NEACRP-U-71

COMITATO NAZIONALE ENERGIA NUCLEARE

REACTOR NOISE FROM CRITICAL ASSEMBLIES TO POWER PLANTS

Proceedings of NEACRP Specialist Meeting on Reactor Noise (SMORN-1)

October 21-25, 1974
C.S.N. Casaccia - Rome (Italy)

March 1975

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Serie simposi

SUMMARY

SMORN-1 (Specialist Meeting On Reactor Noise - 1) has been sponsored by the Nuclear Energy Agency Committee on Reactor Physics, hosted by the Italian National Committee for Nuclear Energy and held at CSN Casaccia, Rome, Italy from October 21 to 25, 1974.

The object of SMORN-1 was discussing every type of noise related to reactor systems: inherent noises and induced noises by imposed perturbations of stochastic or pseudo-stochastic nature. The meeting has been dealing with fluctuations from sources such as vibrations boiling and temperature, acoustic monitoring of anomalies and various diagnosing of malfunctioning via noise analysis. The basic idea was that of covering the widest possible area and to understand where the borderlines with other disciplines are.

Sixtyone participants from twentythree countries and/or organizations have been attending the five-day meeting and fortysix papers have been presented. An up-to-date international picture of the state-of-the-art in both noise theory and experiment was obtained and directions on where to go next thereby developed.

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Edited by Nicola Pacilio
Vincenzo M. Jorio, Andrea Colombino

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The beast went to the well and drank and the noise was in the beast's belly like unto the questing of thirty couple hounds, but all the while the beast drank there was no noise in the beast's belly.

Sir Thomas Malory, *Morte d'Arthur*, Bk. 1

PREFACE

PREFAZIONE

PREFACE

SMORN-1 , Specialist Meeting On Reactor Noise, was held at CSN Casaccia - Rome (Italy), from October 21 to 25 , 1974 .

The number of participants was up to 61 from 23 countries and/or organizations. The atmosphere was relaxed friendly and stimulating : beside that, the schedule was pretty tight and busy all along the five days of the meeting.

This publication intends to complement the special issue of 'Annals of Nuclear Science and Engineering' which published the whole ensemble of papers presented at SMORN-1.

This CNEN technical report,also listed in the NEACRP document series, includes abstracts of papers, discussions, comments and some final statements.

The mentioned two publications might represent fairly well the state-of-the-art of Reactor Noise Analysis at the end of 1974.

The meeting was made possible by the :

* sponsorship of the Nuclear Energy Agency Committee on Reactor Physics and by the active promotion and managerial help of its Secretary, Dr J. Royen ;

* participation of members of the Nuclear Power Plant Control and Instrumentation Working Group of IAEA and by the competent patronage and suggestions of its head member, Dr R.J. Cox ;

* cooperation by Dr A.H. Spano, head of Research Reactor Section, Division of Nuclear Power and Reactors of IAEA .

We also wish to thank the distinguished scientists who agreed to act as chairmen of the different sections : W. Bastl, J.C. Carré, R.J. Cox, J.B.

Dragt, U. Farinelli, G. Kosaly, J.T. Mihalczo, K. Saito, D.M. Shvetsov and J.A. Thie.

Finally, our true gratitude goes to Ugo Farinelli who sponsored and supported the idea of SMORN-1 since the very beginning and helped in guaranteeing to the meeting an international status and a world-wide contribution from specialists in the field.

It has been a real pleasure to work with such a cooperative group of people : we hope to see all of them again at SMORN-2.

Peace and Freedom,

Nicola PACILIO
Vincenzo M. JORIO
Andrea COLOMBINO

Rome, March 1975

PREFAZIONE

SMORN-1, meeting per specialisti di rumore nei reattori nucleari, la cui riuscita é stata garantita dalla partecipazione qualificata di 61 scienziati di 23 paesi, ha costituito un avvenimento scientifico di rilievo mondiale, come dimostra l'interesse di autorevoli organi di informazione energetica e nucleare.

La rivista inglese 'Annals of Nuclear Science and Engineering' ha dedicato un numero speciale esclusivo ai lavori presentati al meeting. Le riviste americane 'Nuclear Safety' e 'Nuclear News' hanno pubblicato reportage scientifici : la prima per mano di Joseph Thie, uno dei massimi esperti del settore.

I segretari di SMORN-1 desiderano ringraziare quanti hanno collaborato alla riuscita della manifestazione.

In primo luogo,il Direttore del CSN Casaccia, Prof. Giancarlo Schileo, per il comprensivo tempestivo e coraggioso intervento nella fase più delicata della organizzazione.

Nell'ambito del Centro, un ringraziamento deve riferirsi al Sig. Antonio Di Venanzio ed al Servizio di fotoriproduzione della Biblioteca Centrale, al Sig. Vincenzo Tatì per le telecomunicazioni rapide, al Sig. Giuseppe Ciampà per il sistema di audio-registrazione e di proiezione durante i lunghi cinque giorni del meeting, al Dr. Massimo De Biase ed alla Sig.na Marcella Cioni per le public-relations e la organizzazione logistica.

Nell'ambito del comitato organizzatore va riconosciuto il lavoro svolto con intelligenza e notevole senso pratico dalla Segreteria nelle persone delle Sig.re Roberta Landini, Renata Sacchetti, Gabriella Segre e della Sig.na Luciana Quinti per rispondere alle esigenze di tutti i partecipanti.

Deve essere inoltre sottolineato il singolare contributo del Sig. Luigi Jannelli al massiccio lavoro editoriale di allestimento del materiale distribuito

durante il meeting.

Speciale - come sempre - la gratitudine nei confronti del Dr. Piero D'Amico per l'indispensabile apporto fornito dalla sua competenza nella ottimizzazione dei sistemi computerizzati di informazione e nelle supervisione del funzionamento dei mezzi di documentazione audio-visiva.

Infine un semplice ma fondamentale grazie ai compagni di lavoro del comitato organizzatore : Dr. Raffaele Mosiello e Dr. Francesco Norelli. Senza di loro e senza il loro spirito di sincera ed autentica cooperazione, l'idea stessa del meeting non sarebbe stata né immaginabile né realizzata.

Nicola PACILIO
Vincenzo M. JORIO
Andrea COLOMBINO

Roma, marzo 1975

S M O R N - 1

OFFICERS

SMORN - 1 OFFICERS

GENERAL CHAIRMAN	Prof Ugo FARINELLI, CNEN
NEACRP SECRETARY	Dr Jacques ROYEN, NEACRP
SCIENTIFIC SECRETARIAT	Prof Nicola PACILIO, CNEN Dr Andrea COLOMBINO, CNEN
MANAGERIAL SECRETARIAT	Dr Vincenzo M. JORIO, CNEN Dr Raffaele MOSIELLO, CNEN
COMPUTER CENTER	Dr Piero D'AMICO

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COUNTRIES AND ORGANIZATIONS

LIST OF PARTICIPATING COUNTRIES AND ORGANIZATIONS

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HUNGARY	3	(S.Horanyi, G.Kosaly, D.Pallagi)
ITALY	4	(U.Farinelli, V.M.Jorio, M.Marseguerra, N.Pacilio)
JAPAN	5	(H.Kataoka, H.Motoda, H.Nishihara, T.Nomura, K.Saito)
NEACRP	1	(J.Royen)
NETHERLANDS	5	(J.B.Dragt, J.Hoekstra, E.Türkcan, H.Van Dam, J.H.C. Van der Veer)

NORWAY	1	(E.Robinson)
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RUMANIA	2	(S.Boeriu, D.Cepraga)
SOVIET UNION	2	(B.Kebadze, D.M.Shvetsov)
SPAIN	1	(A.Perez-Navarro Gomez)
SWEDEN	1	(F.Åkerhielm)
SWITZERLAND	3	(H.Bünschi, J.P.Schneeberger, W.Seifritz)
TURKEY	1	(M.Karasulu)
U.S.A.	4	(D.N.Fry, R.A.Lewis, J.T.Mihalczo, J.A.Thie)
YUGOSLAVIA	1	(B.Mavko)

COUNTRY TOTAL : 23

LIST OF

ATTENDEES

LIST OF ATTENDEES

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2. B. BAERS (FIN)
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4. W. BASTL (GER) Session Chairman
5. S. BOERIU (RUM)
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20. R.E. GREEN (CAN)
21. J. HOEKSTRA (NET)
22. S. HORANY (HUN)
23. JAUDET (FRA)
24. V.M. JORIO (ITA)
25. M. KARASULU (TUR)

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54. S. SIGHICELLI (FRA)

55. D. STRUBE (GER)

56. J. A. THIE (USA) Session Chairman

57. E. TÜRKCAN (NET)

58. H. VAN DAM (NET)

59. J.H.C. VAN DER VEER (NET)

60. D. WACH (GER)

61. U. WESSER (GER)

ATTENDEE TOTAL : 61

LIST OF OBSERVERS

FROM C.N.E.N.

LIST OF OBSERVERS FROM C.N.E.N.

B. Arcipiani	Laboratorio Fisica e Calcolo Reattori
M. Basili	Laboratorio Servomeccanismi
V. Benzi	Divisione di Fisica
R. Cervellati	Divisione Ricerche di Sicurezza
A. Colombino	Laboratorio Fisica e Calcolo Reattori
M. Di Bartolomeo	Laboratorio Ingegneria Nucleare
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A. Merelli	Divisione Ricerche di Sicurezza
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F. Norelli	Laboratorio Fisica e Calcolo Reattori
M. Pezzilli	Divisione Ricerche di Sicurezza
M. Salvatores	Laboratorio Fisica e Calcolo Reattori

S M O R N - 1

DAILY DIARY

OCTOBER 21 - Zero Power Reactor Noise : Theory and Surveys

10:00 a.m.

* Valedictorian Address by prof. G.C. SCHILEO, Director of CSN Casaccia

Chairman : prof. U. FARINELLI

* Introductory Remarks by the Session Chairman

(1) Two-particle correlations in reactor systems - J. MIKA (Poland)

(2) Stochastic kinetics : analytical solutions of detailed probability balance equations - F. Norelli, V.M. Jorio, N. Pacilio (Italy)
* presented by V.M. JORIO

(3) Probability profiles and moments of neutron count distribution via the Kolmogorov equations - B. Arcipiani, M. Marseguerra (Italy)
* presented by M. MARSEGUERRA

(4) A stochastic study of coupled reactor systems - J.P. Genoud (Switzerland)
* presented by J.P. SCHNEEBERGER

2:30 p.m.

Chairman : dr. J.C. CARRE'

(1) Discrete probability distributions in nuclear reactor noise - N. Pacilio, V.M. Jorio (Italy)
* presented by N. PACILIO

(2) Some results about reactor neutron fluctuation analysis - M. DEISS (France)

(3) Theory of correlation measurement in time and frequency domain with Cf-252 - J.T. Mihalczo, V.K. Paré (U.S.A.)
* presented by J.T. MIHALCZO

(4) Reactor gamma noise studies - B. BAERS (Fin land)

(5) Study of power spectral density by a non-linear response to stochastic input - Y. Gotoh (Ja- pan)
* presented by T. NOMURA

OCTOBER 22 - Zero Power Reactor Noise : Experiments, Equipment Design and Operational Pro- blems

9:30 a.m.

Chairman : dr. J.B. DRAGT

(1) Thermoelectrically generated noise in heated thermocouples and in other low level instru- mentation cables - F. Mathieu, R. Meier, M. Soenen, M. Delcon, C. Nysten (Belgium)
* presented by F. MATHIEU

(2) Regression filter for signal resolution - W. MATTHES (Euratom)

(3) Data acquisition and processing system for reactor noise analysis - J. Da Costa Oliveira, C. Morais da Veiga, D. Forjaz Trigueiros, J. Pombo Duarte (Portugal)
* not presented verbally

(4) Time domain measurements for fast metal assem

blies with Cf-252 - J.T. MIHALCZO (U.S.A.)

(5) Spectral density measurements with mock-up of the Fast Flux Test Facility reactor - J.T. Mihalczo, V.K. Paré, M.V. Mathis (U.S.A.)
* presented by J.T. MIHALCZO

(6) Heat transfer coefficient and some other reactor parameter determined from measurements of fuel temperature and neutron flux fluctuations - R. Isnard (Switzerland)
* presented by J.P. SCHNEEBERGER

2:30 p.m.

Chairman : dr. J.T. MIHALCZO

(1) Measurements of kinetic parameters by noise techniques on the Minerve reactor - J.C. Carrè, J. Da Costa Oliveira (France)
* presented by D. DE LAPPARENT

(2) Investigation on the two-detector covariance method for measuring coupled reactor kinetic parameters - M. Edelmann, J. Ehrhardt, W. Vaeth (Germany)
* presented by M. EDELMANN

(3) Studies of neutronic coupling by reactor noise analysis in the time domain for facilities of RCN, Petten - E. Türkcan, J.B. Dragt (Netherlands)
* presented by E. TÜRKCAN

(4) Temperature noise measurements in blocked and unblocked 19-pin electrically heated LMFBR fuel mock-ups - D.N. FRY (U.S.A.)

(5) Dynamic heat transfer experiments in an electrically heated LMFBR fuel element mock-up - D.N. Fry, T.W. Kerlin, W.H. Sides (U.S.A.)
* presented by D.N. FRY

(6) Interval distribution measurement of chain-re

lated nuclear processes using two detectors - P.A. Haldy, M. Chikouche (Switzerland)
* presented by J.P. SCHNEEBERGER

OCTOBER 23 - Power Reactor Noise : Theory and Surveys

9:30 a.m.

Chairman : dr. J.A. THIE

(1) The impact of twenty years of noise research on nuclear power plant design, instrumentation and control - L.G. KEMENY (Australia)

(2) Fundamentals of theoretical analysis of power reactor noise and their application - K. SAITO (Japan)

(3) Theoretical considerations and their application to internals motion from stochastic signals - J.A. THIE (U.S.A.)

(4) Some considerations of neutron instrumentation requirements for malfunction diagnosis in power reactor using noise analysis techniques - M. EDELMANN (Germany)

(5) A stochastic study of noise in boiling reactors - M. Matthey (Switzerland)
* presented by J.P. SCHNEEBERGER

2:30 p.m.

Chairman : prof. K. SAITO

(1) The estimation of vibrations of reactor internals by noise analysis of non-nuclear parameters - W. Bastl, V. Bauernfeind (Germany)
* presented by W. BASTL

(2) Canadian experience in the area of reactor noise - K.J. SERDULA (Canada)

(3) Review of recent applications of reactor noise techniques at Argonne National Laboratory - R.A. Lewis, E.F. Bennett, S.G. Carpenter, C.E. Cohn, C.C. Price (U.S.A.)
* presented by R.A. LEWIS

(4) A simple space dependent theory of neutron noise in a boiling water reactor - G. Kosaly, L. Maroti, L. Mesko (Hungary)
* presented by G. KOSALY

OCTOBER 24 - Power ReactorNoise : Experiments and Operational Applications

9:30 a.m.

Chairman : dr. W. BASTL

(1) Experience from the analysis of noise measurements in a BWR power plant - P.E. Blomberg, F. Åkerhielm (Sweden)
* presented by F. ÅKERHIELM

(2) Power reactor noise measurements in Hungary - D. Pallagi, T. Hargitai, S. Horanyi (Hungary)
* presented by S. HORANYI

(3) Non-linearity consideration when analyzing reactor noise statistical characteristics - B.V. Kebadze, L.A. Adamovsky (Soviet Union)
* presented by B.V. KEBADZE

(4) Analysis of neutron density oscillations resulting from core barrel motion in a PWR nuclear power plant - D.N. Fry, R.C. Kryter, J.C. Robinson (U.S.A.)
* presented by D.N. FRY

2:30 p.m.

Chairman : dr. R.J. COX

(1) The analysis of at-power neutron flux noise in the frequency range of vibrating reactor structures - D. WACH (Germany)

(2) Boiling anomaly detection by acoustic noise measurement - H. NISHIHARA (Japan)

(3) Cross correlation of neutronic and acoustic noise signals from local boiling - S.A. Wright, R.W. Albrecht, M. Edelmann (Germany)
* presented by M. EDELMANN

(4) Noise spectra of BWR and application of noise analysis to FBR - T. NOMURA (Japan)

OCTOBER 25 - Power Reactor Noise : Experiments and Operational Applications

10:00 a.m.

Chairman : dr. G. KOSALY

(1) Plant disturbances and model verification - M.H. Butterfield, J.D. Cummins (Great Britain)
* presented by M.H. BUTTERFIELD

(2) An on-line power-reactor shutdown reactivity meter based on a novel reactor noise analysis technique - K. Behringer, K. Phildius, W. Seifritz (Switzerland)
* presented by W. SEIFRITZ

(3) Measurements of temperature fluctuations in

gas-cooled power reactor - C.P. Greef (Great Britain)
* presented by M.J. BRIDGE

(4) Relation between non-linear and 'not-linear' characteristics in nuclear kinetics and noise analysis of neutron flux - H. KATAOKA (Japan)

2:30 p.m.

Chairman : dr. D.M. SHVETSOV

(1) A fast response thermocouple for temperature fluctuations measurements in sodium coolants - H. Bunschi, W. Seifritz (Switzerland)
* presented by H. BUNSCHI

(2) Correlation analysis of the enviromental influences on radioactive Argon releases from the plume of the reactor Diorit - K. Behringer, K. Feuermann, D. Kostic, W. Seifritz (Switzerland)
* presented by W. SEIFRITZ

(3) Heat transfer time constant of a fuel pin determined by noise analysis - E. ROBINSON (Norway)

(4) Investigation on the influence of feedback and coupling effects on neutron noise in a nuclear reactor - W. Vaeth (Germany)
* presented by M. EDELMANN

ORAL SUM-UP OF THE MEETING

4:30 p.m.

Chairman : prof. U. FARINELLI

(1) Noise analysis in PWRs - J.A. THIE (U.S.A.)

(2) **Noise analysis in BWRs - W. SEIFRITZ (Switzer land)**

(3) **Noise analysis in heavy-water reactors - K.J. SERDULA (Canada)**

(4) **Noise analysis in fast reactors - D. DE LAPPA RENT (France)**

PAPER TOTAL : 46

THE 46 PAPERS :

SUMMARIES AND

DISCUSSIONS

(1) Two-particle correlations in reactor systems-
J. MIKA

For most practical purposes a comprehensive description of a given reactor system is supplied by the neutron equation supplemented by the equations for delayed neutron precursors. Such a system of equations which may be referred to as the generalized transport equation was thoroughly investigated in a Hilbert space of square integrable functions and the existence of its unique solution was proved. That supplied a firm basis for investigating various approximate methods for numerical reactor calculations.

The generalized transport equation involves average distribution of neutrons and delayed neutron precursors and is inadequate for describing the stochastic features of neutron chain reaction. In fact the interpretation of some neutron noise experiments requires the knowledge of the two-particle distribution function to account for the correlation between two particles generated in the same fission event.

The two-particle correlation is obtained from the two-particle distribution function by subtracting the product of one-particle distribution function for each of the two particles. The system of equations describing the time evolution of the two-particle correlation functions or the correlation matrix equation is particularly simple and directly related to generalized transport equation.

The purpose of this paper is to study the relationship between the two systems of equations and indicate how some of the results obtained so far for the generalized transport equation can be simply translated to the correlation matrix equation.

In particular, the semigroup formalism developed for the generalized transport equation will be used to prove the existence and uniqueness of solution to the correlation matrix equation.

(2) **Stochastic kinetics : analytical solutions of detailed probability balance equations -**
F. NORELLI, V.M. JORIO, N. PACILIO

This work intends to formulate nuclear reactor kinetics according to a stochastic approach. A balance equation system is written for the probability of finding the nuclear system in a certain state at a given instant of time.

The Chapman-Kolmogorov equations are this way derived for a reactor.

The state is characterized by the neutron population, the delayed neutron precursor population and the number of detected neutrons.

Equations are treated and integrated in search of a probability profile.

A number of cases is analyzed via a progressive criterium : it tends to start with a very simple model and to take into account an increasing number of physical processes within the chosen system.

The cases under study are :

-1- Source

-2- Non-multiplying medium

-3- Source in a non-multiplying medium

-4- Multiplying medium

-5- Source in a multiplying medium

-6- Prompt neutron system with source

-7- Prompt and delayed neutron system with source

-8- Detector in a non-multiplying medium

-9- Detector in a prompt neutron system

-10- Detector in a prompt neutron system with source

DISCUSSION

M. EDELMANN : What is the meaning of what you call 'detectron' ?

V.M. JORIO : In our stochastic model a detectron is a particle generated by the detection of a neutron that enters a sensor. D.R. Harris was the first to include the detection process in a reactor probability balance in an early study around 1958.

K. SAITO : Two types of probability distributions are obtained in nuclear reactor noise : the discrete and the continuous. The former is obtained, for example, as the distribution of the number of counts measured by a BF_3 -counter and extensive studies, as you mentioned in your paper, are performed. The continuous distribution is obtained, for example, as the distribution of amplitude around the mean current of a current ionization chamber. Approximately it can be regarded as the Gaussian distribution with zero mean and σ standard deviation. Strictly speaking it is not Gaussian. Have you any comment on this point ?

V.M. JORIO : In nuclear reactor noise you are dealing with a process, viz. the fission process, which defies the Gaussian assumption. So you can never expect your experimental profile to be matched by a Gaussian distribution,i.e. a distribution with zero skewness and kurtosis.

N. PACILIO : A sentence, quoted by Poincaré in his 'Calcul des probabilités', focalizes appropriately the role of the Gaussian distribution in statistics applied to experimental observations or adopted for theoretical treatments. It states that 'everybody trusts the Gauss' distribution, the experimenters because they suppose it is a mathematical theorem, the mathematicians because they suppose it is an experimental evidence.' The actual situation is that a distribution according to the profile of the Gaussian law of errors is proved to exist only under some explicit mathematical conditions, which are rarely verified in reality. It has been proved that experimental data are better matched by other types of distri butions such as the Gram-Charlier series, the Edgeworth series etc. They can be regarded as preliminary steps toward the Gaussian distribution.

D. SCHWALM : Do you intend to extend your investigation on problems including non-linear effects, the feedback due to temperature effects ?

V.M. JORIO : Yes, we are extending our investigations to problems including feedback caused by temperature effects. With additional variables, such as fuel temperature and void fraction related pseudo-particles, the problems become non-linear and the mathematical procedure cannot be the same. On the other hand, theoretical methods for dealing with non-linearities have recently been developed a bit : from these improvements new opportunities are available.

(3) Probability profiles and moments of neutron count distribution via the Kolmogorov equation – B. ARCIPIANI and M. MARSEGUERRA

The distribution of neutron counts in a subcritical multiplying system with an external source has been investigated in the framework of the Kolmogorov equations (KE), introducing some generalizations.

The backward KE, without delayed neutrons, has been solved for the probability generating function (pgf) in the case of many counting intervals and suitably differentiated for the determination of joint probabilities and moments.

Attempts have been made to solve the backward KE taking into account the delayed neutrons and a recurrent relation has been obtained for the pgf. However, this solution is too complicated to lend itself to further manipulations.

All the above calculations adopt the usual simplified fission model. Without any such assumption the backward and the forward KE with delayed neutrons have been solved for the first two moments in case of a single counting interval, thus obtaining the most general expression for the reduced variance. This formula, in the frame of the simplified fission model, reduces to a much simpler expression, which is shown to be practically equivalent to the generally used one.

Finally, the backward KE with delayed neutrons and the simplified fission model assumption has been solved for the mean value, variance and covariance of neutrons counts in the case of time-dependent sources.

DISCUSSION

W. SEIFRITZ : Are signal/noise ratios in this context comparable with signal/noise ratios in more conventional contexts ? Is there any improvement ?

M. MARSEGUERRA : The signal/noise ratio may be increased by proper conditioning. However, the total duration of the experiment has to be also taken into account. We have not performed experiments on the matter.

J.B. DRAGT : Just a comment. A technique to use all counts in a Rossi-alpha experiment by means of a process computer has been used at Petten. The work is included in the paper of Türkcan and me, which will be presented tomorrow.

K. SAITO : (1) I understand that 1-conditioned mean value experiment which you mentioned for example in table III corresponds to usual experiment of Rossi-alpha. Is that O.K. ?
(2) I comment that Dr. A. Furuhashi (Tokyo University) also solved the backward Chapman-Kolmogorov equation including detectrons for various situations and various analytical formulas of correlation experiment. He is also trying to analyze 1-conditioned reduced variance experiment.

M. MARSEGUERRA : The 1-conditioned mean value technique is actually closely related to the I-type Rossi-alpha experiment. However, it has to be noticed that in the former method the first interval, i.e. the conditioning one, may have any fixed time length. Therefore the waiting time, which starts at the end of the first interval, is greater than that of the Rossi-alpha experiment which starts at the time the triggering pulse occurs. As I mentioned, in spite of that, the absolute value of the difference between the conditioned and the unconditioned mean values in the second interval decreases exponentially to zero with the waiting time, alpha being the decay constant.

M. EDELMANN : Could one conclude from your investigations that some of the known techniques of noise measurements in the time domain should be modified somehow by introducing conditioned counting procedures? In detailed investigations on the Rossi-alpha experiment we have found that the most efficient way of extracting information from sequences of detector pulses is to use all pulses from neutron detectors.This work is referred to in the paper on covariance measurements I will present later at this conference. However there might be some useful applications to error analysis from your investigations because the number of counts in successive time intervals and their variances are correlated.

M. MARSEGUERRA : We did not consider from the experimental point of view the possibility of extracting more information than usual. An experimental set-up which makes use of a minicomputer to take into account the mutual relations among several time intervals would probably be convenient.

J.T. MIHALCZO : Do you intend to use your method to predict dead-time effects in Rossi-alpha measurements ?

M. MARSEGUERRA : I would like to comment about two possible approaches to the dead-time corrections. The first one consists in obtaining a correction matrix whose inverse when applied to the observed distribution gives the true distribution. We derived such a matrix for Poisson and for mixtures of Poisson distributions. The second approach would consists in introducing the dead time directly in the KE. At present we do not plan to work along this line.

B. BAERS : Coming back to Dr Edelmann's questions and comments I should like to point out that e.g. the measurements of Dr Chwaszczewski (1966) and present and other investigations show that the ratio between the correlation amplitude and the background increases by using conditional procedures. However from the information point of view the data collecting speed is then also reduced. If high-speed on-line computers and data collecting devices are available. it may be more efficient not to use selective data collection procedures. The selective procedure may be justified when the capacity of the data handling channel is limited.

(4) A stochastic study of coupled reactor systems - J.P. GENOUD (presented by J. Schneeberger)

A probabilistic analysis of two cores, loosely coupled by an intermediate medium, is developed. Neutron population, delayed neutron precursors of each core, and neutrons in transit between the two cores, are the random variables considered.

During the transfer, neutron interactions with matter are not considered. The neutron lifetime in this intermediate medium is supposed equal to the transit time. A four-points model is developed, based on the Kolmogorov equation for the Markov processus describing the reactor behaviour.

Fokker-Planck approximation leads to a set of differential equations for the correlation functions depending on the transit time.

First results of theoretical analysis of the model show a significant transit time related sign inversion in the cross power spectral density.

DISCUSSION

D. SCHWALM : What is the difference between your transfer function representation and that of G.Schweitzer (published some years ago) ?

J.P. SCHNEEBERGER : For lack of precise reference, it was not possible to compare the transfer functions of the proposed model with the ones obtained by Mr. Schweitzer. We can neverthless affirm that the transfer function ($\Delta N_1/\Delta k_1$, $\Delta N_2/\Delta k_2$) derived from the four-points model and from the classical kinetic equations of coupled reactors are quite similar.

J.T. MIHALCZO : Where did you obtain the transfer coefficients ? The agreement between model and experiments depends very strongly on these coefficients.

J.P. SCHNEEBERGER : The values of the transfer coefficients (probability per unit time and per neutron that this latter leaves one of the multiplying zones and comes into the associated transfer zone) were chosen according to experimental values of Mr. Viehl.

G. KOSALY : Among the parameters you have used there have been the parameters N_3, N_4 giving the power of the coupling-zones No.3 and No.4. As in reality there is but a single coupling-zone, I do not understand their meaning.

