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NUCLEAR ENERGY AGENCY
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NUCLEAR SCIENCE COMMITTEE
and
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

OECD/NRC Benchmark based on NUPEC BWR Full-size Fine-mesh Bundle Tests (BFBT)

Summary Record of the Fourth Workshop (BFBT-4)
8-9 May 2007
NEA Headquarters, Issy-les-Moulineaux, France

This document is now classed as "Unclassified".

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NUCLEAR SCIENCE COMMITTEE
and
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

OECD/NRC Benchmark based on NUPEC BWR
Full-size Fine-mesh Bundle Tests (BFBT)
Fourth Workshop (BFBT-4)

NEA Headquarters
Issy-les-Moulineaux, France
8-9 May 2007

Hosted by
CEA, Saclay and OECD/NEA, France

SUMMARY RECORD

Sponsorship

The fourth workshop for the OECD/NRC Benchmark based on NUPEC BWR Full-size Fine-mesh Bundle Tests (BFBT-4) was held on 8 and 9 May 2007 at NEA Headquarters, Issy-les-Moulineaux, France, and is a follow-up to the first three workshops as follows:

1. First Workshop (BFBT-1) held on 4 October 2004, hosted by the Japan Nuclear Energy Safety (JNES) Organisation;
2. Second workshop, (BFBT-2) held from 27 to 29 June 2005 at State College, PSA, USA, hosted by the Nuclear Engineering Program (NEP) of the Pennsylvania State University (PSU);
3. Third workshop (BFBT-3) held on 26 and 27 April 2006, at Pisa, Italy, hosted by the University of Pisa.

The BFBT-4 Benchmark is sponsored by the US Nuclear Regulatory Commission (NRC), the OECD, and the NEP of PSU. The experimental data were produced during a measurement campaign by the NUPEC, Japan, and sponsored by the Japan Ministry of Economy, Trade and Industry (METI).

The international benchmark team is organised based on collaboration between Japan and the USA. CEA-Saclay (France) proposed the introduction of an additional uncertainty analysis exercise to the benchmark and joined the benchmark team to define and conducting such an exercise.

This workshop (BFBT-4) was held in conjunction with two other meetings, in order to facilitate co-ordination and sharing of work. These were held at the OECD/NEA Headquarters, 12 boulevard des Iles, 92130 Issy les Moulineaux, during the same week in order to combine efforts in common areas such as computational fluid dynamics (CFD) modelling and uncertainty analysis and to make participation more efficient. The meetings concerned are the fifth workshop for the OECD/DOE/CEA VVER-1000 Coolant Transient (V1000CT) benchmark – V1000CT-5, conducted on 7 May 2007, and the first workshop for the OECD Uncertainty Analysis in Modelling (UAM) Light Water Reactor (LWR) benchmark, conducted on 10 and 11 May 2007. In parallel with this meeting, the annual meeting of the Working Group D involved in VVER reactor dynamics and safety research was also held at the same premises. For further details please contact Soeren Kliem at s.kliem@fzd.de.

Background and Purpose of the Benchmark Workshop

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 droplets 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 to 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., still have to be 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.

Detailed void distribution inside the fuel bundle is regarded as an important factor in the boiling transition in BWRs. With regard to the sub-channel wise void distribution, it is clear that the 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 versions. 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 x 3 or 4 x 4) test data under relatively low pressure (approximately 1 MPa) conditions have been made available.

It was during the 4th OECD/NRC BWR TT Turbine Trip 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. From 1987 to 1995, NUPEC (Nuclear Power Engineering Corporation) 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 of 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. Consequently, the basis of this international benchmark is the data made available from the NUPEC database.

This international benchmark encourages advancement in this uninvestigated field of two-phase flow theory with very important relevance to the nuclear reactors' 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 were kept in mind while establishing the benchmark specification:

- 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 tremendously improved 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 BFBT benchmark is made up of two parts (phases), each part consisting of different exercises:

- <u>Phase I – Void Distribution Benchmark</u>

Exercise 1 (I-1) – Steady-state sub-channel grade benchmark
Exercise 2 (I-2) – Steady-state microscopic grade benchmark
Exercise 3 (I-3) – Transient macroscopic grade benchmark
Exercise 4 (I-4) – Uncertainty analysis of the steady state sub-channel benchmark

- <u>Phase II – Critical Power Benchmark</u>

Exercise 0 (II-0) – Pressure drop benchmark
Exercise 1 (II-1) – Steady-state benchmark
Exercise 2 (II-2) – Transient benchmark
Exercise 3 (II-3) – Uncertainty analysis of the steady critical power benchmark

It should be recognized that the purpose of this benchmark is not only to compare currently available macroscopic approaches but above-all to encourage the development of 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.

