OECD/CSNI SPECIALIST MEETING
ON ADVANCED INSTRUMENTATION
AND MEASUREMENTS TECHNIQUES

Summary and Conclusions

Santa Barbara, CA, USA
17-20 March 1997

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS
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Organisation de Coopération et de Développement Économiques
Organisation for Economic Co-operation and Development

NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

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ORGANIZATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organization for Economic Co-operation and Development (OCED) shall promote policies designed:
- to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
- to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
- to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter: Japan (28th April 1969), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994) and Czech Republic (12th December 1996). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of the OEEC European Nuclear Energy Agency. It received its present designation on 20th April 1972, when Japan became its first non-European full Member. NEA membership today consists of all OECD Member countries, except New Zealand and Poland. The Commission of the European Communities takes part in the work of the Agency.

The primary objective of NEA is to promote co-operation among the governments of its participating countries in furthering the development of nuclear power as a safe, environmentally acceptable and economic energy source.

This is achieved by:
- encouraging harmonization of national regulatory policies and practices, with particular reference to the safety of nuclear installations, protection of man against ionizing radiation and preservation of the environment, radioactive waste management, and nuclear third party liability and insurance;
- assessing the contribution of nuclear power to the overall energy supply by keeping under review the technical and economic aspects of nuclear power growth and forecasting demand and supply for the different phases of the nuclear fuel cycle;
- developing exchanges of scientific and technical information particularly through participation in common service;
- setting up international research and development programs and joint undertakings.

In these and related tasks, NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has concluded a Co-operation Agreement, as well as with other international organizations in the nuclear field.
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

The NEA Committee on the Safety of Nuclear Installations (CSNI) is an international committee made up of scientists and engineers. It was set up in 1973 to develop and co-ordinate the activities of the Nuclear Energy Agency concerning the technical aspects of the design, construction and operation of nuclear installations insofar as they affect the safety of such installations. The Committee's purpose is to foster international co-operation in nuclear safety amongst the OECD Member countries.

CSNI constitutes a forum for the exchange of technical information and for collaboration between organizations which can contribute, from their respective backgrounds in research, development, engineering or regulation, to these activities and to the definition of its program of work. It also reviews the state of knowledge on selected topics of nuclear safety technology and safety assessment, including operating experience. It initiates and conducts programs identified by these reviews and assessments in order to overcome discrepancies, develop improvements and reach international consensus in different projects and International Standard Problems, and assists in the feedback of the results to participating organizations. Full use is also made of traditional methods of co-operation, such as information exchanges, establishment of working groups and organization of conferences and specialist meetings.

The greater part of CSNI's current program of work is concerned with safety technology of water reactors. The principal areas covered are operating experience and the human factor, reactor coolant system behavior, various aspects of reactor component integrity, the phenomenology of radioactive releases in reactor accidents and their confinement, containment performance, risk assessment and severe accidents. The Committee also studies the safety of the fuel cycle, conducts periodic surveys of reactor safety research programs and operates an international mechanism for exchanging reports on nuclear power plant incidents.

In implementing its program, CSNI establishes co-operative mechanisms with NEA's Committee on Nuclear Regulatory Activities (CNRA), responsible for the activities of the Agency concerning the regulation, licensing and inspection of nuclear installations with regard to safety. It also co-operates with NEA's Committee on Radiation Protection and Public Health and NEA's Radioactive Waste Management Committee on matters of common interest.
OECD/CSNI SPECIALIST MEETING ON
ADVANCED INSTRUMENTATION AND MEASUREMENT TECHNIQUES
(Santa Barbara, U. S. A.; 17th -20th March 1997)

1. Introduction

A specialist meeting on Advanced Instrumentation and Measurement Techniques was held in Santa Barbara, California, United States, from March 17th to 20th, 1997. The meeting was organized by the United State Nuclear Regulatory Commission (NEC) for the Organization for Economic Cooperation and Development's (OECD) Committee for the Safety of Nuclear Installations (CSNI). This meeting attracted some 70 participants. A total of 41 papers in identified areas were selected for presentation. The meeting was started by the opening remarks by the commissioner Diaz. It contained ten technical sessions and a session of the round table discussions.

2. Background and Purpose of the Specialist Meeting

In the last few years, tremendous advances in the local instrumentation technology for two-phase flow have been accomplished by the applications of new sensor techniques, optical or beam methods and electronic technology. The detailed measurements gave new insight to the true nature of local mechanisms of interfacial transfer between phases, interfacial structure and two-phase flow turbulent transfers. The new developments indicate that more accurate and reliable two-phase flow models can be obtained, if focused experiments are designed and performed by utilizing these advanced instrumentations.

In parallel with the basic scientific instrumentation there is a great demand for industrially applicable multiphase flow instrumentations. This aspect is quite important for performing various integral tests for reactor of passive safety and incorporate design simplifications based on the extensive operating experience accumulated over the years. The technological challenge involved is making these passive safety systems, which depend on natural forces such as the gravitational force, to work under all emergency or accident conditions. Since these systems do not have pumps to drive emergency systems it is desirable that reliable multiphase flow sensors and diagnostic systems are developed to monitor their function and operation. Such instrumentations are particularly important for integral test facilities focused on passive safety systems.

The purpose of this Specialist Meeting on Advanced Instrumentation and Measurement Techniques was to review the recent instrumentation developments thermal-hydraulic codes and instrumentation capabilities. Four specific objectives were identified for this meeting:

- Bring together international experts on instrumentation, experiment and modeling
- Review recent development in multiphase flow instrumentations
- Discuss relation between modeling needs and instrumentation capabilities
- Discuss future directions for instrumentation developments, modeling and experiments

This Specialist Meeting on Advanced Instrumentation and Measurement Techniques was timed such that it followed soon after the CSNI Workshop on Thermal-Hydraulics Codes (November 1996). At this workshop, the modeling needs for the current and future advanced codes were discussed in detail. This information was brought to the Specialist meeting through several invited papers. Hence, the scope of the Specialist meeting can be logically extended to include the discussions of the modeling needs and instrumentation capabilities. This should lead to the identification of desirable new experiments specially designed to focus on the modeling needs for advanced thermal-hydraulic codes.

Considering these conditions discussed above, the CSNI at its 1995 annual meeting approved a proposal from the Principal Working Group No. 2 on Coolant System Behavior (PWG2) to hold a Specialists Meeting on Advanced Instrumentation and Measurement Techniques. The meeting was
intended to review the recent instrumentation developments for multiphase flow and to discuss the relation between modeling needs and instrumentation capabilities. The results of these are recorded in the proceeding of the meeting for future reference.

3. **Scope and Technical Content of the Meeting**

   The major characteristic of the gas-liquid two-phase flow is the existence of the deformable interface and significant evolution of interfacial structures along the flow. The coalescence and disintegration of fluid particles, entrainment or deposition of droplet at a continuous liquid film surface, and instabilities of an interface are common problems. The change in the interfacial structures, interfacial and turbulent transfers of mass, momentum and energy, and their interactions are the major causes of the difficulty in measuring two-phase flow and modeling various transfer mechanisms.

