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**NUCLEAR ENERGY AGENCY  
NUCLEAR SCIENCE COMMITTEE**

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**NUCLEAR SCIENCE COMMITTEE  
and  
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS**

**OECD-NEA/US-NRC Benchmark based on NUPEC BWR Full-size Fine-mesh  
Bundle Tests ( BFBT) - Summary Record of the First Workshop**

**4th October 2004  
Nara, Japan**

*This document is now classed as "Unclassified".*

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NUCLEAR SCIENCE COMMITTEE  
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**OECD-NEA/US-NRC Benchmark based on NUPEC BWR  
Full-size Fine-mesh Bundle Tests (BFBT) – First Workshop  
(BFBT-1)**

4<sup>th</sup> October 2004  
Nara, Japan

Hosted by

Japan Nuclear Energy Safety Organization (JNES), Japan

**SUMMARY RECORD**

**Content:**

- Background and Purpose of the Benchmark Workshop
- Opening Session - Introduction and Welcome
- Session 1 – Phase 1: Void Distribution Benchmark
- Session 2 – Phase 2: Critical Power Benchmark
- Closing Session - Conclusions and Recommendations
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- Annex 2: BFBT1 Workshop Participants
- Annex 3: Participants in BFBT1 Benchmark and codes

**Background and Purpose of the BFBT Benchmark**

In the past decade, a large amount of effort has been made toward the direct simulation of the boiling transition (BT) for BWR fuel bundles. The most advanced sub-channel codes explicitly take into account droplet along with liquid and vapor. They predict the dry-out process as disappearance of the liquid film on the fuel rod surface without employing any semi-empirical correlations. Through a series of benchmark comparisons with full length/scale bundle data, it was verified that the codes are reliable in predicting the critical power of the conventional BWR fuel types. However, these sub-channel codes are not yet utilized in new fuel design. Adequacy of fuel lattice geometries, spacer configurations, etc., is still confirmed mainly by costly experiments using partial- and full-scale mock-ups. The main reason for this situation is a shortage of high resolution and full-scale experimental databases under actual operating conditions.

The detailed void distribution inside the fuel bundle has been regarded as one of the important factors in the boiling transition in BWRs. With regard to the sub-channel wise void distribution, it is clear that the cross flow across the sub-channel gap dominates void distributions. Most of the well-known sub-channel codes still employ the classical Lahey's Void Drift Model or its modified models. Although there have been substantial efforts to establish a sound theoretical background of detailed void distributions, the

numerical models that are verified in a wide range of geometrical and thermal-hydraulic conditions are not yet available. In this sense, this subject still remains the major unsolved problem in the two-phase flow of BWR fuel bundles. The main reason for this lack of resolution is the lack of reliable full bundle databases under operating conditions. Up to now, only partial bundle ( $3 \times 3$  or  $4 \times 4$ ) test data under relatively low pressure ( $\approx 1$  MPa) conditions have been made available.

It was during the 4<sup>th</sup> OECD/NRC BWR TT Benchmark Workshop on 6 October 2002 in Seoul, Korea, that the need to refine models for best-estimate calculations based on good-quality experimental data was discussed. The needs arising in this respect should not be limited to currently available macroscopic approaches but should be extended to next-generation approaches that focus on more microscopic processes. It is suggested that this international benchmark be based on data made available from the NUPEC (Nuclear Power Engineering Corporation) database. From 1987 to 1995, NUPEC performed a series of void measurement tests using full-size mock-up tests for both BWRs and PWRs. Based on state-of-the-art computer tomography (CT) technology, the void distribution was visualized at the mesh size smaller than the sub-channel under actual plant conditions. NUPEC also performed steady-state and transient critical power test series based on the equivalent full-size mock-ups. Considering the reliability not only of the measured data, but also other relevant parameters such as the system pressure, inlet sub-cooling and rod surface temperature, these test series supplied the first substantial database for the development of truly mechanistic and consistent models for void distribution and boiling transition.

