
ISP 47 "Containment thermal-hydraulics" Computer codes exercise based on TOSQAN, MISTRA and THAI experiments

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Abstract: International consensus is that a detailed knowledge of containment thermal-hydraulics is necessary to predict the local distribution of hydrogen, steam and air inside the containment under representative conditions of severe accident. Looking back at the ISPs that have been reviewed in the SOAR, it becomes all too apparent that every ISP has involved a rather complicated integral test and that there has been a lack of separate phenomena testing within the ISP framework. The main objective of the ISP-47 is to demonstrate the actual capability of CFD and 'lumped parameter' codes in the field of containment thermal-hydraulics, e.g. to predict the hydrogen distribution under LOCA conditions. The proposed activities will lead to a significant improvement of the reliability of severe accident containment models/codes. As recommended in the SOAR this approach follows a strategy being progressive in modelling difficulty and it is proposed to realize this ISP in two main steps, the first one is dedicated to the validation of refined models in the separate effect facility TOSQAN (7 m³) and at larger scale in MISTRA (100 m³) and the second one addresses the validation of codes in a complex and more realistic compartmented geometry ThAI (60 m³). Descriptions of the three experiments on which the ISP is based and the presentation of the specific test selected for the ISP are given.

1. INTRODUCTION

During the course of severe accident in a Pressurised Water Reactor (PWR), large amounts of hydrogen could be generated and released into the containment. The integrity of the containment could be challenged by certain hydrogen combustion modes. As boundaries between the different combustion modes are characterised by narrow gas concentration bandwidths, gas distribution calculations are needed to generate the initial conditions of a subsequent combustion process.

International consensus is that a detailed knowledge of containment thermal-hydraulics is necessary to predict the local distribution of hydrogen, steam and air inside the containment. Considerable international efforts have been undertaken to better understand the associated phenomena by conducting a large number of experiments and then subjecting the test results to extensive analytical assessment: ISP 23 (HDR/T31.5 –

LBLOCA with natural cool down) [1], ISP29 (HDR/E11.2 – SBLOCA, long term gas distribution) [2], ISP 35 (NUPEC/M7-1 – Gas distribution with containment sprays) [3], ISP 37 (BMC/VANAM M-3 – Gas distribution with aerosols injection) [4].

Nevertheless containment thermal-hydraulics remains an open question and in the frame of the OECD-CSNI activities a state-of-the-art report (SOAR) on 'Containment Thermal-hydraulics and Hydrogen Distribution' [5] was prepared and published.

The main objectives of this SOAR were:

- to assess the current capabilities of analytical tools to make relevant predictions for the plant assessment of existing and future containment with respect to pressure, temperature and gas concentration-distribution inside the containment under severe accident conditions
- to address strengths and weaknesses of analytical methods implemented in codes that are in use to predict the hydrogen distribution within a containment (e.g. lumped parameter codes or three-dimensional (3D) field codes also known as CFD codes) or both taking into account important simulation uncertainties.

With respect to the main objectives of this SOAR, the following conclusions have been made.

Progress has been noted in the development of the more recent codes, as demonstrated by ISP recalculations. Several lumped parameter codes have been improved or have been newly developed; the new versions allow a more detailed insight into processes governing various scenarios of interest, specifically the highly important buoyancy-stratification phenomena. Much attention has been devoted to distribution calculations, eventually serving as a basis for a prediction of hydrogen combustion consequences.

Multidimensional field codes have been further developed. These codes provide solutions of the Navier-Stokes equations for multi-component gas flow and allow fine grid discretization of the free containment volume. Various physical subroutines have been added, e.g. improved routines for heat exchange with confining structures including film wise condensation models, combustion models for hydrogen burns etc. However, application of field codes is a developing methodology requiring a great deal of experience, further validation efforts, and the proof of the codes predictive reliability, especially for full-plant analysis.

Furthermore it is stated in the SOAR, that apparent modelling deficiencies have been noted in recent ISP comparison exercises such as lumped parameter models' inability to accurately compute stratifications, especially when the injections are elevated, the injection rates are low or of short duration or both. Since full containment and complete scenario transient simulations are generally lacking for field codes, comparisons with lumped parameter codes are limited to non-prototypical experiments that may limit conclusions with respect to analyses for real containment. In the area of heat and mass transfer, recent ISPs have not provided convincing evidence that the models in either lumped parameter or field codes are accurate under integral testing, which appears to be a fault of the measurement techniques applied in these tests. Additional separate effects testing and improved measurement techniques for integral tests will be needed to directly confirm the accuracy ranges of those models under severe accident conditions.

Looking back at the ISPs that have been reviewed in the SOAR, it becomes all too apparent that every ISP has involved a rather complicated integral test and that there has been a lack of separate phenomena testing within the ISP framework. This oversight is especially true for highly important processes of mixing and transport, where competing effects from surface heat and mass transfer, engineering safety features, or mitigation devices have prevented a thorough evaluation of our modelling abilities.

According to this conclusion, a proposal for a new ISP on Containment Thermal-hydraulics was elaborated and presented to OECD-CSNI on March 2001.

2. OBJECTIVES AND ORGANISATION

The main objective of the ISP-47 is to demonstrate the actual capability of CFD and 'lumped parameter'-codes in the field of containment thermal-hydraulics, e.g. to predict the hydrogen distribution under LOCA conditions. The proposed activities will lead to a significant improvement of the reliability of severe accident containment models/codes especially in the field of accident management procedures, e.g. against hydrogen as a potential risk for early containment failure. Furthermore these activities will lead to an increased understanding of the related phenomena.

