NUREG/IA-0196

International Agreement Report

Analysis of PANDA Experiments P3 and P6 Using RELAP5/MOD3.2

Prepared by

L. Batet, F. Reventós

Department of Physics and Nuclear Engineering
University Politecnica de Cataluna
08028 Barcelona
SPAIN

Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

January 2001

Prepared as part of
The Agreement on Research Participation and Technical Exchange
under the International Code Application and Maintenance Program (CAMP)

Published by
U.S. Nuclear Regulatory Commission

AVAILABILITY OF REFERENCE MATERIALS IN NRC PUBLICATIONS

NRC Reference Material

As of November 1999, you may electronically access NUREG-series publications and other NRC records at NRC's Public Electronic Reading Room at www.nrc.gov/NRC/ADAMS/index.html. Publicly released records include, to name a few, NUREG-series publications; *Federal Register* notices; applicant, licensee, and vendor documents and correspondence; NRC correspondence and internal memoranda; bulletins and information notices; inspection and investigative reports; licensee event reports; and Commission papers and their attachments.

NRC publications in the NUREG series, NRC regulations, and *Title 10, Energy*, in the Code of *Federal Regulations* may also be purchased from one of these two sources.

1. The Superintendent of Documents
   U.S. Government Printing Office
   P. O. Box 37082
   Washington, DC 20402–9328
   www.access.gpo.gov/su_docs
   202–512–1800
2. The National Technical Information Service
   Springfield, VA 22161–0002
   www.ntis.gov
   1–800–533–6847 or, locally, 703–805–6000

A single copy of each NRC draft report for comment is available free, to the extent of supply, upon written request as follows:

Address: Office of the Chief Information Officer,
Reproduction and Distribution
Services Section
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

E-mail: DISTRIBUTION@nrc.gov

Facsimile: 301–415–2289

Some publications in the NUREG series that are posted at NRC's Web site address www.nrc.gov/NRC/NUREGS/indexnum.html are updated periodically and may differ from the last printed version. Although references to material found on a Web site bear the date the material was accessed, the material available on the date cited may subsequently be removed from the site.

Non-NRC Reference Material

Documents available from public and special technical libraries include all open literature items, such as books, journal articles, and transactions, *Federal Register* notices, Federal and State legislation, and congressional reports. Such documents as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings may be purchased from their sponsoring organization.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at—

The NRC Technical Library
Two White Flint North
11545 Rockville Pike
Rockville, MD 20852–2738

These standards are available in the library for reference use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from—

American National Standards Institute
11 West 42nd Street
New York, NY 10036–8002
www.ansi.org
212–642–4900

The NUREG series comprises (1) technical and administrative reports and books prepared by the staff (NUREG–XXXX) or agency contractors (NUREG/CR–XXXX), (2) proceedings of conferences (NUREG/CP–XXXX), (3) reports resulting from international agreements (NUREG/IA–XXXX), (4) brochures (NUREG/BR–XXXX), and (5) compilations of legal decisions and orders of the Commission and Atomic and Safety Licensing Boards and of Directors' decisions under Section 2.206 of NRC's regulations (NUREG–0750).

NUREG/IA-0196

International Agreement Report

Analysis of PANDA Experiments P3 and P6 Using RELAP5/MOD3.2

Prepared by

L. Batet, F. Reventós

Department of Physics and Nuclear Engineering
University Politecnica de Cataluna
08028 Barcelona
SPAIN

Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555–0001

January 2001

Prepared as part of
The Agreement on Research Participation and Technical Exchange
under the International Code Application and Maintenance Program (CAMP)

Published by
U.S. Nuclear Regulatory Commission

Abstract

Between 1996 and 1998 Technical University of Catalonia (UPC) has been participating in the "Technology Enhancement for Passive Safety Systems" (TEPSS) project, in the Fourth Framework Program of the Commission of the European Communities.

One of the purposes of TEPSS has been the study of the residual heat removal by passive means after a loss of coolant accident into a simplified boiling water reactor (ESBWR) type containment. To that end, eight experiments have been performed in PANDA experimental facility of Paul Scherrer Institute in Villigen (Switzerland). PANDA represent a ESBWR scaled 1:1 in elevation and 1:40 in volume.

UPC has supplied analytical support of PANDA tests P3 and P6, using RELAP5/Mod3.2. P3 and P6 simulate Main Steam Line Break scenarios with different initial conditions and different passive safety systems available.

This report shows the results obtained in the simulation of those experiments. Discrepancies between calculated and measured parameters are identified and discussed.

Table of Contents

List of Figures

Executive Summary

Between 1996 and 1998 Technical University of Catalonia (UPC) has been participating, among other European research institutions, in the "Technology Enhancement for Passive Safety Systems" (TEPSS) project, in the Fourth Framework Program of the Commission of the European Communities.

The objective of TEPSS project was to make significant contributions to the base technology of Passive Advanced Boiling Water Reactors. To fulfil this objective, experimental work and analytical research has been undertaken in different areas, one of them being the study of the residual heat removal by passive means after a loss of coolant accident into a simplified boiling water reactor (ESBWR) type containment. UPC has been working in this area, in the analytical support of the experiments performed in PANDA experimental facility of Paul Scherrer Institute in Villigen (Switzerland). PANDA represent a ESBWR scaled 1:1 in elevation and 1:40 in volume.

Eight experiments were performed in PANDA facility for TEPSS project, with the following general objectives:

- to investigate the effect of new designs in the containment's short term response following a loss of coolant accident
- to demonstrate that residual heat removal passive systems perform as anticipated in different accidental scenarios
- to generate a data base usable to code validation and to the analysis of particular phenomena.

UPC provided analytical support of the experiments P3 and P6 using RELAP5/MOD3.2. Test P3 simulates a main steam line break (MSLB) scenario in which the drywell is initially full of air and the facility configuration is highly asymmetrical. Two out of three condensers of the Passive Containment Cooling System (PCCS) are operative. Test P6 simulates a MSLB scenario with the three PCCS units available during the whole test and the IC available during the first seven hours. A leakage path from the suppression chamber to the drywell is postulated.

The results obtained in the analyses are reasonably consistent from an overall point of view, but some important discrepancies with experimental data have been identified, the main causes being the stratification of both temperatures and air-steam mixture and the accumulation of air in anomalous locations. In the considered scenarios it has been experimentally observed that, though the air-steam mixture is not uniform in the large volumes, its behaviour is homogeneous, in the sense that it exhibits a smooth spatial variation. On the contrary, as a monodimensional nodalization has been used in RELAP5 calculation, anomalous accumulations of air and sharp stratifications of the air-steam mixture have been produced in the simulation. These phenomena are dominant over other causes of discrepancy.

Nevertheless, RELAP5/Mod3.2 has shown to be a robust code, reproducing quite well the global behaviour of the system with reasonable computation times. So, it has been possible to perform some sensitivity studies which have lead to improvements in the model used. The fact of studying two tests in parallel has been of great usefulness in

these analyses in order to have a more general scope on the effect of the changes introduced into the model.

Computer codes used by conventional nuclear plant owners are requested to be able to simulate scenarios that are far from those classically studied. So, it is necessary to test the codes in situations they are not designed for. Participation in TEPSS, has been a chance for using RELAP5 to analyze a experiment series involving the containment and the heat removal passive safety systems and implying phenomena such as natural circulation and steam and non-condensable gas mixing, among others. In authors opinion, the results contributed by this study and similar ones are a reference point to be taken in consideration in the development process of future consolidated codes.

Acknowledgements

TEPSS project has been undertaken with the financial support of the Commission of the European Communities into the Forth Framework Program.

PANDA experiments, performed by Paul Scherrer Institut, have been supported by Swiss Federal Bureau for Education and Science.

Authors wish to acknowledge the organizations participating in TEPSS for their co-operation in order to get and publish the experimental results presented here.

1. Introduction

Between 1996 and 1998 Technical University of Catalonia (UPC) has been participating in the "Technology Enhancement for Passive Safety Systems" (TEPSS) project, in the Fourth Framework Program of the Commission of the European Communities. The following institutions participated in TEPSS Project: the research centre ECN (The Netherlands), Paul Scherrer Institute (PSI) of Switzerland, the Dutch companies KEMA and Stork NUCON B. V. and, from the Spanish side, the research centre CIEMAT, Technical University of Valencia (UPV) and UPC.

