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NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

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OECD/NEA THAI Project
Hydrogen and Fission Product Issues Relevant for Containment Safety Assessment under Severe Accident Conditions

Final Report

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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NUCLEAR ENERGY AGENCY

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The mission of the NEA is:

– to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, as well as

– to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

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The NEA Data Bank provides nuclear data and computer program services for participating countries. In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

FOREWORD

The CSNI agreed in June 2005 to set-up an Expert meeting on the German proposal about the THAI Project. The objectives of the THAI project were to carry out a series of experiments in the THAI facility operated by Becker Technologies, Germany, in order to address open questions concerning the behaviour of: a) hydrogen; b) iodine and c) aerosols, in a severe accident situation. The understanding of the respective processes is essential for evaluating the challenge posed on containment integrity (hydrogen) and for evaluating the amount of airborne radioactivity during accidents with core damage (iodine and aerosols). The Programme generated valuable data for evaluating the spatial distribution of hydrogen in the containment, its effective removal by means of equipment such as Passive Autocatalytic Recombiners, and slow hydrogen combustion. Concerning fission products the programme has focused on iodine and aerosol interaction with Passive Autocatalytic Recombiners (PAR) with a quick look on wash down from walls through condensate film flow and impact of the iodine/ozone/ aerosol interaction on iodine volatility. An extensive analytical effort has accompanied the experimental programme, mainly consisting of code calculations for pre-test assessments, result evaluations and extrapolation to reactor situations.

This Project was finally established in 2007 and run until December 2009. The OECD/NEA THAI project was supported by safety organisations, research laboratories and industries from Canada, Czech Republic, Finland, France, Germany, Hungary, Korea, Netherlands and Switzerland. The THAI Project programme was funded by contributions of signatories, the major one being from the hosting country; the overall cost of the project amounted to 2.8 million Euros. As for any other OECD/NEA Joint Project, the reports produced in the frame of the Project are restricted to the project signatories. According to a general practice for Joint project, the Management Board of the THAI Project has agreed that these reports will be disclosed for non-signatories after 31 December 2012 and could be obtained after this date upon request to the NEA secretariat.

However, in order to provide without any delay the CSNI with the main outcome of this OECD/NEA joint project, the Management Board of the THAI Project has agreed to produce this special version of the final report that can be open immediately to non signatories.

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EXECUTIVE SUMMARY

Background

Progress in nuclear reactor containment safety research has led to a deeper understanding of phenomena and processes that may occur during a severe accident. However, a number of safety relevant gaps in this understanding exist due to limitations in the experimental data bases. Such gaps are – among others – related to combustible hydrogen and to the behaviour of fission products, in particular iodine and aerosols.

In the case of hydrogen, uncertainties show up mainly in the behaviour of deflagration flames, and in the performance of Passive Autocatalytic Recombiners (PAR). Some concern exists about the validity of many previous hydrogen distribution experiments where helium was used as replacement for hydrogen. The relevance to reactor safety is connected with the destructive potential of fast deflagrations.

In the case of fission products, a number of interaction processes with operating safety devices such as PARs have not yet been investigated under realistic conditions which may either jeopardize the performance of PAR systems or constitute an additional potential source term. Another important issue related to fission product behaviour in the containment are transport processes which have not yet been investigated in sufficient detail by experiments like e. g. the wash down behaviour of fission products from surfaces and possible retention in small pools, which in turn may result in delayed transport of fission products into the sump.

At international level, large efforts have been undertaken for the evaluation and further development of Lumped Parameter (LP) and Computational Fluid Dynamics (CFD) codes for the analysis and simulation of severe accidents. However, the validity of these LP- or CFD codes has to be assessed against technical and large scale experiments representative for severe accident conditions. The need for such experiments in the frame of an international programme is twofold; first, to enhance the confidence in the performance of passive mitigation systems during severe accident scenarios and second, to establish a common database accessible by a large research community to support further development and validation of LP- and CFD codes.

The OECD-THAI project was started in January 2007 under the auspices of the OECD Nuclear Energy Agency to fill the above mentioned knowledge gaps, by delivering suitable data for evaluation and simulation of hydrogen and fission product interactions. The OECD-THAI project was supported by safety organisations, research laboratories and industries from seven European countries and partners from Canada and the Republic of Korea.