Following the recommendations made in the SOAR, a procedure is defined:

- to bring together CFD- and "lumped parameter"- approaches
- to cover phenomena which are important for the simulation of containment thermal-hydraulics, but which are still uncertain, too: wall condensation, atmospheric stratification, natural circulation, more qualitative insight in turbulent diffusion and interactions between these phenomena
- to contribute to the comprehensive validation of models addressed by the above mentioned phenomena
- to assess the capability of CFD-codes to take into account the change in scale
- to use specific measurement techniques in agreement with the scale of the relevant physical phenomena described above.

First it should be pointed out that it was impossible to define only one experiment fulfilling all of the above-mentioned aspects. Therefore a systematic approach was developed using different available facilities, each with sophisticated instrumentation to validate severe accident containment models/codes to the required levels. As recommended in the SOAR this approach follows a progressive strategy in modelling difficulty and it is proposed to conduct this ISP in two main steps:

- Step 1 will be dedicated to the validation of refined models in the separate effect facility TOSQAN (7 m³). Wall condensation, buoyancy will be addressed under well-controlled initial conditions in a simple geometry. Simultaneously, the validation of the interactions of phenomena such as condensation/stratification, turbulence/buoyancy, ... including the effect of scale-up allowed by the large scale of MISTRA (100 m³) will be addressed with the flow patterns in a rather simple geometry.

- Step 2 will address the validation of codes in a complex and more realistic compartmented geometry. Stratification in a multi-compartment geometry with asymmetric injection will be studied in ThAI (60 m³) - with the possibility to use the PANDA-facility (200 m³) as a second totally different geometry in a further step.

According to Step 1, the following organisation to perform the ISP 47 has been suggested:

- A first phase will concern the tests for air/steam mixture. This phase will be an open exercise on TOSQAN results and a blind exercise on MISTRA ones. It is proposed to calculate the TOSQAN ISP test in order to validate the codes, and then, with an equivalent mesh (i.e. it is suggested to use approximately the same total number of nodes to mesh the larger MISTRA volume, in order to evaluate the effect of scale on the models), to perform the blind calculations on the MISTRA experiment.

This phase will be relevant to evaluate the capability of the codes, validated in a simple geometry at small scale, to predict gas distribution in a similar simple geometry but at larger scale.

- A second phase will concern calculations on air/steam/helium tests. These calculations will be performed in open on TOSQAN results and as a blind exercise on the MISTRA tests.

This phase will be relevant according to the effect of a lighter-than-steam non-condensable gas on the condensation and on the capability of the codes to take into account this effect at different scale.

In the following text, descriptions of the three experiments on which the ISP is based and the presentation of the specific tests selected for the ISP are given.

3. TOSQAN FACILITY

3.1 TOSQAN project

The main purpose of the TOSQAN experiment is to validate the condensation and flow models incorporated in 3D codes for various thermal-hydraulic conditions representative of severe accidents of a Pressurised Water Reactor (PWR).

The main objectives of the tests, performed for turbulent flows in natural, mixed and forced convection regimes and in the presence of non-condensable gases, are the study of the effect on the hydrogen distribution (H₂ simulated by helium) of different phenomena such as steam condensation on walls, mass and heat transfer at the sump-atmosphere interface and steam condensation on spray droplets.

The set-up has been designed to be able to respond with the greatest flexibility to the demands associated with the objectives. In particular it can simulate the pressurisation and depressurisation phases by means of wall temperature control.

Furthermore, since the TOSQAN experiment is intended to validate 3D codes, special attention has been paid to local measurements, which will allow the principal variables under study (temperature, concentration and velocity) to be correctly mapped.

The TOSQAN facility is devoted to the study of different basic modelling, especially for the validation of field codes. It is of relative small size with well-controlled wall temperature, making realistic CFD improvements with actual computer power. It is well instrumented with great possibilities of non-intrusive measurements, so that it allows a quite exhaustive comparison with numerical calculation, and as a result, a good feed back for the modelling included in the concerned field codes.

3.2 TOSQAN experimental facility

3.2.1 Geometry

The TOSQAN enclosure is a cylindrical chamber of stainless steel and a sump. The total internal volume (including the sump) is 7.0 m³. The figure 1 gives the real proportions of the vessel.

The whole wall is thermostatically controlled, being made of double shield of stainless steel, within which circulates the heat-transport fluid (mineral oil). The envelope is divided into two zones, in order to fix two different values of the wall temperature.

The top and bottom (including sump) parts of the vessel have the same temperature, called the "hot temperature". On the middle zone, which constitutes the condensation zone, we impose a different temperature, called the "cold temperature" or the temperature of the "cold wall".

The enclosure is fitted with a total of 14 windows made each of 2 silica glasses (each is 35 mm thick), required for concentration and velocity measurements by laser diagnostics, two of them allow parallel-to-wall measurements.

All the gases (steam, air, and helium) are injected through an injection tube, which comes from the side into the facility, and after a 90° turn is directed towards the top in the centre of the vessel.

The condensed water is collected at the bottom of the condensing area, and flows into a small heated vessel (condensing pot) connected to the TOSQAN vessel.

