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BEMUSE Phase IV Report:
Simulation of a LB-LOCA in ZION Nuclear Power Plant

Main Report

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The enclosed CD-Rom contains full report (including appendices).
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BEMUSE PROGRAMME

Best–Estimate Methods
Uncertainty and Sensitivity Evaluation

BEMUSE Phase IV Report:
Simulation of a LB–LOCA in ZION Nuclear Power Plant.

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Abbreviations

0-D  Zero Dimension or point
1-D  One Dimension
2-D  Two Dimension
3-D  Three Dimension
AEKI  Hungarian Academy of Sciences KFKI Atomic Energy Research Institute
BAF  Bottom of Active Fuel
BE  Best Estimate
BEMUSE  Best Estimate Methods Uncertainty and Sensitivity Evaluation
CCFL  Counter Current Flow Limitation
CEA  Commissariat à l’Energie Atomique (France)
CL  Cold Leg
CSNI  Committee on the Safety of Nuclear Installations
DBA  Design Basis Accident
DNB  Departure from Nucleate Boiling
ECC  Emergency Core Coolant
ECCS  Emergency Core Coolant System
GAMA  Group on Accident Management and Analysis
GRS  Gesselschaft für Anlagen und Reaktorsicherheit mbH (Germany)
HL  Hot Leg
HPIS  High Pressure Injection System
IET  Integral Effect Test
IRSN  Institut de Radioprotection et de Sûreté Nucléaire (France)
ISP  International Standard Problem
JNES  Japan Nuclear Energy Safety (Japan)
KAERI  Korea Atomic Energy Research Institute (South Korea)
KINS  Korean Institute of Nuclear Safety (South Korea)
LB-LOCA  Large Break Loss Of Coolant Accident
LOCA  Loss Of Coolant Accident
LOFT  Loss Of Fluid Test
LOFW  Loss Of Feed Water
LP  Lower Plenum
LPIS  Low Pressure Injection System
LSTF  Large-Scale Laboratory Facility
LWR  Light Water Reactor
MATPRO  Materials Properties correlations and computer subcodes
NPP  Nuclear Power Plant
NRC  U.S. Nuclear Regulatory Commission
NRI  Nuclear Research Institute (Czech Republic)
PCT  Peak Cladding Temperature
PSI  Paul Scherrer Institute (Switzerland)
PWR Pressurized Water Reactor
RTA Relevant Thermalhydraulic Aspects
SB-LOCA Small Break Loss Of Coolant Accident
SET Separate Effect Test
SG Steam Generator
TAF Top of Active Fuel
$T_{sat}$ Saturation Temperature
$t_{que}$ Time of complete quenching
UNIPI University of Pisa (Italy)
UP Upper Plenum
UPC Universitat Politècnica de Catalunya (Spain)
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EXECUTIVE SUMMARY

Background

Since nuclear energy was first used to produce electricity in the 1950s, the evaluation of nuclear power plant performance during transient conditions has been the main issue in thermal-hydraulic safety research worldwide (see State of the Art Report by CSNI and Compendium of ECCS Researches by US NRC, both issued in 1989).

Different computer codes such as ATHLET, CATHARE, RELAP, TRAC and TRACE have been developed since then for this purpose and are widely used. Such sophisticated codes can predict time trends of any quantity of interest during any transient of a LWR. Anyway, in order to assess the capabilities of the codes and due to the lack of suitable measurements in plants, comparison of calculated results with experimental data recorded in small scale facilities is needed. The amount of available experimental data is huge: some have been obtained in very simple loops (like Basic Test Facilities or Separate Effect Test Facilities), others in very complex Integral Test Facilities. The applicability of a code to predict a specific plant situation relies, at least, on two conditions: the experimental data selected for qualifying a code have to reproduce the phenomena expected in the plant and codes have to be able to qualitatively and quantitatively reproduce those data. For best-estimate codes like the above mentioned ones, the calculation of the plant transient has to include an additional analysis evaluating the uncertainties of the obtained results. This analysis can be completed with a sensitivity analysis, which provides additional information.

The BEMUSE (Best Estimate Methods - Uncertainty and Sensitivity Evaluation) programme - promoted by the working Group on Accident Management and Analysis (GAMA) and endorsed by the committee on the safety of nuclear installations (CSNI)- represents in this context an important step towards reliable application of high-quality best-estimate and uncertainty and sensitivity evaluation methods. The application of these methods to a Large-Break Loss of Coolant Accident (LB-LOCA) constitutes the main activity of the programme, structured into two main stages:

- **Step 1**: Best-estimate and uncertainty and sensitivity evaluations of the LOFT L2-5 test (Phases II and III). LOFT is the only Integral Test Facility with a nuclear core where safety experiments have been performed.

- **Step 2**: Best-estimate and uncertainty and sensitivity evaluations of a nuclear power plant (Phases IV and V).

The "a priori" presentation of the uncertainty methodologies to be used by the participants (Phase I) is usually included in the first stage, whereas the final phase (Phase VI) consisting on the synthesis of the results obtained in previous phases with conclusions and recommendations is usually included in the second stage.

Objective of the work

The BEMUSE programme is focused on applications of the uncertainty methodologies to LB-LOCA scenarios. The main goals of the programme are:
• To evaluate the practicability, quality and reliability of best-estimate methods including uncertainty evaluations in applications relevant to nuclear reactor safety;

• To develop common understanding;

• To promote/facilitate their use by the regulatory bodies and the industry

The scope of Phase IV of the BEMUSE programme is the simulation of a LB–LOCA in a Nuclear Power Plant using experience gained in the previous Phase II. Calculation results will be the basis for uncertainty evaluation, to be performed in next phase.

The objectives of the activity are:

• To simulate a LB–LOCA reproducing the phenomena associated to the scenario.

• To have a common, well-documented basis for the execution of the uncertainty evaluation step in Phase V.

Task specification

The activity followed the example of Phase II.

The selection of the plant has been a quite important issue. Some other options were considered. The group finally made the decision of using Zion plant and CSNI approved the choice. Zion Station was a 4 loop dual-reactor nuclear power plant of Westinghouse design. An input deck of the plant existed for TRACE and RELAP5 codes.

NRC provided the input decks of Zion plant for TRACE and RELAP5 codes and the coordinators prepared a specification that enabled the users of different computer codes to produce their own Zion input decks. For this purpose, along with plant parameters, the main features of the LBLOCA scenario were specified in order to assure common initial and boundary conditions.

Similarly to the activity performed in Phase II, a list of sensitivity calculations was proposed to study the influence of different parameters such as material properties, initial and boundary conditions upon the behaviour of key parameters of the scenario.

Main Results

Results can be summarized as follows:

• All participants managed to simulate the scenario and predict the main parameters with credible consistency.

• Maximum values of PCT predicted by participants are quite close one each other.

• PCT time trends and timing of complete core rewet still show some disagreements.

• A database, including comparative tables and plots has been produced. This database is suitable for providing the explanations needed for the following phases.

More in detail and related to steady state achievement, participants managed to reproduce the pressure vs. length reference curve and to match the more significant parameters for the scenario simulation. Discrepancies in steady state appeared only in some other parameters like those related to the secondary system which are not that much influential.
Related to the reference case, the core thermal behaviour is the most interesting aspect to report. Cladding temperature time trends produced show a consistent behaviour. The spread of results for the PCT is about the same order of magnitude than that of Phase II (roughly 260-280 K). The major differences between results come with the reflooding behaviour and mainly its duration. In this case the report correlates this point with some code effect.

Conclusions

Phase IV results are a step forward that contributes to the general goals of BEMUSE project.

At the time when this Phase IV Report is written, all participants are developing a Phase V analysis based on the reference calculations produced in Phase IV. The coordinators want to emphasize this point as a proof of how participants accept the usefulness of Phase IV.

It is clear that dispersion bands exist but it is also clear that the effort of explaining the reasons of such dispersion is a valuable outcome from this phase. The outcome of BEMUSE Phase IV is also helpful to understand the nuances existing inside the user effect and also to clarify the differences between user effect and code effect.

Assumptions made by the user due to the lack of information are not part of the traditional user effect and this report is useful to deal with them.

Participants, in average, have found or corroborated the most influential parameters regarding the their influence on PCT and $t_{REFLOOD}$. The sensitivity study performed in Phase IV has also pointed out that the user and code effects can appear not only in obtaining a reference case value, but also when analyzing variations on the reference case.

Sensitivity calculation results are a good guidance for developing Phase V uncertainty evaluation. BEMUSE Phase IV is a reference good enough to start with Phase V development.
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CHAPTER 1

INTRODUCTION

1.1 Framework

The BEMUSE (Best Estimate Methods — Uncertainty and Sensitivity Evaluation) programme promoted by the Working Group on Accident Management and Analysis (GAMA) and endorsed by the committee on the safety of Nuclear Installations (CSNI) represents an important step towards reliable application of best-estimate codes.

The final objectives of the work performed on this programme are:

- To evaluate the practicability, quality and reliability of best-estimate methods including uncertainty evaluation in applications relevant to nuclear reactor safety;
- To develop common understanding;
- To promote/facilitate their use by the regulatory bodies and the industry.

The present document deals with the activities performed by the participants during the Phase IV of BEMUSE. The experience gained in previous Phase II of BEMUSE is used to simulate a LB-LOCA in a NPP using best estimate codes.

The objective of Phase IV of BEMUSE is to produce a reference calculation of a LB-LOCA in the selected NPP ensuring a suitable starting point for Phase V which is devoted to uncertainty evaluation.