Objective of the work

The overall objective of the OECD-THAI project was to address open questions concerning the behaviour of hydrogen, iodine and aerosols in the containment of water cooled reactors during severe accidents. The understanding of the processes taking place during such events is essential for evaluating the challenge posed on containment integrity (hydrogen) and for evaluating the amount of airborne radioactivity (iodine and aerosols) during severe accidents with core damage. The project was aimed at generating valuable data for evaluating the spatial distribution of hydrogen in the containment, its effective removal by PAR, and slow hydrogen combustion processes. Concerning fission products and their interactions with operating safety devices such as PAR, the project focuses on metal iodide/PAR interaction, PAR behaviour under adverse conditions, and aerosol wash-down from horizontal surfaces or small pools by condensate film flow.

The project contributes to the improvement and validation of simulation codes used for reactor application and provides experimental data e.g. for International Standard Problems (ISP). Furthermore, the project is aimed at maintaining competence and expertise in the field of reactor safety in the OECD/NEA member countries and promotes international co-operation between its member countries.

Work performed

The tests have been performed in the technical-scale, multi-compartment THAI containment test facility (a 60 m³ stainless steel vessel 9.2 m high and 3.2 m in diameter) with exchangeable internals for multi-compartment investigations. The vessel is designed for a maximum overpressure of 1.4 MPa at 180°C and can withstand moderate hydrogen deflagrations. The facility is operated by Becker Technologies GmbH at Eschborn, Germany, under the sponsorship of the German Federal Ministry of Economics and Technology.

The facility is equipped with the necessary supply systems for steam, compressed air, nitrogen, oxygen, light gases (helium and hydrogen), aerosols and gaseous iodine, the latter also radioactive tracered. The vessel walls can be heated and/or cooled to establish the desired thermal hydraulic conditions.

An advanced instrumentation and data acquisition system is installed to monitor the relevant physical quantities with high spatial and time-related resolution.

Within OECD-THAI project, the following test series have been performed:

- Helium/Hydrogen Material scaling (HM).
- Hydrogen Deflagration (HD).
- Hydrogen Recombiner (HR).
- Interaction of Metal Iodides with Passive Autocatalytic Recombiner.
- Passive Autocatalytic Recombiner Poisoning.
- Aerosol Wash-Down (Scoping Test).

Altogether 70 tests have been performed.

In addition to the experimental work, an analytical workgroup was established in the frame of the OECD-THAI project, aimed at the evaluation of the test results for further development and validation of the predictive capabilities of advanced LP codes and CFD codes currently in use in the reactor safety field. For this purpose, a number of experiments have been selected for blind and open post-test calculations, some of them for an ISP.

Results and their significance

The HM tests confirmed that for experiments investigating containment atmosphere flow dynamics helium can be used as a substitute for hydrogen. Furthermore, calculations performed with various LP- and CFD-codes exhibit a major progress in analytical modelling of stratification and mixing processes.

In the HD-tests, by systematic variation of initial pressure, initial temperature, steam content, burn direction and spatial gas distribution their influence on pressure build-up, temperature development, flame front propagation and completeness of combustion was quantified. The data of selected tests have been used for open and blind post-test calculations for the validation of combustion models.

Significant progress in knowledge has been achieved on the behaviour of different PAR designs under severe accident typical conditions. The data obtained for onset of recombination, recombination rate and ignition potential provide better insight on PAR behaviour under the thermal hydraulic conditions investigated with ambient/superheated/saturated steam atmosphere and elevated initial pressure and temperature in the test vessel. An increase in the investigated initial saturated steam content coupled with an increase in the initial temperature level in the HR-test series does not have a significant influence on recombination onset. Recombination rate increases with increasing pressure, and ignition occurs at higher hydrogen concentrations (at PAR inlet) by increasing saturated steam content. Oxygen starvation significantly reduces the recombination rate. A highly important result is that PAR ignition potential is limited to a relatively small area of mixture compositions in the air-hydrogen-steam ternary diagram capable to provide the high catalyst temperatures required for ignition.

The THAI experiment on metal iodide/PAR interaction demonstrated, that under realistic conditions with catalyst plate temperatures of approximately 800°C a marked amount of Cesium Iodide (CsI) is decomposed, producing gaseous iodine with conversion rates up to 3%, which is relevant for the source-term into the containment. The PAR had been exposed to CsI aerosol concentrations up to 4 g/m³.

The results of the experiment with the PAR exposed to excessive aerosol concentrations of insoluble tin oxide (SnO_2), highly hygroscopic and sticky lithium nitrate ($LiNO_3$) droplets, steam and iodine showed, that even under such challenging conditions, PAR recombination efficiency remained in the range of 50-70%. This is comparable to the results of other tests of the HR-series with the same thermal-hydraulic conditions, but without aerosols and iodine. Also, the onset of recombination occurred at the same PAR inlet hydrogen concentration as for comparable HR-tests. Apparently, the effect of aerosols and iodine on PAR performance is not significant.

