Validation of severe accident codes against Phebus FP for plant applications: status of the PHEBEN2 project

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Abstract

The European Commission-funded shared-cost action project PHEBEN2 brings together 13 partner organisations to understand the source term aspects of the integral Phebus FP experiments, to validate integral LWR severe accident codes against the test data, to develop and apply criteria regarding the strengths and weaknesses of the codes for plant applications, and to propose guidelines for their optimum use for this purpose. At the half-way point of the project, contributions to the final interpretation report of the first Phebus test FPT0 have been completed and work on the interpretation of the following test is proceeding. A detailed investigation by CFD and particle tracking appears to have identified the cause of the systematic underprediction of deposition in the steam generator tube of the Phebus circuit. Containment calculations using lumped-parameter codes have been supplemented by extensive CFD analyses, revealing complex circulation patterns within the relatively simple containment geometry of Phebus. Iodine chemistry studies have been made of both FPT0 and FPT1. Concerning criteria and code assessment for plant applications, a short list of safety-important phenomena explored in Phebus has been prepared, and partners have drafted a report analysing for each phenomenon its safety importance, the experimental data available, the modelling approach adopted in PSA codes, and the expected uncertainties.

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1. Introduction

Plant assessment for risk and safety margin determination and the assessment of accident management measures usually relies heavily on one or more integral codes to represent the main phenomena, couple together physically linked events, ensure the respect of mass and energy balances, and highlight the dominant contributors to the risk. Detailed codes are often also applied to features which are both important for risk and where uncertainties associated with the integral code are significant. It is recognised that one of the hazards of such analysis is to be unconsciously guided by the code’s implicit assumptions, especially when experimental evidence is sparse (NRWG, 1996; CSNI, 1996).

The integral in-pile experiments of the Phebus FP series (Schwarz et al., 1998), which are financially supported by the European Commission on behalf of the European reactor safety community, are a unique source of representative integral source term data, and are intended to provide a reality check for plant assessment. They couple together in a scaled but rather realistic manner the degradation of fuel and control rods, (through to the formation of a molten pool), the release of fission products and control materials, their transport through the reactor coolant circuit, their deposition as aerosols in the containment vessel, and medium-term processes such as radiation chemistry which can produce volatile forms of fission products available for release to the environment should the containment leak or be deliberately vented (Tuomisto, 1999).

In Phebus test FPT1, for example, a 1-m grid-ded bundle of 18 fuel rods irradiated to an average of 23 MWd/t, plus two fresh rods and a central silver–indium–cadmium control rod, was surrounded by an insulating thermal shroud in a test assembly and subjected to a power transient in the central cavity of the Phebus pool reactor at CEA Cadarache, as shown in Fig. 1.

Steam was injected at the foot of the test assembly at a rate of 1.5 g/s and a system pressure of 0.2 MPa. Degradation occurred over a period of 5 h during which the bundle power was increased progressively from 3.19 to 34.4 kW, as shown in Fig. 1a. The maximum temperature rise rate was 15 °C/s, the total hydrogen mass produced was 96 g, and during the extensive degradation process, which led to the production of a large pool of molten material and left the bundle with a central open cavity, over 80% of the more volatile fission products (Kr, Xe, Cs, Te) were released, together with control rod components and other structural materials. The total aerosol release was about 150 g.

The released material was swept by the steam flow through an experimental circuit, intended to simulate aspects of the primary circuit of a PWR. As indicated in Fig. 1 this consisted of a vertical line and a horizontal line, both trace-heated to 700 °C, followed by an instrument station at the point marked C, maintained at the same temperature. Point C was in turn followed by an inverted U-tube scaled to the steam generator tubes of a PWR (volume scaling 1:5000), after which came a second instrument station at Point G. A jacket containing circulating liquid lowered the gas temperature to 150 °C over about 1.5 m of the rising leg of the steam generator tube, and the remainder of the circuit was at the same temperature. Circuit instrumentation included on-line gamma scanning stations, filters and impactors, and sequentially operated thermal gradient tubes at Point C.

