, developing, maintaining, and reviewing codes and standards that are considered necessary for the safe and efficient operation and maintenance of nuclear power plants, particularly as related to structural and functional adequacy. The importance and maturation of the field of reactor noise resulted in the publication in 1981 of O&M Part 5 standard on monitoring core barrel motion in a pressurized water reactor using neutron noise techniques. O&M Part 5 was revised and updated in 1989 to reflect current developments in the interpretation of neutron noise. O&M Part 12, a standard on loose-part monitoring, was approved by the Board of Nuclear Codes and Standards in 1990. Other standards using noise techniques, such as the one for a more comprehensive reactor internals monitoring program using neutron noise techniques and another one for check valve monitoring using acoustical techniques, are currently under consideration. *Zigler* went on to discuss the major elements of the updated version of ASME O&M Part 5 and ASME O&M Part 12 and compare it to the current NRC Regulatory Guide 1.133. He concluded with a brief discussion of new O&M standards using reactor noise techniques that are under consideration.

The third paper, entitled "Effectiveness of Neutron Noise and Loose Parts Monitoring Methods in Aging Management for Reactor Relicensing" by *G. Zigler*, *R. Knudson*, *F. Sciacca*, and *R. Walsh* reviewed neutron noise and related monitoring techniques fit into an enhanced inspection, surveillance, test, and monitoring (ISTM) program for ensuring relicensing of nuclear power plants. Several ISTM activities based on reactor noise techniques were suggested, and each ISTM activity was discussed in terms of its quantitative contribution to reducing plant risks.

Two reactor noise-based ISTM activities shown to contribute significantly to a comprehensive aging management program were (1) implementation of a reactor internals vibration monitoring program in accordance with ANSI/ASME O&M Part 5, and (2) implementation of a reactor internals vibration monitoring program in accordance with an early draft of ANSI/ASME Part 12. The methodology developed for evaluating the effectiveness of ISTM activities was reviewed and a comparison of the effectiveness of neutron noise and loose-part monitoring based ISTM programs with other methods was presented.

The fourth paper was "PSAD, an Integrated Tool for Global Vibratory and Acoustic Surveillance of EDF Nuclear Plants in the Near Future" by *J. M. Mazalerat*, *J. Morel*, *C. Puyal*, *B. Monnier*, *G. Zwingelstein*, and *P. Legaud*. EDF has designed, installed, and implemented on-line monitoring systems for the nuclear steam supply system and the turbo-generator of each of its nuclear units. In pursuing new techniques and technologies in the fields of signal acquisition/processing and artificial intelligence, EDF has decided to integrate its current on-line monitoring systems into an integrated on-line monitoring and aid to diagnosis station called PSAD. In its first phase, PSAD will be devoted to the on-line monitoring and diagnosis of the main components in nuclear power plants such as main reactor coolant pumps, loose parts, and turbo-generators. PSAD will offer plant operators aid in diagnostics, in a user-friendly way, and will facilitate communications with the national experts and even with the different specialists on site. It will use a flexible architecture and state-of-the-art technology in computing, acquisition, networks, and artificial intelligence. PSAD is to become the cornerstone of the surveillance and maintenance program for EDF in the coming decades. The objectives of the project and the description of the developments now in progress, with special emphasis on two expert systems -- DIVA for rotating machines and MIGRE for loose parts -- were presented.

Session 5B: AN OPEN FORUM

The following individuals gave presentations on the topics summarized below:

R. B. Perez, University of Tennessee (Coauthor, *Carlos March-Leuba*), gave a presentation on the "Use of Wavelets in Processing Noise Data." The theory of the application of wavelets to data processing was developed and illustrated by two examples. Wavelets are sets of eigenfunctions of compact support.

The advantage of using wavelets is that doing so preserves the time when incidents occur, which would otherwise be "smoothed" by more customary data processing. In one test example, two pulses separated by a time period equal to the pulse width at the base was corrupted with 50% noise. When the data were processed using wavelets, the unique shape of the wave was preserved. In the other example the same signals were corrupted with 100% noise, and the wavelet method of processing still preserved the general features of the waveform. Wavelets appear to be excellent tools for signal and image representation and compression and provide time-dependent PSDs.

Kenneth Serdula (Serdula Consultants Ltd.) gave a presentation entitled "Role of Noise Analysis in Monitoring Detector Aging." There is concern regarding the change of the response characteristics of detectors as a result of radiation exposure and aging in general. For detectors sensitive to both neutrons and gammas, the neutron sensitivity can change with irradiation while the gamma sensitivity remains constant. This can result in changes not only in the detector's total sensitivity, but potentially in the detector's dynamic response as well. In some cases, the detector's "burnup" products can interact further with the neutron flux, contributing also to a change in the detector's response characteristics. Present techniques used to establish the compensation required to eliminate undesirable effects of these changes do not have the inherent advantages offered by noise analysis. *Serdula* posed a challenge to the audience to utilize noise analysis to establish accurately the extent of these potential changes.