The objective of TEPSS project was to make significant contributions to the base technology of Passive Advanced Boiling Water Reactors (General Electric's ESBWR is the reference design of the project). To fulfil this objective, experimental work and analytical research have been undertaken in three areas. The first one is the study of countermeasures to the thermal stratification in the suppression pool in order to mitigate the system's pressure increase following the steam and gas transfer from the drywell and from the passive containment cooling system (PCCS). The second area is the study of the residual heat removal by passive means after a loss of coolant accident into an ESBWR type containment. Last, the third area consists in the study of the behaviour of the aerosol particles that would be generated in a severe accident, their elimination from the containment atmosphere by retention in the PCCS and the performance degradation of that system due to the deposition of aerosols in the internal face of the passive condensers' tubes [1].

The work carried out by UPC, linked to the second area, has consisted in supplying analytical support, both pre and post-test, to the experiments performed in PANDA experimental facility of Paul Scherrer Institute in Villigen (Switzerland).

2. The PANDA experiments in TEPSS project

PANDA facility represents, in its TEPSS configuration, a simplified boiling water reactor (ESBWR) scaled 1:1 in elevation and 1:40 in volume (figure 1). The configuration includes the reactor vessel (the core is simulated by electrical resistances which power is adjustable to the temporal evolution of residual heat), the drywell, the suppression chamber (wetwell), the isolation condenser (IC), the passive containment cooling system (PCCS) and the gravity driven core cooling system (GDCS). It also includes the main vent lines and the vacuum breaker valves (VB), that prevent the pressure in the suppression chamber (WW) to be excessively higher than the pressure in the drywell (DW). The PANDA asymmetrical layout makes possible the study of tri-dimensional effects [2].

Eight experiments were performed in PANDA facility for TEPSS project. The general objectives of such tests were: (1) to investigate the effect of new designs in the containment's short term response following a loss of coolant accident (LOCA), (2) to demonstrate that residual heat removal passive systems perform as anticipated in different accidental scenarios and (3) to generate a data base usable to code validation and to the analysis of particular phenomena.

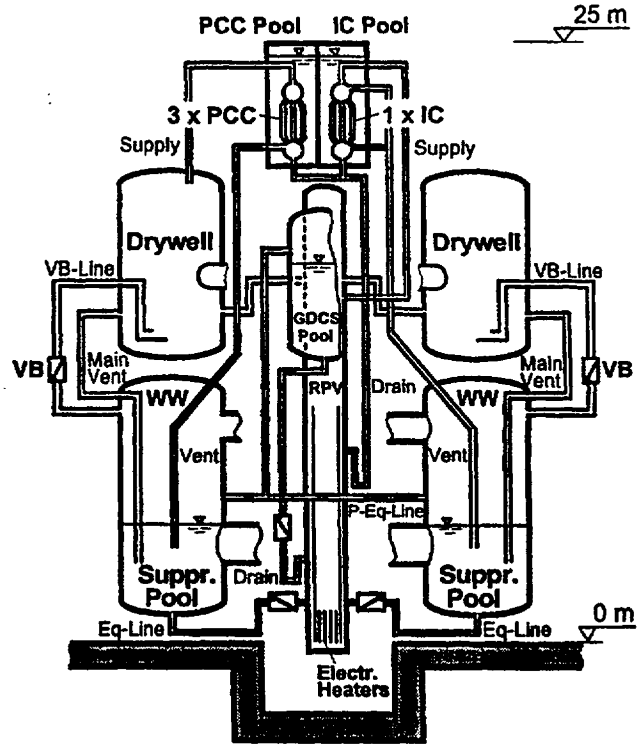

Figure 1. Drawing of PANDA facility.

Among all PANDA tests, UPC provided analytical support of the experiments P3 and P6, which will be outlined later on. Calculations were performed with RELAP5/MOD3.2 using a base input deck originally prepared by ECN [1] (a drawing of the nodalization can be seen in figure 2). UPC, taking advantage of the information received during the project, modified the model in order to better predict the behaviour of the experimental facility in its final configuration [1,3].

3. P3 experiment

Test P3 simulates a main steam line break (MSLB) scenario in which the drywell is initially full of air. All the steam flow generated in the vessel is directed to DW2, where two condensers of the passive containment cooling system (PCC2 and PCC3) are connected. PCC1 and IC are not used in this experiment and are isolated by valving them out from the system. Heating power is maintained at a constant level (850 kW) during the eight hours the test lasts. Both available PCCs are initially full of air [2,4].

The particular objective of this test is to demonstrate PCCS start-up capability under such challenging conditions.

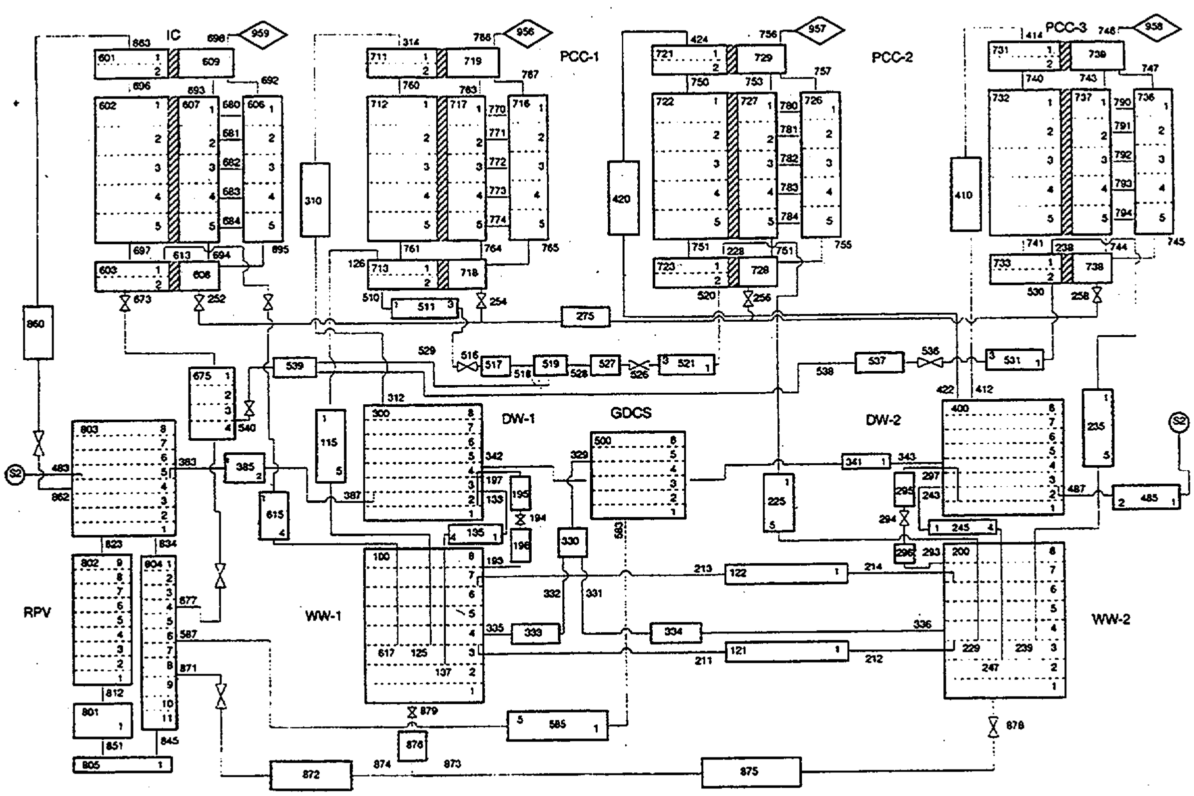

Figure 2. Nodalization of ECN RELAP5/Mod3.2 model for PANDA facility.