The selection of the plant is a quite important issue. When the project started in 2003, TMI-1 was the suggested plant. The main reason for such suggestion was that the plant was known by different participants as its input deck had been used in one previous common exercise. Once BEMUSE project was on-going, participants disagreed on maintaining the original selection and some other options were considered. None of the considered options was actually made available by the different plant owners. At this point the group made the decision of using Zion plant and CSNI approved the choice. Zion Station was a 4 loop dual-reactor nuclear power plant of Westinghouse design. An input deck of the plant existed for TRACE and RELAP5 codes. The main weak point was that, as it is in permanently shutdown condition from 1998, no detailed information could be made available if needed during the development of the project.

NRC provided the input decks of Zion plant for TRACE and RELAP5 codes and the coordinators prepared a specification (see Appendix A) with the main purpose of conducting the exercise but also to make explicit the information needed to allow the users of other codes to produce their own Zion input decks. The input/output specification gives all the necessary detail on this point.

1.2 Content of the document

The framework of the BEMUSE activity and the objectives to be reached during Phase IV are stated in Chapter 1 along with the information on participants organizations.
Chapter 2 deals with the planning and conduct of BEMUSE Phase IV, explaining how the specification has been set up. Taking into account what has been said previously, the information presented in the specification has been mainly derived from the two input decks supplied by NRC. In the areas where this information was not complete enough, some assumptions were made and added to the specification. Assumptions related to fuel were made in accordance with Phase II available information.

Chapter 3 gives a brief description of the input decks used by participants in the present phase.

Chapter 4 compares steady-state calculation results with proposed values for Phase IV exercise.

Chapter 5 compares transient results among participants for the reference case along with some comments evaluating them. The structure of the section includes a comparative table of the resulting sequence of main events, some plots about selected time trends, a table summarizing Relevant Thermal-hydraulic Aspects (RTA) related to the transient and finally some remarks on the comparison.

Chapter 6 summarizes the results obtained after performing a number of sensitivity cases.

Conclusions are established in Chapter 7 and, finally, References follow. The Appendixes provide detailed information on the specification itself, as well as all the calculations performed.

1.3 Participating Organizations

Thirteen participants coming from the following thirteen organizations have been participating in the Phase IV of the Programme.

1. AEKI, Hungary
2. CEA, France
3. EDOGIDROPRESS, Russia
4. GRS, Germany
5. IRSN, France
6. JNES, Japan
7. KAERI, South Korea
8. KINS, South Korea
9. NRI–1, Czech Republic
10. PSI, Switzerland
11. UNIPI–1, Italy
12. UNIPI–2, Italy
13. UPC, Spain

Six different thermal-hydraulic system codes have been used, sometimes with different versions (as shown in the corresponding tables):

- ATHLET (2 participants)
- CATHARE (3 participants)
- MARS (1 participant)
• RELAP5 (4 participants)
• TECH-M (1 participant)
• TRACE (2 participants)

A brief description of each code is given in Appendix C by each participant. The organizations participating and the last version of the files submitted are listed in Tables 1.1 and 1.2.
<table>
<thead>
<tr>
<th>N</th>
<th>Name</th>
<th>E-mail</th>
<th>Organization’s name</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A. de Crecy</td>
<td><a href="mailto:agnes.decrecy@cea.fr">agnes.decrecy@cea.fr</a></td>
<td>CEA</td>
<td>CATHARE V2.5,1 mod.3.1</td>
</tr>
<tr>
<td></td>
<td>P. Bazin</td>
<td><a href="mailto:pascal.bazin@cea.fr">pascal.bazin@cea.fr</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>P. Germain</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>S. Borisov</td>
<td><a href="mailto:fil@grpress.podolsk.ru">fil@grpress.podolsk.ru</a></td>
<td>FSUE EDO</td>
<td>GIDROPRESS</td>
</tr>
<tr>
<td>3</td>
<td>H. Glaser</td>
<td><a href="mailto:gls@grs.de">gls@grs.de</a></td>
<td>GRS</td>
<td>ATHLET 2.1A</td>
</tr>
<tr>
<td></td>
<td>T. Skorek</td>
<td><a href="mailto:skt@grs.de">skt@grs.de</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>J. Joucla</td>
<td><a href="mailto:jerome.joucla@irsn.fr">jerome.joucla@irsn.fr</a></td>
<td>IRSN</td>
<td>CATHARE2 V2.5,1 mod5.1</td>
</tr>
<tr>
<td></td>
<td>P. Probst</td>
<td><a href="mailto:pierre.probst@irsn.fr">pierre.probst@irsn.fr</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>A. Ui</td>
<td><a href="mailto:ui-atsushi@jnes.go.jp">ui-atsushi@jnes.go.jp</a></td>
<td>JNES</td>
<td>TRACE ver.4.05</td>
</tr>
<tr>
<td>6</td>
<td>B.D. Chung</td>
<td><a href="mailto:bdchung@keri.re.kr">bdchung@keri.re.kr</a></td>
<td>KAERI</td>
<td>MARS 3.1</td>
</tr>
<tr>
<td>7</td>
<td>D. Y. Oh</td>
<td><a href="mailto:k392ody@kins.re.kr">k392ody@kins.re.kr</a></td>
<td>KINS</td>
<td>RELAP5/MOD3.3</td>
</tr>
<tr>
<td>8</td>
<td>R. Pernica</td>
<td><a href="mailto:per@ujv.cz">per@ujv.cz</a></td>
<td>NRI–1</td>
<td>RELAP5/MOD3.3</td>
</tr>
<tr>
<td></td>
<td>M. Kyncl</td>
<td><a href="mailto:milos.kyncl@ujv.cz">milos.kyncl@ujv.cz</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>A. Manera</td>
<td><a href="mailto:annalisa.manera@psi.ch">annalisa.manera@psi.ch</a></td>
<td>PSI</td>
<td>TRACE5.0rc3</td>
</tr>
<tr>
<td>10</td>
<td>A. Petruzzi</td>
<td><a href="mailto:a.petruzzi@ing.unipi.it">a.petruzzi@ing.unipi.it</a></td>
<td>UNIPI–1</td>
<td>RELAP/MOD3.2</td>
</tr>
<tr>
<td></td>
<td>F. D’Auria</td>
<td><a href="mailto:f.dauria@ing.unipi.it">f.dauria@ing.unipi.it</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>A. Del Nevo</td>
<td><a href="mailto:a.delnevo@ing.unipi.it">a.delnevo@ing.unipi.it</a></td>
<td>UNIPI–2</td>
<td>CATHARE2 V2.5,1 mod6.1</td>
</tr>
<tr>
<td></td>
<td>F. D’Auria</td>
<td><a href="mailto:f.dauria@ing.unipi.it">f.dauria@ing.unipi.it</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>M. Perez</td>
<td><a href="mailto:marina.perez@upc.edu">marina.perez@upc.edu</a></td>
<td>UPC</td>
<td>RELAP5/MOD3.3</td>
</tr>
<tr>
<td></td>
<td>F. Reventos</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L. Batet</td>
<td><a href="mailto:luis.batet@upc.edu">luis.batet@upc.edu</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>I. Tóth</td>
<td><a href="mailto:tothi@sunserv.kfki.hu">tothi@sunserv.kfki.hu</a></td>
<td>AEKI</td>
<td>ATHLET 2.0A</td>
</tr>
<tr>
<td></td>
<td>I. Trosztel</td>
<td><a href="mailto:trosztel@aeki.kfki.hu">trosztel@aeki.kfki.hu</a></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1.1: List of participants
<table>
<thead>
<tr>
<th>No.</th>
<th>Participant</th>
<th>Organization</th>
<th>EXCEL TEMPLATES</th>
<th>Last Submission</th>
</tr>
</thead>
</table>
| 1   | I. Tóth     | AEKI         | TEMPLATE No.1_STST_AEKI.xls  
|     | I. Trosztel |              | TEMPLATE No.1_TRANSIENT_AEKI.xls  
|     |             |              | SENSITIVITIES_AEKI.xls  | 01/2008  
|     |             |              |                 | 01/2008 |
| 2   | A. de Crecy | CEA          | TEMPLATE No.1_STST_CEA.xls  
|     | P. Bazin    |              | TEMPLATE No.1_TRANSIENT_CEA.xls  
|     |             |              | SENSITIVITIES_CEA.xls  | 01/2008  
|     |             |              |                 | 09/2007 |
| 3   | S. Borisov  | FSUE EDO     | TEMPLATE No.1_STST_EDO.xls  
|     |             | GIDROPRESS   | TEMPLATE No.1_TRANSIENT_EDO.xls  
|     |             |              | SENSITIVITIES_EDO.xls  | 01/2008  
|     |             |              |                 | 12/2007 |
| 4   | H. Glaeser  | GRS          | TEMPLATE No.1_STST_GRS.xls  
|     | T. Skorek   |              | TEMPLATE No.1_TRANSIENT_GRS.xls  
|     |             |              | SENSITIVITIES_GRS.xls  | 11/2007  
|     |             |              |                 | 12/2007 |
| 5   | J. Joucla   | IRSN         | TEMPLATE No.1_STST_IRSN.xls  
|     | P. Prost    |              | TEMPLATE No.1_TRANSIENT_IRSN.xls  
|     |             |              | SENSITIVITIES_IRSN.xls  | 11/2007  
|     |             |              |                 | 11/2007 |
| 6   | A. Ui       | JNES         | TEMPLATE No.1_STST_JNES.xls  
|     |             |              | TEMPLATE No.1_TRANSIENT_JNES.xls  
|     |             |              | SENSITIVITIES_JNES.xls  | 12/2007  
|     |             |              |                 | 12/2007 |
| 7   | B.D. Chung  | KAERI        | TEMPLATE No.1_STST_KAERI.xls  
|     |             |              | TEMPLATE No.1_TRANSIENT_KAERI.xls  
|     |             |              | SENSITIVITIES_KAERI.xls  | 12/2007  
|     |             |              |                 | 12/2007 |
| 8   | D. Y. Oh    | KINS         | TEMPLATE No.1_STSTRev3_KINS071008.xls  
|     |             |              | TEMPLATE No.1_TRANSIENTRev3_KINS071008.xls  
|     |             |              | SENSITIVITIESRev03_KINS071207.xls  | 10/2007  
|     |             |              |                 | 10/2007 |
| 9   | R. Pernica  | NRI-1        | TEMPLATE No.1_STST_NRI1.xls  
|     | M. Kyncl    |              | TEMPLATE No.1_TRANSIENT_NRI1.xls  
|     |             |              | SENSITIVITIES_NRI1.xls  | 12/2007  
|     |             |              |                 | 12/2007 |
| 10  | A. Manera   | PSI          | TEMPLATE No.1_STST_PSI.xls  
|     |             |              | TEMPLATE No.1_TRANSIENT_PSI.xls  
|     |             |              | SENSITIVITIES_PSI.xls  | 10/2007  
|     |             |              |                 | 10/2007 |
| 11  | A. Petruzzi | UNIPI-1      | TEMPLATE No.1_STST_UNIPI1.xls  
|     | F. d’Auria  |              | TEMPLATE No.1_TRANSIENT_UNIPI1.xls  
|     |             |              | SENSITIVITIES_UNIPI1.xls  | 11/2007  
|     |             |              |                 | 11/2007 |
| 12  | A. Del Nevo | UNIPI-2      | TEMPLATE No.1_STST_UNIPI2.xls  
|     | F. d’Auria  |              | TEMPLATE No.1_TRANSIENT_UNIPI2.xls  
|     |             |              | SENSITIVITIES_UNIPI2.xls  | 11/2007  
|     |             |              |                 | 12/2007 |
| 13  | F. Reventos | UPC          | TEMPLATE No.1_STST_UPC.xls  
|     | M. Perez    |              | TEMPLATE No.1_TRANSIENT_UPC.xls  
|     | LL. Batet   |              | SENSITIVITIES_UPC.xls  | 12/2007  
|     |             |              |                 | 12/2007 |