TOSQAN vessel

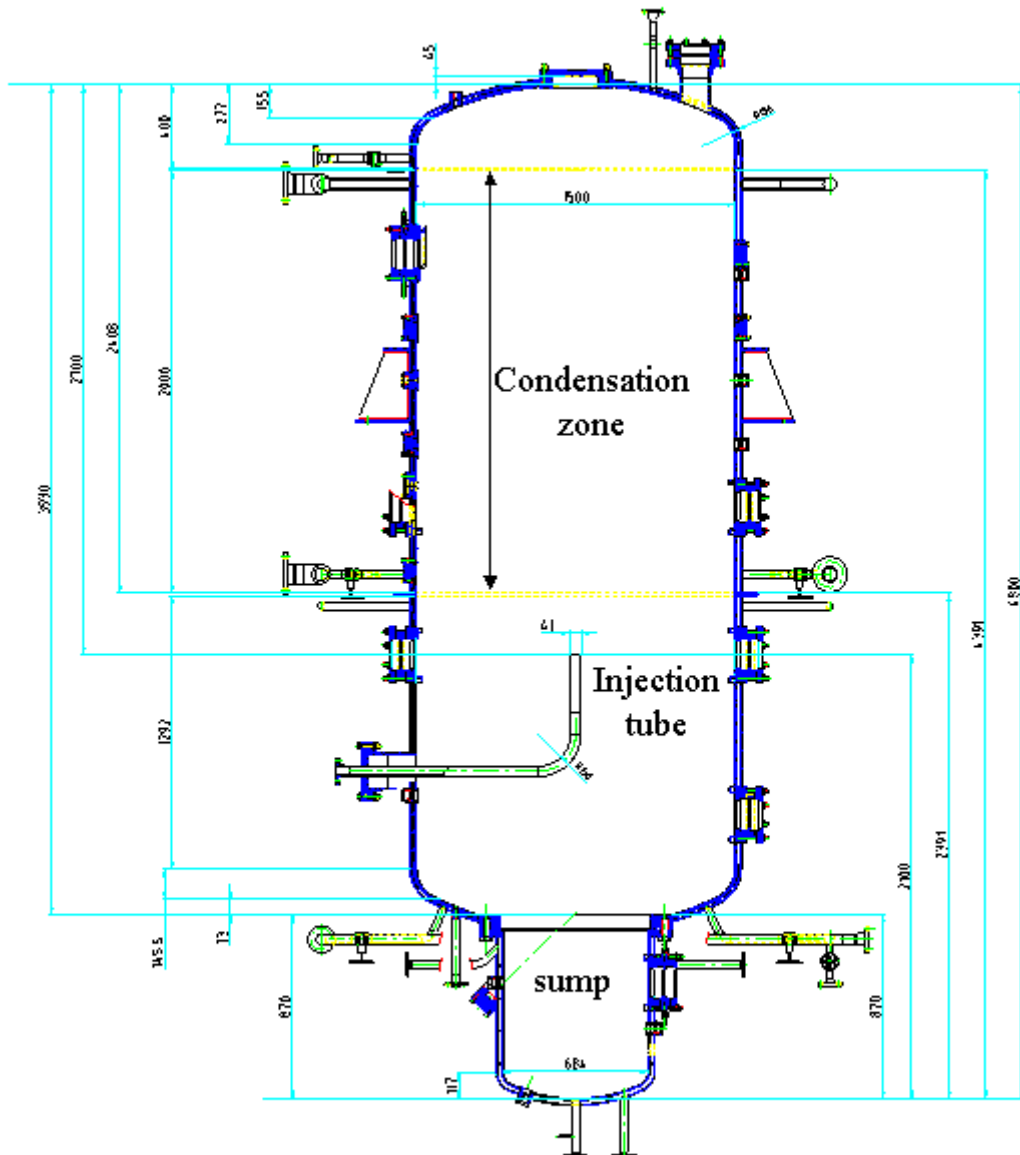


Figure 1: TOSQAN exact geometry

3.2.2 Instrumentation

The TOSQAN facility is equipped with different flow meters in order to measure the injected gases and the condensed water flow rate. Three pressure gauges allow the total pressure measurement in two points in the vessel and one in the injection pipe.

A specific instrumentation is devoted to velocity, gas concentration and temperature measurements.

- Velocities and turbulence

The velocities are measured by non-intrusive laser diagnostics through windows, and more precisely with Laser Doppler Velocimetry (LDV) and Particle Image Velocimetry (PIV).

LDV allows measuring two components of mean and RMS local velocities, and turbulence intensity. PIV allows measuring instantaneous and mean velocities fields (temporal resolution 10 Hz, field area about 300 x 200 mm²).

There are 6 windows at 2 different levels in the condensing zone, and 4 windows at 2 different levels in the lower non-condensing zone. Whole radial velocity profile can be realised at 4 levels with LDV. Velocities fields in the centre part of the vessel can be obtained at 4 levels with PIV.

Velocities fields near the condensing wall can be realised at 2 levels with PIV.

- Gas concentrations

Gas concentrations are measured by two different ways: Spontaneous Raman Spectrometry and Mass Spectrometry.

The first one is an optical diagnostic, based on an inelastic scattering process involving the interaction of a photon with a specific vibrational-rotational state of a molecule, it allows to measure the local gas mean concentration (steam and air) on whole radial profile at 4 different levels.

The second one, the mass spectrometry device, is based on analysis of samples of gas by a quadrupole mass spectrometer. There are 54 gas-sampling points in the vessel, distributed on 9 heated lines located at different heights. Each heated line is connected via a rotating valve to 6 fine tubes fixed on a steel rod that penetrates into the vessel. The length of each rod is 275mm. Six lines are located in the "cold" zone, horizontally, at 4 different heights, 2 of them are horizontal and both at the same height in the lower "hot" zone, and the last one is 45 ° inclined, located in the sump.

- Temperatures

The temperature measurements of the gas are provided by 90 thermocouples fixed on steel rods.