<u>Scope and Technical Content of the Benchmark Workshop</u>

The technical topics addressed at the workshop included:

- Review of the benchmark activities after the 3rd Workshop
- Discussion of the draft version of Volume II of the specifications on uncertainty analysis exercises
- Presentation and discussion of comparison of final submitted results for Exercise 1 of Phase I (I-1)
- Presentation and discussion of comparison of final submitted results for Exercise 0, Phase II (II-0)
- Presentation and discussion of comparison of final submitted results for Exercise 1, Phase II (II-1)
- Presentation and discussion of modelling issues and comparison of submitted results for Exercise 2, Phase I (I-2)
- Presentation and discussion of modelling issues and comparison of submitted results for Exercise 3, Phase I (I-3)
- Presentation and discussion of modelling issues and comparison of submitted results for Exercise 2, Phase II (II-2)

- Discussion of the requested output and templates for submitting results for Exercise 4 of Phase I (I-4), and Exercise 3 of Phase II (II-3)
- Defining a work plan and schedule outlining actions to advance the two phases of the benchmark activities

Organization and Programme Committee of the Benchmark Workshop

An Organization and Programme Committee has made the necessary arrangements for the fourth Benchmark Workshop, organized the sessions, and prepared the final program. The general chair was Eric Royer (CEA-Saclay) and he also hosted the workshop. The other members were James Han (US NRC) who is co-sponsoring this activity, José Aragonés (UPM), representing the NSC, Francesco D'Auria, representing CSNI, L. Hochreiter (PSU), H. Utsuno (JNES), A. Hotta (TEPSYS), K. Ivanov (PSU), representing the benchmark team, and the OECD/NEA Secretariat.

Session 1 – Introduction and openning remarks

The meeting was opened by Eric Royer of the CEA-Saclay that was hosting the meeting. He welcomed the participants on behalf of the CEA and wished them a successful work. He pointed out that the interest in participating in this benchmark is due to the wide range of two-phase flow models (1D, sub-channel, CFD, Computational Multi-Phase Fluid Dynamics (CMFD), porous media, etc.) concerned within the BFBT and by the strong interest for fuel bundle experimental data. Enrico Sartori welcomed the participants on behalf of the NEA Secretariat. José Aragonés representing NSC welcomed participants and commented that the benchmark was a very timely undertaking. The entire modeling philosophy is moving toward the best-estimate analysis with uncertainty analysis included. This benchmark would contribute to this effort.

The agenda was approved with minor adjustments (see Annex I).

The workshop was attended by 25 participants from 19 organizations in 10 countries (see Annex II). The interest in this benchmark was very large, though not all participants having committed themselves to provide results have participated. Overall, 46 experts from 26 organizations in 23 countries agreed to participate, from research (40%), university (30%) and industry (30%).

K. Ivanov on behalf of the benchmark team made a presentation giving an overview and status of the BFBT benchmark activities.

Technical Sessions on Phase I – Void Distribution Benchmark

Sessions 1 to 4 were devoted to the first three exercises of Phase I of the BFBT benchmark. The benchmark team summarized, in three presentations, the comparisons of submitted results for Exercises I-1 and I-2 (macro- and microscopic steady state void distribution) as well as for Exercise I-3 (sub-channel transient void distribution). Based on these presentations the following issues were discussed and suggestions made to the benchmark team:

a) The same scale on figures for comparisons should be used in the final report;
b) In the final report add to figures of comparisons a picture with marked sub-channels for which the results are being compared;
c) Add to the questionnaire a request to participants to provide references for their models and ask them specifically about their sub-cooled boiling models. For CFD codes request information on their turbulent mixing and surface boiling models;
d) Replace the term "power peaking factor" with "relative power in sub-channel";

e) For snapshot comparisons of Exercise I-3 add a figure with the transient shape in order to show at which point during the transient the snapshot is taken;
f) For both steady state and snapshots during the transient provide axial curves for 3 selected sub-channels (the curves should be fitted and smoothed).

Participants made 6 presentations on their models and showed results for Exercises I-1, I-2 and I-3.

ANL made a proposal in their presentation for correcting the existing distortion in measured fine-mesh void distribution data, which is important for code-to-data comparisons of Exercise I-2. Asymmetry in the measurements was identified during the previous workshop. This can be seen in the fine grid measurements where the fuel rods appear not always to be exactly where expected. This could be explained by some misplacement of the rods in the bundle or non verticality of the mock-up. The method for the comparative analysis between code predictions and experimental data will not be changed (experimental data are averaged on equivalent sub-channels). The observed result for the existing distortion in fine-mesh void distribution data would be provided by ANL.