Table 1.2: List of files submitted by participants to BEMUSE phase IV
CHAPTER 2

PLANNING AND CONDUCT OF THE BEMUSE PHASE IV

2.1 Specification for the BEMUSE Phase IV

UPC, acting as coordinator of this Phase IV, proposed and prepared the input/reference database to be used by all participants. The full text of the specification is included as Appendix A.

In order to ensure the connection with Phase II and to take advantage of the lessons learned while analyzing LOFT experiment L2-5, this piece of work has been performed in collaboration with UNIFI which was the organization coordinating Phase II.

It contains the following information:

- Relap5 input deck
- Trace input deck
- Excel file with geometrical data
- Material properties
- Pump information
- Table with steady state values
- Tables for boundary and initial conditions (BIC)
- Imposed sequence of main events

2.2 ZION Nuclear power plant

Zion Station was a dual-reactor nuclear power plant operated and owned by the Commonwealth Edison network. This power generating station is located in the extreme eastern portion of the city of Zion, Lake County, Illinois. It is approximately 40 direct-line miles north of Chicago, Illinois and 42 miles south of Milwaukee, Wisconsin.

The two-unit Zion Nuclear Power Station (see figure 1, was retired in February, 1998. The 25-year old plant had not been in operation since February, 1997. In 1998 Commonwealth Edison, owner of the plant, concluded that Zion could not produce competitively priced power. At this time plans were started to keep the facility in long-term safe storage and to begin dismantlement after 2010. All nuclear fuel has been removed permanently from the reactor vessel, and the fuel has been placed in the plant’s onsite spent fuel pool.

Zion 1 main features:

- Zion, Illinois, United States
• 4 loops
• Pressurized water reactor
• Westinghouse design
• Net Output: 1040 MWe
• Thermal power 3250 MWth
• Permanently shut down.
• Date started: June 1973
• Date closed: January 1998

2.3 LB–LOCA scenario description

The scenario is a cold leg Large Break LOCA in double guillotine without HPIS. The following statements specify the scenario description:

• LPIS injection: 1.42 MPa pressure set point. Driven by a flow-pressure table (see Table A.46)
• Accumulators injection: 4.14 MPa pressure set point.
• Containment pressure imposed as a function of time after the break (see Table A.47)
• Reactor coolant pumps velocity imposed as a function of time after the break (see tables A.49, A.50)
<table>
<thead>
<tr>
<th>Event</th>
<th>Time(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Break</td>
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<tr>
<td>SCRAM</td>
<td>0.0</td>
</tr>
<tr>
<td>Reactor coolant pumps trip</td>
<td>0.0</td>
</tr>
<tr>
<td>Steam line isolation</td>
<td>10.0</td>
</tr>
<tr>
<td>Feed water isolation</td>
<td>20.0</td>
</tr>
<tr>
<td>HPIS</td>
<td>NO</td>
</tr>
</tbody>
</table>

Table 2.1: Time sequence of imposed events

- Decay power imposed by means of a reactor power multiplier as a function of time after the break (see Table A.48)

Besides this, the following tables and figures are supplied:

- Table A.46, LPIS pressure-flow curve.
- Figure A.14, LPIS.
- Table A.47, Containment pressure.
- Figure A.15, Containment pressure.
- Table A.48, Decay heat power.
- Figure A.16, Decay heat power factor.
- Table A.49, Pump velocity for primary coolant pumps in intact loops.
- Figure A.17, RCPs velocity.
- Table A.50, Pump velocity for primary coolant pumps in broken loop.

For more information see appendix A.
CHAPTER 3

COMPARISON AMONG PARTICIPANTS INPUT DECKS

The information and data summarized in this section are discussed in more detail by each participant in Appendix C

3.1 Adopted codes and nodalization resources

Table 3.1 shows the information supplied by each participant on:

- Number of hydraulic nodes;
- Number of mesh points for the heat structures;
- Number of core channels (not including the bypass channel);
- Number of axial core nodes per channel.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Code's name</th>
<th>Hydraulic nodes</th>
<th>Mesh points (heat structures)</th>
<th>Core channels (without bypass)</th>
<th>Axial active core nodes per channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEREN</td>
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Table 3.1: Nodalization resources used by each participant.

(*) The fuel path is simulated by 10 axial nodes.
3.2 Maximum linear heat generation rates

Five active heat structures were be nodalized simulating the fuel elements. Detailed description of these five zones is given in Appendix A.

Figure 3.1 shows a sketch of core heat structures zones, listed below:

- Zone 1: average fuel rods in peripheral channels;
- Zone 2: average fuel rods in average channels;
- Zone 3: average fuel rods in hot channels;
- Zone 4: average fuel rods in hot fuel assembly;
- Zone 5: hot rod in hot fuel assembly.

Axial subdivision for output request:

- Bottom core region — From BAF to 1.22m;
- 2/3 core region — From 1.22m to 2.44m;
- Top core region — From 2.44m to TAF.

Tables 3.2 and 3.3 contain the maximum linear power (kW/m) and the corresponding axial position (m) and, where applicable, azimuthal position for zone 5 and zone 2, for the three axial subdivisions listed below.
Figure 3.1: Core heat structures
### Average rod in average channel (Zone 2)

<table>
<thead>
<tr>
<th>Name</th>
<th>Maximum linear power (kW/m)</th>
<th>Elevation from BAF (m)</th>
<th>Azimuthal position</th>
<th>Maximum linear power (kW/m)</th>
<th>Elevation from BAF (m)</th>
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<td>-</td>
<td>25.46</td>
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<td>-</td>
</tr>
<tr>
<td>CEA</td>
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<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>EDO</td>
<td>24.2</td>
<td>1.745</td>
<td>NS</td>
<td>27.6</td>
<td>1.647</td>
<td>NS</td>
<td>24.7</td>
<td>0.915</td>
<td>NS</td>
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<tr>
<td>GRS</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>IRSN</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>JNES</td>
<td>25.87</td>
<td>2.484 (29/42)</td>
<td>180° against BL</td>
<td>27.53</td>
<td>1.699 (20/42)</td>
<td>180° against BL</td>
<td>26.49</td>
<td>1.176 (14/42)</td>
<td>180° against BL</td>
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<td>19.54</td>
<td>3.253</td>
<td>?</td>
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<td>2.033</td>
<td>?</td>
<td>22.45</td>
<td>0.813</td>
<td>?</td>
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<tr>
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<td>22.24</td>
<td>26.95</td>
<td>?</td>
<td>26.89</td>
<td>2.033</td>
<td>?</td>
<td>19.74</td>
<td>?</td>
<td>-</td>
</tr>
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<td>3.253</td>
<td>?</td>
<td>26.89</td>
<td>2.033</td>
<td>?</td>
<td>22.45</td>
<td>0.813</td>
<td>?</td>
</tr>
<tr>
<td>PSI</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>UNIPI–1</td>
<td>24.19</td>
<td>1.11</td>
<td>NS</td>
<td>26.94</td>
<td>1.73</td>
<td>NS</td>
<td>25.04</td>
<td>2.54</td>
<td>NS</td>
</tr>
<tr>
<td>UNIPI–2</td>
<td>15.95</td>
<td>3.36</td>
<td>?</td>
<td>26.71</td>
<td>2.44</td>
<td>?</td>
<td>16.7</td>
<td>0.3</td>
<td>?</td>
</tr>
<tr>
<td>UPC</td>
<td>22.23</td>
<td>2.95</td>
<td>-</td>
<td>26.94</td>
<td>1.73</td>
<td>-</td>
<td>22.45</td>
<td>0.71</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 3.2: Hot rod temperatures — Zone 2