3.1. Experimental results description

The test is initiated by adjusting the heat power and opening the valves simulating the main steam line break. The steam flow causes drywell pressure to rise, forcing air to circulate to the suppression chamber through the PCCS condensers, so that the pressure in that space also increases. During a first pressurization stage, air contained in the drywell prevents the effective start up of PCC system.

Once air in DW2 has been purged, PCCS condensers are able to start condensing steam, so that pressures become stable and system reaches a quasi-steady state. The capability of the two PCCS operative units is less than heat power supplied electrically to the simulated reactor core, the excess vapour circulates to the suppression pool through the main steam lines, causing an increase in water temperature [5].

3.2. Analytical results description

The results obtained in pre and post-test analyses are reasonably consistent from an overall point of view, but some important discrepancies with experimental data have been identified.

Figure 3 shows the pressures evolution in the containment. During the initial stage of the test, calculated pressure values increase more rapidly than experimental ones. This behaviour is related to the fact that RELAP5 predicts the existence in DW2 of a quite strong stratification in the air-vapour mixture (see figure 4) that delays the steam entrance into the PCCS condensers.

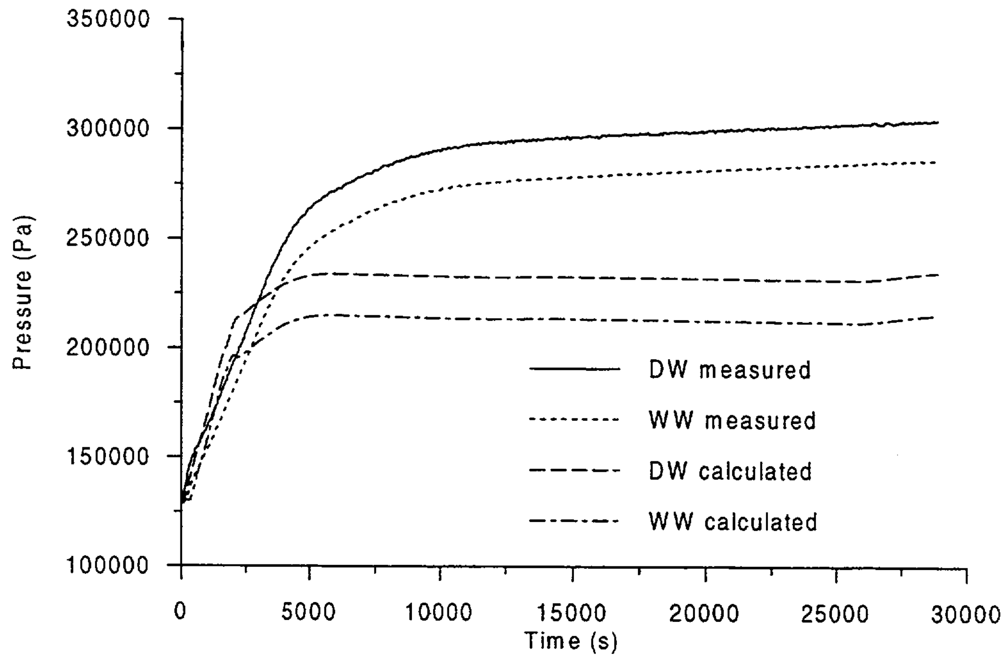

Figure 3. Containment pressures evolution in test P3.

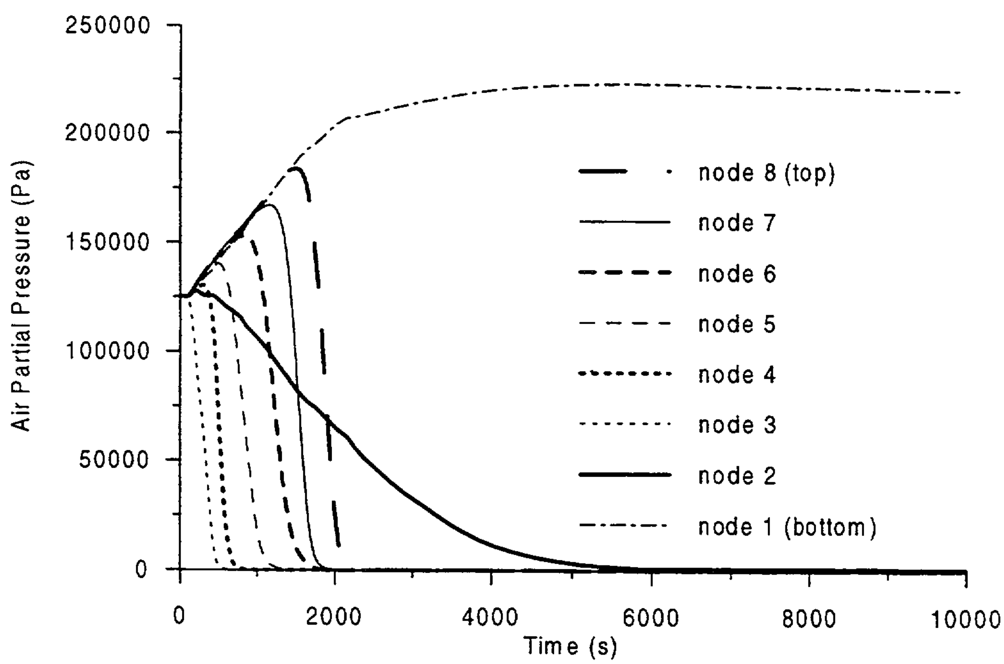

Figure 4. Simulated evolution of DW2 partial air pressures in test P3.

In the long term, calculated system pressures remain always below measured values due to the large amount of air that remains trapped in the upper part of DW1, which acts as a dead end volume. The simulation predicts that steam penetrating DW1, in spite of being lighter than air, turn towards the lower part of that vessel, driving the air of the bottom nodes to the suppression chamber through the main vent line, while allowing an important mass of air to remain trapped in the upper part (figure 5). The fact that the pipe connecting both drywell vessels in PANDA has been modelled as a mono-dimensional volume prevents, in RELAP5 calculation, air convection from DW1 to DW2 and from there to the wetwell through PCCS. In the experiment, air only accumulated in the lower part of DW1 (figure 6). The remainder of the air was purged to the wetwell, causing the system pressure to increase.

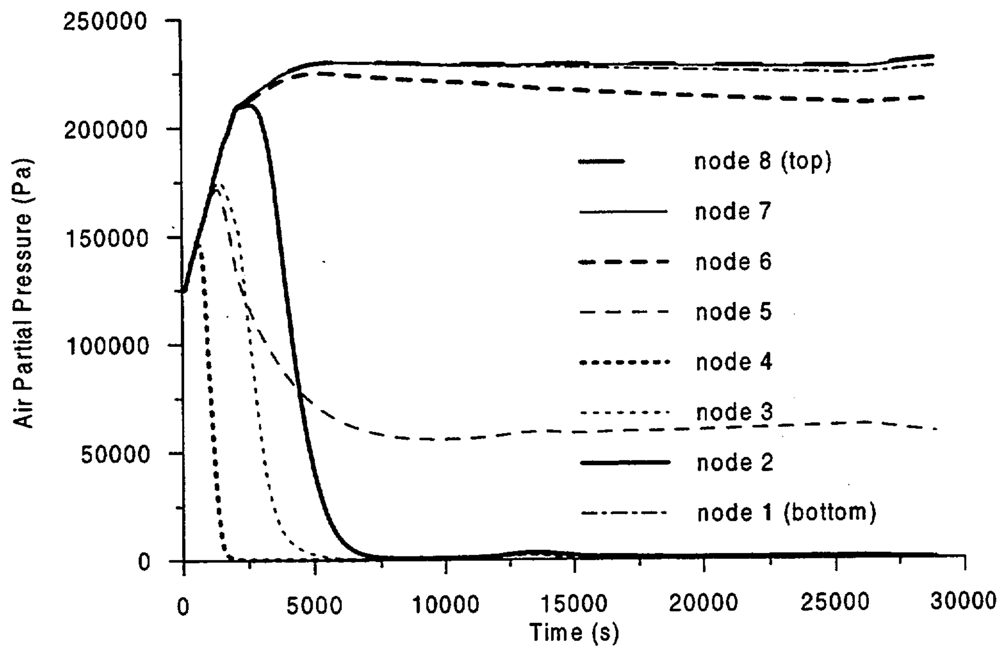

Figure 5. Simulated evolution of DW1 partial air pressures in test P3.