   The design of reactor coolant systems and ability to predict their performance and assess the safety depends on the availability of experimental data and models which can be used to describe various multiphase flow processes with a required degree of accuracy. From a scientific, as well as from a practical point of view, it is essential that the various mathematical models should be formulated clearly based on the physical understanding of multiphase flow processes and supported by experimental data. For this purpose, specially designed instrumentations and experiments are required which must be conducted together with and in support of model development efforts.

   The mechanistic modeling of the constitutive relations for the interfacial transfer and turbulent in two-phase flow require detailed local measurements of the interfacial area, void fraction, interface velocity, phase velocities and turbulence of a continuous phase. In the past ten years, tremendous advances in the local instrumentation technology for two-phase flow have been accomplished. These developments came by due to the advances in electronics, local sensor techniques, and optical and beam methods. Furthermore the industrial instrumentations were also improved by the applications of various techniques such as tomography, non-intrusive beam method and sensor techniques.

   The Specialist meeting is intended to bring together the international experts in multi-phase flow instrumentation, experiment and modeling to review the state-of-the-art of the two-phase flow instrumentation methods and to discuss the relation between modeling needs and instrumentation capabilities.

   The following are topics included in the meeting:

1. Modeling needs and future direction for improved constitutive relations, interfacial area transport equation, and multi-dimensional two-fluid model formulation.
2. Local instrumentation developments for void fraction, interfacial area, phase velocities, turbulence, entrainment, particle size, thermal non-equilibrium, shear stress, nucleation, condensation and boiling.
4. Relation between modeling needs and instrumentation capabilities, future directions for experiments focused on modeling needs and for instrumentation developments.

4. **Concluding Remarks**

   The Specialist Meeting on Advanced Instrumentation and Measurement Techniques was concluded by the session "Round Table Discussion and Conclusions". The panel members were D. Bassette (NRC), J. M. Delhaye (CEA, France), T. Fukano (Kyushu University, Japan), D. Grand (CEA, France), M. Kawaji (University of Toronto, Canada), J. Kelly (NRC), and F. Mayinger (Tech. Univ. Munchen, Germany) and it was chaired by M. Ishii (Purdue).
It was concluded that the meeting accomplished its main objectives very successfully. The objectives of the meeting were:

1. Bring together international experts on experiments, instrumentations and modeling
2. Discuss relation between the current and future modeling needs and instrument capabilities
3. Review and discuss recent development in multiphase flow instrumentations
4. Discuss future directions of multiphase flow instrumentations in terms of scientific measurements, industrial quality measurements and required experiments for model improvements.

In the last ten years a considerable development in the local two-phase flow measurements, flow visualization techniques and tomography has occurred. This new instrumentation technology indicates that now a detailed measurement of two-phase flow parameters such as the local void fraction, local interfacial area, interface velocity, phase velocities, continuous phase turbulence, film thickness and structure of an interface between phase is possible with this advancement in the measurement of local two-phase flow, the local phenomena can be observed in detail and they can be qualified to give us the mechanistic understanding of the micro-scale phenomena and their relation to the macro-scale phenomena.

By performing some fundamental experiments using these new instrumentations, a sufficient data base can be established for the development of more advanced two-phase flow formulations such as the interfacial area transport equation and multi-filed model. This is the first time in the last twenty-five years a truly fundamental improvement of two-phase flow formulations and models beyond the current capability became possible.

In parallel with the development of the local instrumentations, industrially applicable instrumentations for two-phase flow have been improved steadily. However, the adverse conditions of high temperature, high pressure and steam environment continuously challenge the ranges of applicable instrumentations. The major challenges are related to material problems, calibration problems and sensitivity and reliability of an instrument.

This OECD/CSNI Specialist Meeting was timely because of the significant development of multiphase flow instrumentation technology and the continuous need for more accurate two-phase flow formulations and mechanistic constitutive relations.

Since the resources and capability for new experiments are limited, good planning and international cooperation are highly desirable. In terms of the experimental conditions a good scaling analysis for each experiments and a closer cooperation between the experimentalist, modeler and code analyst are necessary. In view of these it is recommended to set up a task force or a working group.

i. to discuss the linking between experimental possibilities and modeling needs,
ii. to develop a reliable scaling method for simulating prototypic conditions
iii. to define the priority experiments for modeling needs
iv. to define the required accuracy of an experiment and for what applications, and
v. to judge what can be measured with what accuracy and at what costs.
Technical Session 1

MODELING NEEDS

Session Chair:  F. Eltawila, NRC, USA

Session Summary

J. Kelly presented a paper on the thermal-hydraulic modeling needs for advanced light water reactors with passive safety systems. D. Grand presented a paper on the thermal-hydraulic modeling requirements for next generation reactor safety analysis codes. These two papers reflected the conclusions reached at the OECD/CSNI workshop on Transient Thermal-Hydraulic and Neutronic Codes Requirements as well as the United States and French experiences with current safety analysis codes. These papers set the overall background for the current needs for model improvements and future requirements that are closely tied to the available experimental data.
Technical Session 2

SPECIAL APPLICATION PROBES

Session Chair: S. Banerjee, University of California, Santa Barbara, USA
Co-chair: T. Fukano, Kyushu University, Japan

Paper Summaries

Special Instrumentation Developed for FARO and KROTOS FCI Experiments: High Temperature Ultrasonic Sensor and Dynamic Level Sensor

(I. Huhtiniemi, E. Jorzik and M. Anselmi, Joint Research Center, ISPRA, Italy)

I. Huhtiniemi and associates presented a paper on the development and application of special instrumentation for FARO and KROTOS fuel-coolant experiments at JRC-Ispra. A temperature sensor based on ultrasonic techniques is described with the discussion on the improvements in sensor fabrication technique design. The sensor can be used to measure temperatures in the range from 1800 °C to 3100 °C with an accuracy of ±50 °C. The design allows local temperature measurements in multiple zones along the sensor element. This sensor has been used successfully in a number of FARO experiments where temperature distributions in a molten corium pool have been measured. Furthermore, a water level meter sensor based on the time domain reflectometry techniques is described. This high speed sensor allows monitoring of liquid level under very demanding ambient conditions, i.e., 5 Mpa, 550 K in FARO. This sensor has been successfully applied in a number of FARO and KROTOS tests where water level rise caused by a molten corium and Al2O3 pours have been measured.

Direct Measurement of Multi-Noncondensable and Steam Mixture Under an Accident of a Passive Containment Cooling System (PCCS)


In the second paper, S. Yokobori et al, wrote that the passive containment cooling system (PCCS) has a function to remove the long-term decay heat following an accident by condensation. As an extension of the PCCS development program, its heat removal capability under a severe accident condition has been tested. The effect of the lighter noncondensables than steam on the PCCS heat transfer characteristics was clarified. Helium gas was used to simulate hydrogen gas which can be generated by a metal-water reaction. In the final stage, multi-noncondensables (i.e., both nitrogen and helium) were simultaneously confined. The GIRAFFE measurement system was accordingly modified so that noncondensable gas concentration was directly measured. Due to installation of direct measurement system of noncondensable, the transport mechanism was modeled so that the analytical code might be remarkably improved.
Technical Session 3

TOMOGRAPHIC METHODS

Session Chair: K. Mishima, Kyoto University, Japan
Co-chair: G. Kojasoy, University of Wisconsin, Milwaukee, USA

Paper Summaries

In session III, six papers were presented of which three papers were concerned with electrical impedance tomography, two papers with X-ray tomography, and one with neutron radiography.

