



INTERNATIONAL ATOMIC ENERGY AGENCY

IAEA Workshop on Neutron Fluctuations, Reactor Noise, and Their Applications in Nuclear Reactors

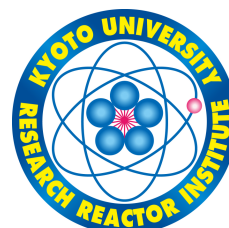
Hosted by the International Centre for Theoretical Physics, Trieste, Italy

22 to 26 September 2008

I2-TR-35632

INFORMATION SHEET

Updated on 15 July 2008



IAEA Workshop on Neutron Fluctuations, Reactor Noise, and Their Applications in Nuclear Reactors

1. PURPOSE OF THE WORKSHOP

The purpose of the Workshop is to provide the participants with the knowledge of fundamental theories, equations, relationships, and applications of stochastic processes taking place in nuclear reactors. Practical applications of signals noise analysis in nuclear power plants (NPPs) will also be discussed with an emphasis on instrumentation and control (I&C) systems for surveillance, diagnostics, and prognostics. The workshop is intended to be the first in a series of workshops on the subject to be delivered over several years. The intention is to gradually expand the scope of the annual workshops as results from the related IAEA regular programme become available. The workshop-like setting will allow all participants to interact and share their experience in the subject. The Workshop is intended for scientists, researchers, engineers, and university personnel interested in broadening their understanding of the topic.

2. BACKGROUND

The Workshop is meant to have a self-contained agenda on the theory and applications of various types of stochastic processes in nuclear reactor cores. The starting point is the classical field of neutron fluctuations in zero power systems, where the system properties are constant in time and the non-trivial statistics of the neutron field, or the neutron detections, is due to the branching in the process (fission). Such neutron fluctuations are described by the so-called Chapman-Kolmogorov or master equations, constituting a balance equation for the evolution of the probability of the number of neutrons in the phase space. From the master equation of the generating function of this probability, a number of properties, moments, asymptotic behaviour etc. can be derived. The information in the higher moments is usually used to determine some parameter of the systems, such as the subcritical reactivity of a reactor core, or the mass of a radioactive sample in nuclear safeguards. Both the theory and applications are described and discussed in depth in the course. The applications received an increased interest recently, since the reactivity measurement methods are used in the projects aiming at the physics of the co-called Acceleration Driven Systems, ADS. Likewise, nuclear safeguards, as part of national security programs, have got significantly increased attention worldwide.

In the case when the medium itself fluctuates in time and space, which is the case in traditional power reactors, the cause of the induced neutron noise is not the branching process but the cross section fluctuations in the system. This is the case of power reactor diagnostics, where the induced noise carries information on the properties of the system fluctuations, such as the boiling and instabilities in BWRs, vibrations, moderator temperature fluctuations in PWRs, and fuel channel vibrations, zone control level fluctuations in CANDUs. Hence power reactor noise is not restricted to neutron fluctuations, rather it concerns a large number of process variables. Correspondingly, the goal of the diagnostics is to determine operational parameters (e.g. reactivity coefficients) or detect/quantify anomalies such as excessive vibrations. Also the mathematical tools used to describe power reactor noise are different from those of zero power neutron noise; they are based on the Langevin approach.

One special part of the course will concern the random problems envisaged in connection with future advanced reactor types. Some of the planned Generation-IV or other advanced reactor types, or the advanced fuel to be used in the future even in traditional reactors, has a characteristic of spatially random composition of the fuel. The stochastic effects in deterministic transport calculations are important in presence of heterogeneities that are optically thick. The physical understanding and correct quantitative treatment requires methods of transport of neutrons in stochastic media to be applied. One part of the course will address the problems and the methods to be applied for such reactors.

The methods of power reactor noise and noise diagnostics are then described. The strategy of power reactor diagnostics is to identify main types of noise sources, make a simple mathematical model, calculate the induced noise, and then invert the arising equations, in order to express the sought noise source parameters from the measured neutron noise. Methods of signal analysis, sensor diagnostics, are also explained. The applications are illustrated on a number of real problems using measurements taken at operating nuclear power plants.