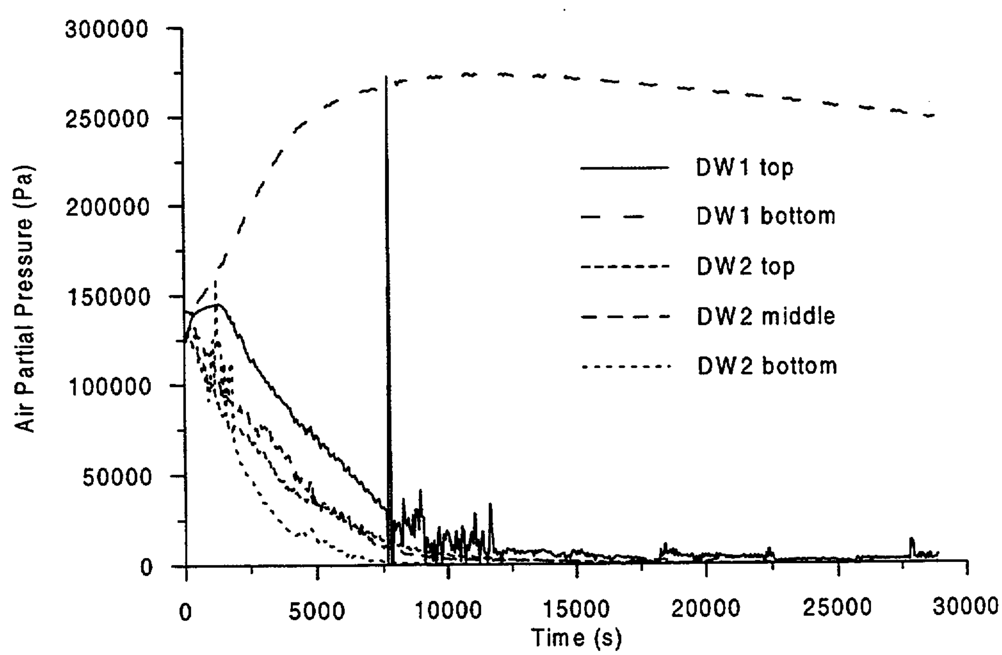

Figure 6. Measured partial air pressures in test P3.

In a less extent, the lower calculated pressures are also related to the predicted stratification of water temperatures in the suppression pool, that leads to lower surface temperature and, consequently, to lower vapour partial pressure. That stratification results from the injection of hot steam through the main and PCCS vent lines into some specific nodes of the suppression pool. Instrumentation in PANDA facility indicates that no actual stratification occurs.

As it is deduced from the stated above, observed discrepancies (stratifications and air accumulation in anomalous sites) have to do with the fact of using a mono-dimensional model of the vessels that, in PANDA, simulate the containment spaces.

4. P6 experiment

Test P6 simulates a MSLB scenario with the three PCCS units available during the whole test and the IC available during the first seven hours. Steam flow is symmetrically directed to both drywell vessels. The test is assumed to begin one hour after the postulated break, when GDCS injection phase has finished and boiling in the reactor pressure vessel (RPV) resumes. A leakage through one vacuum breaker (VB) valve, connecting wetwell and drywell, is postulated to start at four hours after the beginning of the experiment [2,6].

The particular objectives of the test are, on the one hand, to investigate the effect of the interaction between the PCCS and the IC on the containment and the passive safety systems performance and, on the other hand, to study the effect of a possible leakage path between drywell and wetwell on the containment performance.

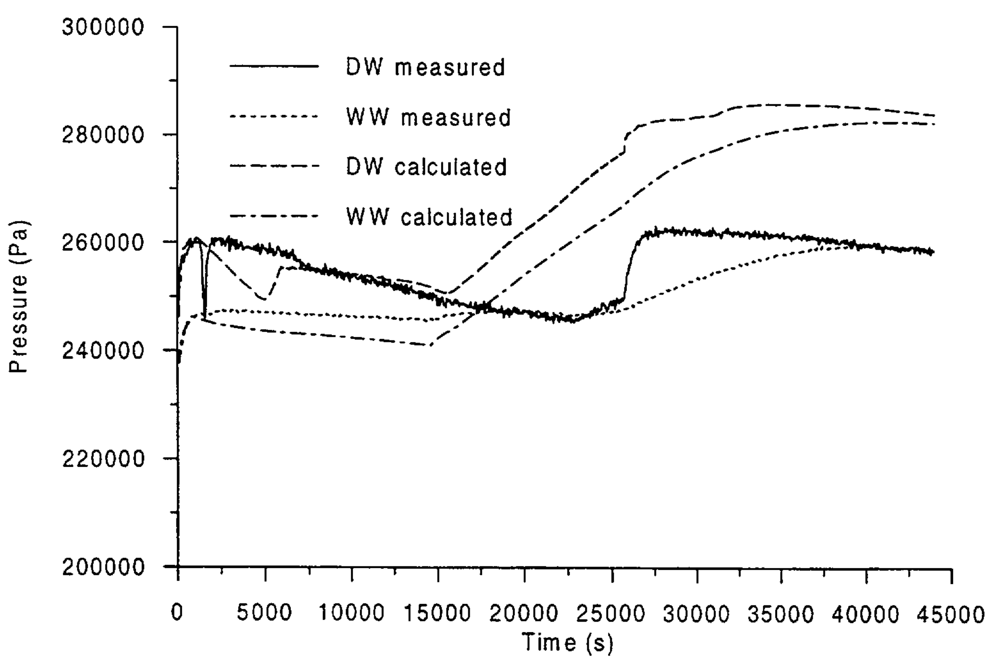

Figure 7. Containment pressures evolution in test P6.

4.1. Experimental results description

Figure 7 shows the evolution of main pressures, for both the experiment and the simulation. After the initial pressurization, pressure values stabilize due to the combined effect of PCCS and IC, that starts operating very soon, as it can be seen in figure 8. The observed valley in the drywell pressure plot was caused by a momentary loss of core heaters' electrical power. In this first stage of the test, drywell pressure plot has a negative slope because of the efficiency of cooling systems.

Four hours after the beginning of the test the leakage from drywell to wetwell started. Due to the fact that, at that moment, the pressure difference between both vessels was quite small, pressures become rapidly equal. The leakage path had little relevance in the behaviour of PANDA facility.

Three hours later IC was valved out of service. Containment pressure rised until the PCCS condensers assumed the power fraction corresponding to IC [7].

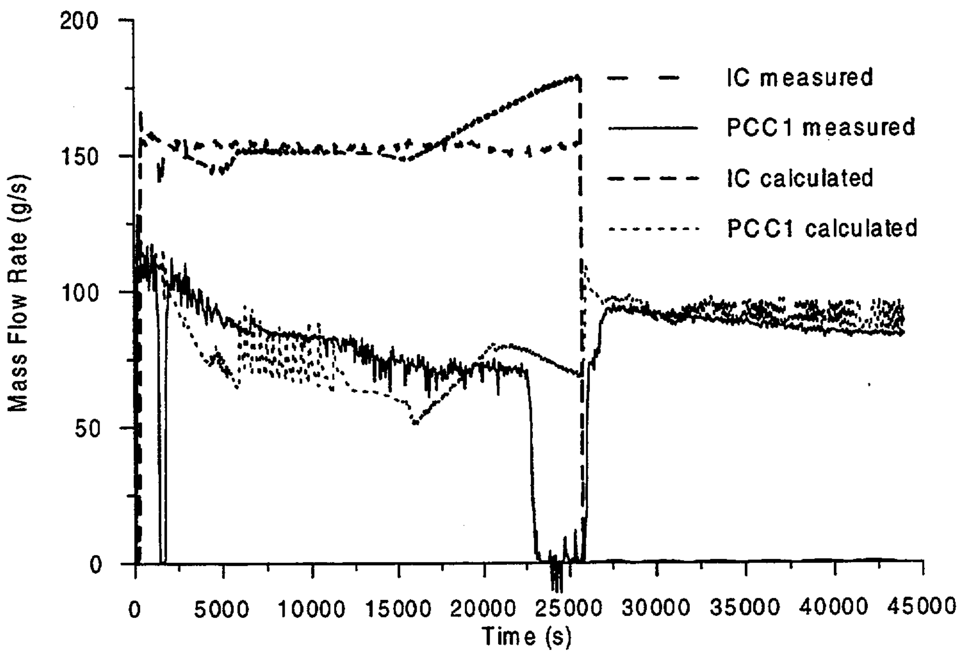

Figure 8. Steam flow to IC and PCC1 in test P6.