The results of the aerosol wash-down scoping test showed, that slightly inclined surfaces have been subject to wash-down of CsI-particles in the time range of minutes to hours. The characteristic time of the transport process and its completeness are dependent on the water flow rate and the surface characteristics (steel or paint). Under low water flow rate, rivulets are formed, and the wash-down was incomplete. A shallow puddle was acting as intermediate storage and decelerated the transport of CsI significantly.

Conclusions and recommendations

A broad spectrum of safety related issues has been addressed and was subject of the investigations which could fill existing knowledge and data gaps. In case of PAR investigations, an almost complete picture of its behaviour has been obtained and the results of the experimental program have provided assurances of PAR performance under realistic conditions. The database developed in the frame of the OECD-THAI project has been and will be extensively used for improvement, further development and validation of CFD codes and Lumped Parameter codes applied in reactor safety analysis and thus, to improve confidence in the available Lumped Parameter and CFD tools. The accompanying analytical activities of the project partners provided intensive analyses of the experimental data by pre- and post-test calculations performed.

Remaining open questions shall be addressed in future investigations. An OECD-THAI-II project is envisaged to be started in late 2010.

1. INTRODUCTION

Progress in nuclear reactor containment safety research has led to a deeper understanding of phenomena and processes that may occur during an accident transient. However, a number of safety relevant gaps in this understanding exists due to limitations in the experimental data bases. Such gaps are related to combustible hydrogen and to the behaviour of fission products, in particular iodine and aerosols.

In the case of hydrogen, uncertainties show up mainly in the behaviour of deflagration flames, and in the performance of Passive Autocatalytic Recombiners (PAR). Some concern exists about the validity of many previous hydrogen distribution experiments where helium was used as replacement for hydrogen. The relevance to reactor safety is connected with the destructive potential of fast deflagrations.

In the case of fission products, a number of interaction processes with operating safety devices such as PARs have not yet been investigated under realistic conditions which may either jeopardize the performance of PAR systems or constitute an additional potential source term. Another important issue related to fission product behaviour in the containment are transport processes which have not yet been investigated in sufficient detail by experiments like e.g. the wash down behaviour of fission products from surfaces and possible retention in small pools, which in turn may result in delayed transport of fission products into the sump.

In order to develop a high level of confidence that nuclear reactor containment systems and components establish an acceptable level of safety, it is of utmost importance to understand the aforementioned phenomena and processes which may occur during a severe accident transient. At international level, large efforts have been undertaken for the evaluation and further development of Lumped Parameter (LP) and Computational Fluid Dynamics (CFD) codes for the analysis and simulation of severe accident conditions. However, the validity of such LP or CFD codes can only be assessed against technical and large scale experiments reasonably representative of dominant accident sequences or conditions. Additionally, as more and more passive safety systems are being installed in current reactors and also planned for future reactors, the aforesaid issues need to be coupled with operation of passive safety systems in phenomena-oriented experiments. The need to carry out such coupled-phenomena experiments in the frame of an international programme is twofold; first, to enhance confidence in the performance of passive mitigation systems during severe accident scenarios and second, to establish a common database accessible by a large research community to support further development and validation of Lumped Parameter and CFD codes.

In such a context, the OECD-THAI project was started in January 2007 under the auspices of the OECD Nuclear Energy Agency to fill knowledge gaps and to deliver suitable data for evaluation and simulation of the hydrogen and fission product interactions mentioned above. The tests were performed in the technical-scale, multi-compartment THAI test facility (a 60-m³ stainless steel vessel 9.2 m high and 3.2 m in diameter) with exchangeable internals for multi-compartment investigations. The THAI test facility is operated by Becker Technologies, Eschborn, Germany. The vessel is designed for a maximum overpressure of 1.4 MPa at 180°C and can withstand moderate hydrogen deflagrations.

From July 2007 until December 2009, more than 70 experiments defined and agreed with the project signatories during the Project Review Group meeting discussions held regularly along the three years have been conducted successfully at the THAI containment research test facility in Eschborn, Germany.

The following research areas have been addressed:

- Helium/Hydrogen Material scaling (HM).
- Hydrogen Deflagration (HD).
- Hydrogen Recombiner (HR).
- Interaction of Metal Iodides with Passive Autocatalytic Recombiner.
- Passive Autocatalytic Recombiner Poisoning.
- Aerosol Wash-Down (Scoping Test).