Philip Thomas of Risley Laboratory of AEA Technologies made a presentation on "On-Line Corrosion Monitoring based on Ultrasonic Principles." An ultrasonic probe capable of operating in environments up to 600°C was encased in a special capsule that could be welded to a pipe or vessel wall. Measurements taken during the welding of the probe show how unwanted reflections were eliminated as successive layers of weld were applied, leaving the reflection from the inside of the pipe (or vessel) as the principal reflection, thereby indicating the thickness of the wall. As corrosion reduced the thickness of the wall, this probe was capable of detecting the thinning.

Ed Ford of Oak Ridge National Laboratory (Coauthor, *Carlos March-Leuba*) gave a presentation on "GOOSE: Generalized Object Oriented Simulation Evaluation." This computer program is truly object oriented and utilizes public domain and low-cost software programs to the maximum extent possible. It had a graphical interface that presents information in pictorial fashion on the SUN SPARC workstations operating under UNIX. GOOSE can be ported to a personal computer with a minimum of difficulty. It is considered to be a substitute for other commercial simulation languages, and it is said to be superior to ACSL and much less expensive and more flexible than Modular Modeling Systems because of the object-oriented features that permit objects to be interconnected in any arbitrary fashion using simple connecting statements.

Evren Eryurek of the University of Tennessee (Coauthor, *B. R. Upadhyaya*) gave a presentation on "Use of Neural Networks for Signal Validation and Nuclear Power Plant Monitoring." He described how a part of EBR-2 and a 4-loop PWR were modeled with a neural network using three input variables (there could have been many more) to predict a fourth variable. The neural network was trained when all sensors were known to be working properly. The actual output of each sensor was compared with the corresponding predicted value from the neural network, and excellent agreement was found. However, when a sensor deteriorated or was damaged, the actual output and the predicted value deviated, indicating that one of the sensors was malfunctioning. Similar modeling using all but one input variable enabled the operator to determine whether the omitted input variable was valid. By a process of elimination, the faulty detector could be identified.

A similar procedure using the same variables as inputs and outputs was used for monitoring nuclear power plants. Again, the neural network was trained over the pertinent range of operation when all sensors and the plant were known to be operating properly. Then when a sensor or a system failed, the predicted variable deviated from the actual value, thereby providing a means of detecting the failure.

SESSION 6:

ADVANCES IN SIGNAL PROCESSING METHODS

M. Kitamura
Tohoku University, Sendai, Japan

Reflecting the title, most of the eight papers presented in this session reported newly developed or introduced methods and techniques of signal processing. One important paper describing evaluation of autoregressive (AR) modeling was also presented.

The paper by *Kishida* reported, on the basis of his several preceding papers, a new procedure for obtaining the zeros of an autoregressive moving average (ARMA) model. Since the zeros are known to have considerable influence on the accuracy and credibility of the conventional AR modeling, the author suggests use of the proposed method as a supplementary procedure of ensuring validity of the AR analysis. The importance of what he calls a "data-oriented innovation model" in conjunction with dependable system identification was described through numerical experiments. It is the session chairman's opinion that the usefulness of the method could be made much clearer by applying it to real power reactor noise.

The next three papers are related to analysis of nonlinear reactor noise. *Hayashi*, *Shinohara*, and *Konno* proposed utilization of a method called GMDH (Group Method for Data Handling), which is basically a multilayered perceptron-like modeling technique. The advantage of the GMDH over the conventional AR modeling was demonstrated by applying the method to time series data obtained from a simplified nonlinear model of a boiling water reactor.

The paper by *Kuroda* and *Miyamoto* discussed the methodology for resolving difficulties in handling a chaotic signal disturbed by a stochastic fluctuation component. Use of three measures— correlation dimension, maximum Lyapunov exponent, and q-order Lyapunov exponent— was proposed as means by which to detect a chaotic signal. The usefulness of the method was examined through analysis of transient data of the Borssele reactor. *Suzudo* and *Hayashi* applied a similar technique to signals from a research reactor. Two descriptors, fractal dimension and the maximum Lyapunov exponent, were estimated for signals measured by instrumentation of the NSRR (Nuclear Safety Research Reactor) at JAERI. Existence of a chaotic component was successfully detected in terms of the two descriptors.

These results clearly illustrated the possibility of detecting the existence of nonlinear processes. Apart from physical and theoretical interest, however, the technical and safety implications of these methods are as yet unclear. Extensive comparisons of the methods with conventional techniques in more practical problems are recommended for future studies.

One of the more important applications of reactor noise analysis has been, and will continue to be, on-line anomaly detection. To meet this need, *Ciftcioglu* and *Türkcan* proposed a failure detection algorithm called Kalman filtering methodology with adaptive lattice modeling. The lattice parameters estimated recursively by a PARCOR (Partial Correlation) prediction filter algorithm were subsequently processed by a Kalman filter to obtain the minimum variance estimate of the parameter values.