J.P. SCHNEEBERGER : The third and fourth zones of the model have no direct connection with the intermediate zone (so-called 'coupling zone') made of a moderator medium. They represent fictive zones where no reaction (such as leakage, capture or fission) takes place but in which a fictive neutron 'life time' is defined to represent the transfer time from one multiplying zone to the other. The neutron losses (capture, leakage) in the real intermediate zone are taken into account by the coupling coefficients ε_{ij}. The difference between the output currents of each of the multiplying zones.

(5) Discrete probability distributions in nuclear reactor noise -
N. PACILIO and V.M. JORIO

A presentation is given of recent contributions that reactor noise analysis brought up to the theory of probability and its applications, in terms of new profiles and distribution families.

A time documentary approach is adopted.

The well-known PMZBB (Pal-Mogilner-Zolotukhin-Bell-Babala) distribution, Türkcan and Dragt's first try to derive the probability profile from the generating function and Routti Szeless and Ruby's elegant computational procedure - based on the partition of integer numbers - are progressivelly recalled.

In search of new probability distributions approximating the PMZBB profile, a number of generating functions have been introduced, analyzed and mutually compared by the authors of this paper.

These functions led to :(1) the Logarithmic distribution, (2) the Radical distribution, (3) the Algebraic distribution, (4) the Poisson-Logarithmic distribution, (5) the Poisson-Radical distribution and (6) the Poisson-Algebraic distribution.

Distribution (4) is also known as Polya or Pascal or Negative Binomial distribution.

Distributions (2) (3) (5) and (6) are an absolute novelty in the field of probability theory.

Distributions (4) (5) and (6) belong to the class of 'generalized Poisson distributions', introduced by Gurland some years ago.

DISCUSSION

J.C. CARRE : You mentioned an interval $1 \leq \alpha t \leq 5$. What practical field does it correspond to ? What can we do in that 'no-man land' ?

N. PACILIO : The need for compact and recursion-formulated distributive profiles is absolutely stringent in the evaluation of experimental data. The Poisson-Logarithmic distribution and the Poisson-Radical distribution are pretty good matches of observed profiles in the intervals $\alpha t < 1$ and $\alpha t > 5$, respectively. On the contrary . in the $1 \leqslant \alpha t \leqslant 5$ interval there is no closed-form distribution available.

Unfortunately. the abovementioned no-man interval is of basic importance for the auto- and cross-correlation function as well as for the relative variance of neutron counts vs. time. These functions have their most relevant die-away (the former two) and build-up (the latter one) in this very interval.

(6) Some results about reactor neutron fluctuations analysis-
M. DEISS

Two sets of neutronic measurements were achieved on two different reactors and the results of analysis are given.

First study was made on a research reactor. Very low frequency periodic fluctuation has been revealed. The cause of this fluctuation is not yet obvious.

Second study was led on a power reactor. It deals with the possible influence of reactor mechanical vibrations on a long ion chamber. This influence was proved and hypothesis made concerning a peculiar effect of it.

DISCUSSION

G. KOSALY : In your presentation you mentioned correlation measurements performed at SENA. It is not clear to me where the detectors have been situated between which the correlation has been measured. Have been you speaking about axially placed, or radially situated detectors?

M. DEISS : These measurements have been performed on usual ionisation chambers, which are located in holes radially distributed around the core center ; axis of chambers and axis of core being parallel. Then it was speaking here about radially situated detectors.

J.C. CARRE : Could you precise on what type of reactor you have performed the first set of measurements and also at what power level this reactor was operated during your measurements?

M. DEISS : This reactor was a swimming pool reactor for research. Power levels at which it was operated during the measurements were respectively 70 MW and 300 kW.

J. THIE : Have you the 3.5 and 5.2 Hz frequencies of pendular motions been quantitatively studied to the point of beeing able to state the amplitude of these pendular motions ?

M. DEISS : It was not in our intentions for these measurements to study particularly such pendular motions. We have only observed they and didn't attempt to state their amplitudes.

M. EDELMANN : Could you please tell me the break frequencies of the two reactors where you have measured the neutron power spectra ? It seems to me that you have measured resonances beyond the break frequency of the reactor which should be difficult to explain.

M. DEISS : In the second set of measurements we can estimate that the break frequency is about 20 Hz.
In consequence I made in my talk the hypothesis that the resonances appeared beyond this break frequency would be probably induced on the chamber structure or on the electrical connection of the detection line. by means of a microphonic process.

(7) **Theory of correlation measurement in time and frequency domains with Cf-252**
J.T. MIHALCZO and V.K. PARE'

The theory of cross-correlation measurements between the pulses from an ionization counter containing a Cf-252 neutron source, which furnished the initiators of fission chains in a neutron-multiplying assembly, and the pulses from a detector observing the particles from the fission chains is reviewed.

The expression for the detector response in this type of measurement is first presented in the time domain. Then the cross-power spectral densities in the frequency domain measurements are developed. The theory of the usual two-detector noise measurement is reformulated to incorporate a modified Diven factor that includes the effects of neutrons from external sources such as spontaneous fission of Cf and the reactor fuel. Finally, the equivalence between both the time and the frequency domain expression is demonstrated.

A new method of reactivity determination is proposed that avoids some of the difficulties of the present methods, such as dependence on detection efficiency and inherent source strength, and the requirement for a calibration near delayed criticality.

(8) Reactor gamma noise studies -
B. BAERS

A review is given of reactor gamma noise studies, with the main emphasis laid on experience gained from subcritical reactors at Otaniemi, Finland, along with a survey of the development of stochastic models, numerical studies and gamma noise measurements.

Within the framework of a space-independent two-energy-group model that has been developed, all of the simplified correlation functions associated with the detectors signals i_J and i_ℓ assume the form $\langle i_J(t) \cdot i_\ell(t+\tau)\rangle = A + B_1 \exp(-\omega_1\tau) + B_2 \exp(-\omega_2\tau)$; the subindexes 1 and 2 here refer to the fast and thermal groups of neutrons respectively. The detection model includes the detection of gamma rays, thermal neutrons and fast neutrons, absorption, recoil and fission type detectors, gamma-compensated detectors and response fluctuations.

Explicit expressions are given in regard to the influence of a large number of reactor and detector parameters.

The gamma radiation, which is emitted with long delay, can be regarded as spurious, and in the main degrades the measurement quality. With respect to detector effects, the model further provides some insight into the analysis of power reactor noise.

It has been experimentally confirmed that information on the thermal and fast groups of neutrons in a thermal reactor is derivable from noise measurements by means of photon detection, or alternatively the joint use of thermal neutron and photon detection. Ex-core measurements and measurements on fast reactors have also been effected.

The use of gamma detection in reactor noise measurements may be regarded as a complement to and a substitute for thermal and fast neutron detection.

Other distinct and useful features of gamma detection include the possibility of acquiring energy-sensitive detectors with excellent time resolution, the possibility of making use of energy selection by the agency of electronic amplitude discrimination, the relatively small disturbance in the system that arises from a gamma detector, particularly in ex-core measurements and the great relaxation length of high energy photon radiation as compared with thermal neutrons.

DISCUSSION

J.C. CARRE : You have used gamma pulses for correlation measurements : is it possible to measure a gamma current and, if it is possible, with what device to deal with ?

B. BAERS : Gamma detectors, which are operated in the current mode, can be used in noise measurements. They do however have certain limitations due to their time resolution (circa 1 msec), because the selection or discrimination of gammas with specific energies is not normally possible and there are low signal strengths at subcritical reactors. On the other hand, fast-response (circa 1nsec) pulse-type detectors also have limitations and cannot be operated in high gamma fields due to saturation effects such as limited counting rates. Thus current mode detectors, such as ionization chambers, seem to be preferable at high gamma fields,e.g. in power reactors, if no energy selection is needed and if only a low or moderate time resolution is required.

W. SEIFRITZ : The problem of a detector for only a fast neutron sensitivity is related to the efficiency problem. All fast neutron detectors show a very low efficiency.

B. BAERS : The low efficiencies of fast neutron detectors require long, perhaps impractically long, observation times. Other, and perhaps more crucial, drawbacks of fast neutron detectors are the limited time resolution, which is not enough for many applications, and the difficulty in separating thermal and fast neutron detections in a simple, fast manner. To my knowledge no fast neutron detectors have so far been used on thermal reactors for observing the fast decay mode (ω_1).

G. KOSALY : In your verbal presentation you refer to the time constants ω_1 and ω_2 , which are the eigenvalues you obtain from the two-energy group, one-space point model. In a space dependent two-group theory ω_1 would correspond to the fundamental prompt decay constant while ω_2 would correspond to the first slowing-down harmonic. It is well known that there are a lot of decay constants falling in the range between the two of them. My question is that how were you able to get rid of those decay constants while you succeded in keeping ω_2 . I feel that one either removes all the decay constants other than the fundamental one, or keeps many decay constants but I do not see any practical means to keep ω_1 and ω_2 and remove all the others falling between them.

B. BAERS : The space-independent two-energy-group model predicts two distinct and fundamental relaxations (EQ.13) , which are associated with the fast and thermal groups of neutrons respectively. Other relaxation modes associated with space and energy effects have not been estimated but their amplitudes are probably smaller than the fundamental modes. The following data support our interpretation of the results and reduce the probability of misinterpretation. The estimates for the relaxation constants are obtained in several different ways, i.e. for detectors located in different places and for auto- and cross-correlation of neutrons and gammas. The experimental estimates roughly agree with theoretical predictions and gamma-neutron correlations specifically yield negative correlation amplitudes.

H. VAN DAM : In these highly subcritical systems you always have contamination by higher modes which give rise to a series of relaxation constants. This may partly explain the discrepancies between theory and experiment in your table IV. Would you comment on this ? Could you see these higher modes in your measurements ?

B. BAERS : The measurements indicate that there is some contribution from higher order modes in the vicinity of ω_1. These and other simplifications in the theory, inaccurate parameters in the calculations. and the poor statistical accuracy contribute to the discrepancies between theory and experiments in table IV.

K.J. SERDULA : How do you treat the delayed gammas that are a direct result of the fission events when you use only the gamma detector ?

B. BAERS : Based on the delay, the gamma (and neutron) emission can be divided into three categories (ref.4) : (1) the promptly released ($\lambda > \omega MAX$), (2) the slightly delayed ($\omega MAX > \lambda > \omega MIN$), (3) the spurious gammas which are emitted with a long delay ($\lambda < \omega MIN$). The constants ωMAX and ωMIN are the upper and lower bounds of the frequency range of interest. The delayed fission gammas. which mainly belong category (3). mostly contribute to the non-correlated part (A) of the correlation function and degrade the quality of the measurements. Because the delayed fission gammas on average have a lower energy than the prompt fission gammas, which mainly contribute to the correlation, the relative correlation amplitude (B/A) can be increased by discriminating against the low energy gamma radiation. In counting techniques such an improvement in the measurement quality can be achieved by electronic amplitude selection.

(9) Study of the power spectral density by a nonlinear response to the stochastic input -
Y. GOTOH

The non-linear response of a reactor to the stochastic reactivity input has been studied. The conditions for the system to be stable in the mean and in the mean square are derived for the Gaussian steady and for the white noise. respectively.

Taking the ensemble average of the equation for a covariance function and through the Fourier transform of it, an integral equation for the power spectral density is obtained, which includes the effect of a non-linear response on the stochastic input.

(10) Thermoelectrically generated noise in sheated thermocouples and in other low level instrumentation cables-

F. MATHIEU, R. MEIER, M. SOENEN, M. DELCON, C. NYSTEN

Starting from the fact that thermoelectric emfs of thermocouples are generated in the thermal gradients and not at the hot junction, it is shown how thermoelectric heterogeneity in conjunction with natural and forced convection phenomena gives rise to unwanted noise called : 'thermoelectric noise' in the technological sense.

A distinction is made between four different types of noise - i.e. uncorrelated noise, correlated noise, spectral noise and thermoelectric noise in the physical sense - each of which has its own characteristics.

The experimental results presented reveal that noise amplitudes may be quite embarassing when dealing with problems of quantitative signal fluctuation analysis.

It is however emphasized that thermoelectric noise may also convey useful information which, without noise, may be lost.

DISCUSSION

L.G. KEMENY : Could you please tell us the frequency content or the time constants of your observed noise signals ? What contrbutes most to the amplitude and frequency content of these signals ; is it
(1) heterogeneities in the thermocouples wire ?
(2) coolant transport along the length of the wire ?
(3) extraneous electrical field pick up ? How can these the eliminated so that only the desired hot junction signal is observed ?

F. MATHIEU : The generation of thermoelectric noise requires simultaneously : (1) a thermoelectrically heterogeneous wire, (2) thermal eddies. Amplitudes and frequencies depend on parameters like the degree of heterogeneity, the shape, magnitude and velocity of thermal perturbations, etc.---For the reported experiments a low level DC amplifier has been used which set a limit of 1.5 - 2.0 Hz to the upper frequencies. This value must however not be taken as a reference for practical applications where the noise frequencies are generally considerably higher. Noise injected by external sources is known from several years experience to be neglegibly small. One way to eliminate thermoelectric noise consists in making use of thermoelectrically homogeneous wires.

W. SEIFRITZ : Is it a presupposition to observe temperature fluctuations that a thermal temperature gradient along the cable is time dependent ?

F. MATHIEU : Yes, it is;uncorrelated, correlated and spectral noise are considered under this hypothesis. Thermoelectric noise in the physical sense on the other hand should be a property of matter, observable in the absence of any external thermal perturbation.

E. TÜRKCAN : In one of the figures you had P.P. noise level of 0.12 μV which means fluctuations of 0.003 °C . What is your amplifier noise level ?

F. MATHIEU : Fig. 8 reproduces, for documentary purposes only, the output of two instruments connected in series . Amplifier plus recorder. No quantitative use is made of these results. The amplifier noise level is higher than 0.12 μV but lower than the threshold value of 0.4 μV .

U. WESSER : What do you mean by nonhomogeneous wire ? Material composition, diameter variation, material composition variation, crystal structure variation or density effects ? Have you done measurements of diameter variations or correlations between noise and diameter variations ?

F. MATHIEU : The paper is based on a definition of heterogeneity which does not call upon the metallurgical, physical or geometrical condition of a wire.

A conductor is considered to be thermoelectrically heterogeneous if peak to peak signal fluctuations exceeding a given threshold are observed when a thermal perturbation moves along its length. We carried out experiments with wires of several nominal diameters but did neither measure diameter variations of the individual wires nor establish correlations between noise and diameter variations. This would in fact be a very tedious task with results difficult to apply to practical situations. As a rule the thermoelectric noise level increases with decreasing wire diameter.

H. NISHIHARA : I wonder if the author considered the difference in response times of the hot junction and of the heterogeneities along the elements? Usually the tip responds much faster to temperature than the heterogeneities of the elements sheathed in tubes.

F. MATHIEU : Our experiments were carried out without hot junctions. It depends on many parameters whether a hot junction responds faster than heterogeneities to external excitations, but it should not be forgotten that a slowly varying external periodic perturbation can generate much higher frequencies as illustrated by Fourier decomposition of the record og Fig. 6a .

(11) Regression filter for signal resolution -
W. MATTHES

We consider the problem of resolving a measured pulse-height spectrum of a material mixture (e.g. Raman-spectrum, gamma spectrum) into a weighted sum of the spectra of the individual components of the mixture.

If the measured spectrum is contaminated with noise, the standard least-square method cannot be used to unfold the spectrum into its individual components for small signal-to-noise ratios.

To improve the identification of the components in the mixture we constructed a 'stepwise regression' method which gives very good results even for signal to noise ratio of the order of one.

The new method is a combination of the least-square mechanism and repeated application of statistical tests.

DISCUSSION

M. MARSEGUERRA : Do you think that the procedure you reported will work if the components in the library change slowly going from one to the successive, as it may happen in unfolding of continuous spectra ?

W. MATTHES : Due to the lack of experience this question can not be answered generally. However this method was applied to unfold a superposition of Gaussian pulses of unknown number, positions and widths. Even in this case, where the components in the library changed very slowly the pulse-identification and the pulse-separation capability of the method was very satisfying. Note that in this case each library component is a Gaussian pulse of a well defined width at a fixed position and the components differ in a small change of the width and a small shift in position.

W. SEIFRITZ : What happens in the analysis using the 'regression filter' when the input functions are correlated with other ? Did you also compare your novel method with the standard method called 'partial correlation coefficient technique' which is usually used to treat these problems ?

W. MATTHES : The regression filter tries to identify given deterministic structures contained in a measured signal. This means that the library components are always more or less correlated due to the usual definition of a correlation between two signals as a time average of the product of the two components. Even in the case of strong correlation in this sense (slow change in the library components) the regression filter has good resolution performance. Up to now the regression filter was only compared with the standard least square mechanism.

D. SCHWALM : (1) How many iterations did you need in your example ? (2) Does the number of iterations depend on the number of components ?

W. MATTHES : In the calculations done up to now, including the example presented, the number of iterations was just equal to the number of components actually contained in the measured signal. The forward selection procedure identified step by step the correct components.

M. EDELMANN : (1) The power of the method you presented for identification of signal components is very impressive. However, it seems to me that it has the disadvantage that you have to know the components possibly present in the signal in advance. Is there any chance to overcome this draw-back,for instance in applying this method to the interpretation of power noise spectra? (2) Have you checked whether some of the components you added to the subset in the forward selection procedure could be omitted again in the backward elimination procedure ?

W. MATTHES : (1) If you consider it a disadvantage to require some knowledge about what you are trying to find, you are right. On the other hand, I would not know what to do with a measured signal without a specific question. (2) In one calculation (out of about 20) the backward elimination procedure was needed to eliminate one component. In all other cases the forward selection procedure was sufficient and the calculations terminated after the first elimination trial.

L.G. KEMENY : Have you made an assessment of the ultimate limotations of the non-linear least-square fitting technique ? At what signal-to-noise ratios and with how many unknown coefficients does this method become inefficient ?

W. MATTHES : The limitations of this method and its range of applicability were not investigated from the theoretical point of view. It could be a good work to construct a theoretical frame for this procedure. As much as I can say the resolution power of this regression filter breaks down for a signal-to-noise ratio smaller than one and for a signal-to-noise ratio of the order of ten the results of the direct least-square method and of this method converge. As for the number of unknowns, this method was applied to the resolution of mixtures containing at most ten components.

(12) Data acquisition and processing system for reactor noise analysis -
J. COSTA OLIVEIRA, C. MORAIS DA VEIGA, D. FORJAZ TRIGUEIROS, J. POMBO DUARTE

A data acquisition and processing system for reactor noise analysis by time correlation methods is described, consisting in one to four data feeding channels (transducer, associated electronics and V/f converter), a sampling unit, a landline transmission system and a PDP-15 computer. This system is being applied to study the kinetic parameters of the 'Reactor Português de Investigaçao', a swimming-pool 1 MW reactor.

The main features that make such a data- acquisition and processing system a useful tool to perform noise analysis are :

(a) the improved characteristics of analog-to-digital converters employed to quantize the signals ;

(b) the use of an on-line computer which allows a great accumulation a rapid treatment of data together with an easy check of the correctness of the experiments ;

(c) the adoption of the time cross-correlation technique using two detectors which bypasses the limitation of low efficiency detectors.

(13) **Time domain noise measurements for fast metal assemblies with Cf-252 -**
J.T. MIHALCZO

In this paper the author reviews and summarizes measurements made in the time domain with Cf-252 sources and a variety of fast critical assemblies. Cross-correlation measurements in the time domain were made between the two pulses : from (1) an ionization counter containing a Cf-252 neutron source, which provided the initiators of fission chains in a neutron multiplying assembly and (2) a sensor that detected the particles from the fission chains. These measurements were made with both unmoderated and polyethylene-moderated uranium-metal (circa 93 wt% U-235) cylindrical assemblies. The uranium masses were varied from 12 to 160 Kg , and the prompt-neutron decay constant ranged from $3 \cdot 10^3$ to 10^8 sec^{-1}.

The possible application of this method to determine the prompt-neutron decay constant in plutonium was studied with unmoderated plutonium-metal assemblies. The plutonium masses were varied from 2.2 to 16 Kg, and the spontaneous fission rate from Pu-240 ranged from 4.5 10^4 to 8.2 10^5 fissions/sec. These assemblies included spheres and parts of spheres of plutonium, with 4.5 to 20.1 at.%Pu-240.

Conventional one- and two-detector Rossi-alpha measurements were also made for many of these systems. The ratio of the correlated count rate from a Cf-252 measurement to the correlated count rate from a Rossi-alpha measurement was inversely proportional to detection efficiency and as large as 8000 for some assemblies when both measurements were made. The decay constant could be determined within a few percent in less than 10 min for a uranium cylinder with a mass as small as 12 Kg . The decay constant can be measured by this technique for plutonium with as much as 20 at.%Pu-240 . Thus, the use of Cf-252 allowed the determination of the prompt-neutron decay constant without the use of a complex pulsed neutron source. A subcriticality monitor for uranium and plutonium metal based on this technique is feasible.

Other measurements at delayed critical were performed to determine the effective delayed-neutron fraction for bare and natural-uranium-reflected uranium and plutonium delayed critical spheres. These measurements, in which the various other parameters in the time correlated component of the decay were individually measured to 1% accuracy, serve as the basis for a verification of the theory of the measurements in the time domain to within a few percent. Measurements with uranium spheres were made of the Oak Ridge critical experiments facility, and those with plutonium or natural uranium reflectors were made at the Pajarito critical mass laboratory of the Los Alamos Scientific Laboratory.

In the delayed-neutron determination, the ratio of the correlated counts was obtained with a type 1 analyzer with a variety of Cf-252 sources and detectors. The location of the Cf-252 source and the detector were varied to verify that the value of the delayed-neutron fraction did not depend on the location of the detector. The spatial distribution of the neutron importance, required for determination of the spatial effects factor R, was measured by positioning a 'point' source of Cf-252 at various radii in the spheres and assuming that the count rate for externally located detectors was proportional to the neutron importance. The relative importance of the neutrons from Cf-252 ionization chamber was obtained from similar measurements, since the absolute values of the source intensities were known. The fission density also require for the calculation of R was obtained from foil activation measurements. The quantities involving the number of prompt neutrons per fission are obtained from other measurements. The values of the effective delayed-neutron fraction agreed with the accepted values for this system within a few percent.

(14) Spectral density measurements with a mockup of the Fast Flux Test Facility reactor - J. MIHALCZO, V.K. PARE, M.V. MATHIS

This paper describes two series of noise analysis measurements that were made witha mockup of the FFTF, which is a liquid-metal fast breeder reactor (LMFBR). The first demonstrated the adequacy of in-core noise analysis measurements for reactivity determinations down to 30 dollars subcritical and resolved the discrepancies of previous measurements. The second tested the feasibility of a new reactivity determination method.

In the first series the reactivity of the mockup was determined by breakfrequency noise analysis (BFNA) over a wide range of reactivities down to 34 dollars subcritical. The purpose of this first series was to test and evaluate all reactivity measurement methods that showed promise for use in critical experiments and LMFBR applications. These measurements also verified the adequacy of the proposed detection system and reference concept for subcriticality monitoring in the FFTF. The results from the BFNA were compared with results from the inverse kinetics rod-drop (IKRD) method for reactivities down to circa 10 dollars subcritical and from the modified source neutron multiplication (MSM) measurements for reactivities down to 34 dollars subcritical.

Another purpose of this first series was to resolve the discrepancies observed in 1970-72 by different experimenters (at ORNL, HEDL and ANL) between their results from β/Λ measurements at delayed criticality and from subcriticality determinations in fast plutonium-fueled reactor systems. Some of these discrepancies were briefly : an apparent dependence of β/Λ on detector type and location was observed at delayed criticality with the homogeneous mockup of the FFTF ; and BFNA and IKRD measurements made with the mockup of the FFTF were different but measurements made by these two methods at the SEFOR were in agreement.

To resolve these discrepancies and to evaluate spatial-and energy-dependent effects on these measurements, 15 detectors (Li-6 glass scintillators, fission counters and He-3 ionization chambers) were installed at various locations in the core radial and axial reflectors and in the low-level flux monitor position outside the reactor in the shield. Measurements of β/Λ at delayed criticality showed no dependence on detector type or location . However, as the reactivity was decreased, the dependence on detector location increased until the reactivity determined by BFNA between the core and the reflector differed by 50% at 30 dollars subcritical. The agreement of results from BFNA measurements with in-core detectors and those from IKRD or MSM measurements was excellent, i.e., at 34 dollars subcritical, the difference between BFNA and MSM results was only 4%.

The purpose of the second series was to determine the feasibility of a new method of determining reactivity by using Cf-252 as described in the previous paper. For these studies, the loading of the mockup of the FFTF was changed to simulate the initial loading of the reactor. The real and imaginary parts of spectral densities were measured simultaneously as a function of frequency for reactivities from 0.8 to > 50 dollars subcritical to form the ratio $G^{*}_{12}G_{13}/G_{11}G_{23}$. The constancy of this ratio with frequency and the ratio of the real to imaginary part of G_{12} multiplied by frequency verified the theory presented in the previous paper based on point kinetics. The reactivities determined in the preliminary analysis by a variety of methods showed general agreement among methods, thus demonstrating the feasibility of the method employing Cf-252 in the frequency domain.

(15) **Heat transfer coefficient and some other reactor parameters determined from measurements of fuel temperature and neutron flux fluctuations-**
R. ISNARD (presented by J.P. Schneeberger

Noise analysis experiments were performed in the swimming pool type reactor SAPHIR at the Institute for Reactor Research in Wuerenlingen and SILOETTE at the Nuclear Studies Center in Grenoble : from these experiments the fuel-coolant heat transfer coefficient, the neutron lifetime and the decay constant of precursors were determined. The reactor power was in the range 1,50 W to 50 kW. The temperature fluctuations were measured using small thermistors built respectively in a fuel plate and in a dummy aluminium fuel plate, the two thermistors being branched in a Wheatstone bridge; maximum sensitivity of the device being 5×10^{-5} °C. Conventional ionization chambers were used as neutron fluctuation detectors. After amplification and filtering the temperature and neutron signals were recorded on magnetic tape for further processing with correlator and Fourier tranformer, giving the thermal and neutron power spectral densities.

The stochastic point model representing the reactor involved the number of neutrons, of precursor nuclei and the fuel temperature as random variables. Good agreement was achieved between measurements and theoretical values :

Measured and calculated heat transfer coefficient γ [W/m² °C]

normal convection	230 ± 35	252
forced convection	890 ± 90	959

DISCUSSION

L.G.KEMENY : Were you able to obtain some phase information in your measurements ? If so, did you calculate the neutron flux to fuel element temperature transfer function and fuel element time constant ?

J.P. SCHNEEBERGER : Yes, theoretically, because we have recorded fuel temperature fluctuations and neutron noise. As it is shown in the first part of reference (1), it is easy to calculate the cross-power spectral density between neutron population and fuel element temperature, and so, the gain and the phase of the neutron flux to fuel element temperature transfer function. The fuel element time constant is given by the relations (3) and (4). Unfortunately, we could not get this time constant by measurement of $\hat{P}_{NT}$. The pieces of recorded fuel temperature and neutron fluctuations are disjoint, because we had to adjust the neutron flux signal (to remove the DC current) more often than the fuel temperature one. Then, it was not possible to perform further measurements in this reactor in a suitable time delay, so we cannot get the neutron flux to fuel element temperature transfer function. However the fuel element time constant is given by the cut-off pulsation of $\hat{P}_{TT}$.

M.J. BRIDGE : Why could the fuel temperature coefficient not to be obtained from the measurement and what is the sensitivity of the fitted heat transfer coefficient to the fuel temperature coefficient ?

J.P. SCHNEEBERGER : The reactivity temperature coefficient modifies the power spectral densities or cross power spectral densities only in low frequency range (f some 10^{-3} Hz). The cross power spectral density between neutron population and fuel element temperature is rather sensitive to this coefficient if this one is equal or greater than a few pcm/°K , and if the heat transfer coefficient is not too large. So, if measurements of this cross power spectral density had been made, we could have got an order of magnitude for this reactivity temperature coefficient. On the other hand, neutron power spectral density $\hat{P}_{NN}$ and fuel temperature power spectral density $\hat{P}_{TT}$ are insensitive to the reactivity temperature coefficient of few pcm/°K .

L.G. KEMENY : Have you thought of obtaining both amplitude and phase information in your measurements and determining the fuel rod transfer function and perhaps reactivity coefficient ?