Releases from the circuit passed through a conical nozzle at Point H in Fig. 1 into a 10 m³ vessel simulating a large dry PWR containment, scaled to preserve fission product concentrations. The vessel wall temperatures were controlled to produce a relative humidity of the order of 70%. The vessel pressure was limited and a degree of natural circulation induced by three cylindrical structures with internal cooling systems, termed condensers, suspended within the vessel as shown in Fig. 1. The vessel wall was of electropolished steel and was expected to remain neutral, while the painted condenser surfaces were scaled to provide surface area for chemical interaction with fission product aerosols and vapours similar to the containment vessel and internal compartments in a PWR. Water from the condensers was periodically conducted to the pool of water at the bottom of vessel representing the reactor sump. Containment instrumentation included hydrogen sensors, filters, impactors, an optical aerosol sizing device, and on-line gamma scanning of the wall, condensers and sump. For further details, see Schwarz et al. (1998).

A variety of codes is currently employed for the analysis of the results, (Jones et al., 1999). In order that
Fig. 1. (a) Schematic of the Phelbus FP installation; (b) bundle power and steam flow histories, test FPT1.
they may be used with more confidence and certainty in plant analysis and the evaluation of severe accident measures, they require validation and quantification of their quality, particularly as regards the treatment of strongly coupled processes such as occur in severe accidents and in the Phebus tests.

This project concentrates on source term aspects of Phebus FP: transport of fission products in the circuit (Allelein, 2000a), their abatement in the containment, and risk-important aspects of containment chemistry. Full results (final experimental reports) are now available from the first two Phebus tests, FPT0, (Hanniet-Girault and Repetto, 1999), (Clement et al., 2002) and FPT1 (Clement et al., 2000), and those from FPT2 should become available late in the 4-year lifetime of the project. The PHEBEN2 project aims not only to compare calculations with experiment, but also to derive from the comparisons indications regarding code accuracy as well as guidelines for optimum application of the plant analysis codes.

2. Objectives, structure and work programme

The objectives of the PHEBEN2 RTD project can be summarised as follows:

- by the application of detailed codes and partners’ expertise, understand and quantify the physical and chemical phenomena underlying the Phebus results;
- validate integral codes for LWR severe accident analysis versus available Phebus test data;
- develop assessment criteria for integral codes based on the intended application in plant safety analysis and understanding of the key phenomena;
- apply the criteria to provide objective information on the absolute and relative strengths and weaknesses of the codes for plant applications;
- propose guidelines for optimum code use for the various applications and, where possible, quantitative information on uncertainties for use in safety margin assessment, risk studies, etc.

The extensive data on the behaviour of radioactive materials in a nuclear power plant during a severe accident arising from the multifaceted Phebus FP programme are being analyzed in two main ways. Detailed codes for circuit transport and chemistry, CFD codes and lumped-parameter coupled thermal-hydraulics and deposition codes for containment aerosol behaviour, as well as iodine chemistry codes are applied by experts to gain understanding of the phenomena underlying the measurements made in the Phebus experiments and to identify key mechanisms; the same codes are applied to determine the main sensitivities and to identify the strengths and weaknesses of state of the art models. The results and conclusions are documented in interpretation reports for the individual Phebus experiments.

While understanding of phenomena is essential in risk analyses, what the practising plant safety analyst also wishes to know are the uncertainties and any systematic errors associated with the application of a limited number of integral codes (Eglin et al., 1999). In this part of the project the codes ASTEC (Jacq and Allelein, 2000), ECART (Parezi et al., 1996), MELCOR (Gautt et al., 2000) and MAAP (Jacqmin et al., 1995) are being applied to Phebus tests in “best-shot” analyses, supplemented by sensitivity studies, as is usual in plant assessments (Eglin et al., 1999). Using the results and the understanding gained from the analyses with detailed codes, judgements will be formulated on the models in the integral codes and on the way in which they are integrated into an overall framework. Both absolute results (code to Phebus data) and relative information (code to code) will be factored into the judgements. The information from this aspect of the project will again go into the test Interpretation Reports of the project and into the project progress reports, which will provide a more integrated view spanning several tests.