This international benchmark, based on the NUPEC database, encourages advancement in this uninvestigated field of two-phase flow theory with very important relevance to the nuclear reactor's safety margins evaluation. Considering the immaturity of the theoretical approach, the benchmark specification is being designed so that it systematically assesses and compares the participants' numerical models on the prediction of detailed void distributions and critical powers. Furthermore, the following points are kept in mind while the benchmark specification is being established:

- As concerns the numerical model of void distributions, no sound theoretical approach that can be applied to a wide range of geometrical and operating conditions has been developed.
- In the past decade, experimental and computational technologies have improved tremendously through the study of the two-phase flow structure. Over the next decade, it can be expected that mechanistic approaches will be more widely applied to the complicated two-phase fluid phenomena inside fuel bundles.
- The development of truly mechanistic models for critical power prediction is currently underway. These models must include elementary processes such as void distributions, droplet deposit, liquid film entrainment, etc.

The first workshop of the OECD/NRC Benchmark based on NUPEC BWR Full-size Fine-mesh Bundle Tests (BFBT) was held on 4<sup>th</sup> October 2004. The workshop was hosted by the Japan Nuclear Energy Safety (JNES) Organization. The BFBT Benchmark is sponsored by the US Nuclear Regulatory Commission (NRC), the OECD, and the Nuclear Engineering Program (NEP) of the Pennsylvania State University. The experimental data was produced during a measurement campaign by the NUPEC, Japan, and sponsored by the Japan Ministry of Economy, Trade and Industry (METI).

The BFBT benchmark consists of two parts (phases), each part consisting of different exercises:

- Phase 1 – Void Distribution Benchmark
  - Exercise 1 – Steady-state sub-channel grade benchmark
  - Exercise 2 – Steady-state microscopic grade benchmark
  - Exercise 3 – Transient macroscopic grade benchmark

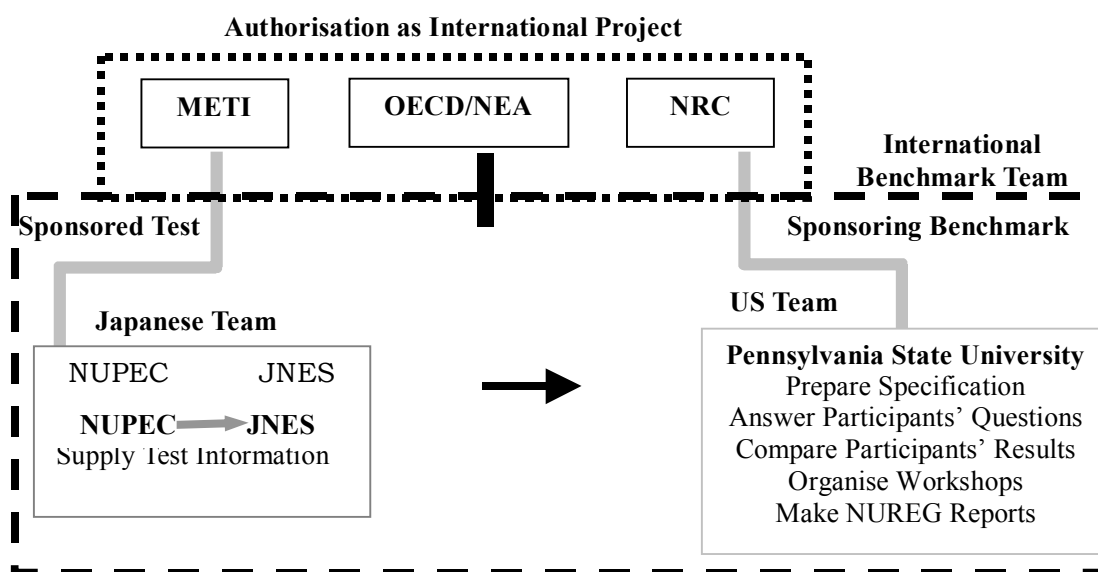
- Phase 2 – Critical Power Benchmark

Exercise 1 –Steady-state benchmark

Exercise 2 – Transient benchmark

It should be recognized that the purpose of this benchmark is not only the comparison of currently available macroscopic approaches but above-all the encouragement to develop novel next-generation approaches that focus on more microscopic processes. Thus, the benchmark problem includes both macroscopic and microscopic measurement data. In this context, the sub-channel grade void fraction data are regarded as the macroscopic data and the digitized computer graphic images are the microscopic data.