O.C. Jones and his coworkers (Rensselaer Polytechnic Institute) presented two papers describing a summary of the use of electrical impedance tomography (EIT) for producing cross sectional images of the distribution of insulating media imbedding in conducting media.

Progress in Electrical Impedance Imaging of Binary Media:
1: Analytical and Numerical Methods and
2: Experimental and Developments and Results

(O. C. Jones, et al, RPI, USA)

The concept of impedance imaging is to use the response taken out through boundary electrodes to the electrical excitation imposed on a volume of a liquid-vapor mixture. The response is measured and the internal distribution of electrical properties is determined which best matched the measured response, which can then be used to reconstruct the phase distribution in the mixture. This is an inverse problem where the field properties and boundary conditions are known and the electrical field is computed. Both electrical resistivity and permittivity of the fluids could be utilized for imaging, although the authors found it quite difficult to measure the capacitive reactance accurately in their system.

In their first paper, the basic analytical methods developed for this system were reviewed. These methods were then extended to three dimensions, a method for preconditioning voltages for error corrections was added, methods for optimizing the resolution of a target by providing optimal excitation patterns and then overall numerical sensitivity were described. In their second paper, comparisons are provided for images obtained with both rod- and plate-electrode geometries demonstrating the superiority of the latter. It was shown that EIT has the ability to image multiple, separate, differently-sized, two-dimensional or three-dimensional targets with demonstrated linear sensitivity of over 30:1 and the absolute limits of resolution to be one part in 1300. It was pointed out, however, in the discussion that it may be difficult for this method to detect the dispersion of numerous bubbles.

Is 2D Impedance Tomography a Reliable Technique for Two-Phase Flow?

(H. Lemonnier and J. F. Peytraud, CEA, France)

In the third paper, there was a question raised on whether or not two-dimensional EIT is a reliable technique for two-phase flow measurement. Impedance tomography is an ill-conditioned problem in its nature and designing a tomography therefore requires the quantitative knowledge of the sensitivity of the reconstruction to the measurements noise. They adopted an EIT inversion algorithm particularly well suited to particular features of impedance reconstruction in two-phase flow, utilizing all known information on the media and exactly accounting for the piecewise nature of the conductivity distribution. In spite of all the precautions they took and of the shown efficiency of the numerical algorithm in handling noisy data, the ill conditioning of the problem lead nevertheless to unavoidable bad consequences. Moreover, it was shown that interface impedance may generate artifacts and requires careful calibration procedures. Finally, when 2D algorithm were utilized to reconstruct actual data, strong 3D artifacts were identified. For all these reason, they concluded that it does not seem reasonable to
suggest further development of EIT for accurately measuring void fraction distribution in arbitrary two-phase flow conditions. It was suggested also the EIT has a well defined potential for qualitative analysis.

High Resolution X-Ray Tomography for Stationary Multiphase Flows

(D. Schmitz, N. Reinecke, G. Petritsch, and D. Mewes, Universität Hannover, Germany)

The second topic was the X-ray tomography in which two different objectives, i.e., high resolution and high speed, were pursued by two different research groups. D. Schmitz et al. (University of Hanover) studied a high resolution X-ray tomography for stationary multiphase flows. The high resolution which can be obtained by computer assisted tomography was used to investigate the liquid distribution and void fraction in random ceramic packing of spheres and a structured metal packing. The experimental set-up consisted of a custom-built second generation tomography. The experimental results showed that X-ray tomography is applicable for the measurement of the phase distributions of stationary multiphase flows. It was demonstrated that with a spatial resolution of 0.4 x 0.4 mm², it was possible to detect thin liquid films on structured packings. The disadvantage of this method, however, is the long measurement time, which could be reduced when using an X-ray tomography of third or fourth generation.

Advanced High Speed X-Ray CT Scanner for Measurement and Visualization of Multiphase Flow

(K. Hori, T. Fujimoto, K. Kawanishi and H. Nishikawa, Mitsubishi Heavy Industries, Japan)

On the other hand, Hori et al. (Mitsubishi Heavy Industries) developed an ultra-fast X-ray computed tomography (CT) scanner to be used in transient or unsettled flow conditions. Ultra-fast scanning was achieved by adopting the electrical switching of the electron beam of an X-ray generation unit. A prototype system with a scanning time of 3.6 milliseconds was developed as the first step, and the feasibility of measuring dynamic events of two-phase flow was confirmed. In order to meet the further requirement for much faster scanning speed in thermalhydraulic research field, an advanced type X-ray CT scanner with the scanning time of 0.5 milliseconds was developed. This system was applied to the measurement of void fraction in a 3 x 3 rod bundle and its usefulness was demonstrated. A merit of this system is that a tomography can be taken without rotating the object, and can be used for visualization of not extremely fast transient flows as well. The significant problem, however, is that this system is extremely expensive for the purpose of multiphase flow measurement.

Three-Dimensional Void Fraction Measurement of Steady Two-Phase Flow by Neutron Radiography

(N. Takenaka, H. Asano, T. Fujii, Kobe University and M. Matsubayashi, JAERI, Japan)

The last topic in this session was a computed tomography by neutron radiography (NRCT). N. Takenaka et al. (Kobe University) applied NRCT to 3D measurement of void fraction in two-phase flow. With use of a high-neutron -flux research reactor, JRR-3M of the Japan Atomic Energy Research Institute, as a neutron source and a cooled CCD camera as well as an STT tube camera, they visualized two-phase flows in a 4 x 4 rod bundle. By using a cooled CCD camera, visualization with a high spatial resolution up to 0.18mm was achieved. Some of the results of 3D void fraction distributions of steady two-phase flows in the bundle were demonstrated by the computer visualization. Since the principal constraint of NR is that the neutron source cannot be rotated, therefore the object must be rotated very slowly in order not to disturb the flow, which means that the time needed for measurement is rather long and this method cannot in principle be used for transient flow. As for the measurement of void fraction, in addition, no discussion on the measurement error was given.

As a summary, three different tomographic methods were discussed in this session. It was demonstrated that these tomographic methods can be very useful tools to obtain 2D or 3D information of the structure of multiphase flows. The merit of using those tomographic methods is that they are non-intrusive methods.
and can be used for opaque fluids. They take advantage of the difference in the properties of materials on which those methods are based, and if stated reversely, the limitation exists on this point. Moreover, it seems that those methods are not fully discussed in view of the measurement error if one applies those to quantitative measurement of multiphase flows. Both theoretical and experimental studies may be needed on this point.