### Hot rod in hot FA (Zone 5)

<table>
<thead>
<tr>
<th>Name</th>
<th>Maximum linear power (kW/m)</th>
<th>Elevation from BAF (m)</th>
<th>Azimuthal position</th>
<th>Maximum linear power (kW/m)</th>
<th>Elevation from BAF (m)</th>
<th>Azimuthal position</th>
<th>Maximum linear power (kW/m)</th>
<th>Elevation from BAF (m)</th>
<th>Azimuthal position</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEKI</td>
<td>37.52</td>
<td>2.54</td>
<td>-</td>
<td>40.49</td>
<td>1.83</td>
<td>-</td>
<td>38.18</td>
<td>1.12</td>
<td>-</td>
</tr>
<tr>
<td>CEA</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
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<td>NS</td>
</tr>
<tr>
<td>EDO</td>
<td>36.5</td>
<td>1.745</td>
<td>NS</td>
<td>41.6</td>
<td>1.647</td>
<td>NS</td>
<td>37.2</td>
<td>0.915</td>
<td>NS</td>
</tr>
<tr>
<td>GRS</td>
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<td>40.38</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>JNES</td>
<td>39.73</td>
<td>2.484 (29/42)</td>
<td>90° against BL</td>
<td>41.29</td>
<td>1.699 (20/42)</td>
<td>90° against BL</td>
<td>38.81</td>
<td>1.176 (14/42)</td>
<td>90° against BL</td>
</tr>
<tr>
<td>KAERI</td>
<td>29.31</td>
<td>3.253</td>
<td>?</td>
<td>40.34</td>
<td>2.033</td>
<td>?</td>
<td>33.67</td>
<td>0.610</td>
<td>?</td>
</tr>
<tr>
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<td>33.72</td>
<td>40.00</td>
<td>?</td>
<td>40.34</td>
<td>2.033</td>
<td>?</td>
<td>30.32</td>
<td>?</td>
<td>-</td>
</tr>
<tr>
<td>NRI-1</td>
<td>29.31</td>
<td>3.253</td>
<td>?</td>
<td>40.34</td>
<td>2.033</td>
<td>?</td>
<td>33.67</td>
<td>0.610</td>
<td>?</td>
</tr>
<tr>
<td>PSI</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>UNIPI–1</td>
<td>36.28</td>
<td>1.11</td>
<td>NS</td>
<td>40.42</td>
<td>1.73</td>
<td>NS</td>
<td>37.56</td>
<td>2.54</td>
<td>NS</td>
</tr>
<tr>
<td>UNIPI–2</td>
<td>23.92</td>
<td>3.36</td>
<td>?</td>
<td>40.06</td>
<td>2.44</td>
<td>?</td>
<td>25.04</td>
<td>0.3</td>
<td>?</td>
</tr>
<tr>
<td>UPC</td>
<td>33.35</td>
<td>2.95</td>
<td>-</td>
<td>40.42</td>
<td>1.73</td>
<td>-</td>
<td>33.67</td>
<td>0.71</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 3.3: Hot rod temperatures — Zone 5
3.3 List of imposed sequence events and set-points

In table 3.4 the imposed events for the LB–LOCA simulation are listed.

<table>
<thead>
<tr>
<th>Event</th>
<th>Time(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Break</td>
<td>0.0</td>
</tr>
<tr>
<td>SCRAM</td>
<td>0.0</td>
</tr>
<tr>
<td>Reactor coolant pumps trip</td>
<td>0.0</td>
</tr>
<tr>
<td>Steam line isolation</td>
<td>10.0</td>
</tr>
<tr>
<td>Feed water isolation</td>
<td>20.0</td>
</tr>
<tr>
<td>HPIS</td>
<td>NO</td>
</tr>
</tbody>
</table>

Table 3.4: Time sequence of imposed events
CHAPTER 4

COMPARISON AND EVALUATION OF STEADY–STATE RESULTS

This chapter shows different pieces of information. In section 4.1, tables and figures related to normalized pressure drop curves are presented, while section 4.2 is devoted to nodalization development data as well as Steady-State results. Section 4.3 is a brief discussion on results achievement.

4.1 Normalized pressure drops curves along the loop

Table 4.1 contains the values of the absolute pressure versus loop length. Pressure is normalized to the hot leg inlet.

Normalized pressure versus loop length curves are depicted in Figure 4.1, where SPECS curve has been built by coordinators as participants agreed on the Paris meeting (June 2007).

![Figure 4.1: Normalized pressure curve along the loop](image-url)
|   | Position along the loop | SPECS 15,53 | AEKI 15,49 | CEA 15,63 | EDO 15,50 | GRS 15,51 | IRSN 15,55 | JNES 15,53 | KAERI 15,577 | KINS 15,54 | NRL-1 15,54 | PSI 15,61 | UNIPI-1 15,50 | UNIPI-2 15,54 | UPC 15,53 |
|---|------------------------|-----------|----------|--------|-------|--------|--------|--------|-----------|--------|--------|-------|--------|--------|--------|-------|
| 1 | Hot leg inlet          | HL IN     | 15,53   | 15,49  | 15,63 | 15,50 | 15,51 | 15,55 | 15,53     | 15,577 | 15,54  | 15,61 | 15,50  | 15,54  | 15,53 |
| 2 | Hot leg outlet         | HL OUT    | 15,51   | 15,48  | 15,62 | 15,49 | 15,50 | 15,53 | 15,52     | 15,513 | 15,52  | 15,58 | 15,48  | 15,52  | 15,51 |
| 3 | Steam generator        | SG IN     | 15,50   | 15,49  | 15,64 | 15,47 | 15,51 | 15,53 | 15,53     | 15,477 | 15,51  | 15,51 | 15,52  | 15,51  | 15,51 |
| 4 | U-tube top             | UT Top    | 15,33   | 15,37  | 15,43 | 15,29 | 15,32 | 15,34 | 15,35     | 15,365 | 15,34  | 15,31 | 15,30  | 15,33  | 15,33 |
| 5 | Steam generator        | SG OUT    | 15,33   | 15,37  | 15,41 | 15,25 | 15,30 | 15,33 | 15,35     | 15,345 | 15,35  | 15,30 | 15,40  | 15,30  | 15,33 |
| 7 | Bottom of loop seal    | LOOP SEAL | 15,28   | 15,34  | 15,38 | 15,27 | 15,26 | 15,30 | 15,29     | 15,304 | 15,29  | 15,25 | 15,37  | 15,24  | 15,29 |
| 10| Cold leg inlet         | CL IN     | 15,75   | 15,86  | 15,93 | 15,81 | 15,79 | 15,77 | 15,81     | 15,806 | 15,80  | 15,80 | 15,88  | 15,74  | 15,78 |
| 12| Lower plenum (0.2m from bottom of vessel) | LP | 15,81 | 15,74 | 15,85 | 15,71 | 15,75 | 15,84 | 15,82 | 15,726 | 15,83 | 15,83 | 15,81 | 15,79 | 15,81 | 15,83 |
| 13| Bottom of active core  | BAF       | 15,75   | 15,73  | 15,78 | 15,71 | 15,73 | 15,79 | 15,74 | 15,708 | 15,75 | 15,76 | 15,81 | 15,72 | 15,76 | 15,75 |

Table 4.1: Absolute pressure versus loop length
4.2 Nodalization development and steady-state results

Table 4.2 shows relevant data related to nodalization development and steady-state results. Surfaces, volumes and linear power used by participants are compared in the first part of the table and steady state values in the second part.

4.3 Analysis of results

The normalized pressure drops are quite acceptable. Most of the participants manage to reproduce the reference curve. Part of the differences are due to the small changes performed by participants after the reference curve was agreed. This small changes (like those related to re-splitting the downcomer from 2 to 4 pipes in the coordinators case) produced only small deviations in the comparative plot but came up with some improvements in the reference case.

The nodalization development comparison shows agreement in the most significant parameters for scenario simulation. Discrepancies appear in some other parameters like those related to the secondary system which are not that much influent in the predicted behaviour of the transient.

The steady state results are also quite acceptable. The agreement is good except again for mass inventory in the secondary side. The agreement on upper head temperature has been treated in one of the meetings. As it can be observed 3D calculations show a temperature closer to the hot temperature while in 1D simulations it is closer to the cold one. This was considered acceptable after performing some sensitivity calculations. Other discrepancies affect only 1 or 2 out of 13 participants.