J.P. SCHNEEBERGER : As we just said the cross power spectral density between neutron population and fuel element temperature could not be measured, so we had no phase information. But $\hat{P}_{TT}$ gives the same amplitude information as $\hat{P}_{NT}$. Theoretically, there is an other way to get the reactivity temperature coefficient. The covariance equations, which are limit conditions of the correlation equations determinated from Fokker-Planck equation gives $\partial\rho/\partial T_u$ the reactivity temperature coefficient, if you make some assumption and if you measure σ_N and σ_{Tu}. This idea is included in the historical Harris'paper.

(16) Measurements of kinetic parameters by noise techniques on the Minerve reactor -
J.C. CARRE and J. DA COSTA OLIVEIRA
(presented by D. de Lapparent)

This paper is dealing with two topics :

- noise measurements on ERMINE without feedback
- noise measurements on ERMINE with an automatic control rod.

ERMINE is a fast thermal coupled reactor built in MINERVE.

There are two applications, in low power reactor, of the pile noise theory with a point kinetic model.

The first one concerns the measurements of auto and cross power spectral density obtained with one or two neutron detectors, and the determination of several parameters :

- neutron lifetime
- efficiency for one ion chamber
- power level of the reactor
- maximal speed and acceleration of a control rod for the design of an automatic reactor control actuator.

The second one is dealing with the measurements of the auto power spectral density in reactivity for the control rod and the estimation of :

- the transfer function of the automatic pilot
- the neutron lifetime
- the standard error affecting the results obtained with the oscillation method.

DISCUSSION

T. NOMURA : What is the noise source of external noise source you mentioned ? Is the vibration the only noise source ?

D. DE LAPPARENT : The noise sources are multiple : vibrations of core, of control rod, vibrations of coolant flow pump, temperature fluctuations of coolant flow---

K. SAITO : In connection with Dr Nomura's question, I make a comment. Variance is one of the characteristic figures of fluctuations. Dr Oka in Tokyo University also measured variance and studied its power dependence. In zero power reactors variance increases in proportion to P. As the nuclear power increases, the variance increases more rapidly. Dr Oka also found the term which is proportional to P^2. He attributed the origin to the temperature fluctuations.

M. EDELMANN : As a comment to the question raised by Dr Nomura, I would like to point out that in the paper by Dr Väth I will present in the last session of this meeting the effect of a control loop on the power spectral density of neutron detector signals is investigated in detail. In this paper it is shown that the additional noise in a controlled reactor is due to the detection noise of the control detector which drives the control system, as predicted by Borgwaldt from theoretical considerations. This detection noise causes a reactivity modulation in the control loop which produces the power fluctuations responsible for the additional power spectral density contribution.

D. SCHWALM : I believe that the formula $\sigma^2 = aP+bP^2$ is theoretically incomplete in a power reactor. The complete formula must contain a term cP^4.

D. DE LAPPARENT : With our simplified model we obtain only

$$\sigma^2 = a + bP + cP^2 .$$

We are presently working in order to improve this model.

(17) Investigations of the two-detector covariance method for measurement of coupled reactor kinetics parameters -

M. EDELMANN , J. EHRHARDT , W. VAETH

For the measurement of point kinetics parameters of zero power reactors many different methods have been widely used and described in the literature. These include Rossi-alpha, probability distribution, variance-over-mean, frequency analysis and polarity correlation of neutron detector signals. The determination of coupled kinetics parameters using the two-point reactor model has been published for a variety of methods including the Rossi-alpha method and frequency analysis of neutron noise.

This paper describes for the first time investigations of two-detector covariance measurements and their application to the determination of coupled kinetics parameters. The results will be compared with the afore-mentioned two methods.

The measurements have been performed at the Argonaut Reactor Karlsruhe (ARK) with a symmetrical two-slab core loading for different subcritical levels. Signals from two neutron counters placed in each zone of the reactor were analyzed in two different ways.

In the first method the two-dimensional probability distribution of the number of counts from the detectors was measured using a small digital computer. The computer was used to control the gating times of two specially designed counting registers and to calculate the first and second moments. From that the covariances were calculated in real time and displayed on a CRT as a function of the counting time interval.

In the second method the variance and the covariance of the detector pulses were directly measured without using the probability distributions. For this purpose a new analyzer based on a special calculational algorithm was developed. This method has the advantage that a relatively small amount of hardware is necessary.

Theoretical formulas for the varaince and covari ance in a symmetrical two-point reactor model were derived. The material properties and neutron lifeti mes for each reactor zone were assumed equivalent. The transport time of neutrons from one zone to the other was neglected. The parameters in the model in clude the decay constant of prompt neutrons and the coupling reactivity of the two core zones. These pa rameters were determined by least-squares fitting the experimental data to the theoretical curves.

The results are in good agreement with those of independent measurements done by a dead-time-free Rossi-alpha method. However for two-point reactor model the covariance method is applied advantageous ly because information about coupling influences all measuring points. Therefore covariance method exhibits a smaller error in estimation of coupling para meters than Rossi-alpha method. This is in contrast to point reactor experiments, where both methods are almost equivalent. In addition the strong influence of detector dead-time losses was taken into conside ration and a correction formula was developed.

DISCUSSION

W. SEIFRITZ : Did you generalize your formalism to non-symmetrical systems as it is done by Dr Viehl ? Is Dr Mihalczo interested in extending the Cf-method to measure the coupling reactivity in metal systems presented previously ?

M. EDELMANN : No, we derived formulas for Rossi-al pha and variance measurements only for symmetrical reactor models. But as far as I can see at the moment, the same procedure would apply to non-symmetrical systems too. However, the resulting equatio ns would be much more complicated due to the incre ased number of parameters which have to be taken in to account in this case. And if the difference between kinetic parameters of the two nodes were small, it would be difficult to determine all of them from the mesured curves by least square fitting methods.

N. PACILIO : In 1967 pulsed-neutron experiments were made on two organic-moderated and -reflected coupled cores of the ROSPO (a zero-power organic-moderated reactor) nuclear system in order to investigate their time response and to measure some kinetic and reactivity parameters. At least for loose coupling, the fundamental mode has been observed to have two time-decay constants in any point of the system (except in the vertical symmetry plane), which are strongly interrelated. For two identical cores, these decay constants can give separate information on the intrinsic and coupling reactivity as well as on the reduced neutron lifetime of the system.

(18) Studies of neutronic coupling by reactor noise analysis in the time domain for facilities of RCN,„Petten

E. TURKCAN and J.B. DRAGT

After a review of the existing literature on determination of neutronic coupling parameters from reactor noise, the paper gives a survey of the work on this subject done from 1967 at RCN, Petten, using noise analysis in the time domain.

A summary is given of the Avery theory and its approximations to describe coupled reactor systems and the formulas used for the analysis of the noise are reviewed. In particular a method is described which is based on a differential equation which connects measurable auto- and cross-correlation functions with a matrix of kinetic parameters, including couplung parameters,('reactor matrix'). By a matrix inversion technique this reactor matrix and eigenvalues (= decay constants of prompt modes) can be found from the set of correlation functions as a function of the delay time. If matrix elements and eigenvalues are found to reach quickly asymptotic values for increasing delay time, the measurements support the underlying model.

A short description is given of the experimental set-ups. Both continuous signals from ionization chambers in critical systems and pulses from neutron counters (BF_3 or He-3) in subcritical conditions have been processed with digital computers, partly on-line in real time. Auto- and cross-correlation functions are determined by direct calculations,by a multi-detector Rossi-alpha algorithm and in a few cases by a probability method. Neutronic coupling measurements have been performed in the LFR with two slab core and annular core, in the STEK-Argonaut with four coupled thermal cores, and with the various fast-thermal coupled systems STEK-4000, -3000, -2000 and -1000 with a detector in each zone.

Experimental results are shown, namely an early determination of coupling reactivity for two weak-

ly coupled slabs in the LFR, the application of the matrix inversion technique for various LFR-cores and the STEK-Argonaut, and the attempts to determine the reactor matrix in more-or-less strongly coupled fast-thermal STEK cores.

It was found that the methods of analysis worked well, that accurate coupling parameters could be determined, and that theoretical predictions were confirmed for the various weakly coupled thermal cores. The measurements in the fairly strongly coupled core STEK-4000 could be interpreted by a two-point model but the matrix inversion technique could not be applied. This technique could be used for the slightly weaker coupled other STEK cores with more pronounced higher modes effects.

It was found for these cores that the asymptotic values of the reactor matrix elements and eigenvalues are only very slowly reached. Moreover, the amplitude of the fundamental mode appear inconsistent with the expectation of a two-point model. Also Avery model calculations (two-dimensional 26-group diffusion theory) have been applied for these cores, but led to correlation functions and reactor matrix different from the experimental data. It is concluded that the straightforward two-zone Avery model does not apply here and that a two-mode analysis is not sufficient to describe a system like STEK.

An extension of the analysis to more than two modes or nodes would require a modification of the present theory, which gives no possibility to account for more nodes (or modes) than detectors.

(19) Temperature noise measurements in blocked and unblocked 19-pin electrically heated LMFBR fuel subassembly mockups -
D.N. FRY

Introduction - Sodium temperature noise was measured at the exit of a simulated fast reactor fuel subassembly to determine the feasibility of using temperature noise monitors to detect flow blockages in fast reactors. Noise from both blocked and unblocked test bundles is being characterized using various noise signal descriptors such as power spectral density, amplitude probability distribution, and root mean square (rms).

Investigations by others - Bentley suggested that small, slowly occurring blockages might be detected by measurement of coolant outlet temperature fluctuations (noise) due to turbulence. He investigated this hypothesis in a mockup of a sodium-cooled fuel element with electrically heated simulated fuel clusters. In this reference, he proposed a simple theory of how the thermal mixing process of the coolant causes temperature noise.

Mika et al. observed that coolant temperature fluctuations depended on the sodium flow rate and heat flux, and from this observation they concluded that temperature noise monitoring might be useful for detecting anomalous reactor behaviour during power reactor operations.

Investigations at ORNL - These previous investigations were with unblocked bundles. We extended these studies by measuring outlet sodium temperature noise at the Failed Fuel Mockup (FFM) with and without blockages in the test bundle. The FFM is a 19-pin, electrically heated mockup used to simulate the wirewrapped fuel pins in a portion of a liquid-metal fast breeder reactor fuel subassembly. To block the flow of sodium coolant, a 1/8-in. thick plate was placed 4 in. down-stream from the start of the heated zone (total heated length was 18 inc.). Approximately 1/3 of the cross-sectional flow area was blocked. Sodium temperature noise was measured in the center of flow channels across the bundle exit by 11 stainless steel sheated, grounded-junction, Chromel-Alumel thermocouples. Measurements were made for flow velocities of 2.7 to 7.2 m/sec and heat fluxes of 71 and 85 w/cm^2. Thermocouple analog signals were recorded on magnetic tape and are being analyzed using a fast Fourier transform digital frequency analysis program.

Results - The data were analyzed to determine power spectra and rms noise levels within the band-pass of the thermocouple (0-1 Hz). The observed dependence of rms temperature noise level on sodium flow rate and heat flux agrees with earlier observations by Mika et al. ; that is, the bundle exit temperature noise increased as the coolant flow rate decreased and increased as the heat flux increased. An unexpected result was that the exit rms temperature fluctuations with a blocked bundle were circa 3 times lower than with an unblocked bundle at the same heat flux and flow rate. We are analyzing the recorded thermocouple signals in greater detail to find an explanation for this unexpected result.

(20) Dynamic heat transfer experiments in an electrically heated LMFBR fuel element mockup
D.N. FRY , T.W. KERLIN , W.H. SIDES

Experiments were performed at the Fuel Failure Mockup Facility to obtain data for use in determining transfer of heat and flow paths in simulated LMFBR fuel bundles that were operated with and without flow blockages. The heat input to one rod of a 19-rod bundle was modulated, and the temperature responses were monitored with thermocouples at various positions of the bundle. The experimental data were processed to yield frequency responses for the measured thermocouple-heater pairs.

The frequency responses showed that the measure ment is sensitive to local heat transfer and flow conditions, especially for blocked bundles. However, the current state of the capability to analyze the detailed behavior of complex bundles with blockages is inadequate to provide theoretical models that will assist in interpretation of experimental results. Therefore, this report is limited to a discussion of the experimental results and the influence of bundle features on these results.

The results are grouped into two categories : steady state, and higher frequency. The steady state results are obtained from the low-frequency gain, which is identical to the asymptotic response to a step input. The reason for using frequency response tests to obtain steady state results is that, in essence, the step change is made many times and averaged to give amore precise estimate. The higher-frequency results are exploited when differences in time constants, transport delays, etc., cause the frequency dependence of the output to vary from one system configuration to another.

The steady-state results indicate the following :

(1) The steady-state gain varies with flow to the -0.75 power for thermocouples 'near' the heated rod, and to the -1.7 power for thermocouples 'far' from the heated rod.

(2) Steady-state gain can be used to construct energy flow maps with vectors whose lengths are proportional to energy flow, relating selected heater effects to selected thermocouples responses. These maps show the edge swirl effect caused by the wire wrap spacers in the bundles.

(3) The ratio of temperature increases detected by two thermocouples at two different axial positions was compared with the ratio of respective heated lengths. In an isolated, uniformly heated channel, the ratios should be equal, and deviations from equality would indicate either overcooling or undercooling. Both of these effects were observed, including a radial dependence of the ratio for thermoco-

uples near an edge blockage.

The higher-frequency results show the following :

(1) Results obtained at a point 12 in. into the heated section of a bundle with a blockage 3 in. upstream from the start of the heated length are identical with those obtained from an unblocked bundle.

(2) Four different types of behavior are observed near the breakfrequency.

(a) Gains at all flow rates were different at low frequencies, but converged at higher frequencies. This behavior is observed for at least some of the heater-thermocouple pairs in all blocked and unblocked bundle tests.

(b) Gains at all flow rates were different at low frequencies, and gain vs frequency curves cross at higher frequencies. Curves that start at the lower frequencies with the lowest gain values reach values at the high frequencies that are as much as 20% higher than gains for other flows. This occurs mainly with unblocked and entrance blockage bundles.

(c) Gain curves cross as described in the preceding paragraph (b), but the crossing is much more pronounced. Curves that start at the lower frequencies with the lowest gain values reach values at the higher frequencies that are three times as large as gains at other flows. This occurs only for bundles with centrally located blockages in the heated section.

(d) Gains start at different values and never converge. This occurs only for bundles with edge blockages in the heated section.

Although these results were obtained for several heater-thermocouple combinations, many potential comparisons could not be made because sensors were not available in desired locations. These results indicate that this type of measurement is sensitive to changing heat transfer effects in different bundle configurations.

The data presented here provide an initial data base for any correlations of theory and experiment that will be needed should an analytical capability be developed for predicting the detailed performance of wire-wrapped bundles with internal blockages.

DISCUSSION

L.G. KEMENY : Have you carried out any single pin experiments prior to looking at a cluster ? Is there any correlation between single pin and pin cluster experiments ?

What is the effect of axial eccentricities of individual pins on the heat transfer in the cluster ? Did you calibrate your test section by making flow and temperature measurements prior to placing the cluster into position ?

D.N. FRY : We have performed no single pin experiments; all dynamic heat transfer and temperature noise work in the FFM has been utilized in 19-pin bundles.

If by 'axial eccentricities' you are referring to pin bowing , the answer to your question is that we have not investigated this phenomenon and its effects on heat transfer in any detail. It is our opinion that eccentricities of individual pins will not noticeably affect the total bundle heat transfer. There may be a small local effect but the very high coefficient of heat transfer between the stainless steel cladding and sodium is expected to minimize the overall effect.

There were no calibrations made before the test bundle was installed, nor do we see the need for any. Isothermal runs were performed, however, before each test to calibrate the thermocouples. Heat balances between electrical power input to the cluster and flow-Δt measurements were calculated for each test.

M. EDELMANN : (1) You conclude that faster thermocouples than those you were using are needed to detect blockages from temperature fluctuations. Are there some indications that at higher frequencies the magnitude of the temperature fluctuations will be larger than below 1 Hz where you have measured them ? (2) In any case the magnitude of the temperature fluctuations due to the blockage seems to be small compared to that of the fluctuations present at normal operating conditions. Is there a chance to detect blockages in spite of this background problem ?

D.N. FRY : (1) We have no reason to believe that the magnitude of the temperature fluctuations will be larger at frequencies above 1 Hz. However, if one is measuring the magnitude of root-mean-square noise the statistical uncertainty will be smaller for a given measurement duration if the noise bandwidth is larger. Fast response thermocouples would also allow the investigation of the total temperature noise spectrum caused by blockages, and thereby a better understanding of the mechanisms that cause temperature fluctuations and the manner in which the noise spectrum changes as a function of distance from the blockage.
(2) This is the question we are attempting to answer with our investigations, but we don't have the answer yet. The blockages studied thus far have been of the thin plate type. It is possible that longitudinal blockages (due to pin bowing or swelling) may produce more noise than the blockages studied thus far.

H. BUNSCHI : (1) Are there forseen experiments where you vary the distance between the blockage and the detector ? Because, if the named distance gets small, the contribution of the high frequencies can not be neglected anymore,i.e. a fast thermocouple is important. (2) What was the lower break frequency of your band pass ?

D.N. FRY : (1) Yes, I plan to propose either a moveable thermocouple rake or an axial string of fixed thermocouples for future experiments. (2) The low frequency cutoff was approximately 0.02 Hz in these measurements.

D. SCHWALM : (1) Did you use also the histogram in order to detect blockages ? (2) As you asked for suggestion I would like to give you one : you want to detect a blockage in subassembly with the aid of only one detector. In your experiment the detectors were installed just at the end of a subchannel. Hence such a detector cannot 'see' what is going on in the neighbouring channels. Hence my suggestion would be to look for a detector position downstream the coolant flow at a certain distance from the bundle exit where it 'sees' the total subassembly cross section.

D.N. FRY : (1) Yes. Our observation was that the amplitude probability density function of temperature fluctuations was not always Gaussian. (2) We hope to have detectors at different locations downstream of the bundle exit in future experiments.

W. SEIFRITZ : You asked for thermocouples with a fast response ; I call your attention to the paper of Dr Bunschi and myself in which a prompt response thermocouple (for temperature fluctuations measurements in sodium coolant) will be presented. It is not strange to observe a probability density distribution of temperature fluctuations which is not Gaussian. The skewness of such distributions are often used in turbulance research to extract useful and additional information.

D.N. FRY : I am looking forward to hearing your paper. We hope to shorten the response times of the thermocouples employed in future FFM experiments. We share yuor opinion that the probability density distribution can provide additional information about the character of the temparature fluctuations caused by blockages.

L.G. KEMENY : What background effects do you have due to vibration ?

D.N. FRY : We aren't aware of any temperature noise that is due to vibration.

G. KOSALY : In your presentation you mentioned the contribution of the conduction to the axial heat transport. People usually neglect this contribution at these high velocities thinking that it is the convection that dominates. Have you found any indication showing that this is not the case ?

D.N. FRY : No. My statement was, in conclusion, that it might conceivably be possible to separate convection and conduction effects by measuring the dynamic heat transfer. We have not attempted this for two reasons: (1) we lack a good dynamic model of heat transfer in multi-pin geometry, and (2) owing to a combination of slow heater and thermocouple response times, the transfer functions could be obtained experimentally only up to a frequancy of about 1 Hz (which is probably too low to separate convection and conduction effects at the flow velocities used) .

K.J. SERDULA : In determining your response functions between thermocouples, you would require that the transfer function of the thermocouples are the same. Was this checked out ?

D.N. FRY : Yes. Although the thermocouples were of the same manufacture, they could not be expected to have identical time responses. We did not have a reliable method to measure the in situ response characteristics of installed thermocouples. Therefore, all of our data interpretations were based on single thermocouples at different flow rates or, when comparing measurements between thermocouples, we restricted our attention to frequencies well below the breakfrequency of either thermocouple.

(21) Interval distribution measurement of chain-related nuclear processes using two detectors - P.A. HALDY and M. CHIKOUCHE
(presented by J.P. Schneeberger)

On the basis of the Kolmogorov's theory of branching stochastic processes a probability generating function of neutron counts in four time intervals was developed. This generating function leads to the distribution of time intervals separating counts collected by a trigger detector from those collected by a second one.

Experiments were performed in the CROCUS U-H_2O zero power thermal reactor at the Swiss Federal Institute of Technology in Lausanne, using a BF-3 counter as trigger of a multichannel analyser and a He-3 detector for the intervals determination. From these measurements the neutron generation time as well as the detector efficiencies were determined with good accuracy.

(22) The impact of twenty years of noise research on nuclear power plant design, instrumentation and control -

L.G. KEMENY

Some 20 years have elapsed since the first technical papers began to appear in a general field which can be loosely described as the statistical nature of the nuclear fission reaction and its influence on the criticality and dynamics of nuclear power systems. A few years subsequently, the first zero energy 'neutron noise' measurements were reported in the scientific literature. These investigations clearly demonstrated that the time constants and the dynamic characteristics of low energy nuclear systems could be elegantly determined by the correlation or spectral analysis of fluctuating signals from ion chambers and proportional counters. The analysis of the time series information and the multi-filtering operations in the frequency domain were time consuming and tedious projects due to the non-availability of suitable data processing equipment.

In the 1960's, the significant advances in the field were the recognition of the advantages of the two-channel cross-correlation technique and the realization that the dynamic behaviour of the nuclear power plant at power could be monitored and studied in depth by the cross-correlation method of mechanical, thermal and hydrodynamic signals with neutronic information. The former concept gave the spur to the development of theoretical models for spatial and energy dependent noise fields within a nuclear system. The latter technology, in principle at any rate, opened a floodgate of potential advances in nuclear power plant design optimization, control and safety instrumentation, and control and safety diagnostic systems.

The present decade has seen the interaction of workers in the reactor noise field with workers investigating general vibrational phenomena and the structural mechanics of nuclear power plant. Despi te this, it is sobering to reflect in retrospect that neither design, nor instrumentation and control concepts arising from noise research, have fo und any great measure of practical acceptance in current nuclear technology.

This paper explores the reasons for this unsati sfactory situation, surveys the few available prac tical examples of accepted noise technology, and makes some definitive proposals with regard to the future implementation of nuclear power plant design , instrumentation, and control procedures, based on the concept of stochastic models and noise analysis.

DISCUSSION

H. KATAOKA : In the nuclear science and engineering field, often technical terms are confused and the conception of them is also confused. Today you mentioned a power reactor and I would like to know how do you mean by your power reactor. The technical term 'power reactor' is used for different meaning depending on each case, as follows, : (1) reactor which is used for power production, (2) reactor in which feedback effect is influential, (3) reactor which can be operated at high power, (4) reactor which is operated nearly at full power ,(5) etc.

L.G. KEMENY : In context of my review paper, the term 'power reactor' implies a nuclear chain reactor system which has been designed for power produ ction. From a purely physical point of view it would not be incorrect to class reactors with significant temperature feedback effects as power reactors.

H. KATAOKA : You analyzed the transfer function of HIFAR. In order to apply transfer function techniques we must assume the system is strictly linear. On the first day Dr Nomura introduced Dr Gotoh's paper and in this paper Dr Gotoh showed so called non-linear characteristics of reactor kinetics.

What do you think about non-linear kinetics of HIFAR ? And the other reactors ?

L.G. KEMENY : The theme for our meeting here in Rome is reactor noise. One of the main attractions of the noise signal from nuclear plant is that it is closely associated with linear or self-linearizing systems. In other words, in most of our stochastic models for reactor noise we do expect the cross product of neutron density with reactivity to significantly influence the physical characteristics of the relevant noise fields in a non-linear sense. The non-linear characteristics of reactor kinetics are important when we are considering large reactivity excursions leading to significant power surges. These are vital considerations when we simulate start-up, shut-down and accident conditions, such as loss of coolant in power reactor studies. It is of lesser importance in an 11 MW research reactor such as HIFAR.

D.N. FRY : (1) What sensor was used to detect the 10 Hz vibrations of control rods ? (2) Was the 5.2 Hz frequency also due to control rod vibration ? (3) How did you eliminate the vibration of the control rods ? (4) Did you cross-correlate the thermocouples you placed on the fuel elements with neutron signals ?

L.G. KEMENY : (1) We used sensitive RC6EB enriched boron ion chambers and the two channel cross-correlation technique. (2) The 5.2 Hz frequency is also a control arm vibrational effect but seems to disappear more easily than the 10 Hz resonance as the control arm angle changes or the number of D_2O pumps in operation is varied. (3) We have a simple mathematical model for the control arm vibration and, in principle, can eliminate the vibration in a simulation on a computer. However, it has not so far been considered an important enough engineering task to design and build hardware for on-line vibration control. (4) So far there has been no cross-correlation of neutronic and temperature signals. Our work on fuel element identification has recently commenced and the investigation of thermal and neutronic interaction and its potential application to safety diagnostics will be one of our first tasks.

(23) Fundamentals of theoretical analysis of power reactor noise and their applications -
K. SAITO

The present paper consists of two parts : part 1 describes the basic concepts and the fundamental physical-mathematical methods which have been and the present author believes will be used in the due course of theoretical analysis of power reactor noise ; whilst part 2 is concerned with the results of the practical application of the above concepts and methods.

Part 1 - Zero-power reactor noise is now basically so understood that the phenomena stand as a field of branching processes in the theory of stochastic processes. The concepts and the methods developed bring about novel consequences in the conventional theory of branching processes as well as furnish a sound basis for constructing power reactor noise theory.

Power reactor noise can be, however, more explicitly understood, when one regards that it covers a field of the non-equilibrium classical statistical physics. Furthermore, in order to attain our aim of applying the noise analysis method to reactor diagnosis, we cannt avoid confronting with the non-stationary noise phenomena. No complete or general theory of the non-equilibrium, non-stationary statistical physics is developed. Rather, we are contributing to building up, at least, the non-quantum aspects of the grand theory.

The familiar Langevin's method, which is based on the linear response theory of the first-order Markoffian processes, has been successfully applied also to analyze the power reactor noise.

Power reactors have, however, the retarded or feedback effects in their nature. When one tries to explicitely incorporate the effects, then one must treat the non-Markoffian processes. An applicable method of their treatment is the recently developed Langevin's method which centers upon the fluctuation dissipation theorem.

Sometimes we encounter the problem of random parametric excitation in formulating our noise phenomena, particularly in solving the random vibrations of fuel/control elements and the random transportation of bubbles in fluid. Then we have a set of non-linear stochastic equations which requires a fairly sophisicated mathematical consideration to have a reasonable solution.

When a nuclear reactor happens to be subjected under an abnormal state, then it gives rise to a non-stationary noise at the onset. The basic theoretical formalism is still lacking, because the non-stationarity is often defying the ergodicity.

Part 2 - Most of the actual theoretical analysis on power reactor noise have been performed in the framework of the linear response theory of Markoffian processes. The results obtained are fruitful in spite of the fact that the actually used analytical models are too simple to completely describe the power reactor noise phenomena which are the coupled ones of neutronics, thermo-hydrodynamics as well as mechanics.

Analysis upon the lumped model of reactor dynamics succeeds in explaining fairly well the often observed anomalous rise in the lower frequency region of the power spectral density (PSD) of power noise.

Numerical analysis upon the distributed model gives, on the other hand, quitely peculiar pattern of PSD's, which will be observed when a prevailing noise source exists in a particular state variable of cores at a particular position of the fuel/coolant channel. Its analytical model is still too simple, but the obtained reslts stand the promising starting point to apply the noise analysis to reactor diagnosis.

Numerous sheets of figures collected at the laboratory of the present author will endorse the above statements.

DISCUSSION

G. KOSALY : I do not understand your Fig.14. The presence of the dip-lump structure reflects a transport behavior by flowing coolant. On the other hand the water being incompressible the fluctuations of pressure are not transported with coolant velocity but much faster.

K. SAITO : The direct fast effect of pressure fluctuations will appear in the much higher frequency range, probably in the KHz region. The dip-lump structure in the Hz region reflects an indirect slow effect which is propagated via coolant velocity/density - coolant/fuel temperature - reactivity.

(24) Theoretical considerations and their applications to experimental data in the determination of reactor internals' motion from stochastic signals -
J.A. THIE

It is intended to show here that a variety of mechanical-motion induced neutron noise data can be understood in terms of a simplified noise source model using lumped mass m and equivalent forces F_i :

$$\ddot{x} + 2\rho\omega_0\dot{x} + \omega_0^2 x = \frac{1}{m}\sum_1^N F_i(t) \qquad (1)$$

where the resonance $\omega_0 = 2\pi f_0$ has damping ρ .