3. TOPICS TO BE COVERED

Part I.: Neutron Fluctuations in Zero Power Systems

I.1 Elements of the theory of branching processes

Basic concepts and definitions

- Definitions of the process in the source-free case
- Forward and backward equations for the generating functions
- Moments: subcritical, critical and supercritical systems
- The Yule-Furry process

Generalization of the problem

- Joint distribution of particle numbers at different time instants
- Branching process with two particle types
- Extinction and survival probability

Injections of particles

- Distribution of the number of particles
- Expectation, variance and correlation

Detection of particles

- Statistics of detection: distribution of the number of absorbed particles
- Expectations and variance
- Covariance between the number of absorptions in two time integrals

I.2. Applications

Reactivity measurement methods in traditional systems

- Feynman-alpha with the forward method
- Feynman-alpha with the backward method
- Evaluation of reactivity measurements
- Rossi-alpha method

Reactivity measurement methods in accelerator driven systems

- Feynman-alpha formula for accelerator driven systems: continuous spallation (multiple emission) sources
- Feynman-alpha formula for accelerator driven systems: pulsed Poisson sources
- The case of narrow pulses
- Pulsed, multiple emission (spallation) sources
- Rossi-alpha formula for accelerator driven systems: pulsed and multiple emission sources
- Applications of the theory: pulsed measurements in the KUCA reactor with
 - Feynman and Rossi-alpha methods
 - The KART experiment and ADS research in Japan

Theory and application of multiplicity in nuclear safeguards

- Derivation of the basic equation
- Factorial moments of the neutrons and gamma photons generated in the sample

Calculation of the probability distributions
Factorial moments of the emitted and detected neutrons and gamma photons
Joint probability distribution and moments of the detected neutrons and gamma photons

Part II.: Random Aspects of Future Advanced Reactors

II.1. Transport in stochastic media

Small stochastic perturbations

Determinism versus stochasticity
Formal perturbation expansions, Bourret's approximation and the Dawson equation
The method of smoothing, generalized Fourier expansions

Large stochastic perturbations

The statistical set of physical realizations
Material statistics, material and interface fluxes
The atomic-mix limit
Balance equation for the material fluxes and the problem of closure
Transport in purely absorbing stochastic materials, chord length statistics
The Markov closure, the Levermore-Pomraning (LP) model
Statistical averaging of the integral transport equation
Renewal chord length statistics, the renewal equations
Covariance calculation
The modified LP mode, the stochastic transition matrix method

Numerical exploration

Benchmarking
Levermore-Pomraning model
The rod problem

II.2. Applications

MOX and Gadolinia-poisoned fuel calculations

Stochastic dispersion of optically large microscopic grains in a homogeneous matrix,
The double heterogeneity (DH) problem
Heuristic collision-probability calculations
Asymptotic solution of the renewal equations
Treatment of the DH problem by the method of characteristics

Stochastic modelling of the pebble bed modular reactor

Pebble motion, layer geometry
Modeling of a stochastic layer, basic geometric probabilities
Layer dynamic homogenization and diffusion core calculation
Direct transport model

Part III.: Reactor Noise Analysis in Power Reactors

III.1. Signal processing and modelling used in reactor noise analysis for diagnostic purposes

Definitions of statistical functions

Properties of reactor noise signals
Definitions of time- and frequency domain statistical functions used in noise analysis
Relationship between statistical functions
Estimation of statistical functions from measured time series
Accuracy and physical interpretation of statistical functions

Elements of reactor kinetics and dynamics

- Reactor kinetics in one-group diffusion theory
- The reactor kinetic approximations (point kinetic, adiabatic, quasy-static)
- Space-dependent fluctuations in the frequency domain
- Reactor kinetics in two-group theory

Data Acquisition Requirements

- Dedicated high-speed multi-channel high-resolution data acquisition systems
- Isolation and synchronization requirements
- Data from station computers
- On-line monitoring

III.2. Applications in Power Reactors

Specific applications in PWRs

- Core barrel motion
- Vibration of fuel assemblies
- Vibration of detector tubes
- Estimation of reactivity feedback parameters
- Estimation of in-core coolant flow
- Detection of sub-cooled boiling