There exist other tomographic methods, such as those using MRI and charged particle beam. Similar discussions may hold for those methods. The MRI method was discussed in the other session of this meeting.
Technical Session 4

CONDUCTIVITY AND VELOCITY PROBE METHODS

Session Chair: R. Deruaz, CEA, Grenoble, France
Co-chair: D. Bessette, NRC, USA

Paper Summaries

Local studies in horizontal gas-liquid slug flow

(S. Sharma, S. Lewis and G. Kojasoy, University of Wisconsin, Milwaukee, USA)

A hot film anemometry method has been implemented to investigate the time-averaged local void fraction due to small and large slug bubbles, the local axial velocity and turbulence in the liquid phase of an air-water intermittent flow in a 50.3 mm ID horizontal channel, at room temperature and atmospheric pressure. The technique consists of using two miniature conical shaped HF platinum probes, one being devoted to the identification of phases, while the other probe is used to measure the local liquid velocity and the turbulent fluctuations in the axial direction at different locations along a vertical diameter of the pipe. A threshold phase separation technique is used in order to adequately remove the part of signal related to gas phase and a time-domain filtering method is introduced to cope with the wave motion of probe signal when the probe is located underneath the slug bubble. The transient nature of the liquid velocity both between and below gas slugs is clearly demonstrated by the preliminary results presented in the paper.

Local measurement of interfacial area, interfacial velocity and liquid turbulence in two-phase flow

(T. Hibi, Kyoto University, Japan, S. Hogsett, US NRC, and M. Ishii, Purdue University, USA)

A complete data set of radial profiles of local parameters has been established for a vertical upward air-water bubbly flow in a cylindrical tube 50.8mm ID at room temperature and atmospheric pressure. The measurement techniques which have been developed to meet this objective are based on the use of a double-sensor conductivity probe and hot film anemometry:
- local void fraction, Sauter mean diameter, local interfacial velocity and local interfacial area concentration measurements are performed with the double-sensor probe.
- liquid velocity and turbulence intensity are obtained from the signal of a conical shaped hotfilm probe.

A careful description of the probe design, of the calibration techniques, of the theoretically based methodologies and of the validation of the assumptions, is given. In particular, successful comparisons are made between the local time averaged interfacial area directly deduced from the interfacial velocity and the results of a photographic method, while HFA and conductivity probe results are shown to be consistent as far as the local time averaged void fraction is concerned.

Results obtained for three different L/D values highlight the local characteristics of the bubbly flow regime and their evolution vs. elevation.

Measurement of time varying thickness of liquid film flowing with high speed gas flow by a constant electric current method (CECM)

(T. Fukano, Kyushu University, Japan)

A conductance method has been developed which basically consists in supplying the two-phase flow medium with a constant electric current by means of (power) electrodes, while the voltage drop between
(sensor) electrodes, located on both sides of the section of interest and mounted flush with the inner wall of the pipe, is measured through an isolation amplifier. According to the case, the sensor electrodes may be some mm to hundreds mm away from one another, provided their distance is significantly smaller than between the power electrodes. Such an arrangement has several definite advantages compared to the classical conductance methods, especially: the output is far less sensitive to the flow the voltage drop increases when the film thickness decreases which makes the method particularly attractive for the investigation of this flow regime.

The principles of the method are detailed, the results of calibration for void fraction measurement with various shapes of non-conductive fillers are given as well as a rather large number of applications to real two-phase flow which illustrate the capabilities of the method: wavy liquid films in a horizontal rectangular duct, flow in a horizontal capillary tube, simultaneous measurement of void fraction at different axial locations in horizontal and vertical flows in circular pipes.

Measurements of local two-phase flow parameters in a boiling flow channel

(Byung-Jo Yun, Chul-Hwa Song, Suk-Ku Sim and Moon Ki Chung, KAERI, and Goon-Cherl Park, Seoul National University, Korea)

Local parameters of a steam-water bubbly flow have been measured in an annular space formed by a 33mm ID tube and a 16mm OD heater rod at atmospheric pressure and with subcooled conditions at the entrance of the test section.

A double-sensor conductivity probe and a small size pre-calibrated Pitot tube equipped with a cold water injection system have been used to perform those measurements.

A new algorithm has been developed for phase discrimination on the conductivity probe. Basically, it consists in applying the usual/pulse height criteria to each bubble, instead of making use of a predetermined cutoff level for all bubbles. This method has been checked successfully on an air-water experiment, comparing the cross-sectional average void fraction with values obtained by an entrainment techniques.

Radial profiles of local void fraction, bubble frequency, vapor and liquid velocities, interfacial area concentration, Sauter mean diameter, measured at z=1.6m on the 2m long annular test section are given for local void fraction lying within the range 0-40%.

Local measurements in turbulent bubbly flows

(C. Suzanne, K. Ellingsen, F. Risso and V. Roig, Institut de Mécanique des Fluides, France)

Several types of local measurement methods for bubbly flows are discussed which include measurement of liquid velocity, void fraction bubble size and velocity on the basis of the results of various and careful experiments.

Regarding liquid velocity HFA is preferred to LDA which is no longer suitable for void fraction larger than about 2% as it does not allow a clear phase discrimination. For HFA a signal processing has been developed for improving phase discrimination, which consists of a thresholding technique applied on the derivative of the signal. The question of the meaning of the large rear peak which is sometimes observed just after the passage of a bubble is addressed. Simultaneous LDA and HFA measurements have been performed whose results lead the authors to conclude it is representative of the local liquid velocity.
Void fraction measurement is performed with a small size (<50μ), sharp geometry, optical fiber probe which has the advantage of an excellent response time and of good piercing capabilities even at low velocities. For bubble size and velocity the method is based on a numerical multichannel analysis of the binary signal delivered by a double optical probe which is described in detail in the paper.

Some examples of results obtained with these measurement methods in the case of the concurrent bubbly plane turbulent shear layer are presented.
Technical Session 5

OPTICAL PROBE METHODS

Session Chair: P. Ingham, AECL, Whiteshell Laboratory, Canada
Co-chair: A. M. C. Chan, Ontario Hydro Technologies, Canada

Paper Summaries

Measurement of Local Flow Pattern in Boiling R12 Simulating PWR Conditions with Multiple Optical Probes

(J. Garnier, CEA, France)

For a comprehensive approach of boiling crisis phenomenon in order to get more reliable predictions of critical heat flux in PWR core, a flow pattern study is under progress at CEA GRENOBLE. The study is performed on the DEBORA loop with Freon 12 as the coolant fluid. The first study of flow conditions shows that the flow pattern is essentially a bubbly one with vapor particles of low diameter (about 300 μm) and high velocity (up to 7 m/s). A multiple optical probe is developed for detecting small bubbles at high velocity. Details are given on how to calibrate the probes. The development of data acquisition and data treatments is presented in detail. A criterion is obtained to check if the bubble shape is spherical. It is shown that the rise and fall times of the electrical signal are strongly correlated with the gas velocity. It is expected that it will be possible to perform velocity measurements with a single fiber probe.