The quality of the steady state calculation results is considered sufficient to develop the transient analysis.
<table>
<thead>
<tr>
<th>No.</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>m³</td>
<td>Primary circuit volume</td>
</tr>
<tr>
<td>2</td>
<td>m³</td>
<td>Secondary circuit volume</td>
</tr>
<tr>
<td>3</td>
<td>m²</td>
<td>Core heat transfer area</td>
</tr>
<tr>
<td>4</td>
<td>m²</td>
<td>SG-tube heat transfer area</td>
</tr>
<tr>
<td>5</td>
<td>m²</td>
<td>Core heat transfer area (w. tube sheet)</td>
</tr>
<tr>
<td>6</td>
<td>m³</td>
<td>SG-tube heat transfer area (w. tube sheet)</td>
</tr>
<tr>
<td>7</td>
<td>kW/m</td>
<td>Maximum of the axial power distribution for the hot rod</td>
</tr>
<tr>
<td>8</td>
<td>kW/m</td>
<td>Maximum of the axial power distribution for the hot fuel assembly</td>
</tr>
</tbody>
</table>

### Steady State

<table>
<thead>
<tr>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MW</td>
<td>Core power</td>
</tr>
<tr>
<td>MW</td>
<td>Reactor coolant pump</td>
</tr>
<tr>
<td>MPa</td>
<td>Primary system hot leg pressure</td>
</tr>
<tr>
<td>MPa</td>
<td>Presurizer pressure (hot loop)</td>
</tr>
<tr>
<td>MPa</td>
<td>Steam generator 1 exit pressure</td>
</tr>
<tr>
<td>MPa</td>
<td>Accumulator 1 pressure</td>
</tr>
<tr>
<td>K</td>
<td>Reactor coolant temperature</td>
</tr>
<tr>
<td>K</td>
<td>Reactor coolant outlet temperature</td>
</tr>
<tr>
<td>K</td>
<td>Heat exchanger surface temperature (near vessel)</td>
</tr>
<tr>
<td>K</td>
<td>Reactor temperature (lower vessel)</td>
</tr>
<tr>
<td>K</td>
<td>Rod surface temperature (near vessel)</td>
</tr>
<tr>
<td>rpm</td>
<td>Reactor coolant pump of loop 1 velocity</td>
</tr>
<tr>
<td>kPa</td>
<td>Reactor pressure vessel pressure loss</td>
</tr>
<tr>
<td>kPa</td>
<td>Core pressure loss</td>
</tr>
<tr>
<td>kPa</td>
<td>Primary system total loop pressure loss</td>
</tr>
<tr>
<td>kPa</td>
<td>Steam generator 1 pressure loss</td>
</tr>
<tr>
<td>kg</td>
<td>Primary system total mass inventory (pressurizer, without accumulators)</td>
</tr>
<tr>
<td>kg</td>
<td>Steam generator 1 total mass inventory</td>
</tr>
<tr>
<td>kg/s</td>
<td>Primary system total core coolant mass flow</td>
</tr>
<tr>
<td>kg/s</td>
<td>Steam generator 1 core coolant mass flow</td>
</tr>
<tr>
<td>kg/s</td>
<td>Core bypass mass flow (LP, UP)</td>
</tr>
<tr>
<td>m</td>
<td>Presurizer level (collapsed)</td>
</tr>
<tr>
<td>m</td>
<td>Secondary side-downcomer level</td>
</tr>
</tbody>
</table>

**Table 4.2: Steady state relevant values**
CHAPTER 5

COMPARISON AND EVALUATION OF REFERENCE RESULTS

This Chapter shows the information detailed hereafter: section 5.1 shows a table with the calculated sequence of events, section 5.2 shows the time trends, in section 5.3 the most Relevant Thermalhydraulic Aspects (RTA) are shown and, finally, section 5.4 shows some comments on the tables presented in this Chapter in order to enlight similarities and discrepancies found among the different groups.

5.1 Table of resulting sequence of main events

Table 5.1 is the list of the most relevant events along with their occurrence time calculated for the simulated LB-LOCA scenario by all participants.

5.2 Selected time trends

Table 5.2 is a list of the twenty five selected time trends. Although the most relevant information on transient behaviour can be derived from a more limited number of time trends, the purpose of the provided set of figures is to allow participants to understand their own deviations for their future activities.
<table>
<thead>
<tr>
<th>EVENTS</th>
<th>AEKI</th>
<th>CEA</th>
<th>EDO</th>
<th>GRS</th>
<th>IRSN</th>
<th>JNES</th>
<th>KAERI</th>
<th>KINS</th>
<th>NRI-1</th>
<th>PSI</th>
<th>UNIPI-1</th>
<th>UNIPI-2</th>
<th>UPC</th>
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<tbody>
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<td>Break initiation</td>
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<td>0</td>
<td>0</td>
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<td>0.00</td>
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<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>Reactor scrammed</td>
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<td>0</td>
<td>0</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>DNB in core</td>
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<td>0.48</td>
<td>0.184</td>
<td>0.15</td>
<td>0.25</td>
<td>0.800</td>
<td>-</td>
<td>0.4</td>
<td>0.19</td>
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<td>0.12</td>
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<td>0</td>
<td>0</td>
<td>0.01</td>
<td>0.00</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
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<td>10</td>
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<td>11.00</td>
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<td>3</td>
<td>5</td>
<td>3.70</td>
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<td>Reactor scrammed</td>
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<td>0</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>Pressurizer emptied</td>
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<td>9.85</td>
<td>18.6</td>
<td>11.2</td>
<td>10.00</td>
<td>19.103</td>
<td>13</td>
<td>17</td>
<td>12</td>
<td>40</td>
<td>11.9</td>
<td>9.84</td>
<td>10.21</td>
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<td>14.8</td>
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<td>15.00</td>
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<td>16.2</td>
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<td>12.4</td>
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<td>15.12</td>
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<td>18.1</td>
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<td>5.30</td>
</tr>
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<td>3.8</td>
<td>1263.51</td>
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<td>46.22</td>
</tr>
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<td>22.17</td>
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<td>63.00</td>
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<td>80.1</td>
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Table 5.1: Resulting time sequence of events
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</tr>
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<td>Fig. 5.2</td>
</tr>
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<td>3</td>
<td>Broken loop pressure in cold leg</td>
<td>Fig. 5.3</td>
</tr>
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<td>SG pressure — Secondary Side</td>
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<td>Lower plenum vapor temperature</td>
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<td>Intact loop hot leg liquid temperature</td>
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<td>Fig. 5.11</td>
</tr>
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<td>13</td>
<td>Integral break flow</td>
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<td>14</td>
<td>ECCS integral flow</td>
<td>Fig. 5.14</td>
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<td>Primary side total mass (with pressurizer)</td>
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<td>16</td>
<td>Steam generator 1 pressure drop</td>
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<td>17</td>
<td>Primary pumps pressure drop</td>
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<td>Zone 5 — Bottom level temperature</td>
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<td>Zone 5 — 2/3 Core height temperature</td>
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<td>Zone 5 — Top level temperature</td>
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<td>Zone 2 — Bottom level temperature</td>
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<tr>
<td>22</td>
<td>Zone 2 — 2/3 Core height temperature</td>
<td>Fig. 5.22</td>
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<td>23</td>
<td>Zone 2 — Top level temperature</td>
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<td>24</td>
<td>Maximum cladding temperature</td>
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<td>25</td>
<td>Hot rod fuel centerline temperature at 1.6 - 1.8 m</td>
<td>Fig. 5.25</td>
</tr>
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Table 5.2: List of time trends
**Intact loop hot leg pressure.**

![Graph](image)

**Figure 5.1:** Time trends of intact loop 1 pressure in hot leg

**Broken loop - reactor vessel side - pressure.**

![Graph](image)

**Figure 5.2:** Time trends of broken loop pressure in hot leg
Figure 5.3: Time trends of broken loop pressure in cold leg

Figure 5.4: Time trends of steam generator 1 secondary side pressure
Figure 5.5: Time trends of accumulator 1 pressure

Figure 5.6: Time trends of lower plenum liquid temperature
Lower plenum vapor temperature.

![Lower plenum vapor temperature graph]

Figure 5.7: Time trends of lower plenum vapor temperature

Upper head temperature.

![Upper head temperature graph]

Figure 5.8: Time trends upper head liquid temperature
Figure 5.9: Time trends of intact loop hot leg liquid temperature

Figure 5.10: Time trends of intact loop hot leg vapor temperature
Figure 5.11: Time trends of broken loop mass flow in cold leg

Figure 5.12: Time trends of broken loop mass flow in hot leg
Figure 5.13: Time trends of integral break mass flow

Figure 5.14: Time trends of ECCS integral mass flow
Figure 5.15: Time trends of primary system mass (including pressurizer)

![Primary side mass graph](image)

Figure 5.16: Time trends of pressure drop in steam generator 1 (absolute value)

![Steam generator 1 pressure drop graph](image)
Reactor coolant pump 1 pressure drop (absolute value).

Figure 5.17: Time trends of reactor coolant pump 1 pressure drop (absolute value)

Zone 5. Cladding surface temperature at 0.4 - 0.6 m.

Figure 5.18: Time trends of cladding temperature of hot rod in hot fuel assembly (zone 5) — bottom level
Zone 5. Cladding surface temperature at 1.6 - 1.8 m.

Figure 5.19: Time trends of cladding temperature of hot rod in hot fuel assembly (zone 5) — 2/3 level

Zone 5. Cladding surface temperature at 2.8 - 3 m.

Figure 5.20: Time trends of cladding temperature of hot rod in hot fuel assembly (zone 5) — top level
Figure 5.21: Time trends of cladding temperature of average rod in average channel (zone 2) — bottom level

Figure 5.22: Time trends of cladding temperature of average rod in average channel (zone 2) — 2/3 level
Figure 5.23: Time trends of cladding temperature of average rod in average channel (zone 2) — top level

Figure 5.24: Time trends of maximum cladding temperature
Hot rod fuel centerline temperature at 1.6 - 1.8 m.

Figure 5.25: Time trends of hot fuel centerline temperature at 1.6 - 1.8 m. — top level
5.3 Relevant thermal-hydraulic aspects (RTA)

As done also in BEMUSE Phase II, Table 5.3 shows a number of Relevant Thermal-hydraulic Aspects (RTA) selected for the scenario. The selected RTAs are the following:

- Break flow rate behaviour
- Pressurizer behaviour
- Dry-out occurrence
- Upper plenum pressure behaviour
- Accumulator behaviour
- LPIS behaviour
- Accumulator plus LPIS behaviour
- Primary mass (with pressurizer) behaviour

5.4 Analysis of the reference results

The goal of this section is to establish some comments on similarities and discrepancies found among the different results provided.