Adequacy for Phebus is not the same as adequacy for plant assessment, because Phebus represents the individual plant and accident sequence only approximately. Based on indications of risk importance from Framework 4 projects such as STU (Ang et al., 1999), SAMIME (Vaysier et al., 1999) and VASA (Allelein et al., 2000b), as well as OECD/NEA/CSNI publications and the expertise of the partners, criteria for the assessment of integral codes for plant assessment are being developed, including information on uncertainties and the determination of safety margins, and consideration of their application in the evaluation of severe accident management measures. Finally, by combining the judgement of the integral codes versus Phebus with the criteria for plant application, the Final Report, expected to appear in mid-2004, will
contain guidelines for the optimum use of integral plant assessment codes, with indications (quantitative where possible) of the expected uncertainties. It is hoped that such guidelines will be appreciated by all end users of such codes, whether for design, planning of operations and operator training, or for regulators applying the codes for the assessment of plants.

The work packages (WP) into which the project is subdivided correspond directly with its objectives. Integral code validation takes place under WP1, while analysis of Phebus phenomena with detailed codes and partners’ expertise is gathered in WP2. Criteria for the application of integral codes to plant assessment are developed in WP3 and then applied within the same WP using the results of WP1. In the same WP, guidelines will be developed for integral code application, together with uncertainty estimates. There is also a coordination activity, which includes reporting to the Phebus committee system (Schwarz et al., 1998), with which PHEBEN2 has a symbiotic relationship.

3. Main achievements to date

At the time of writing, the project is at the halfway mark, with two years to run. The contribution to the Final Interpretation Report of Phebus test FPT0 has been issued (Jones and Mueller, 2002), and the Interim Interpretation Report for test FPT1 is close to completion. The intention of the latter report is to present the state of the art in the interpretation of this test before work begins on the Nuclear Energy Agency’s International Standard Problem 46 (Haste, 2002), to help the participants in that exercise focus on the most interesting and challenging features of the test. Overall project achievements will be documented in subsequent publications.

3.1. WP1: validation of integral codes

Four integral codes are applied in this project: ASTEC, ECART, MAAP and MELCOR. ECART (U. Pisa) and MELCOR (UPM, Martin-Fuertes and Ramirez, 2001) have been applied to the circuit and containment of FPT0, while MELCOR and MAAP are being used to study the fission product behaviour in FPT1. The FPT0 calculations have brought out the important effect the user may have. The ECART predictions of circuit and containment fission product deposition, all made with the same nodalisation, were rather sensitive to the assumed forms of the elements at the circuit entrance (vapours or aerosols) and also to any restrictions on the possible chemical species they may form. Summarising the results of the ECART circuit analysis, the following conclusions may be drawn:

- aerosol formation is quite different for the calculation in which all elements entered as vapours, with a higher predicted value of the aerosol mass median diameter in the region of the inlet;
- the main deposition mechanism in the circuit is thermophoresis, principally in the steam generator, followed by gravitational settling;
- bend deposition (small in the experiment) is only predicted to be significant when large particles are calculated as a result of the injection of elements as vapours;
- the calculated total retentions are qualitatively similar in all the calculations, and somewhat greater than the experimental values.

The containment portion of the analysis predicts that the majority of the deposition takes place by settling on the vessel bottom, with some additional removal by diffusiophoretic deposition on the condenser structures. This finding confirms previous results obtained with lumped-parameter containment codes (Jones et al., 1999).

The MELCOR 1.8.4 calculations (Martin-Fuertes and Ramirez, 2001) subdivide the FPT0 circuit into 8 or 9 volumes, with the rising leg of the steam generator represented as 2 or 3 sections. This portion of the circuit is the most critical, because it is known from the experimental data that thermal conditions vary sharply (the gas temperature drops from 700 to 150 °C over a distance of about 4 m) and that most of the deposition takes place there. Sensitivity of the calculated deposition to nodalisation is observed. For instance, the deposition of the volatile element Caesium in the steam generator is strongly affected by the more or less strong temperature averaging effect of the control volumes:

- Case 1, with three rising segments, predicts that 44% of the injected mass is retained in the rising part of the steam generator;
• Case 2, with only two rising segments which calculates a single temperature in the first 1.5 m segment predicts that 64% (51 mg) is retained: 60% being condensed between 0 and 1.5 m while 4% deposits as aerosols between 0 and 4 m on the wall. The experimental value for Cs retention is of the order of 15%.