Performance of the failure detection method was examined via application to Borssele reactor signals. Further modification of the method to incorporate SPRT (Sequential Probability Ratio Testing) was reported by *Ciftcioglu*. By applying the method to the benchmark test data adopted at SMORN V, he showed that the method is sensitive to both fast and slow anomalies in their incipient stages. The sensitivity is, however, certainly dependent on the adjustable parameters in the SPRT algorithm. Further studies are needed before implementation of the failure detection scheme in an automatic operational mode is practical.

The treatment of uncertainty is a difficulty common to failure detection based on noise analysis or other means. *Ding* and *Wach* proposed the application of "fuzzy logic" to this problem. The study focused on the feasibility of using fuzzy rather than standard statistical techniques to handle uncertainty relevant to human expert cognition. The authors indicated that fuzzy logic can be a promising way to future diagnosis using knowledge engineering. The session chairman likewise believes that the use of fuzzy methodology can reduce considerably the difficulty of expert system development. It should be stated, however, that validation and verification of the expert system would be more difficult in a fuzzy framework; thus, caution must be exercised.

It is obvious that development of new techniques, as presented in the papers of this session, is desirable for enhancing our capability to monitor and diagnose the condition of a plant. However, it is also obvious that the proposed techniques need to be evaluated carefully prior to field application. The activity reported by *Hoogenboom* is highly important and appreciated in this regard. Through careful examination of the results contributed in SMORN V, he found that the quality of analyses was much improved compared to pre-SMORN V counterparts. The causes of interparticipant discrepancy were, to some extent, clarified. However, additional studies are needed regarding the estimation of physical parameters and transfer functions. The need for study of false alarm rate management was also addressed in *Hoogenboom's* paper.

The overall session indicated that development of new methods of signal processing and characterization is quite active within this scientific assembly, despite the general slow-down of the nuclear industry. In conclusion, it would be appropriate to state that balanced pursuit of the two activities reported in this session— methodology development and credibility evaluation — is an indispensable driving force for achieving higher reliability, operability, and safety of nuclear power plants.

SESSION 7:

PARAMETER ESTIMATION TECHNIQUES

K. Behringer
P. Scherrer Institute, Würenlingen, Switzerland

The parameter estimation techniques discussed in this session, and which also appeared in other sessions, apply to safety-related subjects. They refer to kinetic or dynamic parameter determinations in models for code verification, but also, as the present trend, for surveillance in combination with on-line monitoring. The session included seven papers.

There were two presentations related to the determination of the moderator temperature coefficient of reactivity (MTC) in PWRs by noise methods. It is well known that the MTC can be obtained by cross-correlating the incore neutron noise with the core-exit temperature fluctuations. The work presented by *Thomas* and *Clem* is concerned with improvements in signal analysis using time-domain methods and autoregressive modeling instead of the usual FFT techniques in the frequency domain. It was stated that the MTC can be estimated accurately from a 10-min data record, as opposed to the requirement of a 3-hour data record when frequency-domain methods are used. The MTC results obtained at the McGuire Unit 2 PWR show excellent agreement between the parametrically and nonparametrically estimated values and design predictions as functions of fuel burnup.

In the paper by *Kostic*, *Husemann*, *Runkel*, *Stegemann*, and *Kahlstatt*, linear relationships between the normalized root mean square (NRMS) values of the neutron noise in the low-frequency range and the boron concentration have been determined experimentally at the 1350-MWe Grohnde PWR. It has also been proven experimentally that there is good linear correlation between the NRMS value of the neutron noise and fuel burnup. A simple procedure to evaluate the MTC for some practical cases as a function of the neutron NRMS has been verified using actual data.

In the 183-MWth Dodewaard BWR the recirculation flow is driven by natural convection; coolant flow is not directly controllable. *Stekelenburg*, *van der Hagen*, and *Nissen* reported novel downcomer flow studies that were conducted to determine the coolant flow rate through the core at several different operating conditions by analysis of downcomer thermocouple noise. A clear transit time was found to be present between the signals from two axially displaced thermocouples. The transit time estimator and the applied prewhitening procedure used are of special interest. Turbulent-flow computer simulations are described for linking the measured transit time to the total downcomer flow rate.

The interpretation of coolant flow velocities measured by cross-correlating the signals from two axially displaced in-core neutron detectors in BWRs is an old problem, in particular with respect to the appearance of the "second transit time" effect in the upper part of the core. In the paper by *Kozma* a further theoretical contribution to this problem is given, based partially on models used previously. However, in such model calculations many assumptions and parameters are unknown and values must be attributed. In the session chairman's opinion, the solution of this problem requires experimental investigations; in particular, experiments performed on a well-instrumented BWR bundle, which would be a very expensive task.