As said in section 1.1, the selection of the plant has been quite an important issue that has had some impact on Phase IV development. Nevertheless, Phase IV results are a useful outcome for the general goals of the phase. On the one hand, they allow the group to face Phase V and, on the other hand, they are an important database suitable to enlight subjects needed of detailed definition. When BEMUSE participants made the decision of using Zion plant and CSNI approved the choice, the group was aware of advantages and difficulties that may appear. After completing Phase IV, the group has some evidence of the previous suspicion. The advantages are there: quantitative comparisons, plots and tables have been produced and have provided useful information on the transient phenomena. The difficulties, mainly related to the lack of detailed data on Zion Station, are also there: quite an important effort has been needed to carry out the reference case calculation.

Most of the items listed in Table 5.1 are strongly dependent on primary pressure time trend. Despite of the dispersion shown in Figures 5.2 and 5.3, some events are predicted in a consistent way by participants among these:

- Subcooled blowdown ended
- Cladding temperature initially deviated from saturation (DNB in core)
- Pressurizer emptied
- Accumulator injection initiated
- LPIS injection initiated
Events related to the partial top-down rewet need some explanation. After analyzing Figures 5.18 to 5.24, despite of a non-negligible dispersion, the shape of the curves shows some consistency. All participants predict a first PCT, a temperature decrease (at the initiation of the partial rewet) and a further temperature increase (at the end of the partial rewet). These events are not so clearly shown in Table 5.1 when participants are asked to define a time quantity related to each event but there is a general agreement on the shape of the curves. Clearly the time trend analysis (instead of the simple comparison of the time of occurrence of the events) is the best way to show the discrepancies and similarities among results.

A similar comment can be made regarding accumulator behaviour. Despite injection initiation is consistently predicted by participants and properly shown in both Table 5.1 and Figure 5.5, the prediction of accumulators emptying shows some dispersion. As it is a phenomenon depending on intact leg pressure, pressure error and cumulative time error have a strong effect on the occurrence of the event and dispersion increases.

Finally, the core thermal behaviour, and mainly the full quench, is another event needed of some clarification. Figure 5.24 is maybe the best information for discussion that has some comments involving code effect. The spread of results for the first PCT and for the second is not so high (roughly 200 K for each peak). The lowest of PCT have been obtained by KAERI (1159.1 K) and highest of PCT by EDO "GIDROPRESS" (1326.15 K). Difference between lowest and highest of PCT for RELAP users is about 100 K, for CATHARE and ATHLET users is about 40 K, and for TRACE users is 20 K. Eight participants predicted the time of PCT between 40 s and 60 s except for NRI-1, CEA, GRS, JNES and IRSN. These participants predicted more early the time of PCT (about 10 s). Ten participants predicted the time of PCT between 40 s and 60 s except for NRI-1, CEA and IRSN. NRI-1, CEA and IRSN predicted more early the time of PCT (about 10 s). The major differences between results come with the reflooding behaviour and mainly its duration. Concerning this aspect, among the 13 participants, 8 of them show a medium reflood duration (total core quench obtained between 160 and 250 s), 3 other computations show a long reflood duration (total core quench between 320 to 420 s) and the other 2 show a kind of slow cladding temperature decrease in which it is difficult to establish the time of full quench.

The group of 8 is mainly composed by users of codes like Relap5 or codes having an origin related or at least "not far" from Relap5 development (TRACE and MARS). The group of 3 is completely composed by CATHARE users. Since by now there are only two ATHLET users, no special group is considered for ATHLET users. The results of these participants (GRS, AEKI) are plotted among those of the group of 8.

As all the codes have their own complete consistent qualification process in which reflood tests are considered, and after taking into account the comments of participants (see Appendix C: Codes and Input decks), it is the coordinators opinion that the point cannot be treated as a simple user effect but as a code effect.

Another statement reinforces this point. The overall behaviour of all the calculations is rather similar as long as the pressure (Figures 5.1 to 5.5 and 5.16 to 5.17) and the mass inventory (Figures 5.11 to 5.15) are considered and most of the dispersion appears when the final reflood is predicted.

According to Relevant Thermal-hydraulic Aspects (RTA) selected for the scenario, Table 5.3 corroborates what has been said before. The spread in items like pressurizer behaviour or RTA related to pressure and mass (break, accumulator and LPIS) is not so high, while in others like dry-out occurrence (and mainly its duration) it becomes more significant.

Temperature curves in figures 5.6, 5.7, 5.9 and 5.10, obtained with using TECH-M-97 code, are the same curves. TECH-M-97 is a thermodynamic equilibrium code. Fluid and vapor in each volume is in equilibrium state. The coolant temperature is determined by mass and enthalpy of water and steam in each node and corresponds to the coolant state at respective time moment (water,
steam-water mixture, steam).

Temperature curve in figure 5.8, obtained with using TECH-M-97 code, is not upper head liquid temperature. It is coolant temperature in the calculated cell 76 (see Appendix C) at respective time moment and is determined by mass and enthalpy of water and steam in it (See also comment to Figures 5.6, 5.7, 5.9 and 5.10).

Today difference between the highest and the lowest prediction of maximum PCT is about 170 K (EDO "GIDROPRESS" (1326.15 K) and KAERI (1159.1 K)).
<table>
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<tr>
<th>RTAs</th>
<th>UNIT</th>
<th>AEKI</th>
<th>CEA</th>
<th>EDO</th>
<th>GRS</th>
<th>IRSN</th>
<th>JNES</th>
<th>KAERI</th>
<th>KINS</th>
<th>NRI-1</th>
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<td><strong>Upper Plenum pressure behaviour</strong></td>
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Table 5.3: RTA — Comparison among participants
## Upper Plenum pressure behaviour

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<td>Pressure at core quenching time</td>
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## Accumulator 1 behaviour

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<th>IRSN</th>
<th>JNES</th>
<th>KAERI</th>
<th>KINS</th>
<th>NRI-1</th>
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<td>ACC1 Pressure 10 s after injection initiation</td>
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<td>3.32</td>
<td>3.01</td>
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<td>MPa</td>
<td>1.96</td>
<td>1.93</td>
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<td>MPa</td>
<td>1.12</td>
<td>1.19</td>
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<td>23590.00</td>
<td>23229.50</td>
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<td>23274.00</td>
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<td>ACC1 emptied</td>
<td>s</td>
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## LPIS1 - behaviour

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<td>33040.00</td>
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<td>15898.00</td>
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<td>42330.00</td>
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<td>21000.00</td>
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## ECCS behaviour

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## Primary System Mass (with pressurizer) behaviour

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<tr>
<td>Minimum mass / initial mass</td>
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<td>0.06</td>
<td>0.05</td>
<td>0.05</td>
<td>0.08</td>
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<tr>
<td>Primary mass/initial mass at core quenching time</td>
<td>kg</td>
<td>0.25</td>
<td>0.23</td>
<td>0.17</td>
<td>0.22</td>
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<td>0.26</td>
<td>0.26</td>
<td>0.24</td>
<td>0.24</td>
<td>0.26</td>
<td>0.30</td>
<td>0.31</td>
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<tr>
<td>Primary mass/initial mass at 500 s</td>
<td>kg</td>
<td>0.26</td>
<td>0.23</td>
<td>0.22</td>
<td>0.25</td>
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<td>0.28</td>
<td>0.28</td>
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<td>0.30</td>
<td>0.31</td>
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Table: 5.3 continued
CHAPTER 6

COMPARISON AND EVALUATION
OF SENSITIVITY RESULTS

Following the guidelines of previous Phase II, a number of sensitivity calculations were proposed and agreed by participants in Phase IV during a meeting held in Paris (June 2007). It was also agreed in the meeting that the variations of the analyzed parameters had to be defined as realistically as possible (see Appendix B).

The information supplied to the participants in this phase can be found in Appendixes A (reference case) and B (sensitivities). The contribution of each participant can be found in Appendix F.

6.1 Purpose and framework of the study

Ten parameters have been chosen for analysis, which are listed in Table 6.1, along with their respective ranges of variation. Those ranges, as it has been mentioned, have been defined in such a way that a realistic span of values is used in the calculations.

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<th>No</th>
<th>Parameter</th>
<th>Range</th>
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<tbody>
<tr>
<td>1</td>
<td>Fuel conductivity (for all fuel rods)</td>
<td>value_{BC} - 0.4 W/m-K</td>
</tr>
<tr>
<td></td>
<td></td>
<td>value_{BC} + 0.4 W/m-K</td>
</tr>
<tr>
<td>2</td>
<td>Gap conductivity (for all fuel rods)</td>
<td>value_{BC}×0.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>value_{BC}×1.2</td>
</tr>
<tr>
<td>3</td>
<td>Power after scram</td>
<td>value_{BC} - 8%</td>
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<td></td>
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<td>see Table B.2</td>
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<tr>
<td></td>
<td></td>
<td>value_{BC} + 8%</td>
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<td>see Table B.3</td>
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<tr>
<td>4</td>
<td>Power before scram</td>
<td>value_{BC} - 3.3%</td>
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<tr>
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<td>value_{BC} + 3.3%</td>
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<tr>
<td>5</td>
<td>Hot rod power (whole rod, same axial shape)</td>
<td>value_{BC} - 7.6%</td>
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<td></td>
<td></td>
<td>value_{BC} + 7.6%</td>
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<tr>
<td>6</td>
<td>LPIS delay (3/3)</td>
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<td>value_{BC} + 30 sec</td>
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<td>7</td>
<td>Accumulator liquid volume (3/3)</td>
<td>value_{BC} - 33 ft³</td>
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<td>value_{BC} + 33 ft³</td>
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<td>8</td>
<td>Accumulator pressure (3/3)</td>
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<td>value_{BC} + 100 psig</td>
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<td>Containment pressure</td>
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<td>10</td>
<td>Hot/cold conditions for pellet radius</td>
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<td>(for all fuel rods)</td>
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where BC stands for Base Case, and (3/3) means the 3 safety injection systems

| Table 6.1: Sensitivity parameters |
Table 6.2 lists participants’ contributions to sensitivity analysis.