The OECD-THAI project is supported by safety organisations, research laboratories and industries from 7 European countries and partners from Canada and the Republic of Korea (See Table 1).

Table 1: **OECD-THAI project partners with their country of origin**

Participant Organisation	Country
BT Becker Technologies GmbH (Operating Agent)	Germany
AREVA NP GmbH, Erlangen	Germany
GRS Gesellschaft für Anlagen-und Reaktorsicherheit mbH	Germany
RWTH Universität Aachen	Germany
RUB Ruhr- Universität Bochum	Germany
FZK Forschungszentrum Karlsruhe	Germany
IRSN Institut de Radioprotection et de Sûreté Nucléaire	France
NRI Nuclear Research Institute Rez plc	Czech Republic
NUBIKI Institute for Electric Power Research	Hungary
VTT Technical Research Centre of Finland	Finland
PSI Paul Scherrer Institut	Switzerland
NRG Nuclear Research and Consultancy Group, Petten	Netherlands
AECL Atomic Energy of Canada Ltd	Canada
KAERI Korea Atomic Energy Research Institute	Korea
KINS Korea Institute of Nuclear Safety	Korea

In addition to the experimental work, an accompanying analytical workgroup was established in the frame of the OECD-THAI project, aimed at the evaluation of the test results for further development and validation of the predictive capabilities of advanced LP- and CFD codes currently applied in reactor safety.

The data of all experiments have been processed, qualified and stored on a server accessible to the signatory partners. Detailed experimental results and analysis for the user of the data is provided in Quick Look Reports (QLR) and Technical Reports. The Management Board of the THAI Project has agreed that these Quick Look Reports and Technical Reports will be disclosed for non-signatories after 31 December 2012 and can be obtained after this date upon request to the NEA secretariat. These reports are referenced to in Appendix A of this report.

Experiments performed in the HM test series were evaluated in a benchmark exercise organised by the analytical working group in the frame of the OECD-THAI project. The experimental data include detailed information on the turbulent exchange processes at the contact of the rising plume with the stratification interface, including PIV measurements of the velocity distribution. This information confirms the observations made during the ISP-47 THAI test and provides a valuable support to corresponding development and validation of turbulence models.

From the HD test series some tests are also used as a basis for the International Standard Problem 49 (ISP-49) on hydrogen deflagration. This ISP is organised in the frame of WGAMA activities of the OECD/NEA Committee on the Safety of Nuclear Installations (CSNI). In total, three tests from the HD test series have been selected for blind and post calculations along with three additional tests performed in the ENACCEF test facility in France. This ISP is envisaged to be concluded by mid July 2010.

2. OBJECTIVES

2.1 General objectives of the THAI project

The overall objective of the OECD-THAI project is to address open questions concerning the behaviour of hydrogen, iodine and aerosols in the containment of water cooled reactors during severe accidents. The understanding of the processes during such events is essential for evaluating the challenge posed on containment integrity (hydrogen) and for evaluating the amount of airborne radioactivity (iodine and aerosols) during severe accidents with core damage. The project is aimed at generating valuable data for evaluating the spatial distribution of hydrogen in the containment, its effective removal by Passive Autocatalytic Recombiners, and slow hydrogen combustion. Concerning fission products and their interactions with operating safety devices such as Passive Autocatalytic Recombiners, the project focussed on metal iodide/recombiner interaction, PAR behaviour under adverse conditions and aerosol wash-down from horizontal surfaces and small pools by condensate film flow. An extensive analytical effort accompanies the experimental programme, consisting of code calculations for pre-test assessments, result evaluation and extrapolation to reactor conditions.

The project contributes to the improvement and validation of simulation codes used for reactor application by e.g. providing experimental data for International Standard Problems (ISP). Furthermore, the project is aimed at maintaining competence and expertise in the field of reactor safety in the OECD/NEA member countries and promotes international co-operation between its member countries.

2.2 Particular objectives of the Helium/Hydrogen Material scaling (HM) tests

The majority of the available hydrogen distribution experiments have been performed using helium as a substitute for hydrogen in order to avoid safety problems in an experimental test facility. Their results have been applied to validate hydrogen distribution model calculations. However, helium and hydrogen differ in their material properties as follows: Ratios of density 2:1, diffusivity 1 : 1.1, viscosity 2.3 : 1, heat conductivity 1 : 1.2, and specific heat 1 : 2.7. The effects of the different properties on hydrogen distribution and mixing in complex situations (e.g. with condensation) can be assessed only by modelling. In the frame of the OECD-THAI project, an experimental investigation was started with the aim to validate the above approach, respectively to identify any potential effect of the different properties on transport and mixing behaviour.