For PWR core barrel motion, x is an effective water thickness between the barrel and ex-vessel ion chambers. N statistically independent zones of pressure fluctuations times area lead to $(N\overline{F_i^2})^{\frac{1}{2}}$ as the root-mean-square excitation amplitude.

Methods of chamber current i noise calibration, essentially depending only on water density (linearly) are :

(a) theretical calculations of neutron transmission (ex. d ln i/dx = .0003 $mils^{-1}$ for Trino) ;
(b) deduction from measured effects of water density on chamber current (ex. d ln i/dx = .00038 $mils^{-1}$ for Palisades) ;
(c) intercalibration with many other methods.

A measured ω_0 may be used to monitor the extent of barrel clamping at the vessel flange. Solutions of Eq. (1) can related unclamped and clamped measurements : for a typical $\ddot{x}$ spectral density clamped motion should be reduced in amplitude by about $1/150\cdot\sqrt{\rho}$ compared to unclamped.

If amplitude-dependent 'mechanical stops' introduce non-linearities into Eq.(1), gaussian F_i may convert to a non-gaussian x - as is shown by an amplitude probability density (APD) analysis of unclamped Palisades data. Higher moments, $\overline{x^3}$ and $\overline{x^4}$, become unique descriptors of the motion. Effective standard deviations $\hat{\sigma}$ from probability-paper plots are useful in following gradual wear-induced changes in the gaussian-tailed APD : for large amplitudes only, $\hat{\sigma}$ increases from 0.8% to 1.8% of average reactor power over a 5 month interval while, for small amplitudes only, $\hat{\sigma}$ remains constant at about 0.5%.

ρ and ω_0 may be obtained from either amplitude or cross-spectral phase Θ data. Using unclamped Palisades phase data between in-core (representing x) and ex-vessel (representing F) neutron detectors and the equations

$$d\Theta / d \ln\omega \Big]_{\omega=\omega_0} = 1/\rho$$

$$d^2\Theta / d(\ln\omega)^2 \Big]_{\omega=\omega_0} = 0$$

yields $\rho = 0.38$ at a $f_0 = 1.6$ Hz fuel resonance. The ρ can be interpreted as a combination of reresonances damping and multi-resonances spacing. Using these values in Eq. (1) along with an ex-vessel ion chamber measured F/m permits one to calculate the core internals motion relative to the barrel.

Statistical addition of coherent and incoherent fuel motion times local reactivity coefficient $d\rho/dx$ gives the reactivity for affecting a region 's flux.

Any flux-gradient-motion noise my be estimated by

$$\frac{\sqrt{\overline{i^2}} \text{ due to flux gradient effect}}{\sqrt{\overline{i^2}} \text{ due to reactivity effect}} = \frac{d\,\overline{\ln\phi/dx}}{G\,\overline{d\rho/dx}}$$

where G is the local reactor transfer function.

It is concluded that reactor noise data caused by mechanical motion can be conveniently understood within the framework of Eq. (1) .

Further research, especially on spatial flux effects, can be fruitful.

DISCUSSION

D.N. FRY : Do you see any way that we can separate fuel element vibrations from neutron detector vibrations in our power reactor neutron noise measurements ?

J.A. THIE : This is a significant question and deserving of creative thought from the researchers at this meeting. One notes that the relative motion of fuel and detector is involved. Being a composite of the motions of each, theoretical calculations of resonant frequencies or experimental determinations in mockups might identify with sufficient confidence similiar frequencies observed in neutron noise measurements. Another, though more difficult, possibility is to use special motion sensors during startup/commissioning tests to investigate these separate motions in more detail.

W. SEIFRITZ : The following suggestion is made to distinguish between the effects of the in-core detector, on one side and e.g. of an oscillating fuel rod. One should position the in-core detector in the node of the oscillating pattern of the fuel element where the vibration amplitude is zero. One way to find out such nodes is firstly perform an axial traverse of the neutronic noise behaviour and to look into a possible periodicity of the effective noise amplitude.

D. WACH : I want to add to this point that it is not possible to separate noise sources generated by mechanical vibrations only by considering of the resonance peaks of the eigenfrequencies as the forced vibrations mostly are much bigger in amplitude than the amplitudes of the system eigenfrequencies. The exciting forces of these vibrations, e.g. the turbolences of the coolant, are unknown in general and therefore the noise source separation is not possible in this way without further knowledge.

L.G. KEMENY : Do you regard the monitoring of the motion of reactor internals to be so important as to justify the installation of permanent on-line hardware to be sold with each power plant specifically for this purpose ? Or should these measurements be carried out only when some malfunction is suspected ?

J.A. THIE : Rather than trying to give a general answer or opinion here, I would prefer to say that this question deserves a separate answer for each reactor type and for the 'climate' (meaning primarily non-technical policy factors) within it exists. Thus when a recent history of internals' problems exists for a particular reactor type, it would be wise for a subsequent similiar reactors to consider monitoring for this problem. On the other hand special monitoring hardware for components yet to show a history of problems is a luxury only the ultraconservative are likely to suggest.

(25) Some considerations on neutron instrumentation requirements for malfunction diagnosis in power reactors using noise analysis techniques - M. EDELMANN

Noise analysis at power reactors has two major objectives : first, to investigate the capabilities of this technique to extract dynamic information on the reactor from the various fluctuating signals available during normal operating conditions ; and second, to develop a diagnostic tool for malfunction detection indicating developing failures at an early stage in order to reduce shut-down times and costs for repairs, and to increase safety and availability of the nuclear power plant.

Most of the work in this field reported in the literature is of more or less empirical nature. The measured power spectra are complex and only partly understood. Only in some cases have the reactivity driving forces for reactor power noise been identified qualitatively. On the other hand, for anomaly or malfunction detection by neutron noise analysis one needs precise information on the reactivity effect of local faults such as excessive fuel or control rod vibrations, partial blockage of cooling channels or boiling of the coolant in a sub-assembly, as well as quantitative relations between a given reactivity perturbation at a certain position in a large power reactor and the neutron flux fluctuations at the position of a neutron detector.

In the past, noise measurements at power reactors have been made with the standard neutron instrumentation for reactor control. Such instrumentation is usually not designed for noise analysis measurements. This paper deals with the specifications of neutron instrumentation, i.e. number, position and sensitivity of neutron detectors necessary for detecting spefic local reactivity perturbations from changes in the power spectral density of the neutron detector signals.

This work is part of the investigations on the use of noise analysis techniques for detecting boiling of the coolant in an LMFBR. Boiling of the sodium in an LMFBR fuel element has been extensively investigated because of its safety implications. The fault conditions in this case are well-known and its reactivity effect could be calculated for different positions of the boiling fuel element. The power spectrum of the resulting neutron flux fluctuations has been deduced from a numerical calculation of the space-dependent reactor transfer function for different positions of a neutron detector inside and outside the core of SNR 300. For this reactor it has been shown that the out-of-core neutron chambers of the normal reactor instrumentation will be sufficient for the detection of gross boiling in a fuel element. This is an important result because no in-core neutron detectors can be used in this reactor.

DISCUSSION

D. DE LAPPARENT : Up to now, we have not looked at frequencies higher than, say, 20 Hz. What sort of anomaly do you think of between 20 Hz and the break frequency which is about 10 KHz in fast reactors ?

M. EDELMANN: We definitely do not expect high frequency reactivity noise at power reactors. The reason why we calculated the space-dependent transfer functions of SNR up to frequencies beyond the breakfrequency is that we were also interested in the general aspects of space-dependent dynamics of fast reactors and the extension to higher frequencies was possible without significant extra expense.

R. CERVELLATI : Have you in program to check experimentally some of the results which you have shown ? If so, which detectors would be used ?

M. EDELMANN : The main purpose of this work was to find out whether one would need in-core neutron detectors for malfunction diagnosis in fast reactors using noise analysis techniques. The answer is no, sufficiently large detectors outside of the reactor core are equivalent to in-core detectors with respect to detecting local reactivity perturbations. This theoretical result will be checked by measurements at the KNK-II reactor using miniaturefission chambers in the core and B-10 ionisation chambers outside of it. Measurements of power spectra with these detectors have already been performed at KNK-I which had a thermal core in contrast to KNK-II which will have a fast core. The results from the thermal core confirm the predicted equivalence of in-core and out-of-core detectors. There is reason enough then to think that this might also be true for the fast core of KNK.

G. KOSALY : One of your conclusions was that for small distances between detector and disturbance more than one break frequency exists. That might be true but I do not see this second break frequency on your figures.

E. EDELMANN : This might be a rather speculative conclusion to draw from the step-shaped form of the transfer functions. Actually only a decrease in the slope of the decaying part of the curves is observed in the considered frequency range. This behaviour can be interpreted as the sum of two 'one break frequency curves' with different amplitudes and break frequencies. But I agree with you that it has to be shown that at still higher frequencies the roll-of slope increases again.

W. SEIFRITZ : (1) Do you expect to obtain at least the same shape of the reactivity transfer function as you did in case of the source transfer function ? (2) Why did not include the case of He-3 detectors into your model since such detectors show the best detector efficiencies in fast reactors and are therefore of primary interest ?

M. EDELMANN : It is a basic assumption of the paper that the relationship between the space-dependent source and reactivity transfer functions defined in Eq. (10) and (7), respectively are essentially the same as for the point reactor model. And within the scope of this paper it seems to be a reasonable assumption, too. The answer to your second question is twofold. First, He-3 detectors have not be considered for the simple reason that He-3 cross sections are not included in the group constants sets available for these calculations. Secondly, it is correct that these detectors have the highest sensitivity per unit of detector volume. However, since it has been shown that for noise analysis in fast reactors there is no need for in-core detectors space for sufficiently sensitive detectors is no problem. Furthermore, the sensitivity of a neutron detector might be limited by the maximum permissable dc component of the signal.

(26) A stochastic study of noise in boiling reactors

M. MATTHEY

(presented by J.P. SCHNEEBERGER)

The neutron population, the population of delayed neutron precursors, the fuel temperature and the steam content of coolant are random variables considered to describe the behaviour of a boiling reactor. The neutron and the temperature power spectral density are calculated starting from Kolmogorov equations and using the Fokker-Plank and Langevin approximations. First parametric study of the model suggests that experimental information about the boiling characteristics could be obtained from the analysis of the shape of the power spectral density. Experiments are now in progress in order to check the validity of the model.

DISCUSSION

J.A. THIE : Historically, early BWRs with small fuel time constants have shown strongly resonant spectra. Present-day BWRs with longer fuel time constants do not have these strng resonances. Hence what was the value of the fuel time constant used in your work ?

J.P. SCHNEEBERGER : The time constant τ of the heat transfer in the fuel element is defined by :

$$\tau = \frac{1}{a} = \frac{1}{a_{um} + a_{uv}} \quad \text{with} \quad \tau_{um} = \frac{1}{a_{um}} = \frac{C_u}{\gamma\, S_e}$$

where :

C_u is the total heat capacity of the fuel

S_e is the total area for heat exchange

γ is the natural convection coefficient

The values used for these coefficients are :

$C_u \cong 5.10^4$ J/°K ; $S_e \cong 32$ m^2 ; $\gamma = 252$ W/m^2.°K .

These values give $\tau_{um} = 6.2$s.

After discussions with thermodynamicists, we use an estimate value for $a_{uv} = 0.6\ s^{-1}$.

So we have $= \dfrac{1}{0.16 + 0.6} \cong 1.3$ s

and this value was used as a first approximation in the calculations.

K. SAITO : How did you choose the value of heat capacity in your calculation on the basis of the lumped model ? I am wondering how to choose the value for the use for calculation on a lumped model. As shown in Fig.4 and 5 of my paper, patterns of PSD depends much or less upon the value of the heat capacity.

J.P. SCHNEEBERGER : The value of the heat capacity of the whole core used in this work is

$$M_u\ C_u = 4.9\ .\ 10^4\ J/°K$$

(and not $4.9\ .\ 10^4$ J/kg as indicated erroneously in the paper). This value was calculated at 30°C, knowing the exact number and composition of fuel elements in the core. This value does not vary too much between 30 and 100°C, and was used in a first approximation. Let us note that it is quite similar to that used in the Fig.5 of your paper (50 kW s/°C).

D. WACH : In your model concerning the composition of neutron noise spectra you did not consider any contributions to the neutron noise signal resulting from the movement of the bubbles ?

J.P. SCHNEEBERGER : The stochastic variables considered in this point model of a boiling reactor are the total number of neutrons, the total number of delayed neutron precursors, the fuel temperature and the number of bubbles in the coolant. So we completely neglect the effects of pressure, of movements of bubbles and of inlet coolant velocity (or temperature) fluctuations. All these effects give certainly a contribution to the composition of the neu tron noise signal, but they are supposed smaller th-an these resulting from boiling and are neglected in a first step. It would always be possible (but not simple) to include any of these contributions in the model if comparison between theoretical and experimental results asks for it.

T. NOMURA : Do you neglect the pressure effect ? Spectral pattern of tipical noise of BWR is similar to your calculational results. I hope that you extend your theory to BWR noise analysis and compare the calculational results with experimental results.

J.P. SCHNEEBERGER : For these questions please refer to the answers I gave Dr Wach.

(27) The estimation of vibrations of reactor internals by noise analysis of non-nuclear parameters -
W. BASTL and V. BAUERNFEIND

With the application of noise analysis to nuclear power reactors more and more interest arose for investigating non-nuclear parameters. This trend was originating partly from the dynamic process one was faced with and partly from certain problems in the context with reactor internals vibrations. As to the latter problem noise analysis and correlation techniques proved to be a useful tool because for the greater part one has to apply indirect methods in order to measure the vibration behaviour of the internal structure parts. The aim of these measurements and analyses is twofold :

- The finding of methods which facilitate periodic testing during the shutdown of the plant
- The developing of techniques which enable on-line surveillance of mechanic structure parts.

In course of the last year considerable progress was made at our institute with this kind of investigations. We proceeded as follows :

- Extensive participation of the pre-operational tests of nuclear power plants
- Off-line analysis of the recorded data by means of digital codes
- Establishing of models describing the plant dynamics and the vibration behaviour of structure parts
- Checking the model results against measurements taken in the pre-operational test-phase
- Extensive on-line measurements

During the pre-operational phase the vibration signals taken by sensors inside the vessel, which

cannot remain during power operation, were correla
ted with signals of outside sensors. In this way we got the connection between the interesting vibrations of various incore-components and the signals of detectors, which are available during reactor operation.

As useful detectors of that kind we found the pressure sensors at the inlet and outlet nozzle of the vessel and displacement gauges mounted to the vessel lid. The measurement results of the pre-operational tests were extrapolated to the conditions at full power and showed good agreement with the spectra received in that operation mode.

Investigation of the phase shifts between the various vibration signals permitted the separation of vertical and horizontal movements. Hence the vibration behaviour of the vessel and its structure parts was described by two models, one for the pendular movement of the pressure vessel/core barrel and one for the vertical movement of the main mechanical parts. Pump shut-down tests proved to be a powerful method to measure eigen-frequencies of the system. They were used to check the theoretical results.

By means of pressure measurements at several positions it was possible to evaluate the nature of exciting forces and their intensity. The analysis of phase relations between pressure signals measured at several positions and between pressure- and vibration signals was used to locate some dominant noise sources.

DISCUSSION

H. BUNSCHI : In your transfer function inlet pressure-pressure vessel movement you could explain almost all peaks. But one very high peak lies near 95 Hz. Can you explain it ?

W. BASTL : For the interpretation of the measured peaks a 4-mass model representing the 4-lowest eigenfrequencies of the system was used (highest frequency f_4 = 52 Hz) . Using more degrees of fre edom we would certainly reveal the higher peak-frequencies too. More recent investigations showed that most probably the 98 Hz peak is due to the vibration of the sensor support.

J.A. THIE : Can you comment on the status of experimental and theoretical knowledge of the spatial correlation of the local pressure force excitation function ? Do you think additional measurements, such as with moveable pressure sensors in the annulus between barrel and vessel, would assist in a priori calculation of the total force from pressures everywhere ?

W. BASTL : Within the frequency range of the eigenfrequencies of the investigated structure we assumed a white excitation force. This assumption was based upon the shape of the PSD as calculated from the one available pressure signal in the annulus. Further on the good agreement between the calculated and the measured transfer functions (FIG. 7 & 8) support this assumption. Due experimental investigations reported in the literature the highest power spectral densities of the jet noise are to be expected within a frequency range which is lower than the eigenfrequencies of our structure. Additional measurements by means of a moveable pressure sensor would be certainly very helpful. However, due to our experience, it would be rather difficult to realize those measurements on site. The difficulties to transfer model measurements to the actual hydrodynamic situation are well known.

W. SEIFRITZ : In your 2-mass vibration model you have to assume some parameters like spring constants and damping constants. Where did you get the numerical values of these quantities or did you fit the experimental data to the theoretical model ?

W. BASTL : The spring and damping constants were supplied by the constructor (KWU), who applied these figures to the design of the structure and who verified them during pre-operational measurements (excitation of the structure parts by unbalanced masses or by impact).

W.H. DIO : The calculation of eigenfrequencies and so on are done in the theoretical group for the dynamic behaviour of pressure vessel and reactor internals of the KWU-Erlangen. The calculated values, eigenfrequencies and damping ratios, will then be confirmed by measurements at the manufacturers of the internals and measurements on site. Therefore the input data for the LRA-model were available and were given to the LRA.

(28) Canadian experience in the area of reactor noise -
K.J. SERDULA

Some Canadian experience in the application of reactor noise measurement techniques to the development of the CANadian Deuterium Uranium (CANDU) pressure tube reactor system is presented. Primary objectives in the application of such measurements to CANDU power reactors are :

- to provide information to assist in commissioning the nuclear power station ;
- to indicate potential problem areas and provide information to eliminate these problems or reduce their potential consequences ;
- to provide information to operations staff in establishing routine operating procedures and in applying noise measurement techniques ;
- to provide information to designers for the further development of the CANDU reactor concept.

Extentension of measurement programs from the laboratories to power stations requires an evolution in experimental philosophy. Requirements of a successful program at a nuclear power station are outlined.

Development of the reactor noise program, from initial work in a zero-power reactor and loops (both in-and out-of reactor) to successful application in the CANDU boiling light water (BLW) coolant reactor, Gentilly-1, is outlined. During the program growth, measurements of noise in typical nuclear parameter signals have been obtained for :

- excitation of the system parameters by the inherent disturbances ;
- excitation of selected system parameters by pseudorandom sequences.

Some results from initial work, using the excita tion provided by inherent disturbances, are summari zed. These results indicated the potential of appli cation of reactor noise techniques to the Canadian CANDU power reactor program.

The CANDU-BLW reactor, Gentilly-1, with boiling coolant in the channels and a positive void feedback provided an ideal opportunity for assessment of the use of reactor noise techniques in power reactor sy stems. Consequently programs using both : (1) inhe-rent and (2) imposed excitation were carried out. Results from both programs are presented and their significance in satisfying program objectives is di scussed.

Future plans for the role of noise analysis in the Canadian CANDU reactor program are outlined.

DISCUSSION

H. KATAOKA : I heard your experiments were carried out under active pressure-control system and I wo ould like to know about the condition of the neut-ron power control system during your experiment.

K.J. SERDULA : During the measurements at power, both the neutron bulk power and the thermal spatial power control systems were in operation. Therefore, the action of these control systems was to reduce the amplitude of the perturbation applied to the control absorbers as compared to the amplitude of the initiating disturbance. However, with the con-trol system in operation, we were able to determi-ne the response of both the controlled and uncont-rolled reactor by simply obtaining data from diffe rent points in the system.

H. KATAOKA : Because a heavy water moderated boili-ng water cooled power reactor like Gentilly-1 is now under construction in Japan, we Japanese scien tists have much attention to your study. You appli ed reactor diagnosing techniques using not only no ise due to inherent excitation but also to imposed excitation. Usually in the world it is not so easy to impose additional excitation on nuclear power plants even for the test, for the reason of social matters. What do you think about this matter ?

K.J. SERDULA : I agree that in general it can be difficult to obtain permission to impose additional excitation on nuclear system parameters for measuring the response of the system. I think the main concern here is of the measurements initiating a reactor shutdown. This concern can be reduced considerably and the probability of the measurements initiating a shutdown reduced to nearly zero if the station staff are informed of and take an active role in the measurement program. The major factor is balancing the benefits to be obtained against the probability of initiating a reactor shutdown. Since Gentilly-1 was the CANDU-BLW prototype, no operating experience or information was available to verify at power predictions and therefore a program to supply information in this area was accepted.

D.N. FRY : Are you currently developing continuous noise monitors (neutron and other signal) for on-line diagnosis of reactor problems in CANDU systems?

K.J. SERDULA : At present, we do not have any definite program in this area. However, we are looking into areas where the application of noise analysis techniques could assist station staff in obtaining improved station performance.

J.T. MIHALCZO : (1) What general procedure did you use to identify the source of the 1 Hz resonance ? (2) Do you think that these techniques will eventually be used to shat down the reactor ?

K.J. SERDULA : In response to your first question, we use the following general procedure to identify the source of the 1 Hz resonance :

(1) Comparison of time vs. amplitude traces, r.m.s.

values and peak-to-peak values from pressure, flow and neutron sensors located in different positions of the system ;

(2) Comparison of amplitudes at 1 Hz as given from power spectral density analysis of the signals ;

(3) Comparison of response functions (amplitude & phase) between different pairs of sensors : here the phase information was very useful.

In response to your second question, I think that application of these techniques in the immediate future will be used to initiate an alarm condition to which the operator can respond. However, I do believe that eventually these techniques, once established as reliable, will be used to initiate a reactor shutdown. In regard to this, indication of high turbine vibration levels are already being used to shut the turbine down and also high vibration levels of primary circuit pumps are used to initiate alarm conditions.

(29) Review of recent applications of reactor noise techniques at Argonne National Laboratory - R.A. LEWIS, E.F. BENNETT, S.G. CARPENTER, C.E. COHN, C.C. PRICE

Recent applications of reactor noise techniques to the improvement of subcritical reactivity and β_{eff} measurements in fast critical assemblies and to fast power reactor surveillance by neutron/acoustic noise cross correlation are reviewed.

Measurements of the reactivity of subcritical plutonium fast reactor assemblies are of key importance for physics measurements as well as for operational safety. Emphasis has been placed recently on the refinement of inverse kinetics rod drop (IKRD), cross power spectral density (CPSD), and polarity correlation methods for subcriticality reactivity measurements.

IKRD has been the primary subcriticality measurement technique applied at ANL because of its relative insensitivity to counter efficiency and prompt lifetime changes ; a near-critical reference is not needed. Data are taken by banks of high-efficiency ionization chambers and analyzed by on-line computers using a variety of optional algorithms. Estimates of the random errors in IKRD reactivity measurements resulting from noise effects have been developed by simulation studies and theoretical analysis. In the simulation studies, rod drop flux traces are generated from point kinetics theory and analyzed repetitively by the various algorithms, after addition of simulated reactor and detector noise, to produce precision estimates. A theoretical analysis of rod drop reactivity precision involving a nonstationary calculation of the chain-associated conditional probabilities of neutron detection has been carried out for a simplified '3-point' rod drop analysis algorithm in which instantaneous rod drop is assumed. Relative standard deviations of 1 to 20% are indicated by these methods for initial Δk from - 0.0005 to - 0.035, respectively, under conditions typical of the Fast Test Reactor (FTR) mockup experiments in the ZPR-9 fast critical.

Space-dependent kinitics calculations have been applied to the IKRD technique to study systematic errors that are functions of detector locations as well as changes in kinetics parameters and effective source strength in the course of a rod drop. In various situations, systematic errors of several parts per hundred may arise from these causes for detectors located outside the axial reflector due to cancellation of errors. For other detector locations, the principal error components might be in the same direction , thereby amplifying the resultant error.

Noise measurements have been used as cross checks on IKRD results. The break frequency derived from CPSD or polarity correlation has been found not to be a good reactivity estimator in fast power reactor critical assemblies presumably because wide disparities between neutron lifetimes in the core and reflector produce deviations from point kinetics in the range of the break frequency. Various two-detector midfrequency polarity coherence function methods have produced good reactivity estimates, although these methods depend on near-critical reference measurements and are perturbed by differences in detector efficiency between the reference and measured systems. Correction methods to account for detector efficiency and β_{eff} changes have been developed.

The accuracy of fast critical experiment measurements of $\Delta k/k$ are directly affected by the accuracy with which β_{eff} is known. Recent conflicting experimental data on β_i , λ_i has been the incentive for a noise-based integral $_{eff}$ measurement technique. The technique is a modified detector noise variance-to-mean method using sampling intervals from 8 to 200 sec ; β_{eff} has been measured to a precision of $\pm$ 2.9% in the FTR mockup critical assembly.

Exploratory work on the use of neutron/acoustic noise cross correlation as a tool for surveillance of fast power reactor systems has been carried out using the Experimental Breeder Reactor II . Cross correlation of neutron signals from in-core detectors with acoustic signals from accelerometers mounted on various mechanical components connected into the core structure has been studied up to several thousand hertz. Flow-induced subassembly vibrations at about 10 hertz have been observed.

DISCUSSION

M. EDELMANN : I would like to comment on the discrepancy between the break frequencies observed by Cohn at the core center and in the blanket of the FTR engineering mockup. This discrepancy might be due to the spatial dependence of the roll-off slope of the reactor transfer function. As shown in the paper I presented this morning the roll-off slope increases with increasing distance from the core center. The 3 db point will be found therefore at a frequency which in the blanket is lower than in the center of the core.

B. BAERS : How large is the contribution of the reactor gamma radiation to the detection process with glass scintillators (with Li-6 n-γ converters) ? Both the correlated and uncorrelated gamma radiation coming from fission and other processes in the reactor may contribute to the signals, in which case the thory should be modified accordingly. The question is also related to Mihalczo's presentations on october 22, 1974.

R.A. LEWIS : The answer to this question is unknown at this time.

W. BASTL : What do you expect by extending the frequency range up to 1000 Hz for your cross-correlation measurements neutron flux/accelerometer signals ?

R.A. LEWIS : This question cannot be answered without further experiments.

J.A. THIE : This is a comment on Bastl's question about cross-correlating neutron flux and accelerometer at high frequencies. A possible way of extracting a correlation, if any exists, is to first use an envelope detector on the accelerometer. Then the low frequency envelope could be cross-correlated with neutron signals at the 10 to 12 Hz region of interest for example.

W. SEIFRITZ : What is the meaning of $\bar{\nu}$ in Eq.3 of page 28 ? Is it the mean number of neutrons released per Pu-239 fission or per Pu-240 spontaneous fission ?

R.A. LEWIS : $\bar{\nu}$ refers to the mean number of neutron released per Pu-239 fission. $\bar{\nu}$ refers to the mean number of neutrons released per Pu-240 spontaneous fission.

D. WACH : In the Fig.5 of your paper a sharp peak at 10.5 Hz is to be seen as well in the vibration signal as in the neutron noise signal. My question is , why we can not see the other signal components of the vibration signal e.g. the peak round 6 Hz in the neutron noise spectrum. Did you investigate the cross-power spectral density or coherence between the vibration and the neutron noise ?

R.A. LEWIS : Concerning the first question, the reason that components of the vibration signal other than those at 10.5 Hz do not also appear in a neutron noise spectrum is because the accelerometers used to measure the control rod vibrations were attached to the contol rod extension at a considerable distance (30 ft) above the reactor core level. Thus, while the common coupling between the flow induced control rod vibration and the neutron flux oscillation is in the reactor core the physical vibration of the control rod must be passed along the control rod extension. This extension has abrupt changes in cross section and is supported at several locations by bearing sur faces. These bearing surfaces become noed points for lateral (radial) vibrations. Consequently, many of the peaks in the control rod spectrum are related to the natural frequencies of the control rod extension or are induced by vibration of the support structure and are not related to the subassemly vibration. Second question, we did not perform cross power spectral density nor coherence measurements.