Specific applications in BWRs

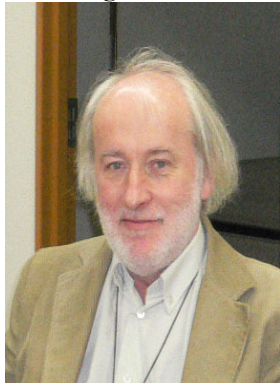
- Detecting and characterizing core instabilities
- Estimation of decay ratios
- Vibration of detector tubes
- Estimation of in-core coolant flow

Specific applications in CANDUs

- Vibration of detector tubes and fuel channels
- Oscillations of zone control level signals
- Monitoring moderator circulation
- Flow-dip diagnostics in inlet coolant signals
- Reactor trip response measurements
- Effectiveness of reactor trips
- Measuring the prompt fractions of in-core flux detectors

The Workshop will be conducted by experts involved in the education, research, and application aspects of the subject:

Professor Imre Pázsit, Department of Nuclear Engineering, Chalmers University of Technology, Göteborg, Sweden



He has over 30 years research experience with applications regarding neutron fluctuations in low power and energy producing systems. His other research interests include transport theory of neutral and charged particles; intelligent computing methods; positron annihilation spectroscopy and positron transport, and recently, nuclear safeguards. He has published about 150 articles in peer-reviewed international journals. Together with L. Pál, he is the author of the book “Neutron Fluctuations – a Treatise on the Physics of Branching Processes” (Elsevier Ltd, 2008). He is a member of the Editorial Board of several journals, including the Annals of Nuclear Energy. Imre Pázsit is a Fellow of the American Nuclear Society, a Working Member of the Academy of Arts and Sciences in Göteborg, and the Head of the Section for Mathematical Physics of the Swedish Physical Society.

Assoc. Prof. Christophe Demazière, Department of Nuclear Engineering, Chalmers University of Technology, Göteborg, Sweden



Education: PhD in reactor physics, Chalmers University of Technology, Sweden, 2002; engineering degree, Hautes Etudes d’Ingénieur, France, 1996. Current position: Associate Professor at the Department of Nuclear Engineering, Chalmers University of Technology, Gothenburg, Sweden (lecturing in Reactor Physics and Nuclear Engineering). Research interests: pressurized water reactor and boiling water reactor physics, reactor dynamics applied to both critical and subcritical systems, mixed oxide fuel, power reactor noise and noise diagnostics, signal processing and data analysis (linear, non-linear, wavelet, and fractal analysis), assembly/core modelling and calculations, coupled neutronics/thermal-hydraulics, and Computational Fluid Dynamics.

Professor Seiji Shiroya, Director, Kyoto University Research Reactor Institute, Kumatori, Osaka, Japan



Seiji SHIROYA is professor and Director of Research Reactor Institute, Kyoto University, Kumatori, Osaka, Japan. He has over 30 years research experience in the field of reactor physics experiments mainly by using the Kyoto University Critical Assembly (KUCA). His current interests include the nuclear characteristics of Accelerator Driven Subcritical Reactor and the explosive detection by using radiation such as neutrons. He also has education experience including the reactor laboratory course on reactor physics at the KUCA for not only Japanese students but also Korean and Swedish students majoring in nuclear engineering. Seiji SHIROYA is a member of American Nuclear Society, and a board member of the Atomic Energy Society of Japan (AESJ).

*Professor **Richard Sanchez**, Research Director, CEA de Saclay, France, Professor at the National Institute for Nuclear Science and Technology*



Over 35 years experience in research on reactor physics modeling, theoretical and applied transport theory, direct and inverse radiative transfer methods, transport in stochastic media and numerical transport methods. He was the technical leader and principal scientist for the spectral APOLLO2 transport code and is currently scientific advisor for the CEA new generation code for assembly and core calculations. He has published over 60 peer reviewed articles. He is a member of the editorial board of Transport Theory and Statistical Physics and advisory editor of Annals of Nuclear Energy. He has been thesis advisor for 14 Ph.D. students and co-advisor for 8 Ph.Ds. He is currently advising Ph.D. research on the method of characteristics, automatic energy meshing techniques, EPR reflector calculation and stochastic numerical methods for PBMR core calculations. Fellow of the American Nuclear Society.