The behaviour of tellurium is even more sensitive: all the mass became aerosol in Case 2 on reaching the steam generator and retention accounts for 26%, while up to 36% was retained in Case 1 (21% condensed; 15% aerosol deposited). Calculated total steam generator retention was somewhat greater than the experimental values (25% versus 15%), while it was correctly predicted that retention in the other portions of the circuit was small. A point of practical importance is that because of the rather high gas velocities in the circuit further subdivision of the steam generator tube would be penalising in terms of computer time. Containment results were performed with 1, 2 and 24 sub-volumes, and results were generally satisfactory. Fig. 2 shows that the vessel pressure could be rather closely reproduced, independent of the number of sub-volumes, while Fig. 3 presents the highly encouraging prediction obtained of the total suspended aerosol mass as a function of time.

It should be noted that containment conditions in FPT0 were those of moderate humidity (50–80% RH), so that hygroscopic effects played a minor role. As far as the global aerosol behaviour is concerned the assumption that the containment is well-mixed appears to be satisfactory.

Of considerable interest are the MAAP calculations for FPT1 now in progress at CEA. MAAP is the most widely used integral code for licensee submissions, and these calculations constitute the first occasion...
on which MAAP validation against an integral experiment with irradiated fuel will be presented. First results indicate that, because of problems with representing the Phebus bundle geometry in a code hard-wired for plant analysis, the calculated degradation transient is too severe. Retention in the rising line and the horizontal line of the circuit are underpredicted, which is probably due to the modelling of these circuit lines in the MAAP calculation, while unusually the steam generator retention is somewhat below the experimental data. Containment thermal-hydraulics and fission product deposition on the vessel floor are well predicted for an integral code.

3.2. WP2: validation of detailed codes

As was explained when presenting the objectives, the purpose of applying detailed codes to Phebus in this project is less to validate the codes themselves than to understand the phenomena involved and their
quantitative contributions to the observed results. The detail of the measurements and the specification of the exact boundary conditions are often of more significance for this purpose than they might be for integral code validation.

PHEBEN2 has made progress in the understanding and prediction with detailed codes of Phebus circuit and containment behaviour, looking in the case of the containment at all aspects: thermal-hydraulics, aerosol physics, and short- and long-term chemistry.

3.2.1. Circuit behaviour

One persistent problem with analyses of the Phebus tests has been over-estimation by detailed codes of deposition in the steam generator tube (Schwarz et al., 1998). This has also been confirmed during this project by a calculation with VICTORIA 2.0 (Bixler and Gasser, 2000) by PSI of circuit deposition in test FPT1 (see Fig. 4). As may be seen from the previous section, integral codes show the same behaviour. From the experimental measurements of deposits in FPT0 and FPT1 it is clear that the difficulty lies not with any uncertainty in the experimental values but with the thermophoresis models common to the codes, (Springer, 1979; Talbot et al., 1980). Such models have achieved good agreement with separate-effect tests, and it has been unclear what feature of the Phebus situation was not being captured by them: high aerosol density, combined thermophoresis and vapour condensation, entrance effects, strong temperature gradients or something else.

One of the early achievements of PHEBEN2 has been to shed light on this question by a combination of CFD to calculate the fluid flow and detailed modelling of the aerosol deposition process. An accurate CFD calculation was made of the temperature and velocity distributions in the rising part of the steam generator during a phase of FPT0 when considerable deposition was taking place. One hundred fifty axial and 23 radial meshes were used and the turbulent mixing was simulated with a $k$-$\varepsilon$ model.

The results are shown below, Figs. 5–7. The calculated centre-line temperatures are confirmed by the experimental measurements. Trajectories were then calculated for particles entering the tube at various radial positions in the steam generator tube, the equation of motion including the thermophoretic force determined by the local calculated temperature gradient, interpolated as necessary, (Kroeger and Drossinos, 2000). As is usual in cases of this kind.

Fig. 4. VICTORIA calculations of circuit deposition in FPT1.
particles entering at more than a certain critical distance from the wall do not deposit and are swept on to the following part of the circuit by the carrier flow. A large number of trajectories with starting points on the inlet cross-section were calculated to obtain an accurate estimate of this distance and also to provide the deposition profile. Assuming a uniform particle concentration at the inlet makes it simple to calculate the percentage retention in the steam generator tube. The results are found to be close to the experimental
measurements, as is the deposition profile (Housiadas et al., 2001).