4.2. Analytical results description

Except for the loss of heaters power (without effect on the remainder of the test), the behaviour of containment pressures is quite well predicted in the RELAP5 simulation for the first part of the scenario (up to four hours). The loss of heaters' electrical power was not simulated to avoid the opening of vacuum breaker (not produced during the experiment). Sensitivity calculations performed with the theoretical scaled decay power curve showed no difference with those performed using the actual power experimental data, except when VB opened. For that reason it was decided to perform the final TEPSS analyses using the theoretical power curve.

For the first hour and a half, the simulation predicts a heat extraction greater than in the experiment, as suggests the greater negative slope in the drywell pressure plot. This effect is related to the retention of air in the bottom part of the drywell vessels, below the main steam lines connection (see figure 9). Gas so accumulated should have been driven to PCCS condensers, slightly degrading their efficiency. Although data on partial air pressure evolution in the drywell are not totally reliable for test P6, temperature measurements suggest that such accumulation of gas does not occur in PANDA (in addition to that, PSI calculations using the GOTHIC code also show an homogeneous air-vapour mixture in the drywell).

The predicted excess cooling rate of PCCS and IC is compensated by the release (due to the depressurization) of the trapped air. When air reaches the PCCs' tubes, the performance degradation of PCCS leads the pressure, after a quick increase, to stabilize at a value near the experimental one.

At four hours the leakage through vacuum breaker (VB) starts and the wetwell pressure increase (much greater than in the experiment) makes air venting from PCCs difficult. Air accumulation in PCCS condensers hinders heat transfer to the pools, causing drywell pressure to rise. Main discrepancies between simulated an experimental results are found in this phase of the scenario. The abnormal behaviour has two possible explanations. On one hand, the pressure difference between DW and WW is greater than in the test, causing a greater mass flow through the leakage path. On the other hand a non negligible amount of air is in PCCs when the leakage starts, due to the slow release of air trapped in the bottom part of the drywell during the depressurization (as seen in figure 9).

Simulation reflects quite well the effect of stopping IC, though system pressures stabilize at values greater than experimental ones. This difference is due to the fact that pressures are too high when IC stops.

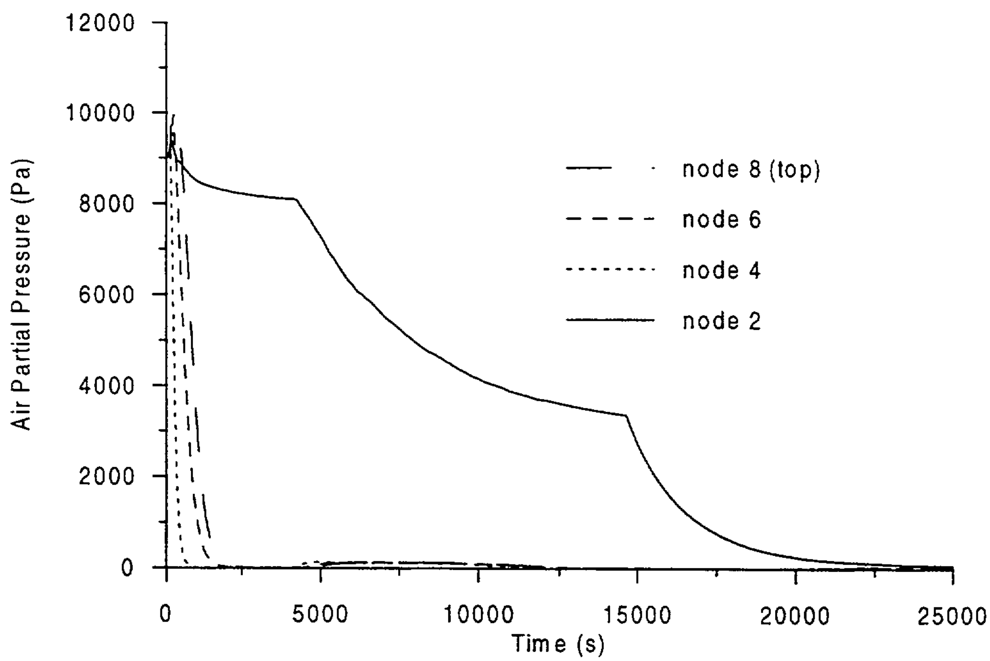

Figure 9. DW1 partial air pressure in test P6 simulation.

Despite of the above mentioned discrepancies, predicted inlet steam flows to PCCS condensers and IC are not far from the experimental ones (as shown in figure 8) and temperatures in PCCS and IC tubes are in close agreement with the test.

5. Analysis of main discrepancies and anomalies

As it has been shown in the two previous sections, the main causes of discrepancy between experiment and simulation results are, on one hand, the stratification of both temperatures and air-steam mixture and, on the other hand, the accumulation of non-condensable gas (air in this case) in anomalous locations. Both effects are closely connected to the fact that a monodimensional nodalization has been used for simulating the big containment volumes [8].

Other causes of distortion between analytical and experimental results have been encountered. Some of them have been corrected without excessive work, for example the effect of the time step and the errors induced by the RELAP5/MOD3.2 default condensation model. Other discrepancies, like heat transfer in both sides of condensers' tubes, seem to have little influence in the final results when compared to stratifications and air accumulations.

Regarding condensation in presence of non-condensable gas, RELAP5/Mod3.2 build-in subroutine contains the Colburn-Hougen iteration method to find the inter-phase temperature and, from it, the heat transfer coefficient. Such method caused huge distortions in the results when, too often, the iteration didn't converge, producing unphysical results.

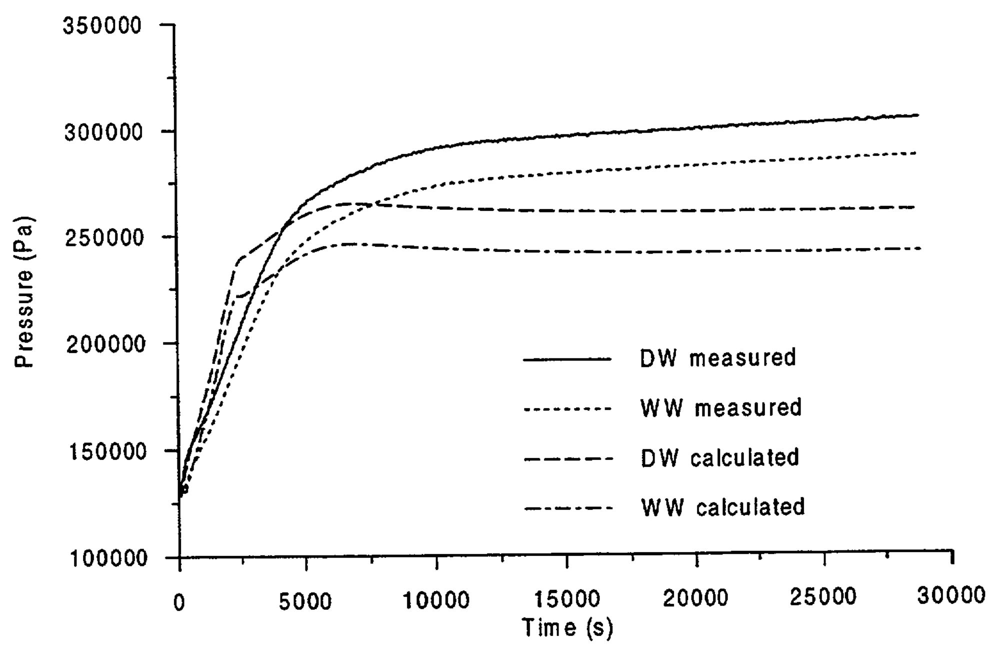

Figure 10. Containment pressures evolution in test P3 (calculation using Colburn-Hougen method).