The international benchmark team is organised based on collaboration between Japan and the USA as shown.



**Opening Session: Introduction and Welcome, Chair K. Ivanov**

The meeting was opened by Prof. Kostadin Ivanov, Pennsylvania State University. The President of the hosting organization - Japan Nuclear Energy Safety Organization (JNES), Prof. Hideki Nariai, welcomed the participants and wished them to engage on and enjoy this benchmark to a successful completion. Dr. Enrico Sartori welcomed the participants on behalf of the OECD/NEA Secretariat and thanked in particular the local organizers for their hospitality. Dr. Sartori discussed the organization of the benchmark activities and introduced the benchmark team.

The meeting was attended by 30 participants representing 19 organisations, from 8 countries (see Annex I). The agenda was approved with minor adjustments (see Annex II). The list of those persons who expressed interest and the intention to participate in this benchmark, as well as the codes they intend to use in the benchmark study is given in Annex III.

Dr. Sartori summarised the activities of the Nuclear Science Committee in the area of coupled neutronics/thermal-hydraulics and transients involving the coupling of core and the plant. Several of these were successfully completed, others are in progress. The activities are now moving towards refined modelling involving CFD. In particular the BFBT benchmark is a challenging one, but will contribute to

the advancement of refined modelling. Refined modelling is needed as simplified, conservative approaches are not conservative in all cases as certain benchmark studies have demonstrated.

### **Session 1: Void Distribution Benchmark, Chair A. Hotta**

Phase 1, Void Distribution benchmark, of the BFBT benchmark was discussed. Dr. Hideaki Utsuno (JNES) presented the specification of Phase 1, Exercises 1, 2 and 3. The presentation was followed by a discussion on the experimental data available to the participants.

One of the issues discussed at length was the dimensions of the spacer grids and ferrules. In the specification detailed graphs on a correct scale are provided. The exact dimensions not being made available by the vendor, it was agreed to make an estimate based on the graphs and overall dimensions given with an estimation of the uncertainty. This should be a guide to participants, but these are encouraged to carry out some sensitivity analysis concerning these dimensions. It is believed that this would provide further insight into detailed modelling of two-phase flow in bundles.

Also the definition of microscopic and macroscopic for this benchmark was discussed. Microscopic is to be interpreted in the sense of the CFD framework.

In his presentation, “Predictions of the Phase Distribution in a Nuclear Fuel Bundle using MATRA, MARS (COBRA-TF) and CFX”, Dr. W. In discussed the experience of the Korea Atomic Energy Research Institute (KAERI) in two-phase flow phenomena modelling.

The presentations were followed by a discussion that identified the following issues:

- In the specification, only bundle average spacer pressure loss coefficients are provided. In order to define local (subchannel) loss coefficients more comprehensive information (grid thickness or grid blockage area) is required.
- The turbulent mixing coefficient will be independently modelled by participants.
- In addition to the exit void fraction distribution data, local (line averaged) measurement of the void fraction at different elevations is to be provided to each participant.
- Two transient cases – turbine trip without bypass and re-circulation pump trip – will be included as cases for Exercise 3 of Phase 1.
- The full set of test cases, defined in the test matrix in the document of JNES-04N-0015, including those non chosen as exercise cases, will be distributed to the participants.
- Participants will clarify the information they require for their analysis including detailed dimensions. The benchmark team will check the current confidential data against data that can be extracted from the drawings.
- Each participant will categorize their code system into one of the following groups:
  - 1) Subchannel code
  - 2) CFD
    - Continuous Fluid Dynamics
    - Interface Tracking Method
    - Particle Method
    - Others ( )
  - 3) Combined CFD and subchannel (for what purpose CFD modules are applied)
  - 4) Other approaches (ex. 1-D Averaged, etc.).