There are 6 horizontal rods corresponding to diameters of the vessel, half of them located in the "cold" zone. On each rod are regularly fixed 7 thermocouples. These rods are not in the same vertical.

There are 2 vertical rods parallel to the condensing wall. Each of these rods supports 10 thermocouples along the height, at 30 mm from the wall. At 3 different heights on these rods are also placed 3 thermocouples more, located at respectively 3, 5 and 7 mm from the wall. There are then a total of 38 thermocouples in the gas near the "cold" wall.

There are 2 other vertical rods parallel to the lower "hot" wall, each supporting 5 thermocouples located at different heights at 70 mm from the wall.

20 thermocouples are placed on the walls: 2 on the dome (upper "hot" part), 12 on the condensing wall at different height, and mainly near the vertical rods, 4 on the lower "hot" wall, and 2 on the wall of the sump.

3.3 TOSQAN ISP test

3.3.1 General overview

The proposed TOSQAN experimental test for this ISP is focused on the evaluation of flows, thermal and mass distribution, and condensation heat and mass transfer modelling. The TOSQAN ISP test is composed of a succession of different steady states obtained by varying the injection conditions in the test vessel (see Figure 2). The main stages of concern for the measurements (and thus for the numerical calculations) are the four steady-states: three steady states of air-steam mixture at two different pressure levels, and one steady state of air-steam-helium mixture. Each steady state is reached naturally by keeping a constant steam injection flow rate: The total pressure increases together with the condensation mass flow rate, until the latter reaches the injection mass flow rate value. The objective of the two first steady-states (steady-states 1 and 2) is to produce two different kinds of flows in the TOSQAN vessel by changing the injection mass-flow rate (multiplying it by 10 in steady-state 2). This will test the numerical modelling under those two kinds of injection conditions.

The objective of the steady-state 3 is to test the influence of initial conditions in the numerical calculations. Flows and gas distribution in steady-state 3 should be quite similar to the one calculated in steady-state one. The only difference is that for steady state one, there is initially no steam in the TOSQAN vessel, and for steady-state 3, steam is already distributed in the TOSQAN vessel.

The objective of the steady-state 4 is to test the numerical modelling with a lighter-than-steam non-condensable gas (helium) on the flow, the mass distribution and the film wise condensation. Furthermore, it is observed experimentally that the time needed to reach this steady-state is much longer than the one of the other steady-states, with a special transient phase that is interesting to be tested in the numerical calculations.

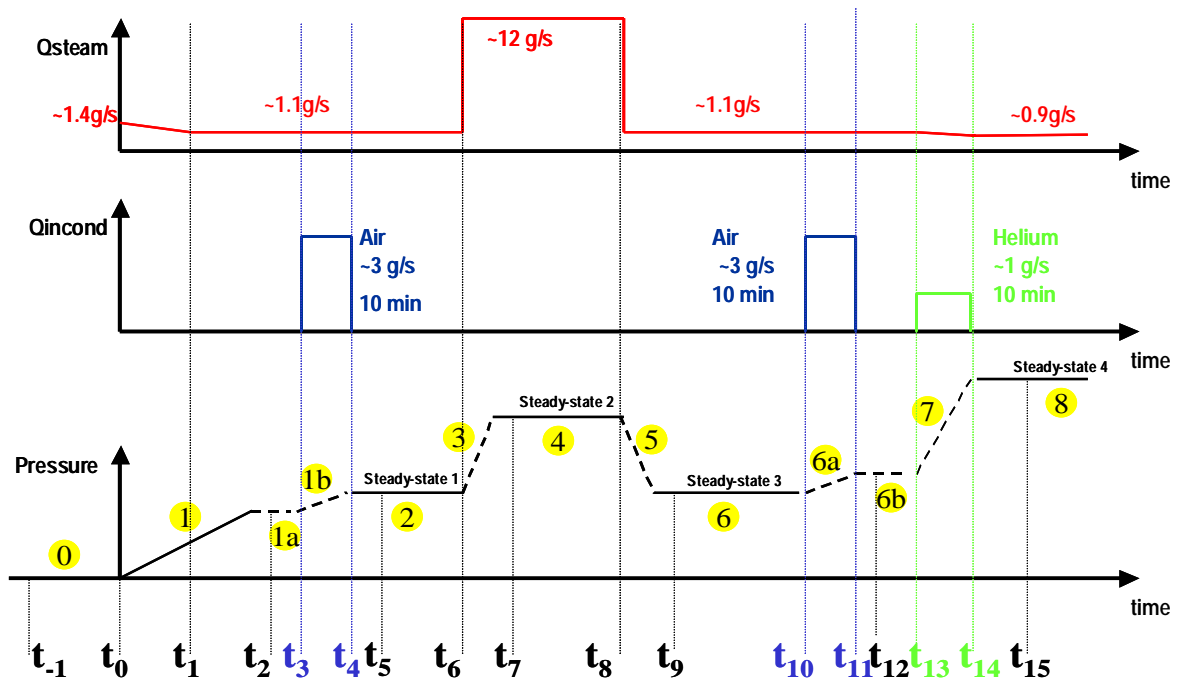


Figure 2: TOSQAN ISP general overview.

3.3.2 Measurements during the ISP sequence

Standard measurements (total pressure, temperature measurements in the gas and closed to the walls and total condensation mass flow rate) will be recorded during the whole sequence duration. The latter is performed experimentally during one day, the so-called day-test. Up to 20 day-tests have been performed and the repeatability on these above measurements (P, T, Q) has been checked on each day-test.