To overcome that problem, the source program was modified in order to use the so called UCB model (Vierow and Shrock, University of California, Berkeley), which is a simpler model that reduces the pure steam heat transfer coefficient using a degradation factor depending on mass fraction of non-condensable gas. This model, though it overestimates heat transfer, is quite robust and doesn't produce non-physical results.

In order to illustrate the reasons underlying the change in the condensation model, figure 10 reproduces the results of a test P3 calculation using the original subroutine. From the analysis of pressure evolution it could be erroneously deduced that Colburn-Hougen method gives better results than UCB model. Such feeling disappears when looking at wetwell space temperatures (figure 11): with the original subroutine, RELAP5 predicts gas phase temperature values that are well above of pure steam saturation temperature at the maximum pressure in the experiment. Figure 12 shows the pressures evolution calculated with Colburn-Hougen method for test P6; it's clear that with UCB model better results are obtained (figure 7).

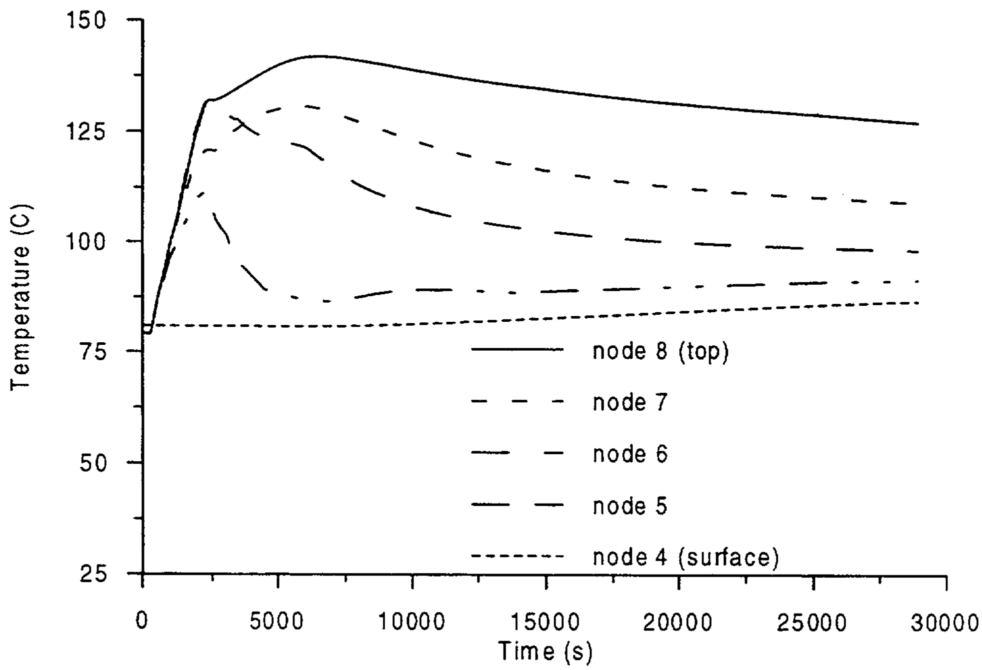

Figure 11. Temperatures in WW1 gas space in test P3 (calculation using Colburn-Hougen method).

After some sensitivity studies it was observed that small modifications in the nodalization helped, in some cases, to mitigate stratification effects. Two solutions of this kind that were incorporated into the RELAP model of PANDA [3]:

· improvements in the connection between suppression pools and

· change in the orientation of the junctions connecting the main vent lines to the suppression pools.

In the original model, the pipe connecting both suppression pools had only junctions to the upper face of node 3 of both wetwell vessels. In such way, part of the air vented through the main vent lines accumulated in the aforementioned pipe, moved the liquid into the pools and caused a sharp increase in the pools level. Such phenomenon has been avoided by complementing the downward oriented junctions with upward oriented ones (from the pipe to the lower face of node 4 of both wetwell vessels).

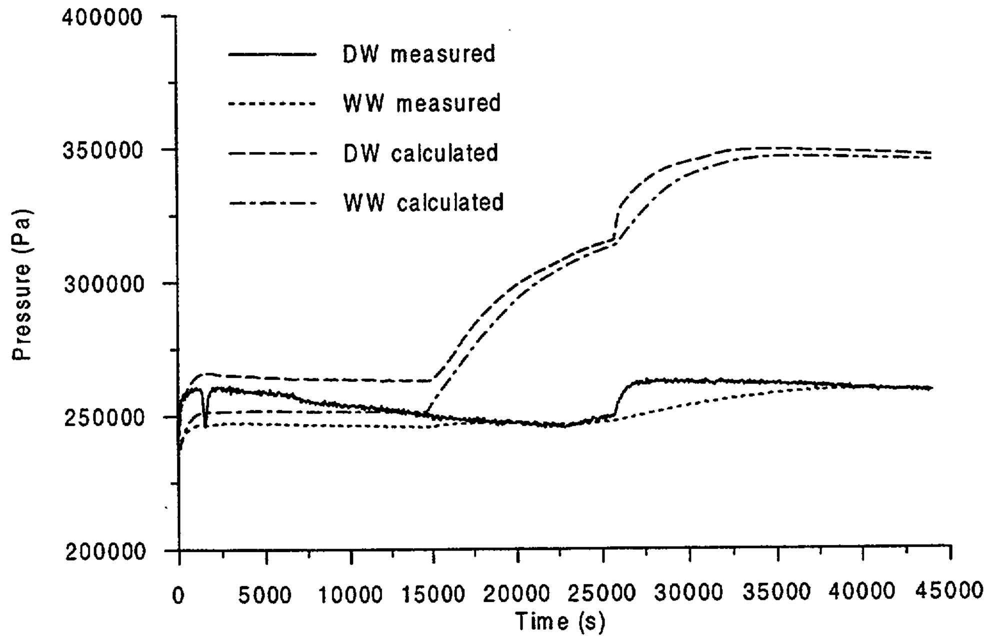

Figure 12. Containment pressures evolution in test P6 (calculation using Colburn-Hougen method).

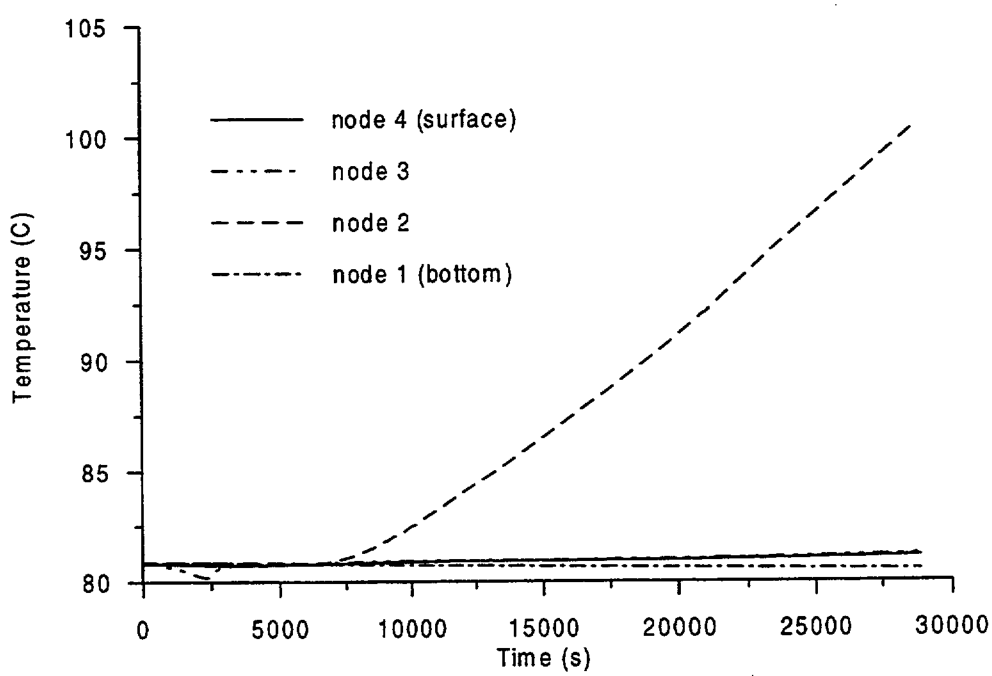

Figure 13. WW2 liquid temperatures calculated using original nodalization. Test P3.