The benchmark team presented a summary with the major conclusions of the study performed by the benchmark team on developing correlation for the transient densitometer void distribution measurements. Void fraction experimental measurements in transient were discussed since there were discrepancies between the two techniques of measurement (scanner and densitometer). A correction has been proposed and agreed on in order to achieve a more consistent comparison of the computed results against experimental data. The AREVA NP presentation demonstrated that the developed correction seems to be practicable for void fractions higher 20 %. ANL suggested providing detail CFD results (as data of numerical experiment) at the 3 axial elevations where the densitometers are located. This data can be used to develop more sophisticated and complex 2-D correlations covering the whole range of conditions of interest. The CFD void distribution data will be extracted for three cases (exit quality of 0.25, 0.12, and 0.05) at the three densitometer axial locations (0.682m, 1.706m, 2.730m).

To summarise, since the previous workshop in Pisa, for Phase I significant progress has been made by the participants for Exercise I-1 for which many sets of results were submitted. Exercises I-2 and I-3 are still ongoing since they are more complex (finer scale or transient phenomena). Some participants asked for an extension of the deadline as they are still working on their models. This extension will allow adding new results for the comparative analysis and increase its value.

Technical Sessions on Phase 2 – Critical Power Benchmark

Sessions 5 to 6 were devoted to the first 3 exercises of Phase II of the BFBT benchmark. The benchmark team summarized in four presentations the comparisons of submitted results for steady state Exercises II-0 (pressure drop) and II-1 (critical power), and for transient Exercise II-2 (critical power) as well as the summary with the major conclusions of the study performed by the benchmark team on evaluating the time constant for BWR bundles utilized in the BFBT benchmark.

Participants made 2 presentations on their models and showed results for Exercises II-0. JNES suggested that a spacer effect would be implemented in the analysis of critical power which enhances droplets deposition on the wall downstream of the spacer. JNES presented a procedure to calculate spacer loss coefficients using the BFBT data.

In summary, since the previous workshop in Pisa, for Phase II significant progress was made by the participants for Exercises II-0 and II-1 for which many sets of results were submitted. Exercise II-2 is still on going since it is more complex (transient phenomena). Some participants asked for an extension of the deadline as they are still working on their models. This extension will allow adding new results for the comparative analysis and increase its value.

Technical Sessions on Uncertainty Analysis Exercises

A draft of the second volume of the Specifications, prepared by the benchmark team, on the uncertainty exercises I-4 and II-3 was presented and discussed in Sessions 4 and 7. Agreement was reached by the participants allowing the preparation and speedy distribution of the second volume of the Specifications covering uncertainty analysis. An elementary task was proposed by JNES focusing the void fraction analysis on one sub-channel only. It was well accepted, particularly for fine models (CFD) for which the full bundle sensitivity or uncertainty analysis is more difficult. This task will be added to the second volume of the Specifications as an optional exercise. The possibility of complementing this exercise by using single channel experimental data was discussed. JNES encouraged participants to commit the provision of such experimental data on a voluntary basis. A request for such data will be made by the OECD/NEA Secretariat. If such data is released an additional exercise will be proposed in the future.

CEA-Saclay presented preliminary results and modelling issues for Exercise I-4. This exercise is composed of two steps. Step 1 consists of an accuracy analysis (or global sensitivity analysis). Step 2 concerns local propagation of uncertainty. CEA presented only the propagation of boundary conditions. The correct definition for the coverage ratio for void distribution was introduced. The most sensitive parameters are related to the code models. Participants can select the most important model parameters to be propagated using Phenomena Identification and Ranking Tables (PIRTs) developed by PSU for Exercises I-4 and II-3 or based on its own judgment and/or sensitivity studies.

Conclusions, Actions and Schedule

In summary, at the BFBT-4 workshop the benchmark team made overall 14 presentations supplemented by 9 presentations from the participants. A special session will be dedicated to the BFBT benchmarks at the NURETH-12 conference in October 2007. Proposals for twelve papers have already been submitted. Participants are encouraged to attend this meeting. As critical power predictions are a more challenging task than the void fraction prediction, participants will be given more time to submit results for Exercises II-1 and II-2.