It appears, then, that the basic difference from the separate-effect tests alluded to is the existence of sharp lateral and horizontal temperature gradients in Phebus, not accurately represented in the usual 1D codes. The partners involved (JRC and Demokritos) ultimately intend to develop a modification which will allow Phebus and similar cases to be calculated with the same codes, but before that is done a necessary preliminary is to check that the particle tracking scheme also works well for other tests available in the literature, and this work is now in progress, although the experimental database on the thermophoretic deposition of fine particles from turbulent flows is unfortunately rather sparse.

3.2.2. Containment phenomena

Phenomena in the Phebus containment have been analysed with both lumped-parameter codes, which have been used to study both thermal-hydraulics and the aerosol behaviour, and CFD codes (thermal-hydraulics only).

3.2.2.1. Lumped-parameter codes. The lumped-parameter code studies made in PHEBEN2 have produced thermal-hydraulics results generally similar to those from previous research but even closer to the experimental values, a reflection of accumulated user experience. As an example Fig. 8 presents the atmosphere temperature in FPT0 as calculated by CIEMAT with CONTAIN 2.0. The results are generally within 1 °C or better of the experimental values. Short-term aerosol behaviour can be similarly well-predicted, as in Fig. 9, also from the CONTAIN study.

The longer-term behaviour of the suspended aerosol mass is somewhat influenced by hygroscopicity and by coagulation, as has been shown in a sensitivity study by IRC (Horvath and Jones, 2001) using COCOSYS (Klein-Heßling et al., 2000). Fig. 10 shows the enhanced settling in FPT0 produced by the inclusion of hygroscopic effects. The FPT0 calculations were thought to fail to predict correctly the measured final distribution of the removed aerosol between the vessel bottom (caused by settling), the cooled condensers (caused by diffusiophoresis) and the heated vessel wall. COCOSYS results for total deposition...
are shown in Fig. 11, and indicate that while the settled mass is correctly predicted, the split between condenser and wall surfaces is not. The code predicts virtually zero wall deposition, while in the experiment 15% of the total aerosol was stated to be deposited on the wall (Hanniet-Girault and Repetto, 1999). CONTAIN results were similar, and a good deal of analytical and theoretical effort has been devoted
to understanding the “anomalous” wall deposition (Jones et al., 1999), which was not observed in FPT1. Subsequent to the FISA’01 conference, at which a shorter form of this paper was presented, the wall deposition data were revised, and it is now thought that they are similar to those of FPT1 i.e. of the order of 1% or less of the fission products reaching the containment. Hence, the problem of “anomalous” wall deposition no longer exists, and the agreement of the lumped-parameter codes with the experimental values for total deposition is quite satisfactory.

### 3.2.2.2. CFD analyses of containment thermal-hydraulics

As mentioned previously, apart from the condensation on the condensers and consequent removal of aerosols by diffusiophoresis, the coupling between the thermal-hydraulics and the aerosol physics in the Phebus containment is rather weak. In the plant situation the relative humidity is usually much closer to 100%, there is more opportunity for stratification, and the coupling plays a stronger role in determining local aerosol concentrations as functions of time (Allelein, 2000a). Nevertheless, thermal-hydraulics experiments with controlled wall temperature conditions are not common, and several partners have felt motivated to make a detailed 2D or 3D analysis of the Phebus containment using CFD codes. NRG previously made an analysis of FPT1 using CFX 4.3 (CFX, 1994) and has now completed a 3D analysis of FPT0 with the same code. ENEA has applied TRIO VF to FPT0 and, like other partners, has calculated rather complex convection patterns determined by the temperature differences between condensers, vessel wall and sump water surface, strongly affected by the injected vapour stream when present. Of considerable interest to the containment chemistry modellers (see below) is the mass transfer rate at the sump surface, largely determined by the convective flows just above the sump surface. U. Pisa has also calculated the thermal-hydraulics of FPT0, using CASTEM 2000 in 3D with a relatively fine mesh (30,000 elements). A non-symmetric circulation pattern is predicted, as may be appreciated from Fig. 12, which shows the resulting asymmetric temperature...
Comparing the various code predictions is a difficult task, and the experimental support is limited, since only a few internal temperature measurements and no internal velocity measurements are available from Phebus. The partners involved are investigating the reasons for differences between their predictions.