Decay ratio (DR) measurements are a part of stability analyses performed at BWRs. *Por, Runkel,* and *Stegemann* presented a new application to PWRs that could be suitable for on-line use. The investigations were made on ex-core neutron detector signals at the 1300-MWe Grohnde PWR. A modified (simplified) DR ("mDR") was estimated from the pulse response function extracted using univariate autoregression analysis with fixed model order (20) and fixed sample length (1024 data points). It was concluded that the estimated mDR characterizes the oscillatory power response to temperature input fluctuations and consequently can be used to monitor the stability state of a PWR.

Jujuratisbela, Arbie, Siswiyanto, Pinem, and *Singh* reported in their paper several research and development activities in the reactor noise field that have been done or are provided on the Indonesian 30-MWth Serba Guna swimming pool reactor, which was commissioned in 1987.

Morita, Tokura, Tokunaga, and *Tamura* presented a study of the fluctuating mechanisms causing water level increase in the containment vessel sump of a Japanese PWR. Multivariate autoregression analysis of various process signals is used to establish a cause-and-effect tree, which should enable one to distinguish the contribution of abnormal reactor coolant leakage from the sump water level fluctuation occurring in normal reactor operation. This work is an interesting new application of noise analysis.

SESSION 8:

POSTER PRESENTATIONS

O. Glöckler
CRIP, Budapest, Hungary

In this session eleven papers were presented. They covered a wide variety of theoretical and application-oriented work, ranging from recursive ARMA modeling to vibration and loose-part monitoring in nuclear power plants.

Blázquez and *Barrio* developed a recursive algorithm for determining the MA parameters of univariate ARMA models. The AR part is calculated by the Yule-Walker equations using higher order correlation values, while the MA part is solved by an iterative algorithm based on the parameters of lower order MA models. The effectiveness of the method was demonstrated in a numerical test. The multivariate version of the algorithm is under development.

The paper by *Du et al.* described a research project aimed at adapting neutron noise diagnostic methods in nuclear power plants. The project also includes the development of a computer-based 16-channel data acquisition and signal processing system. Specially designed experiments were performed in a research reactor in order to test the data acquisition system and study the response of the neutron noise field to artificially introduced noise sources such as vibrating core internals and localized boiling of coolant.

Kantrowitz presented an algorithm based on Kalman filtering that converts the delayed response of a rhodium self-powered neutron detector into a prompt-responding signal by reconstructing the dynamic signal sensed by the detector from the prompt and delayed signal components. In order to apply the Kalman filter technique, knowledge of the detector state equations and the measurement equation, which relates the detector state variables to the measured response, is required. By comparing the performance of the Kalman filter technique to that of the so-called direct inversion dynamic compensation filter (currently employed in CE plants), the author concluded that the Kalman filter technique provided superior response characteristics.

The paper by *Pentecost* and *Weir* described the ECAD (electronic characterization and diagnostics) test system and its utilization at the San Onofre Nuclear Generating Station. The ECAD approach is based on a combination of direct current and radio-frequency testing techniques, and can identify circuit parameters and pinpoint locations of circuit degradation. Selected case histories of problems that have been solved with ECAD were discussed in the paper.

Husemann et al. discussed the results of noise analysis of signals from the standard instrumentation of the 1300-MW Gundremmingen BWR power plant. Noise signals of in-core neutron detectors, reactor pressure sensors, steam rate meters, accelerometers, and absolute displacement transducers have been recorded and analyzed at various power levels. The authors concluded that it was possible to monitor mechanical vibrations of certain components of BWR plants—such as fuel bundles, instrumentation strings, fuel channel boxes, and the pressure vessel—by using in-core neutron noise analysis.

The paper by *Morris et al.* described the investigation of the failure of the main steam check valves at Unit 1 of the Sequoyah Nuclear Power Plant. Failures resulting from fatigue fracture were found in three of the four main steam check valves. A subsequent program for monitoring and trending check valves, based on conventional acoustic and loose-part monitoring techniques, has been implemented. The primary goals of the monitoring program are to detect catastrophic failure of the valve internals, to identify and trend parameters related to valve internals degradation, and to provide guidance for periodic valve inspection.

Morel and *Puyal* described the on-line acoustic monitoring and loose-part diagnostic systems installed at the 900- and 1300-MW units of EDF nuclear power plants. The paper reviewed the experience gained on more than 50 loose-part monitoring systems put into operation in recent years. Loose-part incidents detected by the DEVIANT systems at the 900-MW EDF reactors and by the IDEAL systems at the 1300-MW plants were discussed in the paper. Concepts of new integrated loose-part monitoring systems were also presented.

The paper by *van Niekerk et al.* described an upgraded version of a multichannel on-line noise analysis system installed at the Koeberg nuclear power plant. Noise signals from ex-core neutron detectors and vibration sensors mounted on the pressure vessel, the main coolant pumps, and the turbines were used to monitor vibrating components. The surveillance system is capable of sampling 112 channels and generating the FFT-based APSD, CPSD, and coherence functions of software-selectable signal pairs. Results obtained in the past 6 years are summarized. A proposed surveillance scheme, which makes use of *a priori* knowledge of the monitored system and measured frequency features processed by pattern recognition techniques, was also described.

