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OECD/NEA/NSC PBMR COUPLED NEUTRONICS/THERMAL HYDRAULICS TRANSIENT BENCHMARK - THE PBMR-400 CORE DESIGN

Summary Record of the Second Workshop

26 – 27 January 2006
NEA Headquarters, Issy-les-Moulineaux, France

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OECD/NEA/NSC PBMR COUPLED NEUTRONICS/THERMAL HYDRAULICS TRANSIENT BENCHMARK - THE PBMR-400 CORE DESIGN - Second Workshop

NEA Headquarters, Paris
26 – 27 January 2006

SUMMARY RECORD

Content:

Background and Purpose of the Benchmark Workshop

The Nuclear Energy Agency (NEA) of the Organisation for Economic Cooperation and Development (OECD) has accepted, through the Nuclear Science Committee (NSC), to include in its programme the Pebble-Bed Modular Reactor (PBMR) coupled neutronics/thermal hydraulics transient benchmark problem.

The PBMR is a High-Temperature Gas-cooled Reactor (HTGR) concept, which has attracted the attention of the nuclear research and development community. The deterministic neutronics, thermal-hydraulics and transient analysis tools and methods available to design and analyse PBMRs have, in many cases, lagged behind the state of the art compared to other reactor technologies. This has motivated the testing of existing methods for HTGRs and also the development of more accurate and efficient tools to analyse the neutronics and thermal-hydraulic behaviour for the design and safety evaluations of the PBMR. In addition to the development of new methods, this includes defining appropriate benchmarks to verify and validate the new methods in computer codes.

The benchmark is complementary to other on-going or planned efforts in the reactor physics community. The PBMR 268MW benchmark problem, initiated by PBMR Pty Ltd, PSU (Penn State University) and NRG, served as the predecessor to this effort. The work will be concluded in 2005 and future efforts will focus on this benchmark. The PBMR 400MW core design is also a test case in the IAEA

CRP-5 (TECDOC2 in preparation) but important differences exist between the test case definitions and approaches. The OECD benchmark includes additional steady-state and transients cases including reactivity insertion transients not included in the CRP5 effort. Furthermore, it makes use of a common set of cross sections (to eliminate uncertainties between different codes) and includes specific simplifications to the design to limit the need for participants to introduce approximations in their models.

The purpose of the first workshop, held at OECD Headquarters in Paris, was to introduce participants to the benchmark exercise, obtain feedback on the benchmark definition and to establish the possible range of methods and codes that will be used in the code to code comparisons. It was also important to establish which experiments might be available to include in later phases of the benchmark effort. Therefore the presentations of P. Pohl on the AVR and the identification of possible experiments that may be of interest and the presentation of Y. Sun on the experiments carried out, in progress and planned at the HTR-10 reactor, were of great interest to start already at this stage, to identify possible test cases.

The technical topics presented at the second workshop are shown below per session. In addition, the workshop programme is attached in Annex I with the list of participants in Annex II.

Session I: General Session: (Chair: F. Reitsma)

The session chairman welcomed everyone to the 2nd PBMR400 workshop. Frederik Reitsma gave a short overview of the current status of the PBMR project including positive feedback on the financial support of the project, the good technical progress and the progress on the preparation of the Safety Analysis Report (SAR).

The meeting was attended by 24 participants from 8 countries (see Annex II). The agenda was approved without any major changes (see Annex I). The participants were given the opportunity to introduce themselves with a short description of the field in which they are working and their interest in the benchmark or HTRs in general.

Feedback was then provided on the updates made to the specification. These include, amongst others, clarification on the stagnant helium definitions, clarification on the definition of directional diffusion coefficients, the inclusion of the definition of buckling and the details of the KTA rules as well as clarification on the thermal-hydraulic boundary conditions. A summary of discussions at the PBMRT1.5 ad-hoc meeting at M&C2005 was also provided.

Session II: Feedback by all participants I (Chair: E Sartori)

The session was the first of two where participants gave feedback on the work they have performed related to the benchmark exercises. This included descriptions of the codes and methods, changes made to accommodate the benchmark as well as results. A short summary of the presentations are provided in this summary when deemed applicable, but reference must be made to the presentations (links provided in the program given in Annex I) for the detail.