3.2.3. Containment chemistry

From the point of view of safety analysis one of the most interesting aspects of Phebus is the iodine chemistry, and a number of partners are participating in analysing the containment chemistry using various detailed codes. Partly as a consequence of the predecessor project PHEBEN (Jones et al., 1999) all codes now account adequately for silver–iodine reactions (Krausmann, 2001), and attention is now focused on the contributions to the gaseous iodine measured in the containment atmosphere from the circuit and from interactions with painted surfaces, (Funke, 1999). Experimental data provide not only the total airborne iodine but also the organic and inorganic fractions, so that model validation can be correspondingly more exacting. A study of FPT1 by AEAT using INSPECT, (Dickinson and Sims, 2000), comes rather close to the measurements of total airborne iodine, but underestimates the organic iodine, either because production is underpredicted or because calculated rates of destruction by radiolysis are too high. FZK has applied IMPAIR3 to the same test, and obtained good agreement with measured deposits on painted surfaces. As in the AEAT analysis the organic iodine predictions should be treated with caution. One problem common to both these partners and also to the JRC, which has analysed FPT0 with the IMPAIR code (Güntay and Cripps, 1992), is that a major role in the atmospheric iodine chemistry is played by gaseous iodine arriving from the circuit, but the chemical nature of this iodine is presently unknown. JRC, in collaboration with IRSN, is developing a kinetic model for the circuit chemistry (Cantrel and van Wijk, 1999) in an attempt to identify the gaseous iodine component and to make it possible to predict it.
3.3. WP3: criteria and guidelines for plant applications

Some time has been usefully spent by the partners in this WP in defining the exact scope and planning a route to completion. A first stage has been to set up a list of phenomena which are of key importance for source term evaluation and which are being investigated in the Phedus experiments. A head start on this exercise was provided by the Phedus FP Ad-Hoc group (Schwarz et al., 2001) which in 1999 made a study of the potential impact of the Phedus programme on plant safety analysis. Having identified the phenomena, the various partners have contributed to a report which describes for each of them the safety relevance, the state of knowledge concerning them, the additional information which is expected from Phedus and any other programmes known to the partners, and most importantly, the state of the art in their modelling, distinguishing detailed codes and plant analysis codes. Table 1 presents the phenomena and the partners contributing chapters to the report. PSI is also contributing through an independent review of the partners’ contributions.

The next stage will be to attempt to define actual and acceptable error bands on the prediction of the phenomena for safety evaluation purposes. These will define the evaluation criteria which are one of the main products of this WP.

4. Conclusions and benefits

When complete, the results of the project will be

- a better appreciation of the strengths and weaknesses of the main severe accident codes applied in Europe for plant analyses;
- consequently, better understanding of the main safety issues, for further improved safety with reduced costs, and better targeted accident management procedures with more control over unintended side effects;
- guidance for the optimum use of integral codes for plant assessment;
- risk-oriented indications for research to improve models, helping to focus the limited resources now available on the real needs;
- guidance to the Phedus project, helping to focus instrumentation, post-test laboratory work and test analysis on aspects of most value to the integral codes and their plant applications to the code de-
velopers, by identifying those models whose uncertainties have the greatest impact on risk. Thus far, the project has made substantial contributions to the interpretation and analysis of Phenix tests FPT0 and FPT1. All the major plant analysis codes in use in Europe are being validated against Phenix data within the PHEBEN2 framework. The evaluation criteria for such codes in relation to the phenomena studied in Phenix are being developed, and will shortly be documented for discussion and application by the partners. Future work will concentrate on tests FPT1 and FPT2 and will increasingly be focused on the validation and evaluation of the integral codes for the purpose for which they were designed, i.e. plant analysis. A proposal has been made to the European Commission to extend the PHEBEN2 partnership to organisations in certain accession countries, which have a different perspective on the safety issues as a result of the operation of plants of Russian design by their national utilities.

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References