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</table>

ur: upper range  lr: lower range  NP: not performed

Table 6.2: Sensitivity cases calculated by participants

The impact of the different parameters on PCT and on time of core quenching is analyzed and the results for the participants are compared.

For each sensitivity calculation, time trends for the following variables, obtained by the participants, are compared:

- the primary pressure;
- the primary system mass inventory;
- the cladding temperature of hot rod at 2/3 height.

6.2 Time trends obtained in the calculations

In what follows, the time trends for some selected variables are compared among the different participants. In order to have a reference point, Figures 6.1, 6.2 and 6.3 show the evolution of the Upper head pressure, the Primary circuit mass inventory, and the Hot rod surface temperature at 2/3 height (referred to in the plots simply as ”Rod surface temperature”).

Next, results obtained changing the chosen input parameters are compared:

- Sensitivity No 1 (Fuel conductivity). Figures 6.4 to 6.6 show the time trends for the selected output variables (primary pressure, primary mass inventory, and hot rod cladding temperature), respectively, when the fuel conductivity takes its higher and its lower values.
- Sensitivity No 2 (Gap conductivity). Figures 6.7 to 6.9 show the time trends for the three selected output variables, respectively, when the gap conductivity takes its higher and its lower values.
Sensitivity No 3 (Decay power). Figures 6.10 to 6.12 show the time trends for the three selected output variables, respectively, when the decay power takes its higher and its lower values.

Sensitivity No 4 (Initial power). Figures 6.13 to 6.15 show the time trends for the three selected output variables, respectively, when the steady state power takes its higher and its lower values.

Sensitivity No 5 (Maximum linear power). Figures 6.16 to 6.18 show the time trends for the three selected output variables, respectively, when the maximum linear power takes its higher and its lower values.
• Sensitivity No 6 (LPIS delay). Figures 6.19 to 6.21 show the time trends for the three selected output variables, respectively, when the LPIS start up is delayed compared to the base case.

• Sensitivity No 7 (Accumulator liquid volume). Figures 6.22 to 6.24 show the time trends for the three selected output variables, respectively, when the accumulator liquid volume is at its higher and lower levels.

• Sensitivity No 8 (Accumulator pressure). Figures 6.25 to 6.27 show the time trends for the three selected output variables, respectively, when the accumulator pressure takes its higher and its lower values.

• Sensitivity No 9 (Containment pressure). Figures 6.28 to 6.30 show the time trends for the three selected output variables, respectively, when the containment pressure is lower than the base case.

• Sensitivity No 10 (Pellet radius). Figures 6.31 to 6.33 show the time trends for the three selected output variables, respectively, when the initial fuel temperature takes its lower and its higher values (because pellet radius is maximum or minimum, respectively).

GRS sensitivity calculations were performed using a previous base case (that was improved later), so that they are not completely comparable to the other participants calculations and have been omitted here. GRS sensitivity calculations are fully shown in the corresponding section of Appendix F.

Figure 6.3: Base case, Rod surface temperature.
Figure 6.4: Sensitivity №1, Fuel conductivity — Time trend comparison. Upper head pressure.
Figure 6.5: Sensitivity N°1, Fuel conductivity — Time trend comparison. Mass inventory.
Figure 6.6: Sensitivity No1, Fuel conductivity — Time trend comparison. Rod surface temperature.
Figure 6.7: Sensitivity No2, Gap conductivity — Time trend comparison. Upper head pressure.
S2.a Primary circuit mass inventory (lower range value)

S2.b Primary circuit mass inventory (upper range value)

Figure 6.8: Sensitivity No2, Gap conductivity — Time trend comparison. Mass inventory.
Figure 6.9: Sensitivity No. 2, Gap conductivity — Time trend comparison. Rod surface temperature.
Figure 6.10: Sensitivity No3, Decay power — Time trend comparison. Upper head pressure.
Figure 6.11: Sensitivity N°3, Decay power — Time trend comparison. Mass inventory.
Figure 6.12: Sensitivity No.3, Decay power — Time trend comparison. Rod surface temperature.
Figure 6.13: Sensitivity No4, Initial power — Time trend comparison. Upper head pressure.
Figure 6.14: Sensitivity Nº4, Initial power — Time trend comparison. Mass inventory.
Figure 6.15: Sensitivity N°4, Initial power — Time trend comparison. Rod surface temperature.
Figure 6.16: Sensitivity No5, Maximum linear power — Time trend comparison. Upper head pressure.
S5.a Primary circuit mass inventory (lower range value)

S5.b Primary circuit mass inventory (upper range value)

Figure 6.17: Sensitivity N°5, Maximum linear power — Time trend comparison. Mass inventory.
Figure 6.18: Sensitivity N°5, Maximum linear power — Time trend comparison. Rod surface temperature.
Figure 6.19: Sensitivity №6, LPIS delay — Time trend comparison. Upper head pressure.
Figure 6.20: Sensitivity №6, LPIS delay — Time trend comparison. Mass inventory.
Figure 6.21: Sensitivity №6, LPIS delay — Time trend comparison. Rod surface temperature.
Figure 6.22: Sensitivity No. 7, Accumulator liquid volume — Time trend comparison. Upper head pressure.
Figure 6.23: Sensitivity N°7, Accumulator liquid volume — Time trend comparison. Mass inventory.
Figure 6.24: Sensitivity N°7, Accumulator liquid volume — Time trend comparison. Rod surface temperature.
Figure 6.25: Sensitivity N°8, Accumulator pressure — Time trend comparison. Upper head pressure.
Figure 6.26: Sensitivity No 8, Accumulator pressure — Time trend comparison. Mass inventory.
S8.a Rod surface temperature (lower range value)

S8.b Rod surface temperature (upper range value)

Figure 6.27: Sensitivity No8, Accumulator pressure — Time trend comparison. Rod surface temperature.
Figure 6.28: Sensitivity №9, Containment pressure — Time trend comparison. Upper head pressure.
Figure 6.29: Sensitivity N°9, Containment pressure — Time trend comparison. Mass inventory.
Figure 6.30: Sensitivity Nº9, Containment pressure — Time trend comparison. Rod surface temperature.
Figure 6.31: Sensitivity N°10, Pellet radius — Time trend comparison. Upper head pressure.
Figure 6.32: Sensitivity No10, Pellet radius — Time trend comparison. Mass inventory.
Figure 6.33: Sensitivity №10, Pellet radius — Time trend comparison. Rod surface temperature.
6.3 Sensitivity analysis results

Table 6.3 shows the effect that the variation of the different input parameters has on PCT and on time of core quenching, as obtained by the participants in Phase IV.

Figures 6.34 to 6.44 plot graphically the information on Table 6.3. Some sensitivity calculation results have been omitted, for the sake of clarity, because some misunderstandings were found out. Nevertheless most of the results were valid and properly identified in order to draw some conclusions.

For instance, two participants performed the sensitivity analysis for the fuel dimensions using a previous version of the specification. A third one performed the analysis twice. So Figure 6.43 shows the results for those participants using cold dimensions to calculate this sensitivity. Figure 6.44 shows the results for participants that modified the gap dimensions in order to obtain a $\pm 75$ K variation in the average pellet temperature for the core node having the maximum linear power.