Pitchkov discussed the use of acoustic emission systems for diagnosing reactor vessel structures. First, some general principles of acoustic emission were discussed, then the structure of the acoustic emission diagnostic systems currently used at some of the nuclear power plants in the USSR was described.

Pavelko described a hierarchy of neutron-temperature noise models of pressurized water reactor cores which can be used for interpreting noise measurements and extracting operating parameters such as coolant temperature coefficient of reactivity and heat transfer coefficients.

Türkcan presented a graphically enhanced real-time data acquisition system that is menu-based, real-time, and can accommodate four signal channels. The hardware includes a 4-channel signal conditioning unit, an A/D converter, and a PC/AT. The system is used for both time-domain and frequency-domain analyses.

SESSION 9:

APPLICATION OF NEURAL NETWORKS AND PATTERN RECOGNITION

J.-P. Girard
CEA - Cadarache, France

Session 9 was mainly devoted to neural network applications for nuclear engineering and NPP surveillance and diagnosis. Papers presented by *Shabalin* and *Nagy* also reported developments of advanced monitoring systems for NPP noise signal surveillance. As the neural networks concerned are a new tool, not specific to nuclear engineering, only general advantages or problems in their applications were discussed.

A neural network (NN) is a computer model of the human brain, including neurons linked by synapses. Such NNs are able to perform rough *recognition of situations* or *calculations*. They act as a "black box," handling inputs and outputs. They are trained or "tuned" by known sets of input/outputs.

These techniques are now available because of the latest mathematical demonstrations and the size of computers. Not all the theory is available to date, and, as we don't yet have much experience, we must assume these techniques as being *under evaluation* for nuclear engineering applications. I will now summarize the main features of NNs, their potential applications, and the areas where we should be careful before using them on-line.

The main features of neural networks are as follows. They are (1) easier to use than physical or mathematical models or adjustment techniques. "Easier" means they will require less memory, will run faster, and could be cheaper to develop in terms of manpower. Parallel computers might even allow far faster NN response. (2) They are tolerant, which today is something that has great significance in safety analysis. "Tolerant" means they can accommodate inputs disturbed by noise or even work with "missing" inputs, and also could give a reasonably good answer even if slightly "injured." (3) They are easily updatable with time.

The applications of NNs as presented in this session could be divided into two main domains:

Classification Problems such as pattern analysis.

A paper by *Alguindigue* demonstrated the use of neural networks in vibration monitoring; another by *Korsah* treated neutron power spectra. In this type of problem the neural network is taught either after standard pattern recognition analysis or by using experts to solve the input data. Then the system will be able to recognize patterns even if noise alters the inputs.

Identification Problems is the other field of applications that was discussed.

A neural network will this time replace a sophisticated set of equations, either after an on-site learning process or by first applying a mathematical or physical code.

Fitting NN transfer function on code calculation output has been demonstrated by *Martinelli*, on spectra by *Miller*, and on feedback parameters from power plants by *Glöckler*.

In this type of application the neural network is used as a convenient, cheap, and fast black box to deliver a pretaught output on sets of inputs – it could be used in real time.

Other applications were presented or proposed by Uhrig and others; architecture, number of layers, and number of nodes were discussed. An optimization theory of NN size is still to be determined. Interesting preliminary studies in this field were reported in the various papers.

Judging from the questions, comments, and discussion, these new techniques have to be thoroughly studied and not before then could any compulsory applications truly take place. Before licensing authorities allow such techniques to be used, we must solve or clarify these items:

a. Is it possible to define exhaustively the performance of a neural network in any input condition, or would it be possible to monitor the inputs in such a way that output performances could be predicted? Besides licensing aspects, this point should also be solved for buyer/supplier contract matters.

b. If used with auto-training features, this QA aspect might be even more difficult (as they can be today with expert systems).

c. Nuclear engineering people usually don't like systems that are not explicit, that don't deliver explanations of their choices. Thus, theory must be strong enough to demonstrate the reliability of the black box.

Developments are very promising and work should proceed. Applications, I think, should be chosen carefully, in areas where the following issues are of major concern:

- Fast or cheap resolution is needed.
- The problem to be solved has noisy inputs.
- No other techniques that work correctly are available.

Work on this scheme shifts the objective of the SMORN meeting from signal analysis to diagnosis and should focus our objectives closer to the preoccupations of the utilities.

As the techniques are in an early stage, tight collaboration (in the form, for example, of a benchmark) should be encouraged. It must nevertheless be considered as a modern technique among others with which limited budgets will have to be shared. I am thinking of the signal processing of wavelets that were presented in the open forum; and of chaotic analysis; and, in the diagnosis domain, of fuzzy logic and expert systems.

Thank you all for your participation in this very interesting topic; it should remain a valuable one in future conferences.