The effects of the calculated temperatures stratification in the suppression pool have been mitigated reorienting the junctions at the exit of the main vent lines (originally connected downwards the upper face of node 2 of both wetwells), connecting them to the lower face of node 3. From figure 13 it can be seen that, with the original noding, the energy transferred through the vent lines warmed only the liquid in node 2 and the surface temperature remained constant during the whole simulation. Figure 14 shows the evolution of the temperatures calculated using the final nodalization, as compared with the experimental ones; it can be observed that, although a strong stratification persists, the calculated surface temperature (upper node) exhibits a behaviour closer to the real one.

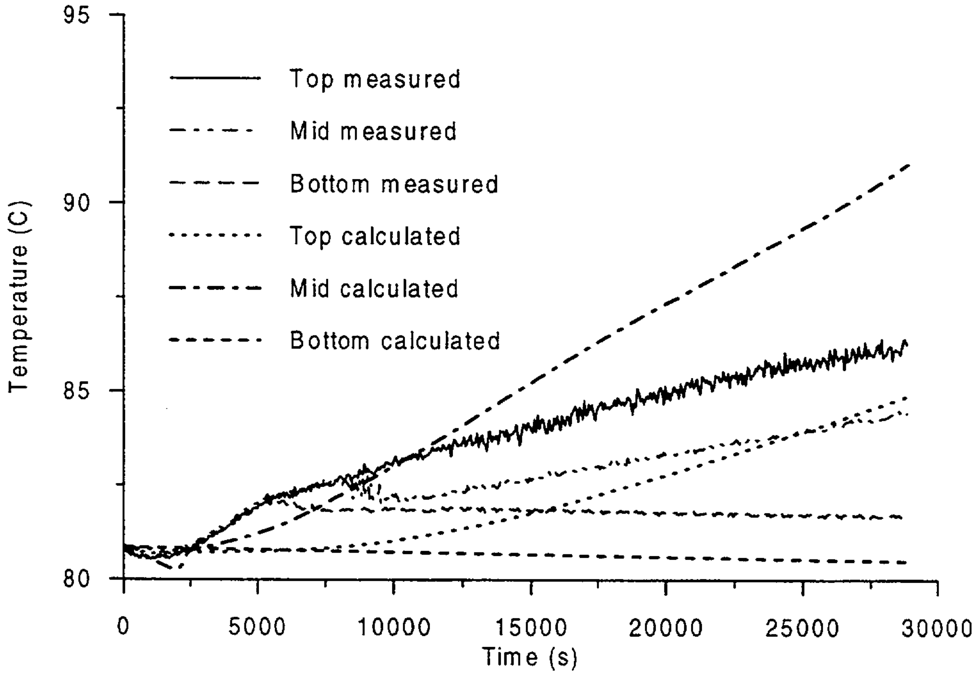

Figure 14. WW2 liquid temperatures calculated using the final nodalization. Test P3.

Although a suitable monodimensional nodalization can sensitively improve the global behaviour of the model, some causes of anomaly (i.e. stratification of air-steam mixture in gas spaces and accumulation of non-condensable gas in some nodes of those spaces) require stronger solutions like the use of three-dimensional models, but RELAP5 shows some limitations in this field.

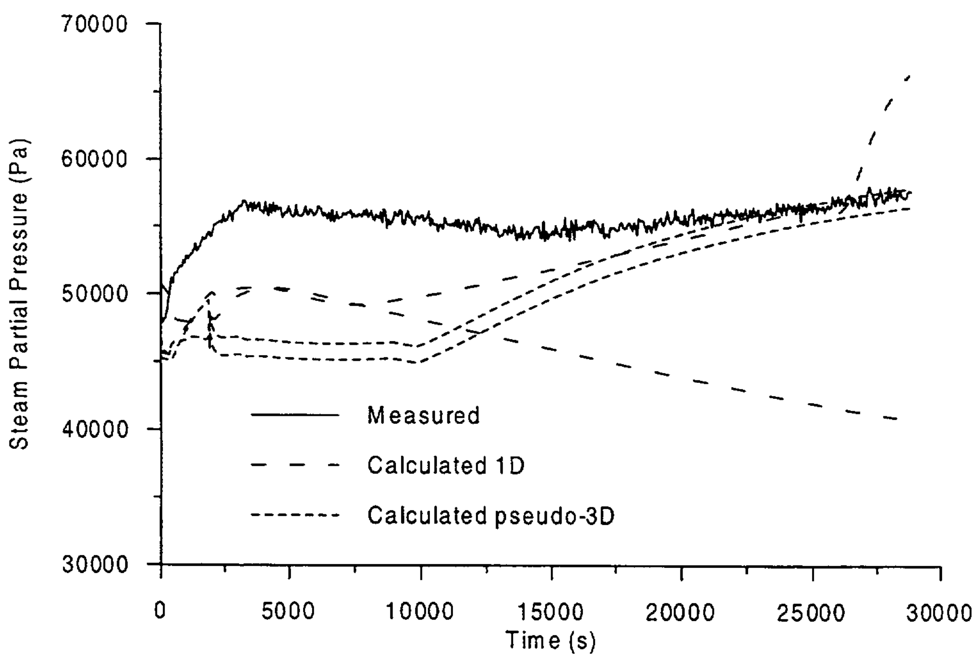

Figure 15. Partial air pressure in WW2 (at different elevations). Test P3.

To illustrate how the predictions could be improved by departing from monodimensionality, test P3 has been simulated using a pseudo-3D noding (two parallel channels with cross-flow junctions) of wetwell gas space. Figure 15 shows the time evolution of partial air pressure at different elevations in WW2, as compared with the experimental value (each wetwell in PANDA is equipped with a single air probe). It can be noticed that the stratification is clearly reduced by using a non-monodimensional model. The behaviour of system pressures (figure 16) also shows a tendency closer to the real one in the simulation with a pseudo-3D model, though the large differences between calculation and experiment have not been corrected (due to the retention of air in DW1 in the simulation)

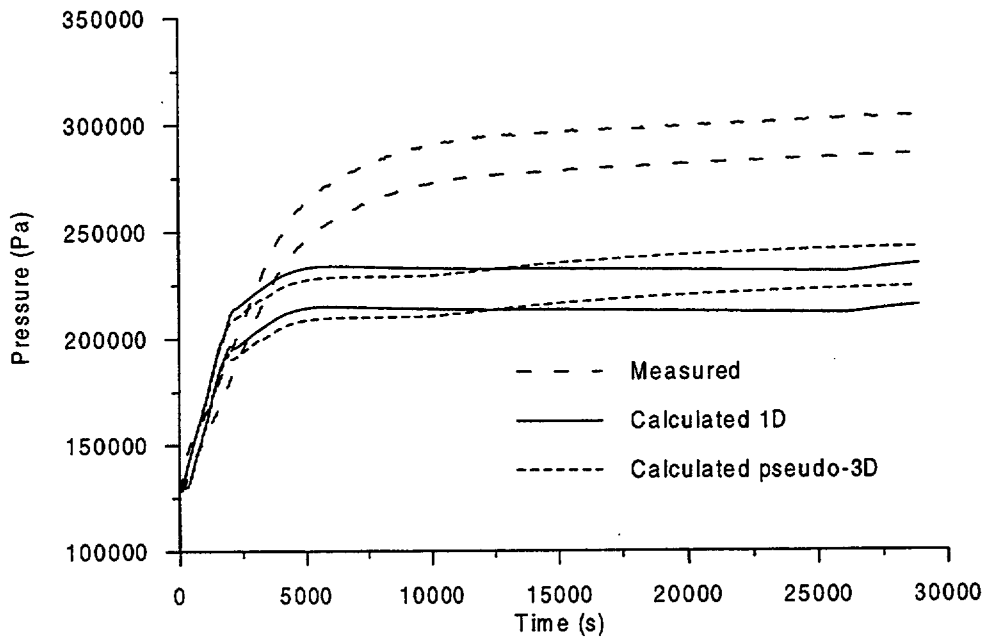

Figure 16. Evolution of pressures in drywell and wetwell. Test P3.