The action items and schedule of benchmark activities were discussed. They are given in the following list:

List of Agreed Actions

1. A brief BFBT-4 workshop summary will be prepared by the benchmark team and distributed by June 15th.

2. Draft Specifications for uncertainty exercises (I-4 and II-3) will be finalized by the benchmark team by end of June 2007

3. Draft Specifications for the elementary task will be finalized by the benchmark team by July 2007.

4. The OECD/NEA Secretariat will request complementary single channel experimental data.(see Annex 3 for references)

5. Extended deadline for final results on Exercises I-1, II-0 and II-1 – End of August 2007

6. Deadline for final results on Exercises I-2, I-3 and II-2 – End of January 2008

7. Deadline for preliminary results on Exercises I-4, II-3 and elementary task – End of February 2008

8. The fifth workshop (BFBT-5) will be held from 31 March, to 2 April 2008 and will be hosted by Gesellschaft für Anlagen und Reaktorsicherheit (GRS), Garching, Germany.

The next workshop (BFBT-5) objectives will be the following:

a) Discussion of final results of Exercises I-2, I-3 and II-2
b) Discussion of preliminary uncertainty analysis results of Exercises I-4 and II-3
c) Preparing a special issue in a journal with participants' BFBT papers

Annex 1

OECD/NRC Benchmark based on NUPEC BWR
Full-size Fine-mesh Bundle Tests (BFBT) – Fourth Workshop
(BFBT-4)

Hosted by
CEA-Saclay and NEA/OECD
8-9 May 2007

FINAL PROGRAMME [B401a]
(B*nnn identifiers relate to file identification on the DVD)*

Participants [B401b]

Day 1: 8 May 2007

Opening Session - Chair E. Royer

9:00 - 9:15 Introduction and opening remarks – E. Royer (CEA), J. Aragones (NSC), E. Sartori (NEA)

9:15 - 9:30 Overview and status of benchmark activities – K. Ivanov [**B402**]

Technical Sessions on Phase I – Void Distribution Benchmark

Session I - Chair H. Utsuno

9:30 - 10:15 Comparative Analysis of the Results of Exercise 1 of Phase I - B. Neykov, K. Ivanov, L. E. Hochreiter, M. Avramova [**B403**]

10:15 - 10:45 Comparative Analysis of the Results of Exercise 2 of Phase I - B. Neykov, K. Ivanov, L. E. Hochreiter, M. Avramova [**B404**]

10:45 - 11:00 Coffee Break

Session II - Chair – A. Tentner

11:00 - 11:20 Comparative Analysis of the Results of Exercise 3 of Phase IExercise 3 of Phase I - B. Neykov, K. Ivanov, L. E. Hochreiter, M. Avramova [**B405**]

11:20 - 11:40 Proposal of elemental task in the BFBT benchmark – H. Utsuno [**B406**]

Participants' presentations on modelling and results for Exercises I-1, I-2, and I-3.

11:40 - 12:00 David Pointer and Adrian Tentner CFD Modelling and Results for BFBT Exercise I-2 using the STAR-CD Generation 2 Boiling Models [**B407**]

12:00 - 12:20 Jaakko Miettinen, Mikko Ilvonen, Antti Daavittila: Present porosity model PORFLO results for the bundle tests **[B408]**

12:40 14:00 Lunch

Session III - Chair K. Ivanov

14:00 - 14:20 Akitoshi Hotta, Hiromasa Chitose, Hideaki Ikeda: Results of Ph-II/Ex-0 and Ph-I/Ex-1 in NUPEC BFBT Benchmark based on NASCA, **[B409]**

14:25 - 14:40 Markus Glück: Status of steady-state and transient F-COBRA-TF recalculations of selected exercises of BFBT benchmark (I-1, I-3, II-0) **[B410]**

14:40 - 15:00 D. H. Hwang, J. J. Jeong, W.K. In: Activities of KAERI BFBT Benchmark Team Using MATRA, MARS(COBRA-TF) and CFX for Phase-I Exercise-3 **[B411]**

15:00 - 15:20 M. C. Galassi, A. Petruzzi, C. Parisi, F. D'Auria: Progress on activities performed at UNIPI on Void Distribution Prediction using RELAP5-3D© system code and CFD codes **[B412]**

15:20 -15:40 J. Jiménez, D. Cuervo, M. Avramova, K. Ivanov: PSU-UPM COBRA-TF Results for Exercise I-3 with measurements correction **[B413]**

15:40 - 16:00 Fatih Aydogan, Lawrence E. Hochreiter, Kostadin Ivanov: Correlation for the Bundle Averaged Void Fraction Measured with X-Ray Densitometers in the OECD/NRC BFBT Benchmark Database **[B414]** and Summary of the major conclusions of the study performed by the benchmark team on developing correlation for the transient densitometer void distribution measurements – M. Avramova [**B415**]