<table>
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<tr>
<th>Participant</th>
<th>$\Delta PCT$</th>
<th>$\Delta t_{\text{REFLOOD}}$</th>
<th>$\Delta PCT$</th>
<th>$\Delta t_{\text{REFLOOD}}$</th>
<th>$\Delta PCT$</th>
<th>$\Delta t_{\text{REFLOOD}}$</th>
<th>$\Delta PCT$</th>
<th>$\Delta t_{\text{REFLOOD}}$</th>
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<td>$\Delta PCT$</td>
<td>$\Delta t_{\text{REFLOOD}}$</td>
<td>$\Delta PCT$</td>
<td>$\Delta t_{\text{REFLOOD}}$</td>
<td>$\Delta PCT$</td>
<td>$\Delta t_{\text{REFLOOD}}$</td>
<td>$\Delta PCT$</td>
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<td>CEA [C25]</td>
<td>95.4</td>
<td>-67.8</td>
<td>42.3</td>
<td>-45.9</td>
<td>15.6</td>
<td>13.1</td>
<td>-35.7</td>
<td>20.6</td>
<td>-46.0</td>
<td>42.4</td>
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<tr>
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<td>18.6</td>
<td>-2.8</td>
<td>-8.9</td>
<td>-6.0</td>
<td>-41.7</td>
<td>27.3</td>
<td>-9.8</td>
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<td>-5.0</td>
<td>0.4</td>
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<td>-2.0</td>
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<td>65.4</td>
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<td>30.2</td>
<td>-48.2</td>
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<td>58.1</td>
<td>-64.4</td>
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<td>-7.0</td>
<td>11.0</td>
<td>1.0</td>
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<td>11.0</td>
<td>2.0</td>
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<tr>
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<td>-1.4</td>
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<td>-5.2</td>
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Table 6.3: $\Delta PCT$ and $\Delta t_{\text{REFLOOD}}$ results from sensitivity calculations.
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<tr>
<th>Participant</th>
<th>∆ value&lt;sub&gt;spec&lt;/sub&gt;-value&lt;sub&gt;RC&lt;/sub&gt;</th>
<th>∆PCT</th>
<th>∆t&lt;sub&gt;REFLOOD&lt;/sub&gt;</th>
<th>S6</th>
<th>S7</th>
<th>S8</th>
<th>S9</th>
<th>S10</th>
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<td>∆PCT</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>CEA [C25]</td>
<td>∆PCT</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>120.7</td>
<td>130.8</td>
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<tr>
<td>EDO [T97]</td>
<td>∆PCT</td>
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<td>-3.3</td>
<td>15.3</td>
<td>-11.1</td>
<td>2.0</td>
<td>-5.3</td>
<td>-20.5</td>
</tr>
<tr>
<td>GRS [A21]</td>
<td>∆PCT</td>
<td>0.0</td>
<td>-1.0</td>
<td>-1.0</td>
<td>1.0</td>
<td>0.0</td>
<td>126.0</td>
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</tr>
<tr>
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<td>∆PCT</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<tr>
<td>JNES [TR4]</td>
<td>∆PCT</td>
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<td>10.9</td>
<td>12.4</td>
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<td>KAERI [M31]</td>
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<td>0.0</td>
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<td>PSI [TR4]</td>
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<td>∆PCT</td>
<td>5.9</td>
<td>6.3</td>
<td>-4.0</td>
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<td>12.0</td>
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<td>126.9</td>
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<td>UNIPI-2 [C25]</td>
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<td>1.7</td>
<td>-19.3</td>
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<td>UPC [R5]</td>
<td>∆PCT</td>
<td>1.6</td>
<td>-7.0</td>
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<td>0.0</td>
<td>-1.0</td>
<td>11.0</td>
<td>13.0</td>
</tr>
</tbody>
</table>

Table 6.3: ∆PCT and ∆t<sub>REFLOOD</sub> results from sensitivity calculations (continued).

(1) Core wide
(2) Hot rod in hot fuel assembly
(3) 2 out of 3 ECCS
(4) Hot channel, hot fuel assembly and hot rod in hot fuel assembly
Figure 6.34: Sensitivity No1, Fuel conductivity — Scalar parameters.

Figure 6.35: Sensitivity No2, Gap conductivity — Scalar parameters.

\(^1\)JNES values for these sensitivities are those provided by the authors, maybe some data crossing has occurred.
Figure 6.36: Sensitivity No3, Decay power — Scalar parameters.

Figure 6.37: Sensitivity No4, Initial power — Scalar parameters.
Figure 6.38: Sensitivity No. 5, Maximum linear power — Scalar parameters.

Figure 6.39: Sensitivity No. 6, LPIS delay — Scalar parameters.
Figure 6.40: Sensitivity No7, Accumulator liquid volume — Scalar parameters.

Figure 6.41: Sensitivity No8, Accumulator pressure — Scalar parameters.
Figure 6.42: Sensitivity N°9, Containment pressure — Scalar parameters.

Figure 6.43: Sensitivity N°10, Pellet radius — Scalar parameters.
Figure 6.44: Sensitivity No10, Pellet radius — Scalar parameters.
6.4 Sensitivity analysis summary and conclusions

The sensitivity calculations performed in Phase IV are helpful in preparing the next Phase V of BEMUSE project. They can be used by participants individually:

- when deciding which parameters are to be included in their respective uncertainty analysis;
- after running the uncertainty calculations (for those participants using methods based in Wilks’ formula);
- when deciding whether to accept or to put in question the results of the sensitivity analysis post-calculation.

In order to provide the reader with a better sight of the sensitivity analysis results, the values for ∆PCT and for ∆t_{REFLOOD} given by all participants have been averaged. As reasonable ranges of variation have been assumed for the input parameters, ∆PCT and ∆t_{REFLOOD} values provide a good measure of the influence that these input parameters can have on the calculation results.

Figures 6.45 and 6.46 show those averaged ∆PCT and ∆t_{REFLOOD} values. In fact, the values shown have into account the range of variation of PCT and of t_{REFLOOD} when the sensitive input parameter changes from its lower to its upper value. Also, in these figures, the standard deviation of the ranges (for PCT and t_{REFLOOD}) found by the participants has been included.

So, Figures 6.45 and 6.46 summarize the results of the sensitivity analysis. For the PCT, participants in average have found that the most influential parameters are those related to the energy stored in the fuel elements (i.e. fuel and gap conductivity, power (before and after the scram) and fuel dimensions) and, among them, fuel conductivity, radial power factor (hot rod power) and fuel dimensions.

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1The influence has to do both with the sensitivity and with the range of variation (large variations of slightly sensitive input parameters can produce a noticeable change in the output, large sensitivities to parameters that do not change at all would produce no changes in the output).
Regarding the $t_{REFLOOD}$, the *average participant* has encountered that the parameters having more influence in the time of reflood are containment pressure, power after scram (decay power), radial power factor (hot rod power), power before scram (steady state power) and volume of liquid in accumulators. Nevertheless a strong range of variation has been found for the influence of this parameters in the $t_{REFLOOD}$ (see Figures 6.46, and 6.36, 6.37, 6.38, 6.40 and 6.42), so that different participants consider that a given parameter has a very different influence.

This dispersion related to the sensitivity studies is also encountered in the PCT case, but it is milder.

The sensitivity study performed in Phase IV has proved to be useful in order to set up the specifications for Phase V, and has pointed out that the *user* and *code effects* can appear not only in obtaining a reference case value, but also when analysing variations on the reference case. So, in an uncertainty analysis, even participants considering the same uncertain parameters, with similar ranges of variation and using the same method could obtain quite different results.
CHAPTER 7

CONCLUSIONS

Phase IV of BEMUSE programme has dealt with the simulation of a LB-LOCA in a Nuclear Power Plant using the experience gained in the previous Phase II. Calculation results can be used in Phase V which is devoted to uncertainty evaluation.

The objectives of the activity have been fulfilled. The LB-LOCA scenario has been simulated reproducing the phenomena associated to it. In addition a common basis for the future comparison of uncertainty evaluation methodologies has been established.

The connection with the previous Phase II has been ensured and the lessons learned in it have successfully been taken into account. Nodalization techniques tested and used in Phase II, have been followed in Phase IV, not only in the final established nodalizations, but also in the efforts made to explain discrepancies and in the sensitivities tests.

The difficulties caused by the selection of the reference plant have been treated and overcome. They have added some spread in the results but they have not blocked the analytical activity and the work has been carried out successfully.

BEMUSE Phase IV brought up the results that can be summarized as follows: All participants managed to simulate the scenario and predict the main parameters with credible consistency. Maximum values of PCT predicted by participants are quite close one to each other. PCT time trends and basically final rewet still show some disagreements.

The data base produced includes comparative tables, comparative plots and some explanations on the discrepancies between results. The data base is also suitable for providing future explanations if they become scientifically interesting once the following phases are on-going.

At the time when this Phase IV draft is written, all participants are developing a Phase V analysis and their studies are based on the reference calculations produced in Phase IV. The coordinators want to emphasize this point as a proof of how participants accept the usefulness of the results produced. Despite the difficulties encountered Phase IV has been fulfilled with enough credibility.

It is clear that dispersion bands exist but it is also clear that the effort of explaining the reasons of such dispersion is a valuable outcome from this phase. The outcome of BEMUSE Phase IV is also helpful to understand the nuances existing inside the user effect. The discussion on the point related to the full quench has been useful to clarify the "border" between user effect and code effect. This item led to include a new appendix (Appendix G) specifically devoted to deal with user and code effect.

Also the exercise has become a good opportunity to understand that assumptions made by the user due to the lack of information are not part of the traditional user effect and this report has put together the material to deal with this problem. The assumptions are explained in Phase IV specification and after different discussions carried out in the project meetings.

The spread on the maximum PCT does not exceed 260 K between the highest and the lowest prediction. This spread is similar to the one obtained in Phase II.

Participants, in average, have found that for PCT the most influential parameters are those related to the energy stored in the fuel elements and, among them, fuel conductivity, radial power factor (hot-rod power) and fuel dimensions. Regarding the $t_{\text{REFLOOD}}$, the average participant has encountered
that the parameters having more influence in the time of reflood are containment pressure, power after scram (decay power), radial power factor (hot rod power), power before scram (steady state power) and volume of liquid in accumulators.

The sensitivity study performed in Phase IV has proved to be useful in order to set up the specifications for Phase V, and has pointed out that the user and code effects can appear not only in obtaining a reference case value, but also when analyzing variations on the reference case.

Sensitivity calculation results are a good guidance for developing Phase V uncertainty evaluation. BEMUSE Phase IV is a reference good enough to start with Phase V development.

This phase of BEMUSE programme is a successful step that supports the general goals of the whole project which are to evaluate the practicability, quality and reliability of BE methods including uncertainty evaluations in applications relevant to nuclear reactor safety, to develop common understanding and to promote/facilitate their use by the regulatory bodies and the industry.
Bibliography


[14] Input and Output Specifications for the LOFT L2-5 Experiment. Phase 2 of BEMUSE Programme, Rev. 2, DIMNP NT 517(03), Pisa, January 2005.