In the presentation from EDF/CEA, E. Girardi presented the status of their work. The neutronics and thermal hydraulics models are mostly in place and the steady-state neutronic calculations were performed. The void regions were treated with very small cross sections. A refined mesh was used and no sensitivity studies needed to be performed since the fine mesh has the size of the mean free path. When the power profile is considered small steps (discontinuities) were seen but can be explained by the piecewise constant diffusion coefficients. The selection of the tool to be used to run the transients cases was not finally decided since the TH code available uses simplified point kinetics and hot channel calculations. In that case input data to the point kinetics models will need to be defined.

The presentation “Recent NEM-THERMIX Computational Challenges and Benchmark Results" focuses on some sensitivity analysis performed with the code and some of the problems experienced. For example, negative fluxes were observed along the outer boundary nodes and were further investigated for their sensitivity to the diffusion coefficient and mesh effects. Another study shows the large differences observed when graphite was used as the core barrel material instead of steel. Results for Exercise 1 were compared and a slight offset on the position of the maximum axial (radially averaged) flux peak was observed. Evaluations are continuing.

Don Carlson presented the models and results of the PARCS-DIREKT calculations. Most significantly parametric studies on the mesh sizes were performed. Although very good agreement with VSOP was found using the same mesh structure, the parametric study showed that the VSOP mesh structure used in the definition of the test case is not converged. It was noted that the VSOP analysis was not intended to serve as the reference analysis and that all participants should report results obtained with converged meshes. Some interesting results that evaluated the cross section libraries were also presented.

The presentation of Brian Boer introduced the use of both a finite element transport code (EVENT) and a diffusion code (DALTON) used in neutronic calculations. Coupled thermal hydraulic neutronic calculations are performed. (EVENT – THERMIX). Since the cross section tables do not include transport cross sections an approximation for Σ_t was applied. The void regions are modelled with small cross section or by applying ray tracing. The differences between the diffusion and transport results were thought to be due to the differences in the cross section approximations.

The final presentation of this session focuses on the TINTE code and results obtained for Exercise 1. More detail was given on the TINTE codes and features. Results utilizing the given steady state test cross section library (provided by VSOP but without any temperature or spectrum dependence) was compared with the standard approach whereby a polynomial cross section library (dependent on temperature, xenon and leakage spectrum changes) is used. Differences in the reactivity and power shapes were noticeable but not larger than expected. The differences in the fluxes, although not directly comparable due to different energy boundaries, were much larger than expected and need further investigation. Implementation of benchmark features is ongoing.

Session III: Feedback by all participants II (Chair: H D Gougar)

The second session of participant’s feedback was opened by a presentation from Korea on the TOPS Nodal Code and solutions for the steady-state cases. The use of a nodal code, compared with the traditional finite-difference treatment used for HTR’s, enhances the diversity of the code-to-code comparisons. Details of the cylindrical nodal implementation (Analytic Function Expansion Method) were presented. The treatment of void regions by Partial Current Translation (PCT) was also introduced, a method that does not require diffusion coefficients but also does not account for “cross-fly” neutrons. Further benchmark analysis were also reported with TOPS results compared with VENTURE and TWODANT. Good comparisons (~100 pcm differences in k-eff values) were obtained but with TOPS run-time much faster.

The presentation of Dr. W. Bernnat focussed on the development and use of the tools available at IKE, Stuttgart University. A variety of codes (including ZIRKUS, KIND, THERMIX/KONVEK, and others) are integrated and used for HTR analysis forming a complete package. Calculations for the benchmark were performed in fine mesh with ZIRKUS (2D) and compared with DORT 2D S_N P_0-transport corrected. DORT results are about 1% lower depending on the S_N order. The reproduction of the reference cross section data was not possible, coupled calculations with interpolated cross sections led to inconsistent results. It is recommended to compare the interpolated data.