J.T. MIHALCZO : Discrepancies mentioned in reactivity measurements with FTR-3 and the inability to confirm these discrepancies in measurements in the SEFOR reactor motivated the reactivity measurement program with the mockup of the FFTF that I described yesterday. IKRD measurements with detectors in the core, in the reflector and in the shield agree down to about 8 $ where statistics precluded further measurements in the shield : but measurements with detectors in core and reflector agree down to about 14 $. The measurements must be corrected for the chance in detector efficiency during the drop. These IKRD results agree with msm measurements. Msm measurements agree at all detector locating and agree with BFNA in-core.

(30) A simple space dependent theory of the neutron noise in a boiling water reactor

G. KOSALY, L. MAROTI , L. MESKO

In a recent work a simple theoretical model was developed and used for the interpretation of in-core neutron noise measurements performed at a large BWR. In this model the neutron-flux fluctuations were considered to be driven by two noise sources : a local source (bubbling) and a global one (reactivity fluctuations).

An extensive series of measurements were performed at the Lingen BWR by Seifritz. Among other quantities he measured the NRMS-values of detector current fluctuations and the critical flux $\Phi(z)$ for different axial positions. In a recent paper Stegemann, Geburek, Mikulski and Seifritz emphasized that the measured curve of the NRMS resmbles, at least to some extent, the calculated curve of the steam void fraction $\alpha(z)$.

In the present paper we use the aforementioned model for the description of neutron noise. Using simple assumptions the result

$$\mathrm{NRMS}(z)^2 = A + C\,F(z)\,\frac{\alpha(z)}{\Phi(z)} \qquad (1)$$

In Eq.(1) the first term accounts for the effect of reactivity fluctuations, while the second term represents the local influence of bubbling.

A and C are constants. The function F(z) is determined by the axial dependencies of average bubble volume, and average steam velocity.

Using measured values for NRMS(z) and $\Phi(z)$ and calculated values of $\alpha(z)$ and F(z) the parameters A and C are determined by a least-square fitting.

The results are instructive concerning the applicability of the model. In cases when the model is applicable a method of measuring steam void fraction by in-core neutron detectors might be developed.

DISCUSSION

W. SEIFRITZ : Just a comment. In the meantime it has been corroborated by independent measurements on the Garigliano as well as on the Mildeberg BWR that the behaviour of the NRMS-value seems to be a general characteristic of BWRs. Therefore, your heuristical development seems to be encouraging.

D. WACH : I believe you are not right taking only the variation of the local steam volume as the driving force of the local noise. Essentially it is the movement of the bubbles,being a density disturbance in the water, which generates a dynamic pulse-shaped signal in the current of the ionisation chambers by the disturbance of the neutrons being detected. Such a pulse corresponds in the frequency domain with a band-limited white noise, not a white noise as you mentioned. The upper corner frequency is determined by the width of the pulse which itself depends on the velocity of the bubble and the length of the way of the bubble inside a sensitive volume of the detector. Using these considerations we see from the PSD's of the in-core neutron noise that the sensitivity length of the detectors to this local 'detection noise' is in the order of about 10 cm.

G. KOSALY : It seems tome that this is a righteous comment of yours but I have the feeling that it refers to a somewhat different situation, than the one investigate in our paper. In fact if one has a few bubbles moving upwards, then whenever a bubble appears in the sensitive volume one gets a signal. In this case one has a time-dependent phenomenon even if the current of bubbles does not fluctuate at all. On the other hand boiling in water (especially at high pressure) generates rather tiny bubbles ($\lesssim 1$ mm diameter) and there is always a large number of bubbles inside the sensitive volume, all moving upwards. In this case the average current of bubbles contributes to the dc component and one gets no time dependent signal unless the current of bubbles fluctuates. This is why in the joint paper with you (Atomkernenergie, 23, 1974, 244-250) the fluctuation of the number of bubbles was considered as the driving source of the local part of the noise-field. In the present work we went further considering the fluctuation of the local steam volume as the driving source of local fluctuations. As regards your second comment may I point out that according to our Eq.(2.12) the local contribution to the APSD of neutron noise is bound limited. The break frequency of hte function $|H_1(\omega)|^2$ which in turn corresponds to the finite time while the disturbance propagates through the sensitive volume of the detector. May I point out also that to speak about local detection-noise seems to me rather misleading in the present context. By detection noise one traditionally means the noise induced by the stochastic nature of the detection-process. The local effect on the other hand is basically the local-response of the neutron-field to local changes in moderation, absorption and attenuation characteristics. In fact one has to be rather cautious not to confuse the characteristic diameter of the sensitive volume around the detector with its geometrical dimensions. It is to be considered that the flux-fluctuation at a single space point are induced by the disturbances contained in a finite volume around the space point, that is even a point -like neutron-detector has a finite volume of sensitivity.

D.N. FRY : Have you included the loss of bubbles between the two axial positions z_1, z_2 in your production term ? I also want to comment that the'C' term is not a straightforward calculation as you stated in the conclusions. The total void fraction is dependent on such quantities as recirculation flow and feedwater flow and the fluctuations in these quantities is difficult to predict because they are dependent on automatic control.

G. KOSALY : Bubble collapsing was neglected in our considerations. It is certainly possible to include this effect to the unspecified second term on the RHS of Eq.(1.7a) but then the first and second terms would become dependent statistically and Eq.(1.11) could not be derived. I feel that the neglection of the condensation of steam is not a too bad assumption in a BWR. As regards your second comment I absolutely agree. What I meant was that the concept of reactivity fluctuations is well understood even if it is rather difficult to provide detailed predictions. On the other hand the concept of a local response to local disturbances is not so widely accepted in the theory of neutron noise.

K.J. SERDULA : Have you considered subtracting the global response from your near-field detector ? This global response can be obtained from a far-field detector and by definition is the same percentage value everywhere in the core. This percentage value can then be subtracted from the near-field detector.

G. KOSALY : I think that this is a very good idea. Another possibility of separating local and global contributions is to work in the time domain where they center at zero time lag and at the transit time respectively.

L.G. KEMENY : You have an elegant and simple model here for boiling water reactor neutron noise but I wonder whether its essentially monoenergetic nature does not introduce significant errors ? It seems to me that to predict neutron number density fluctuations in phase space with a time varying moderator density it is essential to include in the model the slowing down phenomenon. It is not essential to have, at least, a two-group representation ?

G. KOSALY : We have not included any energy-group-subscript but I think that the formulae can be applied at arbitrary neutron energy. Of course the ratio of local to global contributions might depend quite dramatically on neutron energy. On the other hand if one tries to derive the formalism of the paper from microscopic theory one finds that at least two-energy groups are needed to account for the localised behaviour experienced in the experiments of Wach and Seifritz.

E. ROBINSON : What is the driving force of the local flux fluctuations ?

G. KOSALY : It was assumed in our work that the major source of local fluctuation of the local steam-volume resulting in extensive fluctuations of moderator-density. We feel that in the actual case this choice is supported both by 'physical feeling' and by a certain success in the interpretation of experimental results.

T. NOMURA : I was very surprise to see that your philosophy is quite same as ours. As for constant C in Eq.(2.15), how about cutting the low frequency components using high pass filter ?

G. KOSALY : It was nice to realize the similarity of ideas you are mentioning. It is remarkable that basically the same ideas can be found also in the Sweedish-paper presented at this meeting. I think that to remove the C-term by high-pass filtering is a very good idea. Doing this the noise-amplitude becomes directly proportional to the factor $\alpha(z)/V(z)$ which might be very important from the point of view of practical applications.

(31) Experience from the analysis of noise measurements in a BWR power plant -
P.E. BLOMBERG and F. AKERHIELM

With the aim of demonstrating the feasibility and the potential use of noise measurements in a nuclear power plant a limited series of such measurements were carried out in the Oskarshamn I BWR-plant. The results presented in this report indicate that important information can be drawn from the analyzed dynamic data. However, the confidence placed in the interpretation of the results and the possibility to extract information into a quantitative form requires both extensive knowledge of the background characteristics of the plant of concern and access to experience from similar measurements in other plants.

The described study included measurement of the following process variables : neutron fluxes, core pressure drop, steam flow, generated electric power, coolant flow and temperatures.

The sampled data were analyzed by an on-line digital special purpose computer. Mainly power spectra and cross correlation functions were computed. From the results certain information is extracted e.g. on inherent oscillations, transport delays, void fraction distribution and malfunction of electronics.

DISCUSSION

T. NOMURA : In Fig.12 cross correlation function between bottom and top local neutron flux, I noticed that the peak at $\tau = 0$ is much smaller than the peak related with local effect. Did you use something like high pass filter that will make the peak at $\tau = 0$ small ?

F. AKERHIELM : No high pass filter was used in the signal conditioning.

W. SEIFRITZ : I would like to make a comment; (1) the steam velocity derived from Fig.12 of 4.3 m/sec corresponds to the mean steam velocity; (2) comparing Fig.10 (spectrum of reactor vessel pressure) with one of the neutron noise spectra of Fig.2 it is to be seen that both peaks occur at the same frequency of 1 Hz. In the case of Garigliano BWR it has also been observed that the coherence between pressure & neutron flux exhibits a peak. Furthermore it is possible to derive from this appearance the pressure-reactivity coefficient for a BWR.

D. WACH : I agree fully with Dr Nomura. Why you have such a small peak at $\tau = 0$ indicating the global noise. In a power reactor especially in the low frequencies range there exist strong signal components which are of a global effect and therefore cause a strong peak at $\tau = 0$ in the cross correlation function. From your Fig.4 we see that you have powerful global noise. As an example, when we correlated similar in-core noise signals of the Lingen reactor we could see a delayed peak corresponding to the transport time of the local disturbances in the CCF only if we filtered the signals with a high-pass filter in order to suppress a powerful peak in the low frequency range which has been identified as a global noise correlated with core differential pressure very well. This last comment is only given because Dr Seifritz has neglected in his comment to say that this identification has been given by us cross-correlating the neutron noise signals with the noise of the core differential pressure.

F. AKERHIELM : As can be seen from Fig.4 there is a large contribution from locally induced noise which supports the results obtained from the correlation analysis. Also from a visual inspection of analog recordings a conformity was found when the recordings were displaced by 0.7 seconds which again supports the results presented. The strong correlation for zero displacement found elsewhere seems to indicate that the global noise is much higher in these cases.

J.A. THIE : The first of two comments I wish to make is that the excellent work of this paper as well as recent work of Seifritz, Nomura, Wach, Kosaly and others in identifying a local slowing-down noise can be further corroborated by publication in the 1960's on the Pathfinder BWR. Here spectral densities were also interpreted the same way from similar data. The second comment is that we found a resonance in prima ry flow near the same frequency as you found in your Fig.5 . The width of this resonance was found to be quite sensitive to the presence of loose metal pieces in the primary piping whereas these loose parts were affecting the mean value of total flow almost neglegibly . Hence your statement that your measure ments can apport early detection of malfunctions is supported by this experience, and should be encouraged.

K.J. SERDULA : When we observed the 1 Hz resonance in our BWR plant, the turbine representative mentioned that a resonance in this frequency range is common in direct cycle boiling nuclear plants and probably characteristic of this type of system. However since turbine systems have been in existence longer than nuclear plants we did not accept this statement. Our subsequent measurements showed that the operation with the by-pass valves gave rise to a resonance at 1 Hz while operation with a turbine valve gives rise to a resonance at 1.2 Hz . Have you checked the resonances of your turbine condenser pressure control system ?

F. AKERHIELM : No checking of the turbine condenser pressure control system has yet been performed.

M. EDELMANN : I am referring to Fig.3 of your paper. One could conclude from the two curves shown there that no global noise exists in your reactor. It seems to me that you observed only strongly correlated local effects at different axial positions which compensate due to phase shifts when the signals of many axially distributed detectors are averaged.

F. AKERHIELM : The differences observed in the measured spectra as given by average signals from the 8 and 32 detector arrays are assumed to be largely the result of the damping properties of the electronics. The differences might, however, also support the conclusion that the local noise is substancially larger than the global one.

(32) Power reactor noise measurements in Hungary - D. PALLAGI, T. HARGITAI, S. HORANYI

In order to study and develop new instruments and methods for reactor disgnostics purposes, the fluctuations in both the reactor flux and the coolant temperature have been investigated in many years by performing measurements with in-core and ex-core neutron detectors and with thermocouples at the 5 MWt research reactor of the Institute. With special emphasis on investigating the range of applicability of the coolant velocity measurements based on the transit time method, recently an application research program has been started also at a low-power inactive BWR facility and at a sodium cooled experimental loop.

In the paper the main conclusions obtained in connection with the in-core bulk boiling detection and with the coolant velocity measurements through cross-correlating the signals of two thermocouples will be discussed and some preliminary results - e.g. influence of the time constants of the thermocouples - reached in the course of the recently started application research program will be reported.

DISCUSSION

D. SCHWALM : Did you also evaluate the power spectral density of the temperature fluctuations in your Na-loop ? What was the break frequency ?

S. HORANYI : Yes, we have measured the PSD of the temperature fluctuations in our Na-K-loop. The break frequency was about 10 cps and depends on the velocity of liquid metal in a low rate.

H. NISHIHARA : I might add a comment on flow velocity measurement by temperature noise. Instead of using two temperature sensors, you can measure the flow velocity by only one sensor. You can detect the shedding frequency of vortéces behind a heated rod, and this frequency is proportional to the velocity.

S. HORANYI : Thanks for your interesting remark.This well-known method, I think you are of the same opinion, is not useable for in-core velocity measurements. Our process does not require heating, it calculates in the time domain and utilizes the natural temperature noise of liquid coolant to get information.

E. TÜRKCAN : Could you give some details on the sodium loop ?

S. HORANYI : It is a real Na-K-loop which was built to study the heat transfer first of all. The velocity and temperature of the liquid metal could be changed in the range of 0 - 6 m/sec and 50 - 500 °C, respectively. Our measurements were performed in a tube with 28 mm inner diameter.

W. SEIFRITZ : It is important to note that the time constants of the loop are the crucial quantities responsible for the time scale. In the cross correlation function only frequencies beyond the reciprocal values of these time constants should be evaluated. But Dr Türkcan and Dr Kosaly may explain this problem in better detail.

G. KOSALY : Years ago we pointed out that a very special effect, we called it the 'wall effect', might invalidate this measurement. The effect arises from the finite heat capacity of the wall. By its finite heat capacity the wall may store the signal for a while and emit it with a certain time delay. This way instead of measuring the transport time between the two detectors, one might measure the transport time plus the delay time. The case was taken up later by the Hannover-Petten group which found that the effect can be really found in the experiments. It is rather remarkable that in the measurements you have performed you have not seen any traces of this effect.

S. HORANYI : I agree with Dr Seifritz on the question of the importance of the time constants of wall and coolant, but I am surprised at Dr Kosaly's remark because his preliminary calculations also did not point out the mentioned effect in our Na-K-loop.

L.G. KEMENY : Do you take any precautions in the mounting of your ion chambers and in the preparation of your cabling to minimize the effects of external vibrations and microphonic pick-up ?

S. HORANYI : Our ion chambers were not submitted to the shaking effect of flowing water.

(33) Non-linearity consideration when analyzing reactor noise statisticalcharacteristics - B.V. KEBADZE and L.A. ADAMOVSKI

Statistical characteristics of boiling water reactor noises inthe vicinity of stability threshold are studied. The reactor is considered as a non linear system affected by random perturbations. To solve a non linear problem the principle of statistical linearization is used. It is shown that the half width of resonance peak in neutron power noise spectrum density as well as the reciprocal of noise dispersion, which are used in predicting a stable operation threshold, are different from zero both before and after the stability boundary determined based on linear criteria.

In most cases a linear consideration is suitable when carrying out the statistical analysis of reactor systems because of relative smallness of random fluctuations. However, when determining reactor statistical characterisics in the vicinity of stability threshold this approch may be found insufficient. The stability problem is of significance for boiling reactors. To determine the BWR critical (from the stability point of view) power the extrapolation to zero of either the resonance peak halfwidth of neutron flux 'noise' power spectrum density or a reciprocal of 'noise' dispersion is used.

However, since the reactor is a system of nonlinear type affected by random perturbations the above two quantities should have a value other than zero within and beyond the linear stability threshold.

When deriving a quantitative stability criterion and predicting the reactor operation stability threshold a consideration of non-linearity is of significance when statistical characteristics are determined.

(34) Analysis of neutron-density oscillations resulting from core barrel motion in a PWR nuclear power plant -
D.N. FRY, R.C. KRYTER, J.C. ROBINSON

At the request of the U. S. Atomic Energy Commission, the authors investigated unusual neutron noise at the Palisades Nuclear Plant in late July, 1973. Previously the plant operator, Consumers Power Company (CPCO), and the plant designer, Combusting Engineering (CE), had observed abnormal flux oscillations on the output from ex-core detectors in the plant, had investigated and characterized the signals with noise analysis techniques, and had speculated that the oscillations resulted from flow-induced motion of the reactor core barrel. On-site noise diagnosis by ORNL of plant signals such as in-core and ex-core neutron flux, temperature, and vibrations (sensed by ex-vessel accelerometers) with the aid of a computer-based noise analyzer substantiated the previous conclusions of CPCO and CE : the abnormal ex-core detector flux oscillations were attributable to changes in neutron leakage to these detectors caused by a rocking motion of the core barrel and core as a unit inside the pressure vessel.

Following the on-site measurements, an analog magnetic-tape recording of plant neutron detector signals was obtained from CE so that an in-depth study could be conducted at ORNL. Shortly thereafter, while Palisades was shut down for inspection of the steam generator, the reactor pressure vessel internels were visually inspected to confirm the noise analysis diagnosis that the core barrel had rocked during operation. The inspection revealed that an $\sim$0.25 in. thickness of metal had worn from the mating surfaces of the core support barrel flange and pressure vessel and that all fasteners holding the expansion-compensating ring in position were broken, thus confirming the speculte mode of motion.

Our objectives in reporting this work are to show the advantage of using a variety of plant signals, each processed statistically in several ways, in performing unambiguous diagnoses ; and illustrate the reasoning by which an investigator can assimilate the various complementary pieces of information to diagnose the performance of reactor internals. We stress the need for presentation of experimental results in absolute, universally recognized units of measurement so that they will be amenable to comparison with both theoretical analysis and measurements from other plants of similar construction.

Some of the more important observations of the Palisades study were as follows :

(1) In-core detector rms noise was ~ 4 times smaller than ex-core noise in the 0.03-5 Hz range. From this observation, we concluded that the cause of the larger ex-core noise was not due to power fluctuations.

(2) Some ex-core detectors had considerably higher rms noise levels in the 0.03-5 Hz range than others. Furthermore, the relative phase shift among ex-core detectors varied from 0 to 180° with detector circumferential position. These facts indicate a preferred direction of motion.

(3) The amplitude distributions of the ex-core detectors were not symmetric with respect to their mean values, i.e., fluctuationsin signal amplitude had a preferred sign.

This fact reinforces other indications of preferentially oriented core berrel rocking.

We believe that the neutron noise signature associated with the movement of the core barrel in this will be helpful in diagnosing similar abnormalities if they occur in other PWRs.

DISCUSSION

D. WACH : Did you cross correlated in-core and ex-core chamber signals. What was the behaviour of the phase-function of the coherence ? I ask, because the physical mechanism between driving force and noise signals are of different nature for in-core and ex-core chambers : movement of the detector in a flux gradient and attenuation of neutrons in the annulus respectively.

D.N. FRY : Yes. The coherence between in-core and ex-core detectors was essentially zero except in the vicinity of 2 Hz where it was 0.5-1. The phase-function observed depends upon the detectors used for the measurement. Refer to Fig.2 of my paper for detector location. Assuming NI5 Lower as the reference detector, the following phases and coherences were obtained at 2 Hz. (this is only an example : neither the phase nor the coherence were constant with frequency).

	Phase (0)	Coh
NI5 Lower-NI42-5	-122	0.74
NI5 Lower-NI7-5	+ 28	0.82
NI5 Lower-NI6-5	+155	0.55

I agree with your statement regarding physical mechanism and our results support your observation. The coherence between ex-core and in-core detectors is low at frequencies where the noise is attributable to barrel motion (<2 Hz) ; this indicates the in-cores do not 'see' barrel motion-induced noise.

L.G. KEMENY : Have you made an attempt to correlate the results of your measurements with some theoretical model for the neutron density oscillation produced by a randomly vibrating neutron source or sink ? This type of calculation could lead to a specification for optimum detector types, sizes and spacing ?

D.N. FRY : No, but in the near future we will perform calculations that hopefully will allow the determination of the sensitivity of the observed neutron noise to reactor vessel internals movement. We do not anticipate performing calculations on optimum detector types,sizes, or spacing.

W. SEIFRITZ : It is not more advantageous to show the difference between the RMS values of an out-core shamber and a representative in-core chamber so that the direction of the core barrel motion becomes much more clearly borne out ?

D.N. FRY : I doubt that this could add new information, since the in-core RMS noise was essentially the same for all detectors and only 15-20% circa of the ex-core noise level in the frequency range 0.003-5 Hz. Besides, the in-core and ex-core noises are attributed to different physical mechanisms, it does not make sense to treat the in-core values as a 'background' to be subtracted from the ex-core values.

R. BAEYENS : Are their new measurements been performed after repairs ?

D. N. FRY : Yes. The utility that operates the reactor will perform measurements during startup and thereafter on a periodic basis when normal operation is resumed.

K.J. SERDULA : The ratio of the 2 Hz amplitude to the average amplitude in the PSDs is higher for the in-core detector than the ex-core detector. What is the reason for this difference ? Is it due to excitation of fuel element vibration ?

D.N. FRY : Indeed, the ratio of the PSD at 2 Hz to the average PSD is higher for in-core detectors (i.e., there appears to be a more pronounced peak in the spectrum). However, if you refer to Fig.7 of my paper you will see that both in-core and ex-core detectors have approximately the same ampltude PSD at 2 Hz. Therefore I believe the apparent difference in ratios that you have called to our attention is primarily the result of higher ex-core noise at low frequencies (i.e., the barrel motion, which is not seen by the in-core detectors). On the basis of data now available, I don't believe we can say positively that the 2 Hz noise is due to fuel element motion. However, the fundamental frequency of the fuel assembly is believed to be in the 1.5 to 4 Hz range and it is possible that the barrel motion excited the core at its fundamental frequency.

JAUDET : What is the sensitivity of neutron detectors might have toward accelerations and pressure fluctuations ?

D.N. FRY : I don't know what sensitivity, if any, the neutron detectors might have toward accelerations and pressure fluctuations. One could obtain this information by performing measurements with the reactor shut down, which we were not able to do. You may recall that one of my slides showed a correlation between ex-core detector signals and the signal from an accelerometer placed on the upper flange of the pressure vessel. This slide showed a close correspondence between increased mechanical noise and large spikes in the ex-core neutron noise.

W. BASTL : Yuo have made some principal recommendations with respect to on-line monitoring of future plants. Would you rather suggest portable equipment for signal analysis or the use of the digital computers on site ?

D.N. FRY : I believe we will see both on-site and portable equipment used in future plants. One must perform a certain amount of on-line monitoring to assess the healt of the plant. If the on-line monitor should indicate an increase in noise, then more sophisticated equipment (possibly portable) could be employed to diagnose the cause of the increased noise. Owing to the widespread use of the Fast Fourier Transform now, I believe that both on-line and portable noise measuring systems in the future will rely heavily on the use of small computers.

D. WACH : May I add to this point (question of Dr Seifritz) : the differences of the variances of in-core and ex-core signals can not help us to determine a better variance of the core barrel motion as the noise sources are of different nature in the two types of neutron detectors. The phases between in-cores and ex-cores is about 90°. This indicates the different nature of the noise sources.

D.N. FRY : I agree with you. Your reasoning, in addition to my earlier statement in response to Dr Seifritz's question, indicates that there is probably nothing to be gained by subtracting in-core noise from ex-core noise. As you have concluded, the in-core and ex-core noises are attributable to different physical mechanism, (in the 0-2 Hz range) so it does not make sense to treat the in-core values as a 'background' to be subtracted from the ex-core values.

M. EDELMANN : (1) Have you performed any cross-correlation between accelerometers and neutron chamber signals ? One would expect an improvement in detecting barrel motions in this way especially for the lower amplitude motions. (2) Do you have an explanation why the main direction of the barrel motion is almost perpendicular to the line of symmetry of the coolants inlets ?

D.N. FRY : (1) No, because the sensitivity of the installed accelerometers was very low in the 0-2 Hz frequency range where barrel motion was the main contributor to observed ex-core neutron noise. (2) It is postulated that the driving force responsible for the core barrel rocking motion was the pressure of the inlet flow against the barrel. As seen in Fig.8 of my paper, the forces caused by inlets 1A and 2B tend to oppose the forces of inlets 2A and 1B on the opposite side of the barrel. Competition between these nearly balanced forces apparently caused the rocking motion of the core barrel and thus the ex-core neutron noise.

H. KATAOKA : Dr Fry, my question may be trivial, but let me have a tip of lesson by your standard english to improve my broken english. You told us you worked 'whole night' to get the data including for low frequency range. I understand it needs very long time to get good data for low frequency range and night is sometimes more convenient than daytime for experiment for the reason of stability condition of the electric power supply, temperature condition, disturbance by other people's getting in and out and the other conditions. I would like to know your reason why you worked 'whole night' insted of 'whole daytime'.

D.N. FRY : The frequency analyzer we used was able to perform its functions automatically. Therefore, when we went home for the day we started a repetitive program that obtained a frequency spectrum every two hours during the night. The spectra thus obtained were used to determine the stationarity of the neutron noise signal. The choice of the night (versus day) has no significance.

(35) The analysis of at-power neutron flux noise in the frequency range of vibrating reactor structures -
D. WACH

As described in literature and found by own experimental investigations at the German nuclear power plants Obrigheim, Stade (PWRs) and Lingen (BWR) the neutron noise of power reactors shows a very variable and reactor-specific behaviour. Essential differences of power reactors to zero power facilities, i. e. larges geometries, high streaming of the coolant and various reactivity feed back mechanisms result in the factual findings that in contrary to noise theory of zero power reactors the at-power neutron noise cannot be described in a similar exact mathematical way. In many references the power reactor noise is described by extending the relation used for zero power reactors (i.e. the sum of the shot noise, fission branching noise) by the multiple reactivity noise sources. This is completely insufficient for the upper frequency range (above about 1 Hz) where essential other effects are present as shown in details in this paper.
Interpreting noise analises performed at the mentioned nuclear power plants and using phenomenological models, it could be shown that in nuclear power reactors the dynamics of certain structures cause essential, in some cases dominant spectral components.The phenomena observed so far are generated by two types of noise sources :

(a) movement of structure fields of the coolant (temperature, bubbles, chemicals)

(b) movement of mechanical structures of the reactor (vibration of internals)

In (a) dead times of the signal detection of local noise sources have to be considered. This is of principle importance when interpreting coherence and phase functions.

In (b) mainly the vertical and horizontal vibrations of the whole core unit are concerned. Vertical movement of the core barrel and by that the movement of the fuel elements relatively to the control rods acts as a reactivity noise source, whilst the horizontal movement acts as a local source, as a consequence of the modulation effect on the attenuation of fast neutrons corresponding to the variation of the water layer in the gap between core barrel and pressure vessel wall.

At the Stade Reactor, in the frequency range above 1 Hz this latter mentioned noise source forms the main source in the signals of the detectors positioned ned outside the reactor pressure vessel. Using correlation analyses between various vibration signals during the preoperational tests and between representative vibration and neutron noise signals during the power operational period the consistently proof of this noise source could be given at the first time in Stade. Investigations of the long term behaviour and the identification of other noise sources in the same frequency range are the basis of some prectical applications of neutron noise analysis.

DISCUSSION

H. VAN DAM : On page 4 you state that relative movement between control rods and fuel elements is essentially a global noise source. In my opinion this depends on the position of the detector with which you measure the noise. If the detector is positioned near the tip of a control rod, you will measure a relatively strong local effect. In general I think that the division between local and global sources is a good working model, but we must realize that every local effect has also a global effect: the ratio between these effects depends on the position of the sensor relative to the disturbance. Would you commment on this ?

D. WACH : You are right in your first statement. A detector positioned near a local reactivity distur bance will measure a stronger effect (amplitude) than a remote one. The described working model discriminates different natures of noise sources,which are essentially characterized by the particular behaviour of the CPSD-phase in a two-detector-experiment. The noise sources of the first type are 'seen' nearly simulaneously - that means in phase - by all detectors at any positions. All global reactivity disturbances influencing the core as a whole, but also all local reactivity disturbances occurring in a fixed core position belong to this first group. The other groups of noise sources are caused by local disturbances which are detected by the regarded sensors either delayed by transport times (linear phase functions) or with constant phase relations e.g. 180°.