**Session 2: Critical Power Benchmark, Chair A. Hotta**

Dr. Utsuno presented the specification of Phase 2, Critical Power benchmark, Exercises 1 and 2. In the follow-up discussion the issues listed below were clarified:

- Each participant will decide to use either a one-dimensional approach or a subchannel approach.
- The given two-phase pressure drop data are at steady state conditions.
- Data for the pressure drop along with a Reynolds number (Re) will be provided for the single-phase cases and spacer loss coefficient could be evaluated. Data for two-phase cases are available without a Reynolds number.
- No heat losses could be assumed - the measurements were performed at adiabatic conditions.
- The given axial power profile is discretised in 24 axial nodes.
- Fluid velocity and temperature distributions for each phase are not available.
- During the measurements, the transients were started after a steady state condition was reached. The codes' simulations should follow the same sequence.
- Time constant for the heater can be determined based on the heater rod geometry and property, since the thermo-couples are located on the rod surface.
- Participant will use their own steam-water properties table. It was mentioned that use of different tables could cause errors in low pressure regions.
- The exit quality (thermo-dynamic quality) was calculated based on a thermal balance, not measured. Void fraction was directly measured. Perhaps, it is more appropriate to compare not only measured-to-predicted exit void fraction but also code-to-code exit quality.
- Participants have to clarify the needs of their constitutive equations, hydraulic diameter or spacer grid details.
- Microscopic void distribution data is available only for the steady state cases. During the transients only line averaged void fractions was measured.

**Closing Session: Conclusions and Recommendations, Chair: E. Sartori**

JNES has released the full set of BFBT bundle data to the OECD Nuclear Energy Agency for distribution to participants in the benchmark. It consists of 392 cases for steady state void distributions and 151 critical power distribution cases. Participants, before receiving the data and the descriptive information of the BFBT tests have to agree to the following "Conditions for Release, Rules and Restrictions Applying to the Use of the Information":

- The data and information remain the property of the Japan Nuclear Safety Organization (JNES)
- The data and information is exclusively released to participants in the OECD/NRC BFBT Benchmark Study
- Recipients of the data will use it exclusively for model and code improvements in the two-phase flow area and agree to provide in return details of the methods and models used in the interpretation / simulation of the experiments, including results of sensitivity analysis.
- Recipients agree not to make copies of the information and not to further distribute or sell it to third parties
- Recipients agree to provide feedback on deficiencies or errors they may find in the data.

- Recipients agree to inform the benchmark organizers before publishing any study results for which the BFBT benchmark data have been used

Dr. Sartori, on behalf of the OECD NEA thanked the President of JNES and his staff for making such a comprehensive and valuable set of data available to the international community and for the large amount of work and competence they have invested to make the release possible.

This benchmark with its large set of good quality and very detailed data will substantially contribute to refining models for best estimate calculations for two-phase flow analyses.

Prof. Ivanov initiated a discussion about the BFBT benchmark schedule, actions to be carried out to achieve progress and the next workshop. As a result, the following BFBT schedule and list of actions were accepted by the workshop participants:

<b>Action</b>	<b>Deadline</b>	<b>Who</b>
Update Cases in Specification as discussed at BFBT1	20 October 2004	Dr. H. Utsuno (JNES)
Prepare summary record of the workshop	31 October 2004	Penn State, JNES and OECD/NEA
Prepare CD-ROM with papers distributed at the 1 <sup>st</sup> workshop	31 October 2004	OECD/NEA
Scan Spacer grids and ferrules and propose dimensions with range of uncertainty for uniform use by participants and for sensitivity analysis	20 December 2004	Penn State and JNES
Finalize the benchmark specifications taking account of the discussion with participants in BFBT-1	20 December 2004	Penn State and JNES
Arrange for the distribution of the BFBT database to participants having agreed to conditions, rules and restrictions in the use of the data	20 December 2004	OECD/NEA
Set up benchmark e-mail server, web-site and ftp site	20 December 2004	OECD/NEA, Penn State and JNES
Submit results for Exercises 1 of Phase 1 and Phase 2 including spacer-grid dimensions sensitivity analysis	30 April 2005	Participants
Organise Second Benchmark Workshop – BFBT-2 - Discussing the results of First Exercises of Phases 1 and 2, and the modelling issues of Exercise 2 of Phase 1.	27-29 June 2005, Penn State, USA	Penn State and OECD/NEA

### **Proceedings of the Workshop**

Participants will receive with these proceedings a CD-ROM containing all papers discussed at the meetings.