The transient evolution of the measured pressure is given in the figure 3.

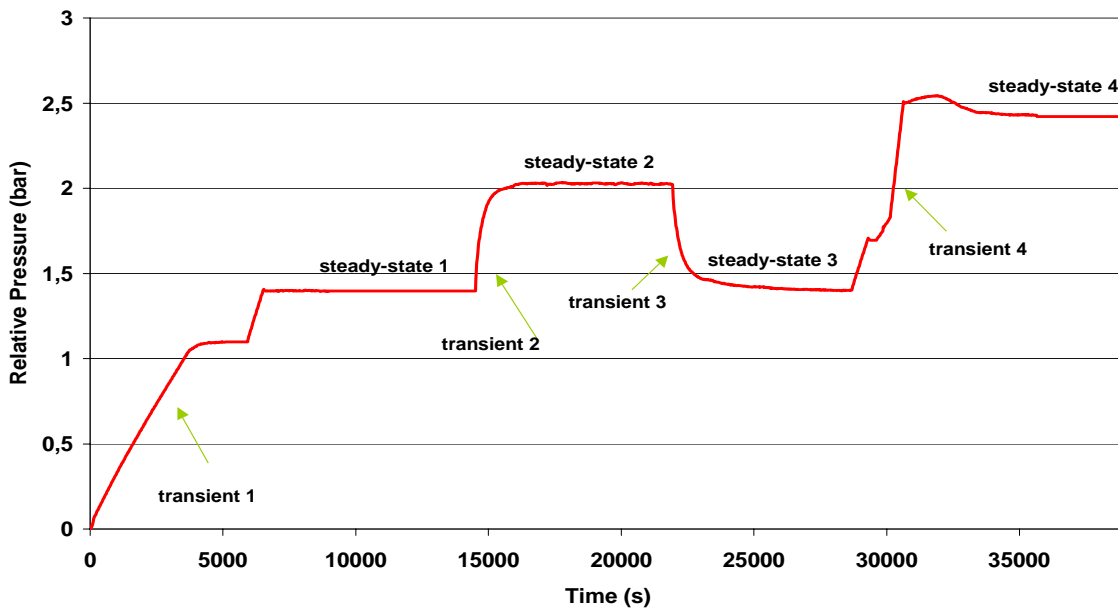


Figure 3: Pressure measured during TOSQAN ISP test

The different stages (1-2-4-6-8) of the sequence encounter specific measurements, which can be collapsed under two different “instrumentation levels”. The first one performed during the stage 1 of the sequence, concerns the measurements based on transient evolution characterization. Velocity and turbulence transient evolutions (LDV) and flow structure near the condensing wall (PIV) measurements are performed at one level in the TOSQAN vessel. Concentration time evolution is performed at 6 different points by mass spectrometry and at two levels by Raman spectrometry in the TOSQAN vessel. The second one performed during stages 2-4-6-8 of the sequence, concerns the measurements based on 3D mapping and local wall measurements. Velocity radial profiles are performed at two vertical levels (LDV) on the whole vessel diameter and velocities are measured near the condensing wall (PIV) at one level. Concentration radial profiles are performed at 4 different levels by mass spectrometry and at three levels by Raman spectrometry (except stage 8 with Helium).

For the local variables (V , v' , C), most of the profiles have been done twice.

3.3.3 ISP expected computational results for TOSQAN

The computational results expected for TOSQAN are in one hand the time evolutions of the global and local variables and in other hand the radial, vertical and near to the wall profiles of the local variables.

The TOSQAN ISP test is thus a complete test case covering many of the different thermal-hydraulic phenomena occurring in a nuclear reactor in the case of hydrogen risk. The associated measurements of a high density of measurement points allow a good qualification of numerical codes.

4. MISTRA FACILITY

4.1 MISTRA project

MISTRA is a coupled effect test facility, whose objective is to support modelling and validation of multi-D codes devoted to containment thermal hydraulics and hydrogen risk, by providing detailed experimental data. The scale of the facility (7 m high, 3.8 m diameter and 100 m³ volume) makes it well suited to the study of turbulent and convective flows with wall condensation. Numerous measurement points near the walls and in the containment gas volume are simultaneously recorded to set up spatial mappings, leading to a fine analysis of the physical phenomena. Although not used in this ISP, off-centred injection, use of compartments and activation of the spray system can be combined to provide flow data for more complex geometries and accident scenarios. This will be investigated in future years (2003-2005).

The test proposed for the ISP 47 is a coupled effect test with central injection that aims to reproduce the main phenomena occurring in an accidental situation relevant for hydrogen risk and in appropriate operating conditions.

In this test, the global flow in the containment results from the complex interaction between the injected upward flow and the downward flow along the cold vertical plates. Each elementary phenomenon to be modelled has already been experimentally tested in analytical but separated effect test experiment (TOSQAN), such as: condensation, turbulence, and natural convective flows. So that the interest of ISP 47 is to assess whether the elementary models used and their coupling are able to finely predict the gas distribution in the larger MISTRA containment, specially the hydrogen (helium) mixing.