*Fil. lic. **Andreas Enqvist**, Department of Nuclear Engineering, Chalmers University of Technology, Göteborg, Sweden*



Education: M.Sc. in Physics at Gothenburg University and Fil. Lic. in Nuclear Engineering at Chalmers University of Technology 2008. He is currently pursuing a PhD at the Department of Nuclear Engineering at Chalmers. Lecturing about and supervising laboratory exercises in reactor physics and nuclear engineering. Research interests: nuclear safeguards and the physics relating to detection processes. Especially methods within non-destructive analysis and applications within multiplicity counting and radiation correlations, sub-criticality measurements and analysis using Rossi- and Feynman-alpha methods. He is a Member of the Institute of Nuclear Materials Management (INMM).

***Dr. Oszvald Glöckler**, Scientific Secretary, Nuclear Power Plant Instrumentation and Control, Nuclear Power Engineering Section, Division of Nuclear Power, International Atomic Energy Agency*



He has 27 years experience in research and applications of nuclear power plant instrumentation and control techniques and measurements, including reactor noise analysis, on-line condition monitoring, systems diagnostics and testing, data acquisition systems, signal processing and modeling. He worked as a post-doctoral research fellow at the Central Research Institute for Physics in Budapest, Hungary, later as a researcher at the Nuclear Engineering Department of the University of Tennessee in Knoxville, USA, and at the University of New Brunswick in Fredericton, Canada. He also worked at Ontario Hydro (Ontario Power Generation) in Canada for 13 years as a senior technical expert before joining the International Atomic Energy Agency in 2004. Currently, he is the scientific secretary responsible for the IAEA's programs on nuclear power plant instrumentation and control.

The tentative Agenda of the Workshop is attached at the end of this announcement. The Workshop will conclude with an optional exit-exam and presentation of Certificates to participants by the IAEA confirming successful completion of the Workshop.

Literature, teaching material:

Lecture notes by the lecturers and slides of the presentations.

Further material:

I. Pázsit and L. Pál: Neutron Fluctuations – a Treatise on the Physics of Branching Processes (Elsevier Ltd, 2008)

J. A. Thie: Power Reactor Noise (American Nuclear Society, 1981)

4. RELEVANCE TO SCIENTISTS IN DEVELOPING COUNTRIES

The workshop's scope includes a broad range of theoretical work which can be performed even at research organizations with no access to expensive facilities or large resources. The Workshop can support the initiation of new research activities in developing countries and can contribute to the foundation of an academic area with the prospect of international recognition. The Workshop will also support education in the area of reactor physics and nuclear engineering in developing countries considering the introduction of nuclear energy.

3. PARTICIPATION

Participants must have a good knowledge of English, the official language of the Workshop. The Workshop is intended for scientists, researchers, engineers working in the nuclear field and post-graduate students wishing to become more informed and involved in noise analysis and its applications.

A basic knowledge in **mathematics, statistics, reactor physics, and nuclear engineering** is required. A science or engineering degree (e.g. in physics, mechanical, chemical or nuclear engineering) or equivalent qualification is necessary. Logistics limit the number of participants to 45.

All persons wishing to participate in the meeting are requested to complete the attached Participation Form and to send it directly to

Mr. Oszvald Glöckler, International Atomic Energy Agency, Wagramer Strasse 5, P.O. Box 100, A-1400 Vienna, Austria, E-mail: O.Glockler@iaea.org

At the same time the Participation Form is sent to the IAEA, please send the form to the competent national authority (e.g. Ministry of Foreign Affairs or National Atomic Energy Authority) of the applicant's country for obtaining an official national nomination. The subsequent transmission from the national authority to the IAEA should reach the Agency not later than **1 July 2008 (new extended deadline)**.

4. WORKSHOP ORGANIZATION

The IAEA staff member responsible for organization of the Workshop is Mr. Oszvald Glöckler. Official correspondence should be addressed to:

Mr Oszvald Glöckler
Department of Nuclear Energy
International Atomic Energy Agency
P. O. Box 100, Wagramerstrasse 5
A-1400 Vienna, Austria

Tel.: 43 (1) 2600 22791
email: O.Glockler@iaea.org
Fax: 43 (1) 2600-29598

The expert responsible for the scientific content of the Workshop is Professor Imre Pázsit.
Correspondence should be addressed to:

Professor Imre Pázsit
Department of Nuclear Engineering
Chalmers University of Technology
S-412 96 Göteborg, Sweden

Tel.: 46 31 772 3081
email: imre@nephy.chalmers.se
Fax: 46 31 772 3079

5. WORKING LANGUAGE

The working language of the Workshop will be English, with no interpretation provided.