The next presentation gave an overview of the MASTER-GCR code system and benchmark solutions. The typical LWR two-step procedure performing 2D transport lattice calculations with HELIOS followed by 3-D whole-core analysis with MASTER-GRC was employed for the benchmark (Hex-Z modelling is used). The active core volume was preserved (to do so the effective inner and outer radius has changed to 99.85 cm and 184.92 cm, respectively) while volume weighted 3-D mapping is used for cross section definitions and editing of results. Results compare good with 2D r-z calculation. One observation made was that the leakage from core is small and this needs to be checked.

A presentation from Necsa, South Africa, on the results obtained using the OSCAR-4 calculational system was presented. At this stage only Case 1 results are presented since the implementation of kinetics and thermal hydraulics is still being planned. A parametric study was performed on the single choice of the diffusion coefficient (three void models) while three different meshing schemes were also selected. The modelling of the void by directional diffusion coefficients will get attention (already available in OSCAR-4 but not for card input as used in the benchmark)

The MARS-GRC Solution to Exercise 2 was presented by J.J. Jeong. The hydrodynamic and heat conduction models were presented along with the main features of the code. Results obtained are physically reasonable although the 2-D conduction was not modelled correctly. In this specific case it is not important due to the overwhelming effect of forced convection. This concluded the specific presentations from participating institutes.

Session IV: Benchmark Steady State Cases (Chair: N. Z. Cho)

In the summary prepared by Pennsylvania State University all the results on Steady-State Excercise 1 were compared. First of all an overview of the exercise was given reminding participants of its purpose and specific features. The case present a neutronic solution with a fixed set of cross sections (no feedback). The details of the cross section data library and the required results were also presented. For easier comparisons the provided results were averaged axially or radially to obtain 1-D (radial and axial) distributions. It was noted that this averaging smoothens the differences and that more detailed 2-D comparisons show larger differences. The profiles generally compared well and in many cases mis-interpretations were identified as the reason for the differences observed. More detailed comparisons do, however, show significant differences. Participants were requested to update there contributions by April for inclusion in the PHYSOR2006 comparison paper.

Session V. Benchmark Steady State Cases II (Chair: M. Methnani)

A summary of results for Excercise 2 was presented and discussed in this session. Once again an overview of the excercise was given and results were also averaged axially or radially for (radial and axial) 1-D distributions. A larger spread of results was observed than for the neutronics steady-state case but once again differences in interpretation of the specification were immediately observed. These analyses will be updated. Another observation was that the conductivity models seem to be different in the different models. The final results on converged mesh from all participants were once again requested by April.

Session VI: Cross section library and related issues (Chair: K. Ivanov)

In this session the cross section library, to be used in the dynamic calculations, was discussed in detail. In the first presentation the Cross-section Preparation path based on MICROX-2 was presented as well as all the additional work preformed since the previous meeting. This includes the addition of many nuclides (40 in total), the automation of the process and the detail of the supplied 5-D and 3-D evaluation libraries. The definition and methods used to calculate some of the additional data not readily available in MICROX was also discussed. Finally details were provided on the unresolved issues or difficulties experienced within this methodology, in particular non-convergence of the flux solution in MICROX for buckling input values needed to cover the range of leakage values obtained in core calculations.

In a next presentation the MICROX libraries were further evaluated by performing TINTE analysis on Steady-state case 3, that also represent the starting conditions for the transient cases. Large differences were observed between the 3-D and 5-D sample library runs for the k-eff (~700 pcm) and flux profiles. Other compared properties, such as 2-D spatial maximum fuel temperatures, also show significant differences (up to 29°C). The need for inclusion of the leakage feedback effects for HTRs analysis was once again emphasized.

The last presentation in this session provided more information on the approach used in graphite moderated HTGR's (and specifically PBMRs) to include leakage effects (in this case by the definition of buckling terms) in the cross section models. Reasons include the long mean free path, the small geometrical (and neutronic) size of the fuel spheres, the mixture of different pebbles with different burnup, and the dependence of the fuel spectrum on its environment. A formal definition of how the buckling term should be defined was discussed while specific examples were presented for HTR's and LWR's.