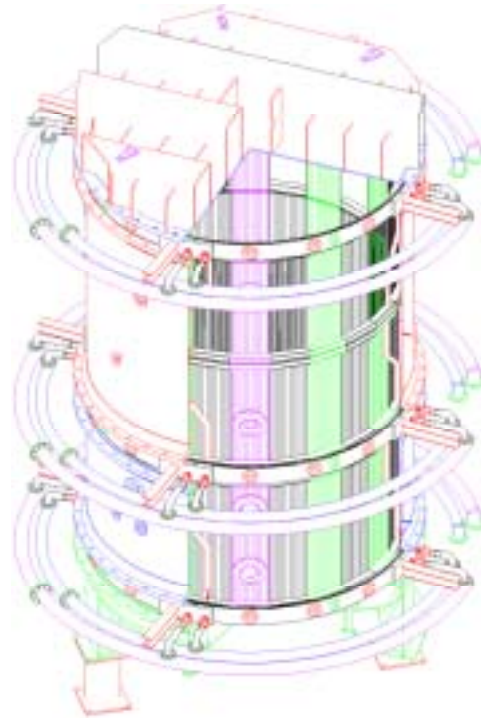


Figure 4: Schematic view of the MISTRA facility, showing the external circuits of the three annular condensers

4.2 MISTRA experimental facility

4.2.1 General design

The facility and its operating conditions are designed with reference to the conditions of a PWR containment in accidental situation: thermodynamic conditions (pressure, temperature, gas composition), thermal conditions (thermal or mass flux exchanged with the wall) and thermal hydraulics conditions (natural to forced convection ratio, turbulence....). The facility comprises a containment inside which three condensers are set up and external circuits.

- The containment

The main characteristics of the containment are the following: a volume of about 100 m^3 , with an internal diameter $D = 4.25 \text{ m}$ and a height $H=7.3 \text{ m}$, so that the linear length scale ratio between the mock up and a nuclear containment is 0.1. Twelve viewing windows are set up at different angular positions and elevations for laser diagnostic measurements.

Built in stainless steel, it comprises 2 shells, a flat cap and a bottom, that are fixed together with twin flanges.

The containment is not temperature regulated, but preheated by steam condensation and thermally insulated with 20 cm of rock wool. First experimental results have shown that this insulation is sufficient to minimize heat loss and therefore, spurious condensation on the structures, since after the preheating phase, the wall temperatures are similar to the gas temperatures.

- The three condensers

Three annular condensers are inserted inside the containment, providing a free gas volume of 3.8m diameter. Inside each condenser, Each condenser has its own regulation circuit. Heated or cooled water circulates through an external then an internal collector, and feeds each elementary cell. It then flows from the elementary cells to an internal then an external collector. This is specifically designed to ensure the most stable and uniform wall temperature: the maximum temperature deviation within the condenser circuit will be lower than 2°C, thereby ensuring well controlled temperature regulated walls . The external part of the condensers is insulated with 2 cm of synthetic foam to limit spurious condensation.

Each condenser is drilled with 4 viewing windows for laser diagnostic, and separated by gutters to collect the condensate.

The condensed steam is collected in six circuits: three circuits for the condensers, in order to set up the local mass balance, and three circuits to control spurious condensation on the wall containment, on the containment bottom and on the condensers' insulated external part. For steady state conditions, the total mass balance relative error between injected and condensed steam is less than 5%. It should be noted that for this test, all the condensed water is continuously evacuated, and that no sump is simulated.

- The injection nozzle

A diffusion cone fitted with a removable cap is designed for gas injection and steam/helium mixing with the injection diameter: $D_{inj} = 200$ mm. It also ensures a flat velocity profile at the injection nozzle. It is set up in the bottom of the containment, on the central axis.

An additional steam line is designed, but only used for the wall containment heating: a ring with four nozzles directed in the so called "dead volume" comprised between the containment wall and the external condensers walls, and four nozzles directed toward the containment bottom.

- The external circuits

Steam and gas (helium or other gases) are injected through two different circuits, and then mixed through the main injection nozzle inside the containment. The two lines are fitted with their own heater. In all cases, the flow rates are controlled and measured with sonic nozzles that ensure a constant flow rate independently of the downward operating conditions.

4.2.2 Instrumentation

- Measurement type

The measurements performed in MISTRA are related to: pressure, temperature, steam and gas composition, velocity and condensed mass flow rate. They will all be simultaneously and continuously recorded during the tests, except for gas concentration measurements which proceeds with successive samplings. The second objective is to set up spatial mapping to locate the different physical phenomena taking place in all the gaseous volume. Third, the use of laser technologies such as laser Doppler velocimetry will be applied to provide instantaneous velocity measurements along radial profiles, for axial velocity and turbulence intensity.

Sensors are located on the walls for boundary conditions control and in the gaseous volume. Table 1 summarizes the experimental technology, the location and number of sensors.

Table 1: Selected technology for the instrumentation in MISTRA

Measurement type	Experimental technology	Location	Number of sensors
Pressure	Absolute Differential	Gas Gas (dead volume)	1
Velocity	Vane wheel L.D.V P.I.V	Gas Gas	1 operating 12 viewing windows
Temperature	Thermocouple (Chromel alumel)	Gas volume Sump Condensing wall Containment wall	57 5 108 102
Gas composition	Simultaneous sampling then analysis by mass spectrometry	Gas	53
Condensed steam flow rate	Continuous mass flow rate measurement Differential pressure measurement	Condensers+sump Wall containment	4 2

- Measurement location

In the MISTRA facility, instrumentation is located on 3 vertical half-planes (105°, 225° and 345°). Measurements are also located in the so-called "dead volume" behind the 3 condensers and on the outer face of these condensers (insulated face).

As the tests are dealing with axially centred flows, most of the sensors are set up in the reference plane (345°). This plane is materialized by a vertical metallic grid, with 10 different elevation levels and different radial positions corresponding to: $R_0 = 0$; $R_1 (=R/4) = 475$ mm; $R_2 (=R/2) = 950$ mm; $R_3 (=3R/4) = 1425$ mm; and finally at 8 cm from the wall for $R_4 = 1815$ mm.