6. Summary and additional considerations

In the considered scenarios and, actually, in all the experiments performed in PANDA for the TEPSS project, it has been observed that, though the air-steam mixture is not uniform in the large vessels, its behaviour is homogeneous, in the sense that it exhibits a smooth spatial variation. This fact has been corroborated with experimental measurements (partial air pressures and temperatures) as well as with 3D fluid-dynamics codes (CFD) [1,9].

On the contrary, the simulations with RELAP5/Mod3.2 performed by UPC, as well as those performed by ECN and PSI, give anomalous accumulations of air and sharp stratifications of the air-steam mixture. These phenomena are dominant over other causes of discrepancy, such as, i.e., the inaccuracy of the condensation models when non-condensable gases are present.

Nevertheless, RELAP5 has shown to be a robust code, reproducing quite well the global behaviour of the system (in the sense that it correctly predicts the function of the facility components and systems) with reasonable computation times [10]. So, it has been possible to perform with relative economy different sensitivity studies, as the above mentioned regarding time step and noding. About the latter ones, it is worth to mention that the fact of studying two tests in parallel has been of great usefulness. On one hand it has been possible to detect which renodalizations, though improving the results of some of the parameters calculated in one of the experiments, hindered the predictions from the overall point of view. On the other hand, it has also been possible to make changes in the model that, although penalizing some partial results, were beneficial to the simulation of the general scenario. In other words, studying both tests has allowed us to better validate the final model.

In addition to the aforementioned, the sensitivity of the model (and of the facility) to the initial conditions (temperatures, partial air pressures, levels...), to the heat losses, etc. have been analyzed.

7. Conclusions

UPC has been co-operating for three years in TEPSS project, giving analytical support of PANDA experiments. Actually, UPC task has been to perform the pre- and post-test analyses of the P3 and P6 experiments using RELAP5/Mod3.2. Despite of the difficulties encountered in the simulations, because of code limitations and of the fact of using a monodimensional model of the facility, results so obtained are considered acceptable from a global point of view, as the goal of reproducing the global behaviour of the facility (functionality of components and systems) has been reached.

RELAP5 as well as the model used have shown to be useful tools in order to analyze transients of the kind of PANDA experiments. It is important to take advantage of the code capabilities to predict the general behaviour of accidental scenarios as well as to perform sensitivity studies.

Computer codes used by conventional nuclear plant owners are requested to be able to simulate scenarios that are far from those classically studied. So it is necessary to test the codes in challenging situations they are, in principle, not designed for. Thus, authors consider very positive their participation in TEPSS, as well as the chance of using RELAP5 to analyze an experimental facility simulating a passive boiling water reactor, in a experiment series involving the containment and the heat removal passive safety systems and implying phenomena such as natural circulation and steam and non-condensable gas mixing, among others.

To conclude, in authors opinion, the results contributed by this study and similar ones are a reference point to be taken in consideration in the development process of future consolidated codes.

8. Run Statistics

Calculations were carried out on a SUN UltraSPARC 450, with SunOS 5.6 operating system.

RELAP5/Mod3.2 was used in all the calculations, with the changes in the condensation model mentioned in section 5.

References

[1] Hart, J. et al, *Technology Enhancement for Passive Safety Systems-TEPSS.* Final Report INNO-TEPSS(99)-D20, 1999.

[2] Huggenberger, M., *TEPSS Project: PANDA P-Series Test Specification.* PSI, ALPHA-703-0, TM-42-97-05, 1997.

[3] Batet, L., Reventós, F., *Relevant results of pre and post-test analysis of P3 and P6 PANDA experiments.* IAEA Technical Committee Meeting on Experimental Tests and Qualification of Analytical Methods to Address Thermalhydraulic Phenomena in Advanced Water Cooled Reactors, PSI (Switzerland), 1998.

[4] Polo, J., *Post Test Analysis of PANDA Test P3. TEPSS Project (WP2).* CIEMAT, INNO-TEPSS(98)-D-14, DFN/SN-17/IF-98, 1999.

[5] Huggenberger, M. et al., *TEPSS Project: Integral System Test P3. Test Report.* PSI, INNO-TEPSS (98) D8, ALPHA-819, 1998.

[6] Polo, J., *Post Test Analysis of PANDA Test P6. TEPSS Project (WP2).* CIEMAT, INNO-TEPSS(98)-D-16, DFN/SN-01/IF-99, 1999.

[7] Huggenberger, M. et al., *TEPSS Project: Integral System Test P6. Test Report.* PSI, INNO-TEPSS (98) D11, ALPHA-819, 1998.

[8] Batet, L., Chiva, S., Muñoz-Cobo, J.L., Reventós, F., *Modelling activities of experimental facilities related to advanced reactors. Considerations on 1D/3D issues.* ICONE7, Tokyo (Japón), 1999.

[9] Bandurski, T., Putz, F., Andreani, M., Analytis, M. *Modelling of particular phenomena observed in PANDA with GOTHIC.* IAEA TCM on Experimental Tests and Qualification of Analytical Methods to Address Thermalhydraulic Phenomena in Advanced Water Cooled Reactors, PSI (Switzerland), 1998.

[10] Lübbesmeyer, D., *Post test analyses of TEPSS tests P2, P3, P5 and P7 using the system code RELAP5/Mod3.2.* IAEA TCM on Experimental Tests and Qualification of Analytical Methods to Address Thermalhydraulic Phenomena in Advanced Water Cooled Reactors, PSI (Switzerland), 1998.

NRC FORM 335
(2-89)
NRCM 1102,
3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER
(Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, if any.)

NUREG/IA-0196

2. TITLE AND SUBTITLE

Analysis of PANDA Experiments P3 and P6 Using RELAP5/MOD3.2

3. DATE REPORT PUBLISHED

MONTH	YEAR
January	2001

4. FIN OR GRANT NUMBER

5. AUTHOR(S)

L. Batet, F. Reventos

6. TYPE OF REPORT

Technical

7. PERIOD COVERED *(Inclusive Dates)*

8. PERFORMING ORGANIZATION - NAME AND ADDRESS *(If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)*

Department of Physics and Nuclear Engineering
University Politecnica de Cataluna
08028 Barcelona
SPAIN

9. SPONSORING ORGANIZATION - NAME AND ADDRESS *(If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)*

Division of Systems Analysis and Regulatory Effectiveness
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

10. SUPPLEMENTARY NOTES

11. ABSTRACT *(200 words or less)*

Between 1996 and 1998 Technical University of Catalonia (UPC) has been participating in the "Technology enhancement for Passive Safety Systems" (TEPSS) project, in the Fourth Framework Program of the Commission of the European Communities. One of the purposes of TEPSS has been the study of the residual heat removal by passive means after a loss of coolant accident into a simplified boiling water reactor (ESBWR) type containment. To that end, eight experiments have been performed in PANDA experimental facility of Paul Scherrer Institute in Villigen (Switzerland). PANDA represent a ESBWR scaled 1:1 in elevation and 1:40 in volume. UPC has supplied analytical support of PANDA tests P3 and P6, using RELAP5/MOD3.2 P3 and P6 simulate Main Steam Line Break scenarios with different initial conditions and different passive safety systems available. this report shows the results obtained in the simulation of those experiments. Discrepancies between calculated and measured parameters are identified and discussed.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

PANDA
RELAP5/MOD3.2
SBWR

13. AVAILABILITY STATEMENT

unlimited

14. SECURITY CLASSIFICATION

(This Page)
unclassified

(This Report)
unclassified

15. NUMBER OF PAGES

16. PRICE

Printed on recycled paper

Federal Recycling Program