Information on the availability of an alternative tool to generate the cross section library was provided. The TINTE library pre-processor has been changed to work as a stand-alone code making use of the MUPO library. Some tests to generate a cross section library were performed. Initial tests show that it is able to generate data for a larger range of input buckling values. This will resolve the problem of extrapolation seen in the MICROX library and no extrapolation was accordingly observed in the steady state calculations performed so far. The spectrum code can thus be used as an alternative to the MICROX-2 procedure. Other comments raised were that transport cross sections also need to be included in the library for the benefit of the transport code users.

Session VII. Transient cases (Chair. Han de Haas)

The final technical session looked ahead to the transient cases. Hans Gougar presented a summary of the Transient Case definitions. Six transient case definitions were presented. Suggested tolerances and time steps are agreed. If required, participants should perform calculations on a fine time steps grid but the results presented must be consistent with the agreed time steps.

Preliminary TINTE results, making use of the MICROX 3D and 5D libraries were also presented. Three cases were selected for the evaluation. The detailed results can be found in the presentation. Since it was decided that the library should be updated using the Spectrum code (to replace the MICROX-2 based libraries) the conclusions from this presentation are no longer relevant but still serve as a record of the large differences seen between the two libraries due to the spectrum effects. One observation made as part of the study is that the control rod withdrawal shows cusping effects due to the relatively large meshes. It is agreed that a model or method must be found to overcome this.

Session VIII. Discussion and closing (Chair: F. Reitsma)

The special benchmark session scheduled at the Vancouver PHYSOR2006 conference in September 2006 was discussed. Agreement on the final submission of abstracts and the topics to be presented was reached. A summary on the future actions and schedule was made, a preliminary date of early February 2007 for the next meeting was announced and the meeting was closed

Proceedings of the Workshop

Participants will receive a CD-ROM containing all papers discussed at the meetings. The CD-ROM also includes all reports from previous workshops which discuss this benchmark.

Annex I

OECD/NEA/NSC
PBMR COUPLED NEUTRONICS/THERMAL HYDRAULICS TRANSIENT BENCHMARK
THE PBMR-400 CORE DESIGN– 2nd Workshop
OECD PBMRT2

NEA Headquarters, Paris, 26-27 January 2006

FINAL PROGRAMME
([n] indicates paper identification on CD-ROM)

I. General Session (Chair: F. Reitsma)

- Introduction and opening remarks **[P202]**– introduction of participants **[P203]**
- Adoption of agenda **[P201]**
- Feedback on Benchmark Specification updates and PBMRT1.5 meeting **[P204]**

II. Feedback by all participants I (Chair: E Sartori)

- E. Girardi, S. Massara, O. Köberl: "CEA/EDF Co-operation on the OECD/AEN PBMR-400 Benchmark: Neutronic results" **[P205]**
- J. Ortensi, B. Tyobeka, P. Mkhabela, J. Han, K. Ivanov, H. Gougar: "Recent NEM-THERMIX Computational Challenges and Benchmark Results" **[P206]**
- V. Seker, T. Downar, D. Carlson: "Analysis of the OECD/NEA/NSC PBMR-400 Benchmark Problem Using PARCS-DIREKT" **[P207]**
- B. Boer, J.L Kloosterman, D Lathouwers, C.R.E de Oliviera: "Pebble Bed Modular Reactor 400MW Benchmark Calculational Results" **[P208]**
- G Strydom, F Reitsma: "TINTE Status and Selected Steady-State Case 1 Results" **[P209]**

III. Feedback by all participants II (Chair: H D Gougar)

- N.Z. Cho, J. Lee, G.S. Lee, and H.J. Yoo: "TOPS Nodal Code Solutions for the OECD/PBMR400 Benchmark Problem – Steady-State Cases" **[P210]**
- W. Bernnat, M Buck, N. BenSaid, K Hossain, M Mesina: Application and Development of Tools for HTR Neutronics and Thermal Hydraulics Analysis at IKE" **[P211]**
- H.C. Lee, J.M. Noh: "MASTER-GCR Solutions of Phase I Exercise 1" **[P212]**
- D. I Tomasevic, R H Prinsloo: "OECD PBMR400MW Benchmark – OSCAR-4 results for Steady State Case 1" **[P213]**
- J.J. Jeong, S.W. Lee, W J Lee: "The MARS-GRC Solution to Exercise 2 of Phase I" **[P214]**