A special attention has been paid to set up instrumentation radially near the walls (one radius at 8 cm from the condensing wall) and axially near the injection device. Away from these regions, the sensors are uniformly distributed in space. In practice, the maximal distance between two sensors is less than 1 meter axially and 0.5 m radially.

The two other planes are lightly instrumented, mainly to check the flow symmetry, with 3*2 sensors (temperature and concentration) on the axis R_2 . The angular deviation between the 3 measurement planes is 120°.

Finally, the confined volume between the containment and the external walls of the condensers is fitted with 6 sensors (temperature and concentration) at 3 elevation levels and differential pressure sensors to control the equilibrium with the whole gaseous volume.

4.3 MISTRA ISP test

4.3.1 General overview

The test is a simplified accidental sequence simulating steam and hydrogen release in the containment. It proceeds in successive phases: the first two phases are aimed at providing the initial conditions for the steam/air and steam/air/Helium sequences. In the first phase, the containment structures are heated by steam injection and heating of the condensers. In the second phase, the temperature of the condensers are brought down to their prescribed level and maintained at this level throughout the test. The pressure evolution with time, given in figure 4, describes the test sequence.

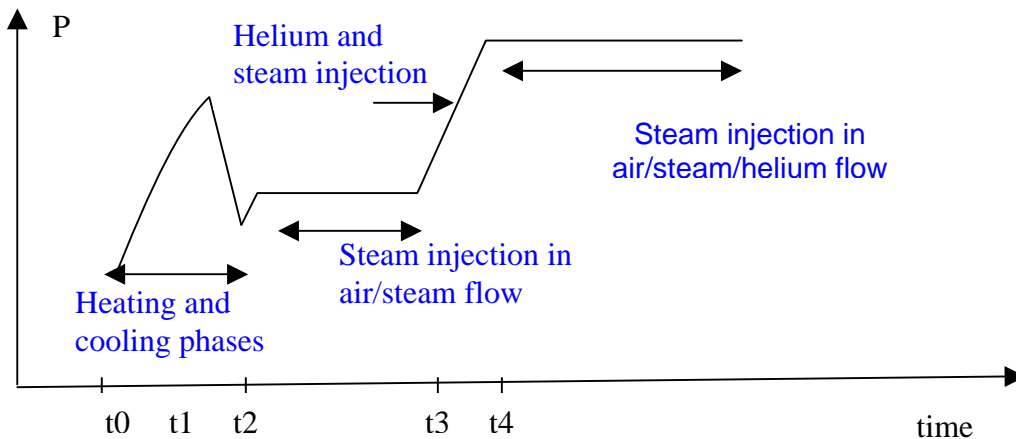


Figure 5: MISTRA ISP test sequence

After the first two phases, a constant steam mass flow rate is injected and kept at this level throughout the test. A first steady state is then reached which allows to study air-steam flow with condensation on the temperature regulated walls. Then helium is injected for a limited time in addition to the steam injection, the main objective of this phase being the study of the transient regime. In the final step, the helium injection is stopped and a second steady state is reached. This phase is dedicated to the study of the mixing of helium in the containment together with condensation in the presence of a light non-condensable gas. The total test duration for the experience is about 13 hours, though a longer time is needed to perform the gas sampling and laser measurements during the steady-state phases. From the point of view of the calculations, the test sequence may be shortened to about 9H 30min, if the pre-heating and cooling phases are not computed.

4.3.2 ISP expected computational results for MISTRA

The expected computational results should be considered as two different types:

- results corresponding to selected measurements performed during the experiment. This means gas temperature versus time, pressure versus time, gas concentration versus time and gas temperature and concentration map for the stationary and transient states (air/steam and air/steam/helium). Velocity profiles along one radius and at one elevation level are also measured using LDV techniques. Others radial and axial gas temperature and concentration profiles can be drawn using the experimental results.

- results which are not connected to selected measurements, but provide vertical or horizontal field data (temperature, velocity, gas concentration, turbulence...). These results can be compared in a code to code comparison.

5.ThAI FACILITY

5.1 ThAI project

ThAI (Thermal-hydraulics, Aerosol, Iodine) aims at providing a data basis for lumped parameter and CFD computer simulation programs. The ThAI equipment enables to simulate various thermal-hydraulic scenarios ranging from turbulent free convection to stagnant stratified containment atmospheres. Its versatility allows to adequately investigate safety relevant phenomena and component behaviour under severe accident typical thermal-hydraulics including hydrogen phenomena, e.g. combustion or recombiner effects. ThAI is also prepared for investigations of transport processes for fission products e.g. iodine and aerosol.

ThAI aims at providing a data basis for codes simulating severe accident sequences. The main objective of ThAI is to fill the still existing gap in the validation of the lumped parameter containment codes. In relation to the use of CFD codes in reactor safety analysis, ThAI is also prepared to perform experiments for the validation of detailed models, e.g. for atmospheric stratification, boundary layer or jet dispersion.