Measurement of Gas Phase Characteristics Using New Monofiber Optical Probes and Real Time Signal Processing

(A. Cartellier, LEGI, France)

Single optical or impedance phase detection probes are able to measure gas velocities, provided that their sensitive length \( L \) is accurately known. In this paper, it is shown that \( L \) can be controlled during the manufacture of optical probes. Beside, for a probe geometry in the form of a cone + a cylinder + a cone, the corresponding rise time/velocity correlation becomes weakly sensitive to an uncontrollable parameter such as the angle of impact on the interface. A real time signal processing performing phase detection as well as velocity measurements is described. Since its sensitivity to the operator inputs is less than the reproducibility of measurements, it is a fairly objective tool. Qualifications achieved in air/water flows with various optical probes demonstrate that the void fraction is detected with a relative error less than 10%. For bubbly flows, the gas flux is accurate within 10%, but this uncertainty increases when large bubbles are presented in the flow.

Local Measurements in Two-Phase Flow Using a Double Optical Probe Technique

(L. F. Mendes de Moura, Universidade Estadual de Campinas, Brazil)

This paper presents the local measurements in a vertical upward air-water flow using the optical fiber double probe technique. The test section is an 80 mm i.d. and 160 cm long Plexiglas tube. A double optical probe is employed for measurements of the radial profiles of void fraction, bubble frequency, bubble interface velocity, interfacial area concentration and Sauter mean diameter. The signal conditioning is discussed and the influence of the threshold level is analyzed. Experimental results are compared with values from the inlet gas flow rate measurements, and a good agreement is showed.
Technical Session 6

ABSORPTION AND SCATTERING METHODS

Session Chair: M. Ishii, Purdue University, USA
Co-chair: M. Aritomi, Tokyo Institute of Technology, Japan

Paper Summaries

Four papers were included in this session. The measurement methods are based on the x-ray absorption imaging, high frame speed neutron radiography, γ-absorption for rod bundle applications, and fast neutron scattering.

Measurements of Void Fraction in a Water-Molten Tin System by X-Ray Absorption

(M. Baker, R. Bonazza and M. Corradini, University of Wisconsin at Madison, USA)

This paper dealt with the imaging of the molten metal-gas-water mixture by continuous high energy x-rays. The visualization of the mixture can be performed at 220 Hz with 256 x 256 pixel resolution or at 30 Hz with 480 x 1128 pixel resolution. The test section had the dimension of 18 cm (width) x 10 cm (depth) x 72 cm (height). The void fraction information was obtained from the stored images by first subtracting a constant representing an image of the empty test section. Then, using the standard absorption relations, line average void fraction was calculated from the gray level of the images. This essentially gave the two-dimensional mapping of the chordal averaged amount of the metal. At an average energy of x-ray at 3 MeV, the gray level depends only on the presence of the molten metal.

Development of High-Frame-Rate Neutron Radiography and Quantitative Measurement Method for Multiphase Flow Research

(K. Mishima and T. Hibiki, Kyoto University, Japan)

This paper reported the development of high-frame rate neutron radiography and quantitative measurement method. The neutron radiography is a non-intrusive method based on the difference in attenuation characteristics of neutron in materials. There are great differences in the neutron attenuation and x-ray or γ-ray attenuation. Thermal neutrons tend to penetrate heavy materials like dense metals and to be attenuated well by light atoms such as hydrogen or molecules containing hydrogen. This implies that liquid water attenuates neutron beam well, whereas metallic structure materials such as steel can be easily penetrated. Therefore, the neutron radiography is a very useful tool for visualization of two-phase flow in a metallic casing. In this paper, the development of high-frame rate neutron radiography is presented. This method requires a steady high neutron flux over 10⁸ n/cm²s and highly sensitive imaging devices. The authors developed not only the qualitative high-speed visualization method, but also quantitative methods to measure interfacial structure and void fraction. By using the differences in attenuation in different materials, the void fraction can be obtained from Σ-scaling method. The spatial resolution is limited by a number of factors such as the statistical variation of neutron sources, available gray levels, skew of neutron beam and neutron scattering. The experiments were performed by using the JRR-3M reactor of JAERI as the neutron source. Three different experiments were conducted for the demonstration of the method. Although this new instrumentation requires a high neutron flux, the details of the information which can be obtained are impressive.
Transient Void Fraction Measurements in Rod Bundle Geometries

(A. M. C. Chan, Ontario Hydro Technologies, Canada)

This paper focused on the more traditional gamma ray absorption technique. This method was applied to a small (7 pin) rod bundle geometry. The method is not new. The paper discusses the details of engineering design. The method is very sensitive to the metallic components of the materials in the test section and not very sensitive to the phase contents of two-phase flow. This implies the physical location of all the metallic materials under the test conditions should be a part of the calibration method.

Void-Fraction Measurement in Rod-Bundle Channels

(P. Han, E. M. A. Hussein, University of New Brunswick and Paul J. Ingham, Atomic Energy of Canada Ltd., Canada)

This paper discusses the application of the fast-neutron scattering to measure the void fraction in a rod bundle geometry. Although the neutron scattering method was developed sometime ago, it has a good potential for applications to a complicated test section geometry. The neutron is much more sensitive to the two-phase contents of the coolant than the common metal components. This characteristic is similar to the neutron radiography. The system is designed by using a portable neutron scattering device (scatterometer). Thus, it is possible to use it as an independent system. It relies on the fact that water is an effective moderator to slow down fast neutrons. The vapor has much lower hydrogen content than water, thus it hardly affects the neutron energy. The scattered slow/thermal neutrons become proportional to the amount of liquid water in the channel.
Technical Session 7

FLOW VISUALIZATION AND EXPERT SYSTEMS

Session Chair: J. M. Delhaye, CEA, Grenoble, France
Co-chair: D. Mewes, Universität Hannover, Germany

Paper Summaries

The paper by Kawaiji presents the photochromic dye technique (PDA), a technique which was invented thirty years ago by Popovich & Hummel but which has never been used quantitatively since then. The principle is rather simple. It is based on a molecular tagging of a clear organic liquid by a photochromic dye which is activated by a laser beam of ultraviolet light. The lines of activated molecules are recorded on a digital high speed video camera at 1000 frames per second. An image analysis is then performed on a computer. The techniques has been applied by the author and his colleagues to different two-phase flows. First the average velocity, the turbulence intensity and the Reynolds stress profiles were obtained in open-channel flows, concurrent and countercurrent wavy flows in a horizontal channel and successfully compared to the data obtained with hot wire anemometry. Second, the mechanism for explaining the existence of a liquid film in the upper part of a horizontal tube was demonstrated by using a spot dye trace technique. Third, the PDA technique was applied to freely falling film and countercurrent annular flow in a vertical tube. An important conclusion concerns the flooding phenomenon which has been shown not to be triggered by the reversal in the flow direction of the liquid film. Finally the PDA technique was applied to slug flows in vertical and horizontal tubes. There again the PDA technique was able to confirm or disprove some mechanisms suggested in previous studies.