You are not right stating that every local effect has also a global effect. All local noise sources in a detector signal which are due to a local attenuation effect,e.g. steam voids in the moderator between fuels and detector or annulus gap variations due to lateral core barrel vaibrations, are at first detector-specific sources. The signals are mutually correlated only, e.g. because of the transport of the nearly unchanged configuration of bubbles in the coolant or because of a correlated attenuation resulting from the same structure vibration.

J.A. THIE : Can you tell us of your experience in the variation of the auto-power spectral-density during a fuel cycle and also after a refueling ? Also you may wish to mention any preliminary idea that could account for the magnitude of these changes.

D. WACH : In KKS we observed an increasing of the normalized power spectral density of ex-core ion chambers during the fuel cycle in a broad frequency range. After the first refueling essentially the same auto-power spectral density was measured like the beginning of the first fuel cycle. Reasons for these variations can be the variations of the magnitude of reactivity coefficients, especially of the moderator temperature coefficient. However, from the phase of ex-core opposite chambers,it is to be seen that also the attenuation noise of the core barrel movement has been changed remarkably. This effect has to be explained by variations of the macroscopic cross sections of the coolant in the annulus e.g. either by operationally changed boron contents or by the 'hardening' of the neutron flux in the core barrel boundary zone due to radial shifting of the power peak during the fuel cycle. The investigation of these phenomena is part of our future research work.

W.H. DIO : It is possible that the observed increase of the power spectral density of the neutron flux in the lower frequency range towards the end of the first fuel cycle of KKS is caused by temperature fluctuations of the coolant. The absolute value of the negative coolant temperature reactivity coefficient is higher at the end of the fuel cycle than at the beginning of the cycle: for example -3 to -5 pcm/C° at the beginning of the fuel cycle and about -35 pcm/C° at the end . These are temperature coefficients at power normal operational conditions.

(36) Boiling anomaly detection by acoustic noise measurement -

H. NISHIHARA

Fuel channel blockage and other reactor anomalies can alter boiling (or non-boiling) conditions of the coolant, which may most easily be detected by acoustic noise measurements. In this paper some fundamental aspects of boiling noise are reported based on the experimental results obtained with water media and the detection schemes of boiling noise in reactor systems are discussed.

Acoustic noise generated by nucleate pool boiling of water by heating electrically a thin platinum wire at atmospheric pressure from the incipience of boiling to the burnout of the heater was investigated experimentally. The water was contained in a cylindrical vessel, approximately 150 cm i.d. by 140 cm high. The power spectral densities (PSD) of the boiling noise extended to and possibly beyond 50 KHz , and behaved differently for heat fluxes above and below a certain flux level at which the overall noise intensity assumed a maximum value.

For heat fluxes exceeding the maximum intensity heat flux, decrease in the acoustic intensity was due to the decrease in the frequency components above approximately 3 KHz, while for lower heat fluxes the shape of the PSD remained practically unchanged. The PSD was also found to decrease for all the frequency components more or less uniformly with an increase in dissolved gas content.

Acoustic noise generated in fluid which is contained in a vessel of a finite dimension can not be free from the effects of standing waves (container system resonances) and from the wall reflections unless special precautions were taken for the construction of the container. In a separate boiling experiment, the container system resonances were so large that, when the noise detected by a pair of detectors placed at different distances from the localized heater was processed in cross-correlation functions, the peaks appeared at the zero-lag positions. It indicates that the container resonances masked the coherent signals which emanates directly from the heater. In fact, if signals in these resonant frequency ranges were eliminated, the cross-correlogram provides information for locating the anomalous coolant channel.

To obtain characteristic signature of the boiling, it is imperative, therefore, to investigate the frequency characteristic of boiling noise fully with pertinent coolant fluid under pertinent conditions (subcooling, pressure, flow and heat flux) and the acoustic characteristicsof the container system,e.g. characteristic resonances, transmission paths and wall reflections. In addition, efforts should be directed towards development of detectors useable in the hostile reactor enviroment.

DISCUSSION

D. SCHWALM : Can you give some answer to the question of the accuracy of your triangulation procedure?

H. NISHIHARA : It all depends on the specific region of the system in which the detectors and the noise source were located because, in some cases, reflected waves and other effects contaminated the measurement. When these effects were neglegible, the accuracy was as good as the size of the detector, or within the error involved in placing the detector.

W. SEIFRITZ : Did you not try to apply some kind of triangulation techniques to find out an unknown heater pin location because in the future such techniques might be of interest for LMFBR people.

H. NISHIHARA : As you have pointed out, the ultimate purpose of the cross-correlation studies of boiling acoustic noise is, of course, directed toward the triangulation. The results obtained here by a pair of detectors can be extended to multi-pair detector cases applicable to actual reactor situations.

L.G. KEMENY : These very interesting measurements, which undoubtedly help to increase our fundamental understanding of boiling phenomena, seem very far removed from a nuclear reactor situation. Would it not be preferable to adopt a more direct approach and use the acoustic noise technique to investigate : (1) the growth and collapse of individual bubbles, (2) boiling in simulated fuel pin clusters ?

H. NISHIHARA : Many items of investigation should be listed as important subjects including the two you have just pointed out, for the whole scope of the phenomena, from the generation of signals to the detection scheme in realistic geometry, is still not well explored. These are being pursued by a host of people including ourselves throught the world both in the fields of boiling heat transfer and reactor applications. There still exists a long way before the whole area is well understood and put together for ultimate application.

H. KATAOKA : Dr Kemeny points out very important problem. Dr Nishihara's experiments use two sorts of model, because his study has two targets. In the earlier period of reactor noise analysis study in Japan, people intended to analyze reactor kinetic themselves. This attempt is successful in zero-power reactors but not yet in high-power reactors. Discrepancy between theoretical calculated values and experimental results is so large in low frequency components of reactor noise and the reason of this disagreement is still unknown. At the first, people wanted to attack this discrepancy and now many people already give it up. Recently most of reactor noise analysts in Japan are directed to detect control rod motion, mechanical vibration and material failure, temperature and the other kinds of trouble like these. For the first purpose rather fundamental models are suitable and for the second purpose rather practical models. Because Dr Nishihara is studious and tenacious, he never gives up the first purpose and concurrently he wants to make his study useful for the second purpose too. Then it is very natural his experiments seem to use two types of models apparently inconsistent with each other. I am very pleased that Dr Kemeny understands the complicated condition in reactor noise analysis field in Japan and I recommend Dr Nishihara to recognize himself these two different sorts of target more clearly. Of course, these two targets actually have very close relation to each other and we expect Dr Nishihara study will be successful both in two purposes.

M. EDELMANN : You stated that acoustic noise analysis would provide the most promising method to detect boiling of sodium in a fast reactor. Could you comment on the basis from which this statement follows ? It seems to me that from the work reported in your paper this conclusion cannot be drawn. We at Karlsruhe were also looking into the problem of boiling detection in fast reactors. However, we are convinced that alternative methods have to be studied in addition to the acoustic method to finally provide a reliable detection scheme for monitoring a fast reactor with respect to boiling of the coolant. We consider the cross-correlation of neutronic and acoustic noise a serious alternative method for the detection of local boiling. The next paper to be presented at this conference will show you why.

H. NISHIHARA : I did not say that the acoustic method is the most promising one, but certainly is one of the most promising methods for the detection of boiling LMFBRs. One basis for this is its ability of detection in the high frequency range where background noise is small. My statement is the conclusion based on our own measurements, but rather intended to draw your attention to its importance in boiling detection. In actual applications, use of cross-correlation of neutronic and acoustic noise may provide an excellent tool. Or, correlating acoustic noise detected by detector pairs for the purpose of triangulation may solve the problem of poor signal-to-noise ratio and the location of boiling as well. Another suggestion is to cross-correlate acoustic noise signals in different frequency domains.

(37) Cross correlation of neutronic and acoustic noise signals from local boiling - S.A. WRIGHT, R.W. ALBRECHT, M.F. EDELMANN

Acoustic and neutronic noise are the primary methods considered probable to detect Na boiling in LMFBR's. However, both methods are feared to have serious signal-to-noise problems due to the large background noise sources. Because the background noise sources for the neutronic and acoustic noise are physically different, one can expect to decrease the effective background noise by cross correlating the two signals. This will improve the signal-to-noise ratio provided the portion of the signals caused by the boiling phenomena is strongly correlated. One should expect such a correlation to occur at the bubble repetition frequency. These facts motivated a boiling experiment in which the neutronic and acoustic noise were cross correlated.

A boiling generator was designed to simulate the volume and pressure effects of local boiling as described by Gast. By forcing superheated steam into cool water, it was possible to produce single bubbles ranging from 1 to 4 cm in diameter and having lifetimes of approximately 60 milliseconds. Following the collapse of a bubble and the growth of the next, a deadtime was observed. Bubble repetition rates could be varied from 4 to 18 Hz.

During the out-of-core experiments, high speed films were made of the bubble growth and collapse. These films were synchronized with the corresponding pressure pulses created by the bubble collapse. From this information characteristic features of the volume and pressure pulses were identified.

In-core experiments were performed in the zero power (10 W) GfK Argonaut reactor. The boiling simulator was placed in the fuel zone of the reactor and the neutron and pressure noise signals were recorded. A wide variety of boiling conditions were simulated and compared with the out-of-core results.

Power spectral densities of the neutron and pressure noise signals are shown in Fig. 1 . Three peaks are apparentin the Auto Power Spectral Density (APSD) of the pressure signals. The first at 7 Hz is due to the large bubble repetition frequency ; the second at 14 Hz is also associated with the bubble repetition rate. This peak is at twice the large bubble repetition frequency because the boiling generator had the characteristic (as seen in the films) of producing a two-bubble pattern. First a small bubble would form and partially collapse, immediately followed by a second but much larger bubble. A third peak at 23 Hz is caused by the duration of the pressure pulse.

The neutron APSD reveals both peaks due to the bubble repetition rate ; however, the second is very weak. This is a result of the reactor transfer function and the two-bubble effect just described. No obvious peak occurs at the frequency corresponding to the pressure pulse lifetime.

The neutron-pressure Cross Power Spectral Density (CPSD) has not only the two peaks due to the bubble repetition rate, but also a peak corresponding to the pressure pulse duration time. This correlation between bubble volume and pressure was not apparent from either APSD but is shown clearly in the CPSD.

A very simple model was found sufficient to describe the general shape of the neutron-pressure CPSD. The model relates the bubble volume to the neutronic signals via the void coefficient and reactivity transfer function and to the acoustic signals via a simple transfer function. For fast power reactors the neutron-pressure CPSD is proportional to the pressure APSD times a transfer function that falls off as $1/\omega^2$.

To summarize briefly, the neutron-pressure signals are strongly correlated with coherences up to .6 at the bubble repetition frequency. This strong correlation will improve signal to noise ratios and thus ea se detection of local boiling. Only simple models are necessary to describe the general shape of the neutron-pressure CPSD. This has an important advantage, since, in the authors' opinion, only simple models can be used in devices that are tied to the safety system of power reactors.

DISCUSSION

W. SEIFRITZ : Did you directly measure the pressure variation or did you calculate this quantity via the second derivative of the gas volume fluctuations ?

M. EDELMANN : The pressure fluctuations have been directly measured by a piezo crystal in both the out-of-pile and in-pile experiments. In the out-of-pile experiments the pressure variation caused by the steam bubbles has also been calculated by differentiating the time-dependent bubble volume twice. This has been done as a check for the volume-pressure transfer function derived from a simple bubble model. This transfer function was needed for the calculation of neutron-pressure cross power spectral densities.

H. NISHIHARA : Where does the vapor bubble collapse ? Have you not chosen the collapsing location where the void reactivity-effect is most strong ? Is your boiling simulator actually simulating real boiling phenomenon in reactors ?

M. EDELMANN : The vapor bubbles collapse slightly above the steam nozzle which produces them because there is no flow of the water inside the boiling generator. In the in-core experiments the boiling generator was placed at a fuel element position in such a way that the bubbles were generated near the midplane of the reactor to produce maximum void reactivity. To what extent real local boiling in a LMFBR has been simulated is an open question because till now it has not happened yet. It has been produced in sodium boiling experiments using small bundles of electrically heated pins only. In our boiling simulator the characteristics of this type of boiling has been reproduced very closely as far as void and pressure effects are concerned. However, the acoustic transmission of a fast reactor which is important for boiling detection by acoustic methods was not included in our simulation of sodium boiling.

D. WACH : I learned from your explanations that the sign of the phase is of great importance for the interpretation of your results. In this context I wish to ask you : how do you use formula 2 of your paper ? What is the input and what the output signal ? In light of the control theory you have to take the complex-conjugate from the X-signal, if this is the input, and not from the Y-signal as done in your paper.

M. EDELMANN : In principle I agree with you completely. However, we do not cross-correlate input and output signals but two signals which are not connected to each other by an input-output relation. Also in this case where we have two output signals the phase angle of the cross power spectral density depends on which of the Fourier transforms of two signals is complex cojugate in the multiplication. Therefore in our case it is only necessary to use the same definition of the cross power spectral density in both theory and data processing. And this we have done. But again, you are right, if one is interested in the phase of CPSD's one has to be careful with the imaginaries of the Fourier transformed signals.

J.A. THIE : In Fig.10, the phase is seen to be approximately constant above 4 Hz at 135 degrees, whereas the amplitude data and Eq.16 of the paper would not lead one to expect this. Is there an explanation ?

M. EDELMANN : This is a joint effect of low coherence between the neutron and pressure signal in the whole frequency range except a small interval centered at 5 Hz and numerical inaccuracies in digital signal processing using 10 bit ADC's. The measured coherence is shown in Fig.11. There it is seen that significant coherence exists only for frequencies between 4 and 7 Hz. Below 4 Hz no pressure fluctuations are produced by the boiling generator. Above 7 Hz the neutron fluctuations are attenuated due to the low-pass characteristics of the reactor having a break frequency of 6 Hz. Therefore the phaseplots had been given for frequencies from about 4 to 7 Hz only instead of the whole frequency range being analyzed. Between 4 and 7 Hz the phase angle calculated from Eq.16 varies only slightly and equals 135° at the reactor break frequency (6 Hz), actually.

K.J. SERDULA : In your model $\frac{\Delta N}{N}(\omega) \propto V(\omega)\; a_V H(\omega)$ and the pressure signal $\Delta P(\omega) \propto -\omega^2 V(\omega)$; therefore the transfer function $(\Delta N/N)/\Delta P$ should be given by,

$$\frac{\Delta N/N}{\Delta P}(\omega) \propto \frac{V(\omega)\; a_V\; H(\omega)}{-\omega^2\; V(\omega)} \propto - \frac{H(\omega)}{\omega^2},$$

assuming $a_V \neq f(\omega)$. Therefore $\left|\frac{\Delta N/N}{\Delta P}(\omega)\right| \propto \left|\frac{H(\omega)}{\omega^2}\right|$

and $\angle\left(\frac{\Delta N/N}{\Delta P}(\omega)\right) = \angle - H(\omega) \mp 180°$. The last equation shows the phase angle should have the same variation as the phase of the zero-power transfer function $\pm$ 180°. Therefore I would expect the phase angle of the transfer function to be above or below the 180° phase line but not to cross the 180° phase line. Would you plase comment on the variation of the measu red phase angle shown in Fig.9 and 10 as compared to the phase predicted by your model ?

M. EDELMANN : The general relation between the pressure-to-neutron and the reactivity transfer functions you just derived follows immediately from Eq.14 of the paper. So, I agree with you that the frequency dependence of the phase angle is solely determined by the zero power transfer function. If the void coefficient α_V is negative the phase of the pressure-to-neutron transfer function $\frac{\Delta N/N}{\Delta P}(\omega)$ and that of the reactivity transfer function $H(\omega)$ are identical. For a positive void coefficient we have

$$\angle \frac{\Delta N/N}{\Delta P}(\omega) = \angle H(\omega) \pm 180°.$$

Therefore you also right that the phase angle should not cross the 180° line. The reason that this appears in the phase plots of Fig.9 and 10 for frequencies below 3 Hz has been mentioned in my answer to Dr Thie's question. Below 4 Hz there is no correlation between the neutron and pressure signal. The real and imaginary parts of the CPSD are very small and may change their sign independently of each other due to statistical errors. This results in positive and negative phase angles which have to be added to 180° in our case. These phase angles can have large values due to the finite amplitude resolution in digital data processing. The phase plots in Fig.9 and 10 are raw outputs from the digital frequency analyzer and should have been reduced to their relevant parts for reproduction in the paper.

(38) Noise spectra of BWR and application of noise analysis to FBR

T. NOMURA

After the Japan-USA seminar in 1968, main subjects in our laboratory were selected, one of which is BWR noise analysis and the other is related with FBR. Some of these parts are related each other. For example, boiling detection and temperature fluctuations are problems in both fields.

In this review paper, mainly those subjects which have been performed in our laboratory are introduced.

(1) The fundamental experiment on boiling detection was performed utilizing Toshiba Training Reactor. Equipment of air void production was set at the botton of the reactor core. The volume of void was parametrically determined and the reactivity change during the pass of each channel was measured by a reactivity meter.

(2) The experiment of absolute power measurement was performed applying two-detector cross correlation method. The benefit of this method is to be capable of elimination of detection noise which is dependent on detector position. The measurement of subcriticality was performed at the minimum critical test on TEPCO-II. The computational results by nuclear design and k_{eff} deduced from experimental noise analysis using beta-effective = .007289 were compared. Both were found to be in good agreement.

(3) Polarity correlation technique was applied to the subcriticality measurement of a zero power fast reactor. The frequency range of the fast-reactor-noise spectra is expanded to higher frequencies than that of a thermal reactor.On the contrary, the frequency response of the instrumentation system is difficult to expand this frequency range. This technique can eliminate the effect of instrumentation system. The measured reactivities are in good agreement with those obtained by positive period method.

(4) BWR noise analysis was performed on TEPCO-II. To know the dynamic behaviour of BWR, the power spectral densities and the cross power spectral densities of neutron flux, core flow rate and core pressure are analyzed by FFT using minicomputer. The experimental results were compared with analytical calculation and both were in good agreement. As a result of this study, the fundamental spectral pattern of neutron flux in BWR was made clear.
(5) In order to detect the local coolant blockage in the LMFBR, simulation test for monitoring the subassemblyoutlet temperature using thermocouples is performed. The measurements of the RMS of the temperature fluctuations and the conventional mixed mean temperature are carried out with a water loop simulating the fuel bundle of experimental fast reactor JOYO. It was found that the RMS of the fluctuation signal is more sensitive for detecting local blockage than the conventional mixed mean temperature.

DISCUSSION

D. WACH : Two small questions :(1) What is the sensitivity length of your in-core neutron detectors used in the BWR ? (2) Have you also looked to the frequency range higher than 10 Hz in the PSDs of the in-core signals ? Is there a corner frequency or not ?

T. NOMURA : As for question (1), the sensitivity length of our in-core neutron detectors is 1 inch. As for question (2), we have not looked to the frequency range higher than 10 Hz. A corner frequency is several tens of Hz in this case.

D. SCHWALM : Did you observe changes in the PSD of temperature fluctuations of TCD in the case of the simulated blockage when you heated the central pin?

T. NOMURA : We do not measure the PSD in case of the simulated blockage, although we can not find any changes in the shape of the measured PSD of temperature fluctuation of TCD in case of the flow change. As we are interested in this problem, we will try it.

(39) Plant disturbance and model verification
M.H. BUTTERFIELD and J.D. CUMMINS

Methods of measuring dynamic properties of plant by injecting pseudo-random and other forms of distu-rbance are compared and examples quoted from zero power and power reactor studies. The use of these disturbance measurements to verify mathematical mo-dels of the plant and derive 'best fit' values of parameters in the model is discussed. In general the set of best fit parameters depends on the criterion adopted. Criteria are proposed which relate directly to the intended use of the model and some corresponding results quoted.

(40) An on-line power-reactor shutdown reactivity meter based on a novel reactor noise analysis technique

K. BEHRINGER, J. PHILDIUS, W. SEIFRITZ

In a heavy-water- or graphite-moderated reactor the slow prompt neutron kinetics cannot be clearly separated from the delayed neutron kinetics. To overcome this problem the low frequency parts of the neutron precursors are removed by proper high-pass filtering of the random output signal of an ion chamber monitoring the neutron flux fluctuations. This leads to a zero-crossing of the correlation function. Based on this method a simple direct reading subcritical reactivity monitor has been designed which uses polarity correlation techniques. Reactivity measurementson the heavy water reactor DIORIT will be presented. As a general method the meter-design is also applicable to fast reactor systems.

DISCUSSION

T. NOMURA : Did you compare this zero-crossing method with the coherence method that you developed before ?

W. SEIFRITZ : All on-line noise techniques which are known up to now are based on the separability of the prompt neutron kinetics from that of the delayed neutrons. This means that the zero-power reactor transfer function has to show a sufficiently long plateau below break frequency β/ℓ . In our case the coherence method was not applicable due to the overlapping of the prompt and the delayed neutron kinetics.

S. CHWASZCZEWSKI : (1) Can you give any information about intensity of the neutron source in the reactor during reactivity determination ? (2)What is the reactivity range of the reported reactivity meter?

W. SEIFRITZ : (1) In a heavy water moderated reac tor the inherent neutron source intensity is very high due to the photo-neutron production. For this reason a reactivity determination from period measurements is not possible. At DIORIT the background source strength in the subcritical state after one week shutdown is estimated to be about $2 \cdot 10^{12}$ neutrons/ sec . (2) The reactivity meter covers a measuring range from delayed critical down to about -10 $, which may be also the lower limit of the reactor point approximation model on which the theory is based. The zero-crossing τ_0 vs ρ^* shows an adequate sensitivity behaviour to this limit.

K.J. SERDULA : I believed you stated you require a calibration of this reactivity meter. Would you like to comment on the calibration requirements during burn up of the core ?

W. SEIFRITZ : The core of the DIORIT reactor is subdivided into five zones. Shuffling is made after a total core burn-up of about 5000 MWd whereby one zone is replaced by a new load. Each time the control rods have to be recalibrated (due to changes of β and Λ). The calibration procedure uses the rod-drop method.

U. WESSER : (1) What time needs the reactivity meter after a reactivity step to obtain the correct value ? (2) What is in the case if you have to change the range of the current amplifier ? (3) Did you have trouble in the presence of the 50 Hz noise ? (4) What do you think about connecting the reactivity meter on a period-meter ?

W. SEIFRITZ : (1) After a reactivity step change one has at first to wait for dying away of the flux transients mainly determined by the short lived neutron precursors. A quasi-equilibrium state will be reached as soon as a further flux change becomes neglegibly small within the control time constant of the meter circuit. Under the measuring conditions at DIORIT correct meter indications were obtained after about 15 to 30 minutes. The control time constant describing the meter response behaviour was estimated to be about several minutes. At a reactor with slow prompt neutron kinetics this figure may not be undercut since this time constant depends not only on the intrinsic set but also on the zero-crossing slope of the polarity cross-correlation function which is again a function of the detector efficiencies. For the latter ones, we had favorable conditions. Opposite to the demand for a fast response a reasonably small variance of the meter indication is desired which requires a compromise in the control time constant set. (2) By the use of the polarity correlation technique the meter characteristics are independent from the selected amplitude range of the amplified fluctuating detector signals. One has only to be sure that the amplitudes are sufficiently high in comparison to the small hysteresis level in the sign generator of each channel. As long as this is observed an amplification change during operation does not affect the meter display. (3) No. The detectors are battery powered (900 V) and completely disconnected from the reactor mass by an additional shielding line. (4) A period meter of the normal reactor instrumentation does not give any information at zero power when the reactor is in the steady state after shutdown. At very high power, one the period meter may work, the detectors of the reactivity meter are withdrawn from the core. So it is not possible to couple the reactivity meter to the period meter. There is also no sense to do this because the purpose of the reactivity meter is to monitor the reactivity of the reactor when it is in the subcritical state.

L.G. KEMENY : I would like to comment that we have been developing the correlation function-zero crossing method to assess subcritical reactivity on the HIFAR reactor of the Australian Atomic Energy Commission for the past year on the basis of proposals I made at a previous conference of this type. What are your views on the influence on a subcritical reactivity determination of this type of (a) positioning of detectors, (b) changes in background and source intensity as fuel burn-up progresses, (c) interpretation of signals in the very far subcritical region ? It seems to me that the construction of the meter is relatively simple compared to the fresh calibration need for start-up according to one's personal interpretation of the concept of reactivity.

W. SEIFRITZ : Unfotunately Dr Kemeny gives no reference to his type of zero-crossing correlation method. Thus, it is impossible to make any comparison study with our method. (a) During the shut-down period our detectors are always positioned in centre of the core to get maximum efficiency. Up to now space dependences were not yet investigated. During normal reactor operation, the detectors were of course withdrawn from the core ; (b) At DIORIT and decrease both with progress in burn up, the latter quantity a little faster than the first one. A rough extrapolated estimate from available data showed that a net increase of β/Λ in the order of 20% may result after a complete burn up of 17000 MWd/to. As mentioned in the answer on the question of Dr Serdula, the core of DIORIT is shuffled from time to time which includes also a recalibration of the zero-crossing vs reactivity ; (c) At a step from a weak subcritical state to the far subcritical region the correlated neutronic information is dying away. The meter receives then nearly white noise. The analog feedback circuit presented here is a proportional control with a smothing time constant. There exists a small inherent trend to force the meter display into a decreasing indication direction. But this will happen very slowly in time. The meter works with a suffioient precision down to reactivities of seven or eight dollars. It is not necessary to measure in the more far subcritical region with a high precision.

T. NOMURA : Yesterday I showed you a normal spectral pattern of BWR. But if something happened in flow or structure etc., spectral pattern will be changed. So, we need a lot of data anyway. I think it is the stage. So, we need the data acquisition system which gets various pattern of BWR very quickly. One of powerful ways by which the anomaly can be found is to make cross-correlation between various signals, I believe.

W. SEIFRITZ : I agree. At the EIR-Wuerenlingen we operate now the new OMNIFEROUS FFT real time analyzer from Federal Scientific Corporation which can meet these requirements.

J.T. MIHALCZO : (1) Can you comment on sensitivity of the method to spatial effect ? Have you made any measurements with detectors outside the core ? (2) If I recall your comment the zero-crossing τ vs reactivity ρ , it looks like it was asymptotic at highly subcriticality which would mean it would be difficult to make a precise measurement. Can you comment on this ? (3) Did you make any corrections for neutron lifetime since in your application boron concentration will change ? (4) Your statement about coherence amplitude as best method is not supported by the recent measurements at ZPR-IX on the heterogeneous mockup at the FFTF.

W. SEIFRITZ : (1) An answer to this question has already been given Dr Kemeny. We do not see any possibility to use the method with out-of-core detector positions. (2) This is just a feature which will make our method attractive. The zero-crossing correlation method is most sensitive in the region of weak subcriticality where the reactor point model is also a good approximation. We would like to remember the purpose of this meter as a safety device to detect an unwanted slowly dispersed approach to the critical state during reactor shutdown. We are never interested in a precise reactivity measurement in the far subcritical region which is a difficult problem due to the interpretation of the concept of reactivity. (3) No. The boron concentration used are very small (maximum 15 ppm of natural boron). On the other hand, it is true here what I just mentioned. (4) I meant that the simplicity of the evaluation of the statistical data is the outstanding feature of the coherence amplitude method. It is well-known that break-frequency method is sensitive to changes in the prompt neutron lifetime and insensitive to changes in the detector efficiency during shutdown, whereas the coherence method is insensitive to changes in neutron lifetime but sensitive to changes of detector efficiencies. Thus, it depends on the specific situation which method should be preferred.

(41) Measurements of temperature fluctuations in a gas-cooled power reactor

C.P. GREEF
(presented by M.J. BRIDGE)

The results obtained from measurements of thermocouple noise signals from a graphite moderated gas cooled reactor are presented.

An overall survey demonstrated that in the frequency range covered (up to .15 Hz), the reactor behaved as a closely coupled system with no significant phase differences between different parts of the core. Furthermore, the temperature noise power spectra could be divided into two distict frequency regions in this range. In the lower part of the range the observed fluctuations were found to be due to overall reactor power fluctuations, and in the upper part to heat transfer coefficient variations.