SESSION 10:

SENSOR MONITORING AND SIGNAL VALIDATION METHODS

F. Åkerhielm
EuroSim AB, Sweden

This is the first SMORN Symposium having a session entitled Sensor Monitoring and Signal Validation Methods. This is remarkable since the subject is essential, both in the respect that no analyses are meaningful unless proper measurement signals are used and also because of problems associated with sensor environment.

J. Barbero described a method to detect and quantify bubbles in the sensing line of a pressure sensor. The system, consisting of fluid, line, and sensor, is simulated by an equivalent electrical circuit. The frequency interval between resonances in the circuit transfer function was demonstrated to be dependent on void fraction in the sensing line. Since the presence of bubbles in the sensing line changes the response time of the signal, this detection method is important from the point of view of safety.

J. Prock described methods for on-line identification of sensor and process faults in real time. The concept consists of three levels: (1) the signal level (comparison of redundant signals), (2) the process level (relationship between signals from the same component), and (3) the system level (transport of quantities between different parts of the system). The combination of these levels will offer sensitivity with respect to faults of different types, a higher degree of information about a fault, and help for more reliable diagnosis of the fault's origin. Techniques belonging to the three levels have been tested separately and their performance has been verified. A three-level concept is in preparation.

E. Türkcan presented a method to detect jumps in signal dc level so as to find signal anomalies. The signal is transferred into a slope, and the appearance of a change from upward to downward slope and vice versa indicates the appearance of a change in signal dc level. Time and duration of signal steps can thus be measured. The method has been tested with a variety of signals from the Borssele PWR and is reported to detect level changes satisfactorily.

S. Arndt presented a comprehensive model of radiation detection noise propagation through ion chamber and sensor line. A method for signal validation compares measured signals with both baseline data and analytical predictions. This method is based on work reported in SMORN IV. The analytical method can distinguish between detector faults, electromagnetic pickup, cable degradation, and improper installation of the detector. The method is tested with signals from two PWRs of different types and is reported to be suitable for implementation in operating commercial reactors.

J. Weiss reported that current testing procedures for detecting degradation and failure in instrument loops have led to several scrams and safety system actuations as a result of manual testing errors. EPRI has performed failure modes and effects analyses on pressure sensors and recommends the following procedure: Transient data are collected during plant transients, such as cool-down, over the operating range of each of the instruments. The transient data from each instrument channel or sensor are then compared to one instrument, which is chosen to be the reference and calibrated. If the other instruments do not deviate significantly from the reference, the redundant instruments can be inferred to be calibrated.

H. M. Hashemian reported that noise analysis has been successfully validated and is used routinely in 15 U.S. PWRs for measurement of response time of pressure transmitters and associated sensing lines. Results from loop testing of pressure sensors and sensing lines show how response time is affected by sensing line length and simulated blockages. The noise results compare well with direct measurements. Determination of PWR sensor response time from noise measurements has also been reported by Bergdahl and Oguma in SMORN V.

J. Weiss described an EPRI program to justify response time testing (RTT) requirements for pressure sensors. The results of the program indicated that RTT is redundant to other periodic testing for all cases except slow loss of fill fluid (where the fill fluid is the working fluid) and variable damping potentiometer misadjustment. For loss of fill fluid, drift trending will provide the necessary verification. Using fixed rather than variable electrical damping or procedurally ensuring that variable damping pots are properly set should alleviate the other response time degradation concern.

O. Glöckler described a technique for generating time series highly sensitive to changes in the process dynamics. The novelty of the technique is the integration of two known techniques: the calculation of the MAR-based residual time series and the sequential probability ratio test. The technique has been applied to noise signals measured at a nuclear power plant. Comparisons between baselines and candidates of both spectra and time series were presented. The technique is reported to be capable of detecting nonstationarities in measured noise signals. The described procedure is part of a multimodule software system being installed at a nuclear power plant.

The many types of contributions to this session show that substantial progress has been made since SMORN V. Both new equipment and new methods have been developed. This is of great importance from the standpoints of safety and availability of nuclear power plants. Reported negative effects of manual testing of instrument channels show the necessity of performing measurements that do not perturb normal operation, such as measurements of signal drift and signal dynamic character. However, more work has to be performed in determining decision levels and in obtaining more robust equipment for the determination of sensor monitoring and signal validation.

SESSION 11:

ADVANCES IN MACHINERY DIAGNOSTICS AND LOOSE-PART MONITORING

E. Türkcan
Netherlands Energy Research Foundation, The Netherlands

In this session six papers were expected for presentation; however, only four papers were presented. One of the papers not presented dealt with "Transient Recorder Monitoring of Machine Vibrations" and the other with "A Diagnostic System and Evaluation of Components' Fatigue Lifetime."

The paper by *J. Eklund* and *B. R. Upadhyaya* (presented by Eklund) deals with an automated system for motor-operated valve (MOV) diagnostics. With reference to the design goals for comprehensive automation of the valve signature characterization and the MOV condition evaluation, the system developed is tested using motor current measurements; extensive testing of the software in use showed the robustness of the algorithms. The diagnostic module determines the MOV condition based on the results of feature extraction.