The objective of the paper by Donevski et al. was to present an advanced image processing technique to quantitatively characterize the structure of the flow in the developing subcooled regime in the vicinity of the point of net vapor generation. Actually not enough details are given in the paper which prevents the proposed technique to be applied by other people.

The visualization technique of a boundary layer pool boiling process is presented in the paper by Cheung et al. Classical camera and high-speed video systems are used. The paper emphasis is more on critical heat flux data than on the description of an instrumentation technique and is of no relevance to the topic dealt with in this meeting.

Neural networks have been successfully employed by Mi et al. to recognize the different flow patterns in a vertical tube. The signals were obtained from a multiple-electrode impedance probe mounted flush with the internal wall of the pipe. Two types of neural networks were used: (1) the supervised neural network where a given set of flow patterns is presented as the outputs and, (2) the self-organized neural network which clusters the data into self-generated categories. The authors show that neural networks are appropriate classifiers for two-phase flow configurations. The method looks very promising and its use will probably spread out in two-phase flow research.

The paper by Hervieu & Seleghim was motivated by the need to detect in advance a change in the flow configuration during an operational transient in offshore pipelines encountered in oil engineering. The underlying assumption is that well defined two-phase flow regimes are more stationary than transition regimes. The authors propose the joint time-frequency covariance as an indicator of unstationarity and apply this concept to each transition occurring in horizontal two-phase flow. The signal delivered by an impedance probe is processed to obtain for each transition the power density spectrum, the Gabor transform and the time-frequency covariance. The results are particularly convincing and the authors conclude that time-frequency analysis is an extremely rich framework which permits not only to characterize two-phase flow regime transitions but also gives access to many important physical features.
Photochromic dye techniques, neural networks, and time-frequency analysis are certainly quantitative techniques which have been proven to be very efficient and their use will certainly propagate in the two-phase flow community.
Technical Session 8

GLOBAL TECHNIQUES AND INDUSTRALLY APPLICABLE INSTRUMENTATION

Session Chair: J. Reyes, Oregon State University, USA
Co-chair: Y. Hassan, Texas A & M University, USA

Paper Summaries

Measurements of Void Fraction by an Improved Multi-Channel Conductance Void Meter

(Chul-Hwa Song, and Moon Ki Chung, KAERI, and Hee Cheon No, KAIST, Korea)

An improved multi-channel Conductance Void Meter (CVM) was developed to measure a void fraction. Its measuring principle is basically based upon the differences of electrical conductance of a two-phase mixture due to the variation of void fraction around a sensor. The sensor is designed to be flush-mounted to the inner wall of the test section to avoid the flow disturbances. The signal processor with three channels is specially designed so as to minimize the inherent error due to phase difference between channels. It is emphasized that the guard electrodes are electrically shielded in order to affect the measurements of two-phase mixture conductance, but to make the electric fields evenly distributed in a measuring volume. Void fraction is measured for bubbly and slug flow regimes in a vertical air-water loop. Statistical signal processing techniques are applied to show that CVM has good dynamic resolution which is required to investigate the structural developments of bubbly flow and the propagation of void waves in a flow channel.

Progress in Reactor Instrumentation and its Impact on Safety Issues

(Addly-Barsoum Wahba, GRS, Germany)

After the TMI-2 accident in March 1979, international attention was given to develop a diverse method to measure the water inventory in the pressure vessel besides the pressurized water level. In this paper, the progress achieved in this field during the last ten years is summarized. Achievements in connection with pressurized water reactors are given. Monitoring of adequate core cooling in Boiling Water Reactors (BWR) together with new developments to avoid stability in BWR-operation are mentioned. Some recommendations are also included for the development of RBMK-type reactors.

Two-Phase Flow Measurements Using a Photochromic Dye Activation Technique

(M. Kawaji, University of Toronto, Canada)

A novel flow visualization method called photochromic dye activation (PDA) technique has been used to investigate flow structures and mechanisms in various two-phase flow regimes. This non-intrusive flow visualization technique utilizes light activation of a photochromic dye material dissolved in a clear liquid and is a molecular tagging technique, requiring no seed particles. It has been used to yield both quantitative and qualitative flow data in the liquid phase in annular flow, slug flow and stratified-wavy flows.
Technical Session 9

OPTICAL METHODS

Session Chair: M. Kawaji, University of Toronto, Canada
Co-chair: F. B. Cheung, Pennsylvania State University, USA

Paper Summaries

All four papers in this session deal with the use of a laser beam to measure void fraction, velocities of continuous and dispersed phases, droplet size distribution, and/or phase distribution in various gas-liquid two-phase flows.

Multiparticle Imaging Velocimetry Measurements in Two-Phase Flow

(Y. A. Hassan, Texas A & M University, USA)

The first paper presents the application of the Particle Image Velocimetry (PIV) technique to various two- and three-dimensional two-phase flows. A study of bubbly flow has yielded the temporal and spatial variations of mean liquid velocity, kinetic energy, Reynolds stress and normal stress during the passage of a gas bubble through a stationary or moving liquid in a vertical tube. A detailed set of data presented can be used for understanding the transient behavior of turbulence induced by a single bubble and validating multi-dimensional two-phase flow models.

Second and third experiments addressed a bubbly flow across a circular cylinder and stratified two-phase flow in a horizontal channel, respectively. In the bubbly flow experiment, a combination of fluorescent and white polystyrene tracers were tracked. In the stratified flow experiment, the interfacial shear force was determined from the measured velocity data. The author found that the interfacial shear results agreed with theory when the local flow conditions near the interface were similar to the space-averaged conditions. However, if the local gas velocity near the interface was unstable and dissimilar from the average gas velocity, the existing theory predicted incorrect results. The PIV is considered by the author to be a promising and powerful tool to study the structure of multiphase flows.

Measurements of Void Fraction in Transparent Two-Phase Flows by Light Extinction

(B. Shamoun, M. El Beshbeely and R. Bonazza, University of Wisconsin at Madison, USA)

In the second paper the authors used Mie scattering of a collimated laser beam by gas bubbles to measure the 2-D distributions of line-average interfacial area and void fraction in a bubbly two-phase mixture. The technique involves scattering of an expanded laser beam by a two-phase air-water mixture contained in a transparent rectangular test section and imaging of the transmitted light through a pin hole using a CCD camera. By applying correction factors that account for the unscattered light reaching the CCD camera and the effect of the bubble size distribution on the extinction coefficient, the authors have deduced the values of the line-averaged void fraction and interfacial area distributions from the measured transmittance distributions. The authors were able to measure bubble sizes up to 5 mm in diameter and void fraction values between 0.5% and 10%. The volume averaged void fraction measurements were shown to compare favorably with those obtained using a level swell approach. The uncertainties in the measurements caused by the imaging system were also estimated.
Evaluation of Pulsed Laser Holograms of Flashing Sprays by Digital Image Processing and Holographic Particle Image Velocimetry

(O. Feldmann, P. Gebhard and F. Mayinger, Technische Universität München, Germany)

The third paper discusses 3-D measurements of flashing sprays by the use of pulsed laser holography and digital image processing techniques. Two 3-D pictures of a spray, which are perpendicular to each other, are first imaged onto holographic plates over a very short exposure time of about 30 ns, either in a single-pulsed or double-pulsed mode using a ruby pulse laser. In the analysis of the data, the holographic plates are illuminated by two continuous He-Ne lasers and the resulting three-dimensional images are recorded by two video cameras one focal plane at a time, so that each instantaneous 3-D image of the spray is thus transformed into a series of 2-D video images.