A simple model of the noise processes in the reactor has been developed and verified by consideration of the transfer function between coolant and fuel temperature.

The channel gas outlet thermocouple response, which was required for reactor fault studies, was measured by conventional rod oscillation techniques and noise analysis using both intrinsic fluctuations and refuelling transients. A comparison of the results showed that noise analysis, especially using refuelling transients, was capable of replacing the rod oscillation technique. This gave the advantage of not interfering with the normal operation of the reactor, reducing the experimental time and extending the frequency range of the measurements.

DISCUSSION

W. SEIFRITZ : At low frequencies (when measuring fuel time constants) it is a good assumption to adopt the point reactor model since the core is sufficiently coupled. What is your feeling to apply your method to a test bundle of GCFR fuel pins with roughened surfaces ?

M.J. BRIDGE : We are considering trying the technique on AGR reactor fuel which has steel clad fuel pins with roughened surfaces.

D.N. FRY : How often you measure outlet thermocouple response using the technique you have outlined in your paper?

M.J. BRIDGE : Thermocouple response times have been measured routinely using the rod oscillation technique. The use of temperature noise during refueling has now been accepted and is now being used on a routine basis.

G. KOSALY : As you mentioned in your presentation the frequencies you are considering are much smaller than the inverse of the transit time of the coolant through the core. Therefore the non-point model like behaviour of the temperatures seems not to be an axial but a radial effect. I would suspect that it comes from the fuel where a space dependent treatment should be used rather than a one-point model.

M.J. BRIDGE : Yes, I agree that the single region representation of fuel in the temperature equations is likely to be inadequate. At present we are investigating the effect of subdividing the fuel and moderator in the model.

R.J. COX : I feel the considerable discrepancies in the moderator reactivity coefficient and time constant needs comment. In some of the Magnox reactors the reactor fuel is enclosed in a graphite sleeve. These reactors show a much faster reactivity-moderator effect than the other reactors; with this fast effect being a large fraction of the total moderator effect. These sleeves act as if they are almost thermally insulated from the mass of the graphite and because of the close proximity of the fuel to these sleeves they contribute by a large proportion of the moderating effect.

I am sure your proposal to model the graphite in a series of annuli would give much better agreement with experiments. Also I feel I should comment that the DRAGON High Temperature Reactor displays a fluctuation in gas flow patterns between the six gas coolant circuits. This can result in fluctuation of the gas temperature rise along a fuel channel of the order of 20°C as well as displaying small filaments of very high temperature gas in the outlet gas ducts. These effects occur in spite of a large gas settling volume above the core. We also saw evidence of this type of flow pattern instability in the early Calder Hall Magnow power stations. It could well be occuring in your reactor and would cause large temeprature noise levels at the very low frequencies.

M.J. BRIDGE : The existence of slight flow instability in the Berkeley reactors has been found. This was inferred from the phase relationship between temperature signals in different parts of the core. The effect is however very small, certainly less than 1°C .

(42) Relation between nonlinear or not-linear characteristics in nuclear kinetics and noise analysis of neutron flux -
H. KATAOKA

The 'not-linear' or 'second-class linear' characteristics in nuclear reactor kinetics combine with the feedback effect in the high-power operation and induce the increase in the amplitude of the neutron flux noise, especially in the very low frequency region.

The author and his colleagues investigated the fundamental behaviour of 'not-linear' characteristics and its effect for the reactor noise.

The application of the reactor-noise-analysis technique to power reactors has not been fruitful because of unknown large disagreement between the result of the conventional theoretical analysis and the experimental facts.

As soon as the cause of this discrepancy gets well clear, the reactor-noise-analysis techniques can be effectively applied to instrumentation, control, monitoring and diagnosis of power reactors.

DISCUSSION

U. WESSER : You start your treatment with the one-point kinetics equation and this equation is not the correct one to start with. You should attack the problem through the neutron transport equation. Thus, from the application of an incorrect equation you cannot expect to derive the correct transfer function !

H. KATAOKA : As I mentioned in my presentation, there are despairingly large disagreements between the calculated values by conventional noise theory and the experimental facts in very low frequency components of reactor power at high power. And this circumstance still remains unexplained in spite of all the efforts. Then it is difficult for us to apply reactor noise analysis techniques in diagnosing nu clear kinetics of power reactors with high reliability. The classical reactor noise theory stands on many important assumptions : all of these seem to be reasonable for zero-power reactors but very suspicious for power reactors. They are :

- Markoffian process and stationary state
- purely linearized nuclear kinetics and Langevin's equation
- spacially one-point model
- white noise source for reactivity
- Gaussian distribution of noise amplitude

Maybe, the consideration of a spacial distribution effect is also important and many scientists have mentioned this problem. But, in spite of their efforts the cause of the abovementioned discrepancy still remains not clear : and then we have to consider another factor too. Since many other scientists' works will be expected for the spacial distribution problem, my mission should be to attack from another point, that is, not-linear or nonlinear kinetics problem. To make the lines of a complicated problem clear, we better attack each side of the problem separately, and not many sides at the same time. Perhaps the consideration of all the abovementioned problems will be necessary in a final stage for completing reactor noise theory at high power. The applicability of Markoffian process and stationary state is also suspicious now but we do not have much time here to talk about them. Anyhow I am sure it is time for us to overcome the limitation by linearized kinetics and Langevin's equation and I am very pleased in finding many excellent scientists are going to investigate from the same viewpoint of mine like prof Akcasu, Dr Karasulu, Dr Kebadze and Dr Gotoh in this very meeting.

D.M. SHVETSOV : What are the main practical benefits we expect from power reactor noise studies ?

H. KATAOKA : This is a very well-timed question.

In my presentation, I said that noise analysis techniques are established for zero-power reactors and have been often applied effectively : but this does not mean that they are absolutely important for zero power reactors. Reactor noise analysis techniques are surely useful for zero power reactors but in the case of zero power reactor diagnosis we have many other diagnostic tools. For example, the use of a reactivity imposed signal is usually very easy for zero power reactors. We can apply the so called 'ringing method', i.e. study of the response to imposed unit-function input, pile oscillator method, imposed pseudo-random signal method and so on as well as inherent noise analysis techniques.

In general, the following merits of use of inherent noise analysis techniques are not absolutely necessary for zero power reactors :

- practicing the test without imposing any disturbance
- carrying out the experimental test in a rather short time

Even the diagnosis of the inside condition via the disassemblying of the reactor and the assemblying of it again is not impossible for a zero power research reactor, if this is necessary effective and important. I do not say this is always easy but I can say this is not impossible and sometimes very easy depending on reactor types. Thus inherent noise analysis techniques are just as important as many other techniques and not absolutely important for zero power reactors.

More specifically the merits of use of inherent noise analysis techniques are absolutely fundamental and benefitial in power reactors because other techniques are difficult to be applied in power reactors. Operators and supervisors of commercial power plants usually do not like to have additional disturbance to be imposed on their reactors even for diagnostic purposes. In order to carry out smooth useful and safe operation of power reactors, I would like to make inherent noise analysis techniques useful for analysis of reactor kinetics and diagnosis of inside conditions in the reactor.

L.G. KEMENY : As I understand Dr Kataoka's work, what he is really saying to us is that - from the models he has developed - the reactor acts as a non-linear filter to applied stochastic perturbations. From the theory of signal analysis it would then follow that non-gaussian stochastic signals representing feed-forward or feed-back perturbations, applied to reactor models , will be amplified or attenuated according to the characteristics of such a non-linear filter.

This certainly appears to be a logical approach. Whether the magnitude of such effects is really significant could perhaps be assessed by some analog or digital simulation experiments.

H. KATAOKA : I guess Dr Kemeny would like to know power levels and other operation conditions and parameters in the experiments mentioned in my presentation. As I wrote in my paper, operation levels are 40 KW , 100 KW and 80 KW for JRR-1 , KUR and HTR. I used 0.02 δk/full power as power coefficient to reactivity for BWR type. This value seems very reasonable and fits to the values in many other papers on the same reactor. For two reactors of swimming pool type I reasonably calculated by myself power coefficient to reactivity based on the data written in references (12) and (13).

Regrettably and unfortunately I am falling into very severe difficulty, because all these reactors have been operated usefully longer than 10 years and are retired or close to be retired now. BWR types are already retired and one of the swimming pool types will be retired next March. Then, it is difficult for me to check or investigate again the data of operation conditions and parameters of these reactors. I would like to get Dr Kemeny's advices in a more complete way : but time is short. Let us continue to talk about them later on.

(43) A fast response thermocouple for temperature fluctuation measurements in sodium coolants - H. BUNSCHI and W. SEIFRITZ

A special chromel/alumel thermocouple was fabricated whereby the bare ends of the wires were fixed about 1 mm apart. In a medium with good electrical conductivity (e.g. liquid sodium) the junction of this thermocouple is replaced by the medium itself. Hence, a fast undelayed response is expected. Experimental data for this device compared with corresponding dynamical data for conventional thermocouples will be presented. While the mean temperature of both elements are in good agreement, the time constant of the open element is considerably smaller.

(44) Correlation analysis of the enviromental influences of the radioactive Argon releases from the plume of the reactor DIORIT - K. BEHRINGER, D. FEUERMANN, L. KOSTIC, W. SEIFRITZ

The influence of meteoralogical parameters (such as e.g. wind speed, wind direction, vertical temperature gradient) on the gamma dose rate from the plume of the 25 MW heavy water reactor DIORIT was studied during a one-month period by means of correlation analysis.

A simple model composed of linear superpositions of the various effects was assumed. The meteorological time records represent nonstationary random processes. To obtain useful information, the time samples were divided into samples of one-day period. Mean values, standard deviations, covariance functions, partial and multiple correlation coefficients were calculated using the ensemble averaging technique. Results will be represented.

DISCUSSION

M. EDELMANN : Is there any theoretical model which justifies the selection of independent sample records as you did it ?

W. SEIFRITZ : Nonstationary random data represent a class of random data whose statistical properties change with time. Therefore, mean values, standard deviations, covariance and correlation coefficients are also functions of time. We wanted to see how these statistical parameters change during a period of one day. It was necessary to gather sample records of the same one-day period and to use the ensemble averaging technique. The one-day period was detected to be a fundamental period in the experimental data. Heuristically it is obvious that a day is a typical period in the metereological scenario, too. I do not know what you mean when you say 'theoretical model' but I answer you that our process makes it absolutely necessary to apply the methods of the analysis of nonstationary nonergodic data.

J.A. THIE : Would you care to speculate how this excellent treatment you have given to this diffi-cult problem of nonstationary data analysis in or-der to determine site boundary doses might find applications ?

W. SEIFRITZ : The application of this method in the future is certainly directed to the forecast of the site boundary doses of nuclear power plan-ts. In analogy to the well-known weather foreca-sting system, a similar 'gamma-dose rate foreca-sting system' in the vicinity of nuclear power plants (or reprocessing factories) may be reali-zed. Presently, this work is only a first step in-to this new field. More extensive research is re-quired. Computerized data handling and theoretical models must be introduced and developed.

H. KATAOKA : Dr Seifritz, I highly appreciate you extended application of noise analysis techniques into environmental safety fields. To detect A^{41}, you used only gamma detectors. As well-known, we can apply beta detector for A^{41} too. If the chim-ney is high and so usually A^{41} flows highly over-head, it seems difficult for us to detect A^{41} by beta detector. But I am sure occurrence of turbu-lence or disturbance of air condition make us pos-sible to detect A^{41} by beta detector even located on the ground near the chimney. If weather condi-tion or wind condition is so stable in Switzerland, I can understand application of beta detector is useless. Anyhow I would like to know the conditions of your investigation a little more clearly.

W. SEIFRITZ : Please remember that the crucial qu-antity, which has tobe monitored due to safety re-asons, is the gamma dose rate to determine the who-le body irradiation. Thus, there is no interest to know the concentration of the Ar-41 on ground le-vel. Our high-pressure chamber 'sees' only the gam-mas from the Ar-41 of the plume. Of course, it would be addiational information to know the concentration of A-41 itself. But in practice this is not necessary because the biological hazard potential of incorporated Ar-41 is of minor importance. On the other hand, a beta-gamma correlation could help to check certain distribution models for the plume. But this kind of investigation was outside the scope of our work.

(45) Heat transfer time constant of a fuel pin determined by noise analysis - E. ROBINSON

The heat transfer time constant of a fuel pin, inserted in a light water reactor, is detrmined by cross-power spectral densities measurements, utilizing power reactor noise.

The phase of a measured transfer function between reactor power fluctuations and the signal of a centre oxide thermocouple in a fuel pin is interpreted by a point model of the temperature dynamics of the fuel rod. The effect of the time constant of the thermocouple is also considered. The model is shown to be adequate in the analyzed frequency region.

(46) Investigations of the influence of feedback and coupling effects on neutron noise in a nuclear reactor -

W. VAETH
(presented by M. EDELMANN)

The neutron power spectral density of power reactors is influenced by many parameters. These can be summarized into two groups. The first being reactivity perturbations whose statistical characteristics are unknown in most cases, and the second being various feedback and spatially dependent transfer functions. In the case of all effects being simultaneously present, which is the case for power reactors, it is extremely difficult to understand the spectra in detail. However some of the reactivity perturbations and their influence on the neutron noise in large power reactors can be simulated in a zero power reactor. In this way the effects can be studied more flexibly without the interference of other effects.

This paper describes investigations of the influence of a known feedback - namely a control loop with known transfer function - on the spectra of neutron chamber signals. Theoretical formulas for the spectra are derived using the point reactor model. Thse formulas were verified by noise measurements in a zero power reactor. In addition special attention is given to the noise generated by the control loop. The influence of this feedback noise on the spectra is verified experimentally.

In large reactors space dependent transfer functions must be taken into account. As a first approximation to handle the spatial dependence, the aforementioned investigations were extended to the two-point reactor model. Corresponding experimental work was done for the Argonaut Reactor Karlsruhe (ARK) with a symmetrical two-slab core loading.

As an application to a more realistic situation coolant boiling in a BWR has been investigated. The boiling must be considered as a feedback mechanism as well as an external reactivity perturbation. In order to simulate the steam bubble content, nitrogen gas was injected into the water-moderator of the ARK. By modulating the total gas flow according to the momentary reactor power the feedback effect was simulated. The gas flow produced a band limited white reactivity noise. The upper break-frequency could be used to determine the travelling time of the bubbles through the core.

FINAL SUM-UP

OF THE MEETING

FINAL SUM-UP OF THE MEETING

FARINELLI : I have a bad habit. I like to ask questions. I have already been asking some questions at the beginning of this meeting in my introductory remarks and I think that the answer to at least a good part of them is included in the reports that have been presented at this meeting and in the discussions that have followed their presentation.

I should like to have a sum-up of some of the conclusions as far as power reactors are concerned : which is, I believe, for all of us the future if not the present. Essentially I wish to iterate some of the most practical questions. They are :

(1) What are the motivations, the state-of-the-art and the possible developments of power-reactor noise-analysis as a tool for obtaining operational information on the systems ? In particular: what are the indications for basic instrumentation to be used during standard operation ?

(2) What are the contributions of noise-analysis methods to safety monitoring and early detection of malfunctioning ?

(3) What is the status of identification of noise sources ?

I should like to ask these questions separately for the different types of reactors. I have tried to identify some specialists that could actually break the ice to a general discussion.

So, with regard to light-water reactors, I think we are going to need two ice-breakers, one for PWRs and one for BWRs.

I believe that Dr. Thie is going to say something about PWRs.

THIE : I think I shall start and then pass the baton to Dwayne Fry. To answer the three questions that have been brought up, I should say :

(1) About the impact of noise technology near-term on plant instrumentation, I would guess from what I heard here that we are ready for a control room display of core barrel motion in PWRs. How the operators are going to interpret this display, I will not comment here on.

(2) About safety and monitoring I think there is likely to be increased noise data in start-ups : this is the opportune time and the increased applications that are coming along indicate that start-up teams may incorporate noise measurements more and more in PWRs - perhaps for no other reason than to obtain some empirical baselines. Furthermore I think we have noticed in the USA the appearance of regulatory requirements for actual monitoring, such as weekly or monthly, with documentation of this being required by law. This concerns the USA, and I am not talking about other countries. An impact on monitoring might be coming about from utility initiatives in the case where the utility sees a chance to forestall a shutdown. If a noise expert can come in and keep the plant from shutting down by monitoring something that is causing trouble , the utility will welcome him with open arms.

(3) In regard to further research on noise sources in the case of PWRs, I think there si a need to establish action limits for these monitoring requirements of control room displays. Research is needed on what criteria we should apply for action, what reliability should be expected and so on. Finally, regarding the status of theory, we are not yet at the point of a priori calculating in absolute units auto- and cross-power spectral densities of all chambers, pressure sensors and temperature sensors. In PWRs I think this moment is on the way but there is a big area for theoretical development. I guess other comments on PWRs might be in order before we switch to BWRs.

SEIFRITZ : Dr Thie, do you a real necessity for the installation of specific instrumentation in the control room for monitoring core barrel motion ? I mean doing this operation routinely not only in the case of suspicious symptoms.

THIE : My answer is yes, from the standpoint of protecting yourself against the probability of a malfunction. There has been a history of thermal shield problems and also of loosening of bolts in core barrels. Statistically in a 40-year life of several hundred reactors one might expect that again.
Considering the amount of money that one could save if he is the one coming up in the future that is going to have the incident, I think he would ahead if he had prior experimental knowledge via a history of control room data logging of his core barrel behavior before the accident occurs.
But it is almost a certainty that between now and when all of us die, there will be another core barrel incident of the order of Palisades. I would bet on that.

KATAOKA : As long as I understand, such kinds of monitoring techniques for safety are not only necessary for the future but indispensable today. Japan has a basic and severe social problem : public does not understand safety of nuclear power plants.
Perhaps social conditions are not quite different from those of USA and many other countries. In this case for nuclear scientists and engineers the effort exists now of (1) keeping inherent safety of nuclear reactors, (2) preserving the population after a big trouble occurred. But I am sure one more important effort should exist, that means, diagnosing the reactor conditions and practicing preventive treatments.
In order to make people forecast malfunctions and potential failures of nuclear power plants and protect the facility from occurrence of a big trouble, we must develop various kinds of monitoring techniques to make people preventively pay attention to reactor

phenomena through some useful methods like noise analysis techniques.
Then all people would be in the condition of understanding that nuclear power plants are quite safe for themselves and would appreciate serious efforts of nuclear scientists and engineers.
Hereby the development of nuclear power would be carried out more smoothly than in the present situation.

THIE : I take your position in support of noise analysis. One other thing came into my mind in answering Dr Seifritz question. We have noticed in the control-rooms the turbine monitor chart with lots of vibration readings and criteria for interpreting these and so on. The turbine is a fairly big monstrosity and is accepted historically that one must monitor its viabrations : I think the core barrel is a comparable monstrosity (maybe because of its cost and size, if for no other reason). You might by analogy be interested in its vibrations.

EDELMANN : In my opinion too little effort has been so far dedicated to the specification of incidents and failures which should and could be monitored by noise analysis. We should define which malfunctions have to be studied with high priority and which ones are of minor importance.
In other words, we should concentrate on the most important noise sources and the noise analysis techniques most suitable to detect them under typical conditions of power reactor operation.
As an example, I would like to point out that for a sodium cooled fast reactor such failures have been identified. For instance, local loss of coolant has serious safety implications. This leads to a strong motivation for investigating sodium boiling effects and neutronic and acoustic noise cross-analysis techniques for detecting boiling in LMFBRs.
I feel that we should have such sort of classification of incidents also in light-water reactors.

FARINELLI : Should we move on to BWRs ? I believe that Dr. Seifritz is going to be the ice-breaker for BWRs.

SEIFRITZ : As far as BWRs are concerned, I believe that in the last five years the activity in the noise-analysis field has been concentrated on the space dependent behaviour of noise inside the core. It seems to me there are three main features that came out. They are :

(1) The NRMS value as a function of the axial core height, which for a point-reactor model should be a constant, has been observed in different reactors now to have a definite shape : a linear increase in the lower part of the core that saturates to a constant value in the upper part. It is a consequence of the simple fact that in the upper part of the core the relative noise amplitude is larger than in the lower part of the core.

This behaviour has been experimentally observed in four reactors : the Lingen reactor (Germany), the Fukushima-1 reactor (Japan), the Garigliano reactor (Italy) and the Muhleberg reactor (Switzerland).

(2) The PSD function amplitude at high frequencies increases for increasing axial core-height position of the detector. This fact has also been observed in the four reactors I have mentioned earlier.

A theory has been developed of this spatial dependance : it deals with a local effect and a global effect.

Actually point reactor theory states that the PSD function should be independent from the detector position in the core.

Practically things seem to behave in a different way.

The global part takes contributions from all over the reactor and consists essentially of the low-frequency portion of the PSD function. On the contrary, the local part is affected by the detector position and contains the high-frequency portion of the PSD function.

At this point, let me few words on the instrumentation now available for noise measurements in BWRs. Not only small mini fission-chambers, which are installed inside the core, but also ion-chambers located in the outer part of the reactor are suitable for neutron noise analysis measurements in power reactors.
In the last years it could also be shown that self-powered neutron detectors are suitable. This fact is not trivial because the sensitivity of these detectors is very small: but could demonstrate that these detectors work. Not only the usual V (Vanadium) and Rh (Rhodium) emitters have been used but also prompt-response Co (Cobalt) detectors, Hf (Hafnium) detectors: they have the capability of seeing mostly fast neutrons, instead of thermal neutrons. Hf has in fact a resonance structure in the higher-energy range. And Ac (Actinium) detectors have been used predominantly by Canadians. These detectors see, beside neutrons, also gammas.
Beyond these neutron-sensitive detectors we used and applied also gamma-sensitive detectors. Mini ionization chambers by Westinghouse have been adopted with an active length of 8-10 cm : these data have not been published yet. It is important to say that one can derive the same information either detecting gamma noise or detecting neutron noise.

(3) A correlation field exists in BWRs, specifically an axial correlation. The early detection, in 1971, in the old Halden (Norway) reactor actually showed an axial transport effect. The observation has been transferred to other BWRs and the movement of steam bubbles has been studied, in time and frequency domain, in reactors

at Lingen, Garigliano, Fukushima, Muhleberg and in the Oskarshamn-1 reactor (Sweden).
It seems also that in BWRs it is possible to measure axially dependent steam velocity. Now the question is, of course : how to measure the slip ratio, because one has to measure the water velocity, independently. At this point it seems to me that this is not possible in a power plant: it is possible in a test loop but not inside a reactor.

So, these are the three main objectives concerning BWRs.

I also see an urgent need for the installation of a safety monitor system. Last year,I proposed to use measurements of steam bubble velocity as an on-line method to survey the conditions of the coolant flow in BWRs.

I believe in a final necessity, at this very moment, for a full-scale cooperation between theoreticians and experimentalists.

FRY : I think there is another problem that we need to tackle in the BWRs. Dr. Thie mentioned that these plants are built to operate over a period of 30-40 years. I believe we are going to face mechanical problems in BWRs similar to those we have experienced in PWRs. Not of the same type, because the construction isn't the same. In the past several years we have already experienced a couple of mechanical problems : in the Muhleberg reactor and in the Vermont Yankee reactor. I believe there were problems with the control shrouds : they were mechanically related.
I also believe that the most important problem we have to tackle in BWRs is to separate the mechanical type of noise from the boiling noise. It seems that we are beginning to get a pretty good handle - both experimentally and theoretically - on the influence of the boiling noise on the neutron spectrum.
We should extend these studies to separate these ef-

fects and understand better the mechanical influence on the spectrum. I think that the long-term applicability of the neutron noise will be in BWRs - pretty much the same as in PWRs - to detect mechanical malfunctions inside the core, where we cannot place mechanical detectors.

SEIFRITZ : What Dr. Fry says is true, but so far in BWRs an experiment is missing as the core barrel experiment in PWRs. In BWRs a single physical process has not been isolated yet.

FRY : What I say is that we may have seen something in the two mentioned reactors if we had been performing neutron noise analysis. So it is my opinion that we at least ought to start acquiring some data from these reactors. And I propose pattern recognition or trend analysis techniques as a possibility where we can leave the system unattended at the reactor to accumulate and catalog spectra and keep these available. And when an incident, like the one happened in Muhleberg and in Vermont Yankee occurs, we will have a signature to see if neutron noise is sensitive to these techniques and whether we can extrapolate to other BWRs.
To me this is the only hope in terms of determining the sensitivity for mechanical malfunctions.
This is, I believe, the most serious initiative right now other than a good understanding of reactor background noise which we are making a good attempt at already.
We cannot put noise analysts at the plant 24 hours a day to look at these data : I think automated algorithms, that will at least catalog and cluster these spectra, are needed to accumulate data according to normal situations and abnormal situations.

BRIDGE : I would comment that abnormal operation is by its very nature unexpected and unpredictable : so we should have all noise methods available as on-line records, as Dr. Fry says.

We cannot draw up a priority list of faults as suggested by Dr Edelmann, because we do not know what might occur. We need all the means available to detect and diagnose any unpredicted fault.

KEMENY : Automatic, computer-based pattern recognition techniques will accelerate the acceptance of noise analysis as an on-line monitoring technique for power reactors.
We have no power reactors in Australia but the Noise Analysis Laboratory of the Australian Atomic Energy Commission has been monitoring fuel element vibrational spectra from the 11 MW research reactor HIFAR and storing these, on a routine, on-line basis for many months.
In principle such patterns, especially when combined with neutronic and temperature signals, could uniquely identify each fuel channel in a power reactor, log its complete life history and actuate emergency shut-down procedures if and when required.

SEIFRITZ : It seems to me that Westinghouse and General Electric are both going in this direction. Dr Rajagopal told me that Westinghouse, for instance, developed very sophisticated monitoring systems to survey the entire reactor plant.

FRY : This is true with Westinghouse, at least in the area of safety. But General Electric people are not performing serious and comprehensive noise records on their power plants. And they are not performing very much neutron noise analysis. In fact, that is the reason why we got involved in the present measurements at Browns Ferry.

SEIFRITZ : I think I understand why. In fact, General Electric BWRs are very noisy, I mean mechanically noisy from the pumps.

SHVETSOV : It seems to me that it is hard to decide a priori which kind of parameter to study and to observe in all different reactors. You may look sometimes after other sources of noise rather than neutron noise.

SEIFRITZ : I agree with Dr Shvetsov but I think it is more convenient to study a combination of neutron noise and other noises.

KEMENY : How about studying structural mechanics ?

SEIFRITZ : In this case, you would have to instrument every pin bundle and this seems a hard task to me.

KATAOKA : Dr Nomura's company is responsible for construction and maintenance of BWR type power plants in Japan and yesterday he presented data from various kinds of important experiments about BWR noise, that is, minimum-fuel critical experiment of Fukushima-II , the results of noise analysis of Fukushima-I in the normal-operation condition and so on.
Fukushima-I seems to have been operated very smoothly without any trouble, but in fact slight faults sometimes occurred in it, although they were not severe. I guess Dr Nomura is to apply his diagnostic techniques by means of noise analysis also to the commercially operated condition of Fukushima-II and moreover both for start-up tests and commercial operations of many other power plants of BWR type in the future. I am sure he will present some comments about this problem.

NOMURA : Yesterday I showed the normal pattern of signal in BWRs. But if the flow gets abnormal, it affects the neutron signal and fluctuations. So,as I said yesterday, it is important to get familiar with the normal noise spectra pattern.
This means that one has to collect a great amount of data to store the correct information. For example, structural vibrations may occur in a in-core monitor : if you have normal operating condition

data you can by comparison tell what is happening in the reactor.

SEIFRITZ : I understand the point perfectly. But if a deviation occurs from the normal pattern, what are you going to do ?

NOMURA : If it is a peak in the cross-spectra between flow and neutron or pressure, we know what it is.

KATAOKA : As Dr Nomura mentioned now, comparing noise patterns of normal conditions with those of abnormal conditions is useful for practicing power-reactor diagnosis by means of noise analysis techniques. Moreover, experiencing abnormal conditions, accumulating the data of noise patterns of various causes of abnormal conditions, and comparing these noise patterns as reference standards with the noise patterns of abnormal conditions, which will occur hereafter, may be effective for identifying the source of the abnormal conditions.