IV. Benchmark Steady State Cases (Chair: N Z Cho)

- P Mkhabela, J Han, B Tyobeka, K Ivanov, F Reitsma: "OECD PMR 400 Benchmark Summary of Results for Excercise 1" **[P215]**

V. Benchmark Steady State Cases II (Chair: M. Methnani)

- P Mkhabela, J Han, B Tyobeka, K Ivanov, F Reitsma: "OECD PMR 400 Benchmark Summary of Results for Excercise 2" **[P216]**

VI. Cross section library and related issues (Chair: K. Ivanov)

- R Mphahlele, S Sen, F Reitsma, K Ivanov: "Cross-section Preparation for the OECD PBMR-400MW Benchmark" **[P217]**
- G Strydom, F Reitsma: "OECD PBMR-400 Benchmark: TINTE Steady-State Case 3 Preliminary Results" **[P218]**
- F Reitsma, W R Joubert: "Leakage Feedback Issues in HTR's" **[P219]**
- Discussion and Finalize Decision on Library and Leakage Feedback Implementation

VII. Transient cases (Chair. Han de Haas)

- H Gougar: "Definition of Transient Cases" **[P220]**
- G Strydom, F Reitsma: "OECD PBMR-400 Benchmark: TINTE Transient Cases 2,5 and 6 Priliminary Results" **[P221]**

VIII. Discussion and closing (Chair: F. Reitsma)

- Discussion of future actions and schedule, contributions to PHYSOR2006 and schedule
- Discussion of plans and next meeting
- Any other business and closure of meeting

Annex II

List of Participants

FRANCE:

GIRARDI, Enrico, EDF R&D, DER/RNE/PhR, Etudes et Recherches
KOEBERL, Oliver, CEA – DER/SPRC
MASSARA, Simone, Research Engineer, Electricité de France R&D
SANCHEZ, Richard, Research Director, CEA Saclay

GERMANY:

BERNNAT, Wolfgang, Institute of Nuclear Technology and Energy Systems (IKE), University of Stuttgart

KOREA (REPUBLIC OF):

CHO, Nam Zin, Korea Advanced Institute of Science and Technology
JEONG, Jae-Jun, Thermal-Hydraulic Safety Research Team, Korea Atomic Energy Research Institute
NOH, Jae-Man, HTGR Development Team, Korea Atomic Energy Research Institute

NETHERLANDS:

BOER, Brian, TU Delft
DE HAAS, J.B.M. (Han), Reactor Physics Analysis, NRG
KUIJPER, Jim C., Fuels, Actinides and Isotopes, NRG

RUSSIAN FEDERATION:

ALEKSEEV, Nikolay I., Institute of Nuclear Reactors, RRC, “Kurchatov Institute”
BOYARINOV, Victor F., Institute of Nuclear Reactors, RRC, “Kurchatov Institute”
OLEYNIK, Dmitry S., Dept. Physical and Technical Research, RRC “Kurchatov Institute”
SHESTOPALOV, Aleyev Alexeyevich, Nuclear Reactor Institute, RRC “Kurchatov Institute”

SOUTH AFRICA:

REITSMA, Frederik, Nuclear Engineering Analysis, PBMR Pty Ltd
SEN, Sonat, Nuclear Engineering Analysis, PBMR Pty Ltd

UNITED STATES OF AMERICA:

CARLSON, Donald E., Senior Nuclear Analysis Engineer, U.S. Nuclear Regulatory Commission
DE OLIVIERA, Cassiano R.E., Nuclear and Radiological Engineering Prog, Georgia Institute of Technology
GOUGAR, Hans D., Manager, Fission & Fusion Systems, Idaho National Laboratory
IVANOV, Kostadin, Head of RDFMG, The Pennsylvania State University
TAIWO, Temitope A., Section Manager, Nuclear Systems Modeling, Argonne National Laboratory

INTERNATIONAL ORGANIZATIONS:

METHNANI, Mabrouk, Unit Head – Gas cooled Reactors, International Atomic Energy Agency
CARON-CHARLES, Marylise, OECD/NEA
SARTORI, Enrico, OECD/NEA Databank