The analysis of the data employs an extensive use of computer image processing. To identify the positions of the individual droplets, two stereoscopic views of the spray are analyzed simultaneously using a focusing criterion based on the limited depth of the focal plane. In the double-pulsed holograms, the information about the droplets' velocities and trajectories is obtained by identifying the coupled images of the same droplet and measuring the displacement over the time interval between the images. The analysis is performed using special algorithms to identify the angles of droplet trajectory with respect to the focal planes.

The powerfulness of this holographic technique was well demonstrated by analyzing the holograms of a spray produced by a hollow cone nozzle to yield both microscopic and macroscopic features of the spray such as the shape of the liquid veil, breakup length and spray angle, droplet trajectories and mechanisms of jet disintegration.

Application of LDA to Bubbly Flows


The authors studied the use of a back scatter LDA technique to measure velocity fields in an air-water bubble column with a void fraction of 25%. A single-bubble train experiment was conducted first to determine the characteristics of both forward and back scatter measurements. In both cases, they found that the LDA would measure predominantly the liquid velocity, and various methods of discriminating the data between the gas and liquid phases did not work well.

In the bubble column experiments with a volumetric-average bubble diameter of 3 mm and gas fraction of 25%, the data rate fell significantly due to scattering by bubbles, and the gaps in the velocity data existed due to the presence of many bubbles in the column. However, it was still possible to obtain liquid velocity data even deep into the flow. Spectral analyses of the liquid velocity data were also conducted to study the turbulence characteristics. The calculated auto power spectral density was found to obey -5/3 power law as in many single-phase flows, but distortion was found at high frequencies. From the autocorrelation of the spectral density, the integral time scale was found which was consistent with the measurements by tracking of a neutrally buoyant radioactive particle in other bubble columns.
Technical Session 10

NMR AND ULTRASONIC METHODS

Session Chair: F. Mayinger, Technische Universität München, Germany
Co-chair: H. Lemonnier, CEA/Grenoble, France

Paper Summaries

Magnetic resonance imaging (MRI) systems have primarily been developed for medical applications. They are well established there and provide pictures of high resolution. Pulsed nuclear magnetic resonance techniques have been used in the past also to study transport properties of fluids and flowing liquids. In a more recent time, studies, known from the literature demonstrated, that nuclear magnetic resonance (NMR) can be also applied to complex liquid flows. Fluids studied with NMR must not be conductive or magnetic to avoid interactions with the magnetic field of the NMR system.

Very interesting papers, presented in the session, proved that NMR and MRI can be successfully applied to two-phase flow also. They can give interesting and reliable insights into the complex structure of multiphase flows.

The Use of Magnetic Resonance Imaging to Quantify Multi-Phase Flow Patterns and Transitions

(J. N. Reyes, Jr., A. Y. Lafl, Oregon State University, USA and D. Saloner, University of California-San Francisco, USA)

The authors used the magnetic resonance imaging technique to study two-phase flow patterns and flow transitions. They presented highly detailed data on two-phase flow structure occurring in a horizontal channel with air-water flow. After presenting magnetic resonance images, obtained for laminar flow of liquid water, Reyes and co-authors showed, that MRI has a high resolution in two-phase flow also. Their MRI technique clearly showed, that in horizontal slug flow, the slugs actually consist of an air-water mixture with void fractions, ranging from 0.4 to 0.8. Their MRI scanning technique allowed a very short repetition time. So highly transient two-phase flows can be reliably studied.

Two-Phase Flow Characterization by Nuclear Magnetic Resonance

(J. Leblond, S. Javelot, D. Lebrun and L. Lebon, ESPCI, France)

Leblond and co-authors used the Pulsed Field Gradient Spin Echo technique (PFGSE-NMR) to characterize multiphase flow. In their paper they studied vertical air-water flow. Comparing liquid volumetric fluxes, derived from the NMR measurements with those, obtained by turbine meters, a good agreement was found. With their NMR experiments, they could prove, that the presence of bubbles in a liquid flow induces an important velocity fluctuation. This clearly demonstrates the high quality of NMR technique, giving a new interesting insight into the fluid mechanics of two-phase flow and presenting very valuable informations for theoretical modelling. In a modified form, PFGSE allows to study fluctuations and instabilities in two-phase flows also, as Leblond and co-authors reported. So this method promises to get insight into transient conditions with two-phase flow, which is very interesting for nuclear safety research. Finally there is good hope, that a periodic PFGSE sequence can be used to analysis the turbulence in bubbly flow.
Visualization of Phase and Velocity Distributions in Gas-Liquid Mixture by NMR Imaging

(G. Matsui, K. Kose and H. Monji, University of Tsukuba, Japan)

Matsui and co-authors reported on visualization of phase and velocity distributions in gas-liquid-mixtures by NMR imaging. They studied slug flow situations in a horizontal pipe and a rising bubble in stagnant liquid in a vertical pipe. Their ultrafast NMR facility allowed very high repetition frequencies. They used both the phase shift method and the spatial tagging method. The first method gave the gas-liquid phase distribution and the second one gave the two-component velocity field in the pipe.

NMR imaging can become a very powerful method to study stationary and transient two-phase flow and to provide valuable informations for a well based physical modelling. Due to the high cost of the equipment, the method however will be restricted to a few laboratories. Those laboratories, which possess such an equipment or can afford to buy one, should be highly encouraged to develop the experimental technique to apply it to two-phase flow studies, which cannot be handled by other experimental methods.

Another part of the session was dedicated to ultrasonic measuring techniques with special application to two-phase flow. There is a strong effort at various laboratories in Japan to improve this method to such an extend, that it provides reliable and accurate informations, not only about the velocity profile of a two-phase mixture, but also on liquid film thickness on a solid surface with spray cooling.

Application of Ultrasonic Echo Technique to the Measurement of 2-Dimensional Local Instantaneous Liquid Film Thickness on a Simulated Nuclear Fuel Rod

(A. Serizawa, T. Kamei and I. Kataoka, Kyoto University, Japan)

Serizawa and co-authors used a new development in high speed ultrasonic echo technique to measure the time-sequential 2-dimentional thickness of the liquid film around a simulated nuclear fuel rod. They succeeded to reduce the necessary scanning time down to 4 ms, required to reconstruct one image. The authors were working with a rotating reflector. In a preliminary experiment, the technique was applied to measure the thickness of a falling film down on an acrylic tube. The assembly of the newly developed measuring device was positioned inside of the tube. The authors are quite optimistic to accelerate the rotating system up to 20,000 rpm, which allows a very high data acquisition frequency. In a second experiment, the authors applied this technique also to air-water annular field flow. The results, gained by the authors, indicate a very promising nature of this new technique.