SEIFRITZ : In principle I agree with you. But the reactor operator is not an expert in noise analysis. So he is not able to judge the gravity of the situation. A noise analyst has to teach him what to do in an abnormal situation.

FRY : The current philosophy in US concerning PWRs is this. They have a core barrel motion display chart in the control room. There are limits set on which the alarm has to sound or at least the yellow caution line goes up. Operators are required to notify the people in charge so that the noise diagnostics team comes in to determine the actual source of noise.
I think the same criteria can be used in BWRs : install a continuous monitoring system which is looking at few selected neutron detectors and let the noise analyst himself establish how much he thinks the noise ought to change before he wants to be notified to come in and to perform the on-line diagnostic measurements suggested by Dr. Nomura . The full complement

of cross correlations with other signals in order to diagnose the reason for this change in the noise.
I think this is the only approach that we can take to begin with : we cannot establish shutdown limits but action limits, as suggested by Dr. Thie.
It is our job as noise analysts to establish what action limits are adequate. When we would like to be called : this is the first action limit to establish.

SEIFRITZ : Yes, I agree with you but there is a difference. In PWRs you have a crearly defined physical effect and understood so far (i.e. the core barrel motion) so that you can design special equipment which detects only this effect, its amplitude and other characteristics.
In BWRs maybe you can do something similar by observing the transit time of the steam bubbles via two detectors located at two different axial positions : and if you have a deviation from the ordinary transit time you can say for sure that something is changing in the coolant flow inside the reactor.
But there is no other effect in BWRs that is comparable to the core barrel motion in PWRs.

So one has still to look after the physical origin of this or that effect, to recognize it before finally designing and installing a surveillance meter on that effect.

FRY : But I don't think that anybody anticipated the core barrel motion in PWRs as a possible abnormal effect. The idea came after observing neutron noise data by Dr. Rajagopal at Westinghouse.
And, after that, some people diagnosed the same kind of effect at Palisades.
I still think that the same approach can be used for diagnosing malfunctions in BWRs : without speculating a priori on the nature of the effects one is to expect.

BUTTERFIELD : There seems to be a neglected way of identifying the character of noise signals. Has anybody tried to listening to them through a loudspea-

ker ? Has anybody any experience of this ? The human ear is incredibly sensitive. I don't believe that any noise analysis between television sound and a kid next door playing violin could tell them apart. The human ear can do that very easily.
I know it is not completely satisfactory relying only on listening but I suggest it as a useful line of possibility. It does not go to very high frequencies but there are forms of demodulation.
So, if you hear something like bong-bong-----bong-bong-----bong-bong going on, it can be something significant : maybe not devastating, but significant.

KEMENY : Sonic monitors have been used extensively with radiation detectors and other instrumentation for some time.
The main problem in this area seems to be that much of our reactor noise is in the sub-sonic or super-sonic band widths. Demodulation or frequency shifting by some tape recorder record/play-back technique could over come this.
However, to escape a very real 'noise pollution' problem inside otherwise environmentally pleasing nuclear power reactor control rooms, we would require a staff of ten or more people seated near the shift supervising engineer, all equipped with earphones doing absolutely nothing but listening ! One suspects that their working lives would be short and their promotion prospects not attractive !

SAITO : When we make a rather long period of experience of operation on a particular reactor, we can have many patterns of the PSD of the reactor under normal operation. And if we have a large computer for on-line processing, we can make the comparison of the just obtained pattern with the previous ones. But the actual, normally operating core emits only a restricted range of patterns. So I think it is necessary to build up an appropriate theoretical model of the core and make an off-line computation to have previously various patterns which are possible to appear.

KATAOKA : Whe we compare what Prof Saito told now with what Dr Nomura told just before, I can see that we have here two directions to go under the present situation in which power-reactor-noise theory is not established yet.
Such two directions were already mentioned by Prof Farinelli in his excellent introductive remarks and I would like to interpret them in my own way.
One is to experience the operation of actual power plants as much as possible, accumulate the data both of normal and abnormal conditions, and practice the previously mentioned diagnostic methods.
Another is to make best efforts both by theoretical and experimental investigations to establish at least the fundamental principle of the theory as quickly as possible, and, after that, to practice analysis and diagnosis based on this foundation.
Now many Japanese reactor scientists and engineers seem to be absorbed into study on the former standpoint, including Dr Nomura and his group. This standing has reasonable points, because actual power plants often bring about unexpected faults from reasons beyond our preliminary studies.
Fortunately or unfotunately, abnormal conditions occurred just very rarely at Fukushima-I, and then it is still troublesome for Dr Nomura to get the data of reactor noise patterns at abnormal conditions.
To tell the truth, I would rather choose the latter standpoint and I am sure it is a scientist mission to prevent the fault from occurring and giving severe damage, without suffering actual experience of severe damage. But now in Japan people with these thoughts belongs to the minority group, even including powerful and influence scientist like Prof Saito and majority members are absorbed in empiricism.
Of course, there are many grades of combination and several types of compromize between the above-mentioned two principles.

SEIFRITZ : There is a point that we forgot completely. This is the inspection of the pressure vessel during the shutdown at the beginning of the fuel cycle by using a new method called 'stress wave emission technique'. It uses the very high frequencies emitted by cracks in the pressure tubes : special microphones made out of piezocrystals, having a frequency range up to 1 MHz, can detect and signal the presence of cracks. It is a pity that nobody reported of this technique at the meeting.

GREEN : Dr Seifritz might be interested to hear that we are now using the stress-wave emission technique he mentioned to look for cracks in pressure tubes of one of the Pickering reactors.

FARINELLI : Shall we move on to heavy-water reactors? The icebreaker of this section is going to be Dr Serdula.

SERDULA : First of all I would like to make a comment. Hearing Dr Kataoka's paper this morning made me reflect on the status and history of 'reactor noise'. In the early days of 1945 and 1946, before my time in the field, people were using what was called a pile oscillator in a zero-power reactor to determine neutron absorption cross-sections of materials. I can only surmise that at the time sophisticated computer codes, knowledge of absorption cross sections and material analysis capability were unavailable. So neutron cross-sections were determined to a few well-known standards.

Note the analogy with the proposed signature analysis concept to be used in noise analysis today where spectra are compared again to standards.

In 1947, at Chalk River, Dr Rumsay published a paper on the effects on non-linear kinetics in pile oscillator measurements. This morning we had a paper on non-linear effects in the interpretation of power reactor noise. I think I see an analogy here and probably this is a question. Are we in a similar development phase, maybe a bit further, in the determination of power reactor noise sources as was the development of determination of cross-sections from zero power pile oscillator measurements in 1947 ?

As far as what we are doing or what we are going to do in Canada, there are few issues that I did not mention in my paper.

They are :

(1) Continue to develop technical competence in the area of reactor noise and dynamics so the capability will be available if the opportunity arises or we are called upon to assist in solving problems encountered in our power reactors. I wish to stress the importance of sensors in this development area. A lot of times people in the field get carried away and they develop exotic sensors that work in special laboratory conditions. Then they go to the power station and ask for these sensors to be installed. Now, the sensors cannt be installed wherever and whenever you like : the utility is reluctant to shut-down the reactor for a couple of days in order to let you place the sensors. Also, once the sensors are installed, you then have to use them there to get your information. To obtain useful information one must have experience with sensors and know how their operating characteristics could be modified by their enviroment. It is of little use to go to the plant, spend one or two days taking noise measurements and then come back to the laboratory and discover the information is of limited use because the sensor response was adversely affected by its enviroment. One should know before he starts if noise measurements obtained with a particular sensor would be of use.

Also in this context one should use, if at all possible, the sensors installed for normal operation. This would assist in the program acceptance since site staff are already familiar with these sensors. It should be noted that the station is normally operated via signals from these sensors and we, using our noise analysis techniques, should be able to obtain addi tional information from these same signals which would be of use to the operation staff. Through installation of special sensors, the operations staff may be able to obtain additional information themselves without the need for noise analysis.

(2) Continue our measurements on the Gentilly-1 reactor. This is a prototype reactor where we have the opportunity to investigate sources of noise in power reactors and also coupling between parameters, e.g. bulk and spatial reactivity to flux, coolant flow to flux, channel flow characteristics etc. Another purpose is to improve our capability in the field of applying digital computers to the control of nuclear power plants. The emphasis in these measurements is on the importance of spatial effects in large thermal power reactors. One may ask why power plant measurements ? The reasons are: (a) it can be difficult to extrapolate data from small scale models to power reactors, (b) noise sources in small scale models may be different from those in power plants and this could give rise to additional problems in the determination of system dynamics.

(3) Use of measurements to verify plant models, space-time reactor dynamic models and the parameters used in these models.

(4) Investigate new areas for application of our capability in the nuclear power field, e.g. in-core flux detector for fuel motion etc.

(5) Continue the transfer of technology from noise specialists to interested users (as, for example, operating staff at utilities) for creating an awareness on uses of noise analysis.

At present, in Canada, we do not have any mandatory regulation by our Atomic Energy Control Board on uses of noise techniques in the operation of a plant. Therefore, utilities and designers are reluctant to accept anything that will (a) increase the capital cost of the station,(b) increase operating costs and may not be required. This is specially true in proven reactor types.

MIHALCZO : Do you think there are any designer requirements on instrumentation that should be imposed on the company builing appliances so that it would be easier for the noise analyst to come in and make meaningful measurements ?

SERDULA : First of all, I think it is a question of economics. For instance, it is not economical to install pressure sensors that operate up to 100 KHz when you may be only interested in pressure fluctuations up to 10 or 15 Hz.

MIHALCZO : But if your pressure sensor only goes up to 5 Hz you are in trouble.

SERDULA : Yes, I agree with you. In that case, you have to find another method for determining the source.

MIHALCZO : I think that a few economical changes in the instrumentation can give you improvements with very little additional cost to meet much better requirements by the standpoint of noise analysis measuremenys.

SERDULA : In measurements at Gentilly-1 we are using the standard operating transducers : the pressure sensor response is up to 10 Hz, the flow response - determined from a Δp measurement - is up to 5 Hz. In the initial stage, the designers asked me whether this would be adequate. At that time I did not have much experience and I said : O.K. this should be alright for noise measurements if it is O.K. for operation.
I think deciding beforehand is rather difficult, that is, to determine what bandwidth you want in the instrumentation. Everybody would like a flat response over the widest possible range of frequencies. Obviously this is impossible, you have to set limits. This presupposes that you have a good knowledge about possible noise sources in the plant.

EDELMANN : I would like to emphasize what has been said by Dr Mihalczo. We should not rely on the instrumentation which is available at power stations. In many cases such instrumentation can be improved to such an extent that you may obtain much more information through noise analysis than in any other way, and this would not interfere much with the price of the power plant. We should convince the manufacturer about the advantages of an accurate noise analysis and the economical benefits one can come out with.

SERDULA : I agree with you wholeheartedly. If you can convince the utility that spending some extra $ 200,000 in instrumentation is going to result in $ 1,000,000 benefits they no doubt will accept a proposal for improved measurement equipment.

GREEN : One has to be careful in changing from proven instruments to those that may have better frequency response. We have had some difficulties with the reliability of RTDs (Pt Resistance Temperature Detectors) in the Pickering reactors. These were much faster in response than earlier devices. However, the older units, while slower, were much more rugged and hence reliable. Thus, although faster devices are desirable and perhaps not much more costly, they must be designed carefully to guarantee the required high reliability.

FARINELLI : Shall we move to fast reactors ? The section icebreaker is going to be Dr. De Lapparent from the Phenix experiment.

DE LAPPARENT : Perhaps a short sketch is better than a long speech. You know that we have ended the commissioning test of Phenix at the beginning of the year and we have just finished with the specifications for Superphenix : so I can give you the exact point of what appears reasonable concerning noise analysis in our fast reactors.
This is what you can face in the control room about the reactor noise analysis.

It is not anything for the expert, just for the operator.
We use four sensors : a neutron detector, an acoustic sensor, subassembly thermocouples a a vibration monitor. For each of them, we have a routine scheme of surveillance : for the output of the neutron detector we have permanent surveillance, for the acoustic sensor and thermocouples a discrete display (every one or two hours), for the vibration monitor it is a periodic surveillance (every six months).
The aim of surveillance is that of giving the operator an alarm. Since the operator is not an expert,we have to tell him what attitude to take in front of variations of the sensor responses: has he to do something, to call the specialists or do nothing at all?
At the same time, we have an automatic recording of the data for diagnosis. As you see, there is no automatic operation : the noise analysis measurements serve as an early detection of malfunctioning or anomalies, so that we have some extra time to make our diagnosis.
Actually, we compute autospectra and cross-spectra of the sensor responses.

The results of the autospectra of all the signals are usually given at one or two fixed frequencies.
So we are not giving the full shape of the spectrum vs. the frequency domain, because we believe that for the reactor operator team the amplitude at two frequencies is sufficient information.
But we think that autospectra are not sufficient for correct diagnosis : the complete answer comes from cross-spectra.
For example, we think - like it has been stated by Dr. Edelmann - that cross-spectra between neutronic and acoustic signals are the right tool for detecting boiling. We can measure it through the coherence function.
Another coupling we have been studying is that between neutronic and vibrational signals.
Another diagnostic procedure that we believe very im

portant concerns the local blockage. We have developed fast-response thermocouples of the type described by Dr. Bunschi (they are stainless steel/sodium thermocouples which have been operating for two years in Rapsodie): they have a frequency response up to 50 Hz.
Unfortunately, up to now we have not been able to give the proper diagnosis of the blockage. We are sure we can monitor the corrosion of the subassembly with this method and it is very important for the assessment of the sensors used for safety action.

KEMENY : Are these your plans for Superphenix or is this something operating in Phenix ?

DE LAPPARENT : In Phenix we have neutronic, thermocoupled and vibrational sensors. We are not very confident on acoustic detection of boiling : there are too many background noises. In the correlation between neutronic and vibrational signals, we have the problem - already mentioned several times - of understanding the real mechanical and hydraulic forces acting in the reactor.

KEMENY : Can you take this monitoring instrumentation right through the start-up range to full power or this is just for normal full power operation ?

DE LAPPARENT : No. Superphenix is a power plant and we must have a very good diagnosis system between 50% and 100% of full power.

KEMENY : Actually, you switch your monitoring instrumentation on after the reactor is critical ?

DE LAPPARENT : Yes, we switch on at 5 to 10% of nominal power.

MIHALCZO : Could you tell us a little bit about the hardware you intend to use to implement your systems on Superphenix ? For example, you have a computer : how large is going to be ?

DE LAPPARENT : We are giving the specifications to the constructors and now they have to think about the best way to realize that.
But we think that certainly a special computer will be needed to do this : it will be located in the control room together with a magnetic tape recorder and a FFT computer for processing our data.

BRIDGE : What will the vibration measurements be ? Axial or radial vibration ?

DE LAPPARENT : We have axial detectors along the control rod mechanism and underneath the core, at the grid level.

EDELMANN : Have you decided already upon criteria on which decision is made on shutting the reactor down or calling for an expert ?

DE LAPPARENT : Any deviation of a factor of 2 or 3 from the operational standard nominal values will immediately call for power reduction.
We did not make any decision yet over the response of the subassembly thermocouples.
For the acoustic signals, once the crossspectra with neutronic signals come out right, we prospect to have an automatic control system.
Finally we have to think about something concerning the local blockage.

WESSER : Have you experience of the sodium boiling ? You spoke about boiling effects : now you cannot simulate these effects. Have you really observed sodium boiling in a test loop or in a reactor ?

DE LAPPARENT : We have been experimentaing boiling in test loops : our first test was in Rapsodie.

KEMENY : I would suggest that if noise analysis is ever to pass from the hands of the specialist and the experimentalist into the field of routine power plant diagnosis and control, the following factors must operative

(1) Noise signals must be acquired and processed in real or close-to-real time ;

(2) Routine scanning of neutronic, thermal, hydraulic and vibrational noise sources will require large computer storage, fast data recall, pattern recognition techniques and simple clear control room display ;

(3) Time-series analysis techniques and algorithms should be standardized and normalized on national or perhaps international basis.

SHVETSOV : It seems there are no more questions and so the meeting reaches conclusion.
I believe it is no coincidence that SMORN-1 took place in Italy. Italy is the country where Enrico Fermi and reactor physics were born : it is also the country where Bruno Rossi, the first experimentalist in noise analysis, was born.
I think that all of us have to say great thanks to the organization of this meeting, for the idea itself and for its gathering such a representative group of specialists.
All of us are also grateful for the excellent time spent in Rome.
Finally, I wish to give a special thank to professor Pacilio and his friends and the people who helped us during the meeting.

PHOTOGRAPHIC

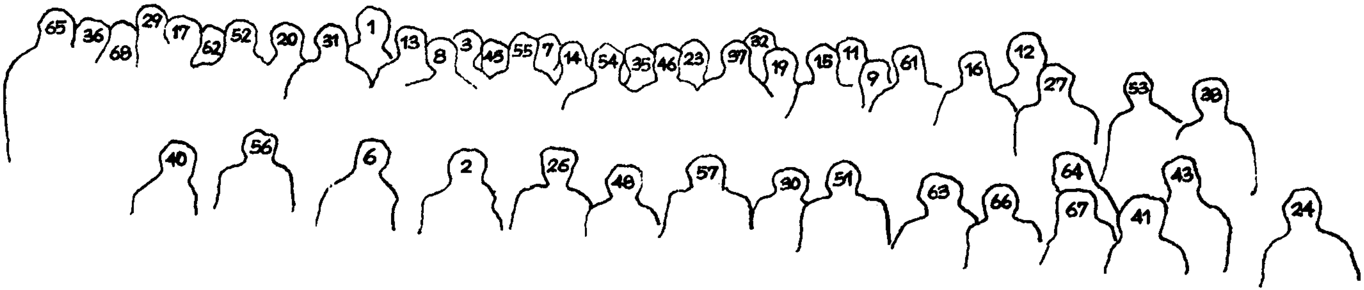
REVIEW OF

SMORN-1

(1) F. Akerhielm (SWE)
(2) B. Baers (FIN)
(3) R. Baeyens (BEL)
(4) W. Bastl (GER)
(5) S. Boeriu (RUM)
(6) M.J. Bridge (GBR)
(7) H. Bunschi (SWI)
(8) M.H. Butterfield (GBR)
(9) J.C. Carré (FRA)
(10) D. Cepraga (RUM)
(11) B. Chabert (FRA)
(12) S. Chwaszczewski (POL)
(13) R.J. Cox (GBR)
(14) M. Deiss (FRA)
(15) W.H. Dio (GER)
(16) J.B. Dragt (NET)
(17) M. Edelmann (GER)
(18) U. Farinelli (ITA)
(19) D.N. Fry (USA)
(20) R.E. Green (CAN)
(21) J. Hoekstra (NET)
(22) S. Horanyi (HUN)
(23) Jaudet (FRA)
(24) V.M. Jorio (ITA)
(25) M. Karasulu (TUR)
(26) H. Kataoka (JAP)
(27) B.V. Kebadze (SOV)
(28) L.G. Kemeny (AUS)
(29) G. Kosaly (HUN)
(30) D. De Lapparent (FRA)
(31) R.A. Lewis (USA)
(32) M. Marseguerra (ITA)
(33) F. Mathieu (BEL)
(34) W. Matthes (EUR)
(35) B. Mavko (YUG)
(36) J.T. Mihalczo (USA)
(37) J. Mika (POL)
(38) A. Mikulski (POL)
(39) H. Motoda (JAP)
(40) H. Nishihara (JAP)
(41) T. Nomura (JAP)
(42) E. Ohlmer (EUR)
(43) N. Pacilio (ITA)
(44) D. Pallagi (HUN)
(45) A. Perez-Navarro (SPA)
(46) E. Robinson (NOR)
(47) J. Royen (NEACRP)
(48) K. Saito (JAP)
(49) J.P. Schneeberger (SWI)
(50) D. Schwalm (EUR)
(51) W. Seifritz (SWI)
(52) K.J. Serdula (CAN)
(53) D.M. Shvetsov (SOV)
(54) S. Sighicelli (FRA)
(55) D. Strube (GER)
(56) J.A. Thie (USA)
(57) E. Türkcan (NET)
(58) H. Van Dam (NET)
(59) J.H.C. Van der Veer (NET)
(60) D. Wach (GER)
(61) U. Wesser (GER)

OBSERVERS
AND
ORGANIZATION

(62) B. Arcipiani
(63) A. Colombino
(64) P. D'Amico
(65) M. Di Bartolomeo
(66) R. Mosiello
(67) F. Norelli
(68) R. Sacchetti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40 56 6 2 26 48 57 30 51 63 66 64 67 41 43 24

Fig.1 - Group photo of SMORN-1 attendees

Fig.2 - From L to R: W.Seifritz (SWI), W.H.Dio (GER), R.J.Cox (GBR), J.Mika (POL)

Fig.3 - From L to R : G.Kosaly (HUN), R.Mosiello (ITA) partially covered by M.J.Bridge (GBR), V.M.Jorio (ITA), A.Colombino (ITA)

Fig.4 - From L to R : J.Mika (POL), E.Türkcan (NET), S.Sighicelli (FRA), B.Chabert (FRA), D.de Lapparent (FRA), J.C.Carré (FRA)

Fig.5 - From L to R : R.E.Green (CAN), M.Marseguerra (ITA), J.T.Mi_
halczo (USA), T.Nomura (JAP), H.Nishihara (JAP), J.A.Thie
(USA)

Fig.6 - From L to R : N.Pacilio (ITA), D.N.Fry (USA), B.V.Kebadze (SOV), S.Chwaszczewski (POL), D.M.Shvetsov (SOV), K.J.Serdula (CAN), R.Baeyens (BEL), Jaudet (FRA)

Fig.7 - From L to R : M.Edelmann (GER), M.H.Butterfield (GBR), F.Akerhielm (SWE), D.Strube (GER), M.Deiss (FRA), S.Sighicelli (FRA), H.Bunschi (SWI), J.A.Thie (USA), K.J.Serdula (CAN), A.Perez Navarro (SPA), R.E.Green (CAN), R.J.Cox (GBR), B.Arcipiani (ITA)

Fig.8 - From L to R : D.M.Shvetsov (SOV), J.B.Dragt (NET), J.T.Mihalczo (USA), D.N.Fry (USA), W.H.Dio (GER), M.Edelmann (GER), U.Wesser (GER), J.C.Carré (FRA), F.Akerhielm (SWE), B.Chabert (FRA), S. Sighicelli (FRA), D.Strube (GER).

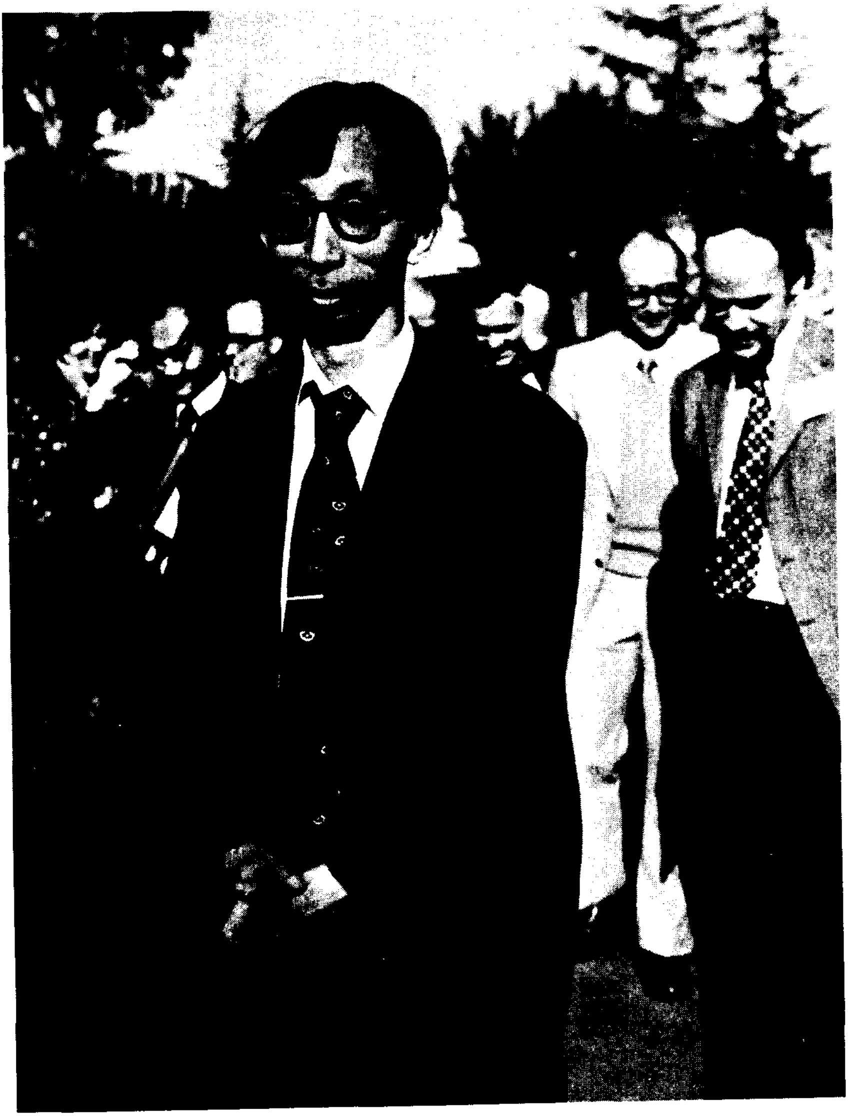


Fig.9 - From L to R : H.Nishihara (JAP), H.Kataoka (JAP), K.J.Serdula (CAN), R.A.Lewis (USA), E.Robinson (NOR)

ASTROLOGICAL

REVIEW OF

SMORN-1

ATTENDEES

BIRTHDATE DISTRIBUTION OF SMORN-1 ATTENDEES

January	* * *	3
February	* * *	3
March	* * * * * * * * *	9
April	* * * * *	5
May	* * * *	4
June	*	1
July	* * * *	4
August	* * * * * * * * * * * *	12
September	* * * *	4
October	* *	2
November	* *	2
December	*	1

Overall total : 50

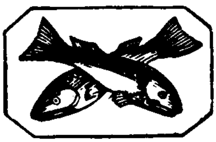
First semester total : 25

Second semester total : 25

ZODIACAL DISTRIBUTION OF SMORN-1 ATTENDEES

CAPRICORN (Dec 21-Jan 19)	*	1
AQUARIUS (Jan 20-Feb 18)	***	3
PISCES (Feb 19-Mar 20)	********	8
ARIES (Mar 21-Apr 19)	******	6
TAURUS (Apr 19-May 21)	*****	5
GEMINI (May 21-Jun 20)	**	2
CANCER (Jun 21-Jul 22)	***	3
LEO (Jul 22-Aug 21)	**********	10
VIRGO (Aug 22-Sep 22)	******	6
LIBRA (Sep 22-Oct 22)	***	3
SCORPIO (Oct 23-Nov 21)	**	2
SAGITTARIUS (Nov 22-Dec 21)	*	1

Eventually, there is an evidence that the noise analyst is either a Pisces or a Leo.
This is his profile according to the famous Ce-leste :



P I S C E S is the sign of the Fishes and is ruled by the pla-net Neptune. Those born in March are highly emotional, highly in-tuitive and generally unreliable because they are so changeable. Most Pisceans li-ve in a dreamy world of their own imagination & resent having to leave it to meet the demands of life. Usually they have little ambition , care little for place or power, and rarely accumulate any money. It is a highly artistic sign and many creative people are born at that time of the ye-ar. They are often better off working by themsel-ves.

L E O is the most regal and fla-mboyant of all the signs. The th-eatre is attractive to them and they excel in it. They are warm-hearted, generous, great spenders and usually full of the love of life. It is the only sign of the Zodiac ruled by the Sun, and th-ey seem to radiate this light. They are trusting people and believe the best of their fellow-men. Leo is called the sign of the Kings, and he is the ideal head of great enterprises, instituti-ons and undertakings. He loves all sports and is the perfect host.

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s m o r n /'smòrn / vb (1) : to perish from excess of work (2) : to suffer from overwork (3) : to kill or severely stress by overwork.
Idiomatics : s. up , s. off , s. oneself to exaustion.
Expletives : smorn you, smorn yourself , smorn one.

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S1.pdf