The next paper, presented by *B. J. Olma*, describes acoustic monitoring of U-tube steam generators using an advanced burst processing method in a portable computer system. The system diagnostics investigations are performed for reliable operation of U-type steam generators of a 1300-MWe PWR. Burst classification is carried out by a neural network method for localization and mass estimation. The system is used for steam generator inlet plenum impact, tube bundle impacts and spacer grid contacts. In addition to KWU reactors, the system has also been used to identify feedwater ring impacts in the Ringhals reactor.

A paper by *J. C. Robinson*, *J. W. Allen*, *J. Quinn*, *L. Oesterling*, and *W. Johnson* (presented by Robinson) reported loose-part activity at the Maine Yankee Atomic Power Station. Long-term trend analysis of the loose-part monitoring system showed clear indication of impacts occurring around the isolation gate valve, caused by an object of mass near 2 kg. The reduction in impacting is aimed to be minimal, and the recommendation is made to trend impact energy with the help of the modified amplitude probability density (MAPD) slope parameter.

The last paper of the session, by *G. L. Zigler* and *B. Bechtold* (presented by Zigler), described design considerations for digital-based loose-part monitoring systems (LPMS). Experience obtained from two generations of digital LPMS over the last five years led to a reconsideration of the new architecture for the current LPMS.

A general conclusion can be drawn from this session: In a complex system like a nuclear power plant, where a number of machinery and internals are involved, machinery diagnostics and loose-part monitoring have an important place. In this respect, advances made and described by the presentations are of major concern and contribute substantially to safe and reliable plant operation.

SYMPOSIUM SUMMARY

B. R. Upadhyaya, Co-Chairman
The University of Tennessee, Knoxville, Tennessee, U.S.A.

The Sixth Symposium on Nuclear Reactor Surveillance and Diagnostics (SMORN VI) was held May 19-24, 1991, in Gatlinburg, Tennessee, U.S.A. Over 75 papers from 25 countries were presented during the symposium, which was attended by 92 persons. In addition to formal presentations, the symposium included a poster session and a panel discussion. All the papers were compiled in a two-volume, 800-page proceedings and distributed to the attendees at the beginning of the symposium. The papers published in these two volumes dealt with the following topics: operational experience with surveillance and diagnostic systems, BWR stability monitoring, leak and boiling detection in fast reactors, modeling and monitoring the motion of PWR and BWR structures, advances in signal processing methods, parameter estimation techniques, application of neural networks and pattern recognition, sensor monitoring and signal validation, and advances in machinery diagnostics and loose-part monitoring.

The symposium technical tour included visits to Tennessee Valley Authority's Sequoyah Nuclear Plant Training Center and the Power System Control and Distribution Center, both located in the vicinity of Chattanooga, Tennessee.

Suggestions were made for a benchmark problem in neural networks. The University of Tennessee and Oak Ridge National Laboratory will review options for a benchmark problem and issue a proposed benchmark problem for comment by mid-1992. The goal is to have results available for SMORN VII.

Some suggestions for future research and development in plant monitoring and diagnostics were also made at a panel discussion. These included integration issues, predictive maintenance applications, applications to component aging problems, further research and development in applications of neural networks, and advanced and nonlinear signal processing techniques.

CLOSING STATEMENT TO SMORN VI DELEGATES

D. N. Fry
Oak Ridge National Laboratory
Oak Ridge, Tennessee, U.S.A.

Our secretariat, *Pierre Nagel* of NEA, has been extremely helpful in organizing and providing guidance in planning this symposium, and he deserves the thanks of this assemblage.

I want to thank our co-chairmen, *Belle Upadhyaya* of the University of Tennessee and *Bob Kryter* of ORNL, for their excellent organization and conduct of SMORN VI. I also thank our sponsors: the OECD Nuclear Energy Agency and the Committees on Reactor Physics and Safety of Nuclear Installations. The cooperation of the IAEA International Working Group on Nuclear Power Plant Control and Instrumentation is also appreciated.

I wish to especially thank all the authors, speakers, and participants for their contributions to our symposium; also the International Organizing Committee for their help in reviewing the papers submitted and in organizing the material into topical sessions.

I believe SMORN VI has successfully met its goal of providing an opportunity for scientists and engineers to discuss research findings and practical experience in the area of nuclear plant surveillance and diagnostics. I'm already looking forward to our next meeting, SMORN VII.

CONCLUDING REMARKS

Robert C. Kryter, Co-Chairman
Oak Ridge National Laboratory
Oak Ridge, Tennessee, U.S.A.

I hope you will permit me to be somewhat introspective and philosophical, rather than purely factual, in concluding this Sixth Symposium. The viewpoint expressed admittedly reflects the prevailing climate in the United States, but some of you from other countries may find our situation not too dissimilar from your own.