5.2 ThAI experimental facility

The test vessel is made of 22 mm stainless steel, its height being 9.2 m including sump and its diameter 3.2 m. It can be operated up to 180 °C and 14 bars. An inner multi-compartment structure is composed of an internal cylinder of 4 m height and 1.4 m in diameter; as an additional internal structure a horizontal partition is installed in the annulus having four open sectors of 30° each. The vessel is thermally isolated. The cylindrical part of the vessel is equipped with three independent heating/cooling jackets over the height for controlled heating or cooling of the wall by means of an organic liquid. Measuring flanges on five levels at five circumferential positions allow the installation of in-situ optical and conventional instrumentation. Large efforts were made to monitor local and large scale flows. The instrumentation includes Particle Image Velocimetry (PIV) which allows an instant view of a 2-D flow pattern within a light sheet of 1 m². A 2-D laser-Doppler-Anemometer (LDA) is equipped to stepwise measure radial profiles of the vertical and circumferential velocity component; the most innovative system is a Micro Radio Acoustic Sounding System (Micro-RASS), which provides instant height profiles of the vertical velocity component with high spatial resolution at selectable radial positions. Further more, newly developed dew point based relative humidity sensors are designed to measure under near-to-saturation conditions at elevated temperatures. Table 2 gives an overview of the main ThAI thermal-hydraulic instrumentation.

Table 2: Thermal-hydraulic instrumentation

Parameter	Location	Measuring Principle	Number of sensors
Pressure	Vessel +pipes	SG pressure transducer	5
Temperature	Vessel atmosphere Inner structures	Thermocouples	Approx. 85 Approx. 10
ΔT	Heat removal system	2 resistance thermometers	6
Mass flow	Heat removal system	Turbine flow meter	3
	Steam, air	Float-type flow meter	5
Heat flux	Heat removal system	Mass flow + ΔT	3
Relative humidity	Vessel atmosphere	Dew point mirror + resistance thermometers	5
Water level	Vessel sump, condensate collector	Float-type flow meter	6
Vertical and circumferential velocity component	Annulus	Laser-Doppler Anemometry (2-D LDA)	Annulus Radial traversable
Vertical and radial velocity component	Annulus	Particle Image Velocimetry (PIV)	2-D area approx.1 m ²
Axial profile of vertical Velocity component	Vessel cross section	Radio Acoustic Sounding System (RASS)	Height profile (sw 0.2m) Radial (sw 0.1 m)

5.3 ThAI ISP test

5.3.1 General overview

The proposed ThAI experimental test is an asymmetrical steam injection into a five-compartment geometry. This configuration is intended to examine in a more complex geometry the influences of two phases (air/steam and water) in the vessel atmosphere, condensation on the vessel walls, and a distinctive stratification. The details of the facility, as e.g. unheated structures, should be taken into account in the calculation. The vessel geometry is no longer cylinder-symmetrical since a steam injection takes place outside the vessel axis.

The sequence is to be performed in three phases. During the first phase the pressure rises to a level of nearly 2 bars. The objective is to show the injection jet effects, the degree of stratification and the flow velocity distribution in the entire vessel. During the second phase the reduced injection rate and the condensation on the cold wall lead to a quasi-stationary condition at an elevated pressure level. The numerical simulations shall investigate the atmospheric flow velocities, steam/air mixing conditions and the condensate flow. During the third phase a passive cool-down of the vessel is to be simulated with specific regard to the question to which degree the flow generated by the cold walls is able to modify the stratification.

5.3.2 ISP expected computational results for ThAI

The computational results expected for ThAI:

- velocity and temperature distribution within the vessel at different times
- local time histories of pressure, temperatures, heat flows, relative humidity, wall condensation rates and volume condensation rates in pre-defined positions.

4. TIMESCALE

The ISP 47 is organised in two steps, the first one is devoted to the evaluation of the refined models and the second one addresses the validation of codes in complex geometry. The actual schedule, presented in table 3, only concerns the step 1, which is composed of two main phases one on air/steam tests and the other one on air/steam/helium tests.

Table 3: Timescale Step 1 of the ISP 47

EVENT	DATE
Preparatory Workshop (step 1)	May 16-17, 2002
Calculation period on air/steam tests TOSQAN open exercise MISTRA blind exercise	June 2002 → January 2003
Comparison Workshop on air/steam tests	April 2003
Calculation period on air/steam/helium tests TOSQAN open exercise MISTRA blind exercise	April 2003 → August 2003
Comparison Workshop on air/steam/helium tests – Start of Step 2 (ThAI)	November 2003

5. CONCLUSION

The ISP 47 is based, for the first step, on the use of Separate Effect Test experiments such as TOSQAN, for the models validation, and MISTRA for the codes validations in a rather simple geometry but at a larger scale than TOSQAN. For the second step, the concern of the ISP 47 is an Integral Effect Test experiment such as ThAI in order to validate the code in more complex and more realistic conditions. All these experiments provide local measurements for the prime variables that are necessary for field code assessments.

Following this strategy, the ISP 47 would demonstrate the capability of the numerical codes devoted for plant applications to predict the containment thermal-hydraulic behaviour and the gas distribution inside the reactor containment under representative conditions of severe accident.

REFERENCES

1. OECD Standard Problem ISP23, Rupture of a large diameter pipe within the HDR-Containment Specification, April 1987 (last version 4/88)
2. OECD Standard Problem ISP29: Distribution of Hydrogen within the HDR-Containment under Severe Accident Conditions, August 1992, Final comparison report, February 1993.
3. OECD/GD29, Final comparison Report on ISP35 NUPEC Hydrogen Mixing and distribution test (Test M-7-1), December 1994.
4. OECD Standard Problem ISP37, VANAM-M3- a multi-compartment aerosol depletion test with hygroscopic aerosol material: comparison report, NEA/CSNI/R (1996) 26,1996.
5. State of the Art Report on Containment Thermal Hydraulics and Hydrogen Distribution June 1999, OECD, NEA/CSNI/R (99) 16