PARTICIPATION FORM

IAEA Workshop on

Neutron Fluctuations, Reactor Noise, and Their Applications in Nuclear ReactorsInternational Centre for Theoretical Physics (ICTP), Trieste, Italy
(22 - 26 September 2008)

All persons wishing to participate in the meeting are requested to complete the attached Participation Form and to send it directly to

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IMPORTANT: Please fill out exactly as in your passport. The ICTP will assist in obtaining visas but they must have complete and exact information.

Surname/Family Name:
Maiden Name (if applicable):
First Name:
Middle Name:
Sex:
Passport number:
Date of issue:
Place of issue:
Expiry date:
Place of birth (*City and Country*):
Present nationality:
Date of birth (*Year - Month - Day*):

Full name/address at permanent Institution:	Tel.:
	Mobile:
	Fax:
	E-mail:
	E-mail:

Full name/address at present Institution: (if different from permanent)	Tel.:
	Mobile:
	Fax:
	E-mail:

Home address:	Tel.:
	E-mail:

Mailing address - please indicate whether: Permanent Present Home

Person to notify in case of emergency -
Name:
Address:

Tel.:
Mobile:
Fax:
E-mail:
Relationship:

Education (higher degrees)
University or equivalent
Name and place

Years attended
from to

Degrees

Scientific Positions Held

Institution(s)
Name and place

Period
from to

Position

State any **positions** you hold in the scientific administration of your institute, or any national scientific institute.

Have you participated in past ICTP activities? If yes, which and when?

Yes

No

Have you previously attended other IAEA workshops or Workshops?
If yes, which and when?

Yes

No

Please include a description of your current scientific activities:

1) Work field:

2) Specific topic of interest:

3) Explain your research experience and your reasons for wishing to participate in this activity:

4) Scientific publications (Title, authors, issue):



Please indicate your proficiency in the English language:

Reading:	Good	Writing:	Good	Speaking:	Good
	Average		Average		Average
	Poor		Poor		Poor

I certify that the statements made by me above are true and complete.

Signature of applicant _____

Date _____

**Workshop on
Neutron Fluctuations, Reactor Noise, and their Applications in Nuclear Reactors
22-26 September 2008
ICTP, Trieste, Italy**

TENTATIVE AGENDA OF THE WORKSHOP

<i>Day 1 – Monday, 22 September 2008</i>		
Time	Presentation Title	Lecturer
08:00 – 09:30	Registration	
09:30 – 10:00	<ul style="list-style-type: none"> • Opening the workshop and introducing IAEA activities • Welcoming and introducing ICTP activities • Welcoming and introducing workshop agenda and lecturers 	O. Glöckler, IAEA C. Tuniz, ICTP I. Pázsit, Chalmers
10:00 – 11:00	<ul style="list-style-type: none"> • Introduction to stochastic processes • The forward and backward equations in general • Definition of stochastic particle transport • Reaction intensities, number distributions • The concept of generating functions 	I. Pázsit
11:00 – 11:20	Break	
11:20 – 12:40	<ul style="list-style-type: none"> • The solution for one initial particle • Forward and backward forms • Moments • Subcritical, critical and supercritical processes • Distributions at two different times • The extinction probability 	I. Pázsit
12:40 – 14:00	Lunch Break	
14:00 – 15:30	<ul style="list-style-type: none"> • Random injection of particles • Injection by a Poisson process • Instantaneous (pulsed) injection • Expectations, variance • Subcritical, critical and supercritical systems 	I. Pázsit
15:30 – 16:00	Break	
16:00 – 17:30	<ul style="list-style-type: none"> • Statistics of detection: distribution of the number of absorbed particles • Expectations and variance • Covariance between the number of absorptions in two time integrals 	I. Pázsit
17:30- 18:00	Time for Discussion	All