As I listened to the papers presented throughout the week and to this afternoon's session summaries, I experienced feelings of both satisfaction and disappointment. *Satisfaction* in the many developments that have taken place since the preceding SMORN meeting—the increased depth of understanding of the various phenomena and process interactions important to the surveillance and control of nuclear reactors and to the prompt and effective diagnosis of problems that occasionally arise in all complex plants, nuclear or otherwise. *Disappointment* that for every finding or development reported here, I suspect that there is at least one companion finding or development that has gone unreported here and largely unrecognized or at least underutilized by the industry for which it was created. And so I mourn the fledgling ideas that have gone unannounced and untried, the theories that remain untested, and the systems that never got designed or built due to the many problems now facing the nuclear industry both here and abroad.

But this is not really a new situation. A glance at the history books shows that Leonardo da Vinci, arguably the finest inventive mind of the Renaissance period, was buffeted throughout his career by an extremely unstable political environment in his native Italy as he attempted to unravel Nature's innermost secrets, dreamed dreams of flying machines and submarines and engines of war, and yet had to satisfy his patrons' appetites for less imaginative creations in order to pay his bills and meet contractual obligations. An example in more modern times is provided by Thomas Alva Edison, who established his now-famous "invention laboratory" (forerunner to the modern industrial research laboratory) at Menlo Park, New Jersey, in 1876. In his early years it seems he was a better inventor than a businessman, and as a consequence of losses incurred on development of unmarketable products, he is said to have adopted a policy that he "would never attempt to invent anything unless he was sure that there was a commercial demand for it." Smart business practice, but surely stifling to research! One can only guess what additional inventions he might have made had he not found it necessary to adopt this tough-minded policy.

Most of us, however, find little comfort in the realization that our present situation is not historically unique. So what is our problem today? I'm sure you know the answer. It is, sadly, that in all but a few industrialized countries commercial nuclear power is presently a beleaguered industry, experiencing opposition to its development activities and further deployment on issues of practical boardroom economics; world politics; concerns for waste disposal and the environment and for nuclear proliferation and safety; unstable regulatory policies; and—most importantly—an underlying distrust of nuclear technology on the part of an increasingly large and often vocal segment of the populace. A beleaguered industry, intent on survival, finds it difficult to believe that innovative means of process control and plant surveillance and diagnostics for off-normal situations are likely to improve its public image and survivability in a climate of doubt and sometimes outright hostility. However, as stated by Alex Zucker in his welcoming speech on Monday, it may be just such development and application of advanced technologies that could prove the key to the process of rebuilding regulatory and public confidences in the ability to operate nuclear plants safely and economically. It will not be easy to build a case for this, and only time will tell what our impact will be. Meanwhile, hard times are with us and it seems likely that we'll face more ahead.

So what do we do? We could "throw in the towel" and seek work in an industry more appreciative of and willing to accept our scientific inquiries and development applications. While this would be an understandable response to prolonged frustrations, I think that *perseverance* and *patience* constitute the better course and will ultimately provide their own reward. Although a difficult thing for scientists and engineers accustomed to working with substantially instantaneous feedback systems, we must realize that the adoption of new ways of doing things—even those potentially beneficial to plant safety or operability—is inherently a long-time-constant process in today's nuclear industry. It is simply unrealistic to assume that "when you invent a better mousetrap, the world will beat a pathway to your door." The farmer who has sown his seed on good soil but is denied a harvest, owing to late frost, drought, destructive insects, or other calamities beyond his control, is understandably discouraged but does not blame himself for the failure and does not regret his choice of occupation or give up entirely. Instead, the good farmer replants his seed—perhaps adopting a different plan (later planting time, different soil preparation technique, and so on), which he feels will improve his likelihood of success—with a continued expectation that a good harvest will be reaped next season. So it must be with us. For inspiration, let us continue to hold fast to the belief that truly valuable discoveries will *eventually* find their way into and become accepted practice for future nuclear undertakings. Ultimate benefit to the nuclear industry should be what we seek, knowing full well that near-term recognition and reward may not be accompanying benefits.

All of which brings us to the subject of a successor symposium, SMORN VII. I was extremely pleased to hear this morning's announcement that plans for holding a seventh in this long-standing series of symposia in about 4 years' time are now in the discussion stage. In light of my earlier remarks, I hope that each of you assembled here will endeavor to inspire colleagues at your home institutions to keep up the good work in increasing the knowledge base available to the commercial nuclear industry, whose future existence presently seems tenuous. To the degree that our individual contributions can make a difference—and, like Dr. Zucker, let us assume that they will—we, as individuals and as organizations, must keep moving forward and do our utmost to keep the nuclear option viable.

In closing, thank you all for participating in this Sixth SMORN Symposium. It has been a distinct honor for ORNL and UT-K to host this prestigious meeting. With a wish for continued success in your future undertakings and a safe journey back home, I hereby declare SMORN VI closed.

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