Measurement of Two-Phase Flow Characteristics in Vertical and Horizontal Channels Using Ultrasonic Velocity Profile Meter

(M. Aritomi, Tokyo Institute of Technology, H. Nakamura, M. Kondo, JAERI, Japan and Y. Kukita, Nagoya University, Japan)

In a combined effort of 3 institutions - the Tokyo Institute of Technology, the Nagoya University and the Japanese Atomic Energy Research Institute (JAERI) studied two-phase flow characteristics by applying ultrasonic technique. Aritomi and co-authors used this method to measure velocity profiles in vertical and horizontal channels, mainly with bubbly and stratified flow. The aim of these studies is to assess and improve numerical codes for multi-dimensional two-phase flow. The authors succeeded to gain very good results, not only for velocity profiles of both phases, but also of the void fraction profile in the channel of an average bubble diameter and an average void fraction. Though the system offers the possibility to determine the probability density function of velocities in both phases and also the turbulence intensity of velocity fluctuation in a continuous liquid phase.

The other part of the combined effort was aiming to measure interface profiles of a wavy flow in a horizontal channel. In this work also the liquid velocity was measured by the ultrasonic method.
Simultaneous Measurement of Liquid Velocity and Interface Profiles of Horizontal Duct Wavy Flow by Ultrasonic Velocity Profile Meter

(H. Nakamura, M. Kondo, JAERI, Japan and Y. Kukita, Nagoya University, Japan)

Nakamura and co-authors reported, that they could reduce the influence of the reflections of the ultrasonic pulses at the gas-liquid interface and at the channel button by using an absorbent and by optimizing the time interval between the pulses. To assess their data, the velocity profile was also measured by particle tracking velocimetry and good agreement was found between the readings of both techniques. For velocity profiles in a wavy flow, also theoretical calculations were performed and the numerical data also were in good agreement with the ultrasonic measurements. Instantaneous turbulence components in the velocity profiles could also be measured by this ultrasonic method.

All three papers, presented by Japanese authors, gave the impression, that the development of ultrasonic devices is very promising for gaining new insights into two-phase flow characteristics. Research groups, being active in two-phase flow and in nuclear safety thermohydraulic research, should be encouraged to develop and to use ultrasonic devices for fluiddynamic studies.

Void Fraction Measurements by Means of Flash X-Ray Radiography

(S. Angelini and T. G. Theofanous, University of California, Santa Barbara, USA)

The last paper in the session presented by Angelini and Theofanous, demonstrated the usefulness of flash X-ray radiography to monitor void fractions in highly transient multiphase flow. The authors applied this method mainly to steam explosion studies and they succeeded to obtain quantitative space and time distributions of the void fractions during the extremely short pre-mixing and expansion period. The authors demonstrated, that X-ray radiography is a viable instrument for the measurement of highly multidimensional multiphase flows during highly-transient situations. It allows to obtain information over large regions. An interesting detail of the presentation was, that under certain circumstances, this technique also allows to extract volume fraction of an opaque phase, which is an additional and unique feature of this method. The data provided by this X-ray technique are a very valuable basis for improving numerical codes for predicting pressure loads of steam explosions.

The papers of session X demonstrated, that very promising and sophisticated measuring techniques, which are known from the literature however for other applications can be used for investigating two-phase flow with good accuracy. The papers in this session were a very valuable contribution to the development of advanced instrumentation and measuring techniques.
Technical Session II

ROUND-TABLE DISCUSSION AND CONCLUSIONS

Chair: M. Ishii, Purdue University USA

Comments by F. Mayinger:

Being more than 35 years active in developing and applying measurement techniques for fluiddynamic investigations in nuclear safety research, some "nostalgic" thoughts may be allowed in starting this panel discussion. Listening to the presentations of the younger generation, we, the older members in the panel are inclined to ask what is a real new development and what is just a re-invention of former ideas. I think we should be more tolerant, because our younger people have the right to try again what we could not finish successfully years ago and they have to collect their own experiences, which means to make mistakes to a certain extent.

What are the new impressions I got during the meeting? There is an enormous push by computer techniques, offering manifold and valuable possibilities to sample data and to evaluate them and there were also presented new measuring techniques and new sensors. Also so called old measuring techniques, which older generations could not successfully apply, got new promising chances in combination with computerized data acquisition and evaluation. Examples are the nuclear magnetic resonance and ultrasonic sensors.

What do we need? For

• a more reliable operation of nuclear power plants
• a better risk assessment and
• hopefully for the design of new reactors
we need
• a much better resolution of physical phenomena
• a better understanding of micro effects, phase-interface phenomena, like interfacial friction and heat and mass transport between the phases

However the material, which an experimentalist can provide, is usually only a part of what theorists or code developers demand. Therefore we have to ask, how to balance the discrepancy between experimental ability and theoretical demand. We need a much closer cooperation between theorists and experimentalists, which hopefully leads to a better understanding of the parties standpoint. In formulating the demand of theorists, we have to ask what is desirable, what can be realized and what can be financed? The last question, usually represents the stringent factor. I therefore would like to recommend to set up a task force or a working group.

• which discusses the linking between experimental possibilities and theoretical demands
• which defines, what is really needed to know, to what accuracy and for what application
• which can judge what can be measured, with what accuracy and at what costs

The task force or the working group should also make recommendations for enforcing certain instrumentation and measuring techniques and theorists should give advice whether and how useful special experimental data probably will be for improving the quality of safety judgments.

• Watching the comprehensive computer activities, I sometimes get the impression, that the "Engineering Instinct" of the older generation is more and more missing. Due to the fact, that older generations had much poorer tools to calculate fluiddynamic processes, they had to estimate and to compare with experimental findings, which resulted in a certain "Engineering Feeling", which one can also call experience.
Comments by J. Delhaye:

1. Is it worthwhile to develop expensive measuring techniques, such as a $2 M X-ray tomograph? What are the laboratories which could afford such a piece of equipment? Pulsed neutron activation techniques were used 15 years ago with a certain success. Did it lead to any scientific breakthrough in two-phase flow modeling? Were PNA techniques used in laboratories other than the one where it had been developed? This is not the case for NMR or neutron radiography. The equipment is available in many research centers and can be adapted to two-phase flow studies without much effort.

2. Computers capabilities have enormously increased for the past few years. The situation allows huge quantities of data to be provided. Are we able to synthesize all these data so that the two-phase flow community can use them as internationally recognized benchmarks?

3. Do we spend enough effort on developing measurement techniques for actual industrial conditions in terms of pressure, temperature, fluid aggressivity, etc.

4. Is there any possibility to use micro electro-mechanical systems (MEMS) such as the ones developed by Professor Ho at UCLA?

5. Do we always qualify our new measuring techniques by comparing the results with other existing techniques?

6. Do we always go back to the literature where the principles of a measuring technique as well as its uncertainty and sensitivity analyses can be found? This would avoid a waste of time and hence a waste of money.