### **Next workshop**

PSU offered to host the 2<sup>nd</sup> workshop from 27-29 June 2005. It was agreed that the 3<sup>rd</sup> workshop should be held in Europe.

## Annex I

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30 participants from 19 organisations, from 8 countries

**Annex II**

**OECD/NRC Benchmark based on NUPEC BWR  
Full-size Fine-mesh Bundle Tests (BFBT) – First Workshop  
(BFBT-1)**

Asu-Nara Big Meeting Room (2F)  
Mitsui Garden Hotel, Nara, Japan

4<sup>th</sup> October 2004

Hosted by  
Japan Nuclear Energy Safety Organization (JNES), Japan

**PROGRAMME [03]**

**Opening Session** (13:30-13:45) – *Chair: K. Ivanov*

- Introduction and Welcome – H. Nariai (JNES)
- Introduction of Workshop [01] and Benchmark [02] Participants
- Approval of Agenda [03]
- Organization of benchmark activities and benchmark team – E. Sartori (OECD/NEA) [04]

**Session 1** (13:45-15:15) – *Chair: A. Hotta*

Phase 1 – Void Distribution Benchmark

- Presentation of the specification of Phase 1, Exercises 1-3 – H. Utsuno (JNES) [05]
- Presentation of related topics from participants
  - D. H. Hwang, J. J. Jeong and W. K. In: Predictions of Void Distribution in a Nuclear Fuel Bundle using MATRA, COBRA-TF and CFX [06]
- Discussion of the specification – K. Ivanov (PSU) [07]

**Session 2** (15:30-16:45) – *Chair: A. Hotta*

Phase 2 – Critical Power Benchmark

- Presentation of the specification of Phase 2, Exercises 1-2 – H. Utsuno (JNES) [05]
- Presentation of related topics from participants
- Discussion of the specification – K. Ivanov (PSU)

**Closing Session** (16:45-17:00) – *Chair: E. Sartori*

- Action item and schedule of benchmark activities - next Workshop (BFBT-2), etc – K. Ivanov (PSU) [08]
- Conclusion and Closing Remarks – E. Sartori (OECD/NEA) [09]
- Summary and Actions [10]

[ ] indicate the identification on the CD-ROM

## Annex III

## NUPEC BFBT BENCHMARK EXPECTED PARTICIPANTS

Organization	Country	Contact Persons	Address	Software	Participation/ report only
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FZK	Germany	X. Cheng	<a href="mailto:xu.cheng@iket.fzk.de">xu.cheng@iket.fzk.de</a>	MATRA	yes
GRS	Germany	U. Graf K. Velkov	<a href="mailto:gra@grs.de">gra@grs.de</a> <a href="mailto:vek@grs.de">vek@grs.de</a>		yes
University Pisa	Italy	D'Auria Francesco Alessandro Petruzzi	<a href="mailto:dauria@ing.unipi.it">dauria@ing.unipi.it</a> <a href="mailto:axp46@psu.edu">axp46@psu.edu</a>	RELAP5	yes
Hitachi	Japan	Akihiko Minato	<a href="mailto:akihiko_minato@pis.hitachi.co.jp">akihiko_minato@pis.hitachi.co.jp</a>		yes
Hitachi	Japan	Koji Nishida	<a href="mailto:kouji_nishida@pis.hitachi.co.jp">kouji_nishida@pis.hitachi.co.jp</a>	SILFEED	yes, likely
JAERI	Japan	Hajime Akimoto	<a href="mailto:akimoto@hflwing.tokai.jaeri.go.jp">akimoto@hflwing.tokai.jaeri.go.jp</a>	NASCA	yes
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Kumamoto Univ.	Japan	Michio Sadatomi	<a href="mailto:sadatomi@mech.kumamoto-u.ac.jp">sadatomi@mech.kumamoto-u.ac.jp</a>	NASCA	yes
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NUPEC	Japan	Masanori Naitoh	<a href="mailto:Ms-naito@nupec.or.jp">Ms-naito@nupec.or.jp</a>	IMPACT/CAPE-BWR	yes

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Last update 6.1.2005 yes = confirmed participation in benchmark