Day 2 – Tuesday, 23 September 2008

Time	Presentation Title	Lecturer
09:00 – 10:30	<ul style="list-style-type: none">• Application to reactivity measurements in subcritical systems• Introduction of delayed neutrons• The Feynman-and Rossi-alpha methods for traditional sources	I. Pázsit
10:30 – 11:00	Break	
11:00 – 12:30	<ul style="list-style-type: none">• Feynman- and Rossi-alpha methods for spallation and pulsed sources	I. Pázsit
12:30 – 14:00	Lunch Break	
14:00 – 15:30	<ul style="list-style-type: none">• Nuclear Safeguards. Statistics of the emission and the detection of neutrons and gamma photons from fissile samples	A. Enqvist
15:30 – 16:00	Break	
16:00 – 17:30	<ul style="list-style-type: none">• Model experiments at the Kyoto University Critical Assembly for reactivity measurement with pulsed methods• Applications of the theory• The KART project: The Kyoto Accelerator Driven Test Facility	S. Shiroya
17:30- 18:00	Time for Discussion	All

Day 3 – Wednesday, 24 September 2008

Time	Presentation Title	Lecturer
09:00 – 10:30	<ul style="list-style-type: none">• Random aspects of future reactors: Transport in stochastic media• Small stochastic perturbations.• Large stochastic perturbations	R. Sanchez
10:30 – 11:00	Break	
11:00 – 12:30	<ul style="list-style-type: none">• Transport in stochastic media: Numerical exploration• Benchmarking• Levermore-Pomraning model• The rod problem	R. Sanchez
12:30 – 14:00	Lunch Break	
14:00 – 15:30	<ul style="list-style-type: none">• Transport in stochastic media: Applications• MOX and Gadolinia-poisoned fuel calculations	R. Sanchez
15:30 – 16:00	Break	
16:00 – 17:30	<ul style="list-style-type: none">• Transport in stochastic media: The pebble bed reactor• The elements and beginnings of power reactor noise	R. Sanchez I. Pázsit
17:30- 18:00	Time for Discussion	All

Day 4 – Thursday, 25 September 2008

Time	Presentation Title	Lecturer
09:00 – 10:30	<ul style="list-style-type: none"> • The Langevin formulation of power reactor noise • Linearisation, frequency domain treatment • The various kinetic approximations: point kinetic, adiabatic • Validity of the various approximations • Applicability of point-kinetics in both critical and subcritical Systems 	I. Pázsit C. Demazière
10:30 – 11:00	Break	
11:00 – 12:30	<ul style="list-style-type: none"> • The Greens function of the system • Treatment of model problems: the absorber of variable strength and the vibrating absorber, in 1D • The principle of spatial unfolding • Propagating perturbations • BWR noise in two-group theory 	C. Demazière A. Enqvist
12:30 – 14:00	Lunch Break	
14:00 – 15:30	<ul style="list-style-type: none"> • Noise methods in realistic cases: the noise simulator • Principles • Noise calculations in realistic systems • Absorber of variable strength and vibrating absorbers • Determination of core global dynamical parameters, primarily the MTC (Moderator Temperature Coefficient) 	C. Demazière
15:30 – 16:00	Break	
16:00 – 17:30	<ul style="list-style-type: none"> • Applications and demonstration of the noise simulator: localisation of a local instability • The concept of BWR instability • Demonstration of global, regional and local instability • The possibility of a space-dependent decay ratio in a BWR 	C. Demazière
17:30- 18:00	Time for Discussion	All

Day 5 – Friday, 26 September 2008

Time	Presentation Title	Lecturer
09:00 – 10:30	<ul style="list-style-type: none"> Continuation of BWR stability. Separation of the modes. Demonstration with the noise simulator 	C. Demazière
10:30 – 11:00	Break	
11:00 – 12:30	<ul style="list-style-type: none"> Applications: Diagnostics of core-barrel vibrations in a PWR and the detection of detector string impacting in a BWR Diagnostic problems and methods in CANDU reactors Vibration of detector tubes and fuel channels Oscillations of zone control level signals Monitoring moderator circulation Flow-dip diagnostics in inlet coolant signals 	I. Pázsit, C. Demazière or A. Enqvist O. Glöckler
12:30 – 14:00	Lunch Break	
14:00 – 15:30	<ul style="list-style-type: none"> Reactor trip response measurements Effectiveness of reactor trips Measuring the prompt fractions of in-core flux detectors 	O. Glöckler
15:30 – 16:00	Break	
16:00 – 17:30	Evaluation of questionnaires and exam sheets (optional).	
17:30	Closing. End of course.	