<u>**Day 2: 9 May 2007**</u>

Session IV - Chair M. Glück

9:00 - 9:20 F. Aydogan, L. Hochreiter, K. Ivanov, M. Martin: Discussion of the Draft of Volume II of Specification on Exercise 4 of Phase I [**B416]**

9:20 - 9:40 M. Martin, F. Gaudier: BFBT Phase 1 Ex. 4 Step 2 : Application of Uncertainty Analysis to Subchannel Void Distribution **[B417]**

9:40 - 10:00 F. Aydogan, L. Hochreiter, K. Ivanov: Discussion of the Requested Output, Templates for Submitting Results, and Questionnaire for Exercise 4 of Phase I **[B418]**

10:00 - 10:20 Discussion of Phase I

10:20 Coffee Break

Technical Sessions on Phase 2 – Critical Power Benchmark

Session V - Chair H. Ikeda

10:40 - 11:00 B. Neykov, F. Aydogan, K. Ivanov, L. E. Hochreiter, M. Avramova: Comparative Analysis of the Results of Exercise 0 of Phase II [**B419**]

11:00 – 11:20 H. Utsuno: Procedure to calculate a spacer loss coefficient using NUPEC BFBT data**[B420]** Proving Test on Thermal-hydraulic Design Reliability of BWR Fuell Assembly by In-Bundle Void-Fraction Measurement (NUPEC Pamphlets) **[B420a] [B420b]**

11:20 – 11:40 B. Neykov, E. Popov, K. Ivanov, M. Avramova: FLUENT 6.2 CFD Applicability for Estimating Single Phase Pressure Drop in a High Burn-up Fuel Assembly [**B421**], Fluent pressure movie [**B421a**], Fluent turbulence movie [**B421b**]

Session VI - Chair D. Cuervo

11:40 - 12:00 F. Aydogan, L. E. Hochreiter, K. Ivanov, M. Avramova: Comparative Analysis of the Results of Exercise 1 of Phase II **[B422]**

12:00 - 12:20 F. Aydogan, L. E. Hochreiter, K. Ivanov, M. Avramova: Comparative Analysis of the Results of Exercise 2 of Phase II [**B423**]

12:20 - 12:40 F. Aydogan, L. E. Hochreiter, K. Ivanov: Summary of Major Conclusions of Study Performed by the Benchmark Team on Evaluating the Time Constant for BWR Bundles Utilized in the BFBT Benchmark [**B424**]

12:30 – 14:00- Lunch

Session VII - Chair - Y. Hassan

14:00 - 14:20 F. Aydogan, L. Hochreiter, K. Ivanov, M. Martin: Discussion of the Draft of Volume II of Specification on Exercise 3 of Phase II [**B425**]

14:20 - 14:40 F. Aydogan, L. Hochreiter, K. Ivanov: Discussion of the Requested Output, Templates for Submitting Results, and Questionnaire for Exercise 3 of Phase II [**B426**]

14:40 Discussion on Phase 2

15:00 Action items and schedule of benchmark activities – K. Ivanov

15:20 Next workshop (BFBT-5) and plans – E. Sartori

15:40 Conclusions and closing remarks – Summary Record **[B427]**

References for Complementary Single Channel Experimental Data

[**A3.1**] Keiichi Hori, Tatuo Kurosu, Shigekazu Sugiyama, Junpei Matsumoto, Yoshiei Akiyama (MHI), Keiji Miyazaki (Osaka University): In Bundle Void Fraction Measurement of PWR Fuel Assembly, ASMEIJSME Nuclear Engineering Conference - Volume 1, ASME 1993, San Francisco, California, March 21-24, 1993

[**A3.2**] Keiichi Hori, Yoshiei Akiyama (MHI), Keiji Miyazaki (Osaka University), Tatsuo Kurosu, Shigekazu Sugiyama (NUPEC): Void Fraction in a Single Channel Simulating One Subchannel of a PWR Fuel Assembly, Two-Phase Flow Modelling and Experimentation 1995, pg.1013-1027

[**A3.3**] Yoshiei Akiyama, Keiichi Hori, Keiji Miyazaki, K. Mishima, Shigekazu. Sugiyama (MHI): Pressurized Water Reactor Fuel Assembly Subchannel Void Fraction Measurement, Nuclear Technology ISSN 0029-5450 1995, vol. 112, no3, pp. 412-421

[**A3.4**] Paul Coddington, Rafael Macian (PSI): A Study of the Performance of Void Fraction Correlations Used in the Context of Drift-Flux Two-Phase Flow Models, 11pgs

Annex 2

BFBT4 (Fourth OECD/NRC BFBT Workshop, Issy-les-Moulineaux, France, 8-9 May 2007)

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Annex 3

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