In order to validate the transferability of experimental findings with helium to H_2 problems, two similar gas distribution and mixing experiments have been performed in the 9.2-m high, 60-m³ THAI vessel: one with He (test HM-1), the other with H_2 (test HM-2). The experimental procedure is slightly simplified, but follows in principle that of the International Standard Problem ISP-47-Part 2 (THAI) [Fis05], which is considered to be very sensitive to gas distribution phenomena.

Apart from this, a further objective of the HM tests was to provide additional experimental data for code validation. The experiment HM-2 was used as a base for a code benchmark. It consisted of two phases: In phase 1 an atmospheric stratification was established by injecting hydrogen near the half height of the facility. In phase 2 the stratification was gradually dissolved by a steam injection into the lower part of the facility. The experimental data of phase 1 were open to the participants of the benchmark [Kan08b], for phase 2 “blind” calculations were performed.

2.3 Particular objectives of the Hydrogen Deflagration (HD) tests

The objective of the hydrogen deflagration experiments is to provide additional data for an improved understanding of hydrogen combustion phenomena (since hydrogen deflagrations cannot be ruled out completely even by use of PAR) and for the further development and validation of containment system codes.

This requires experiments under conditions typical for severe accidents in a relatively large test facility which allows combustion in upward and downward direction, since experimental data exist mainly for horizontal flame propagation and/or small geometries which provide non-conservative data. In large geometries, deflagrations occur faster than in small geometries due to e.g. increased turbulence generation and therefore produce higher loads for the vessel and its internals. The systematic variation of the test parameters and test conditions, i.e. initial pressure, initial temperature, vertical temperature gradient, hydrogen concentration (homogeneous and stratified), steam concentration (homogeneous and stratified), burn direction (upwards and downwards) help to determine the influence of these parameters on combustion behaviour.

The experimental results of some selected tests have been used for open and blind post-test calculations by various institutions of the participating member countries (ISP 49).

2.4 Particular objectives of the PAR performance tests

The particular objective of the PAR performance tests is to provide additional data about the behaviour of Passive Autocatalytic Recombiners under accident typical conditions. Furthermore the experimental data of past investigations are partially proprietary, i.e. not publically available. Experiments to fill this gap have therefore been agreed upon. The experiments aim at the operation behaviour of three PAR designs with focus on:

- Conditions for the start of catalytic reaction (onset of recombination).
- Recombination rate, depending on hydrogen concentration, pressure, steam content.
- PAR operation under lack of oxygen (oxygen starvation).
- Conditions for ignition by PAR, resulting hydrogen deflagration in the vessel volume.

The interaction of PAR operation and gas distribution in the vessel volume is an additional objective, in particular in combination with hydrogen deflagration initiated by PAR.

The data improved the understanding of PAR behaviour in general and also of the characteristics of the different PAR designs. Furthermore, the data were used as a basis for modelling PAR behaviour and PAR-initiated deflagration.

2.5 Particular objective of the test on metal iodide/PAR interaction

The particular objective of this PAR test is to determine quantitatively the possible conversion of CsI-particles to gaseous iodine while passing through an operating PAR under realistic thermal hydraulic conditions. According to the French RECI experiments [Sab05], performed under laboratory conditions high conversion rates have been observed. For the THAI test, more severe accident typical conditions were established, and a commercial PAR, operated at high hydrogen concentrations (up to 8.5 vol %) to achieve high catalyst and gas temperatures was used. A high steam content was established in order to exclude ignition of the hydrogen-rich gas by the PAR.

Gaseous iodine, possibly produced from CsI aerosols by the operating PAR is of relevance for the radiological source term, since it is chemically more reactive, longer airborne than particles, and more difficult to retain in filters.

2.6 Particular objectives of the test on PAR poisoning

The particular objective of this PAR test is to provide data about the start-up behaviour, recombination rate and recombination efficiency (defined as % hydrogen conversion per pass) of commercial PARs operating under extremely adverse conditions like high steam content at saturation state, relatively high aerosol concentration both of soluble and non-soluble aerosols, presence of gaseous iodine as catalyst poison, in order to assess the reliability of PAR operation under conditions as conceivable during a severe accident.

2.7 Particular objectives of the Aerosol Wash-Down test

The particular objective of the Aerosol Wash-Down test is to explore some of the dominant influence parameters and transport mechanisms on aerosol relocation by draining condensate. Predictive models for wash-down as an integral part of a fission product transport model are required for best-estimated accident analysis and risk assessment. Such models do not exist at present.

The wash-down process is affected by complex interactions of geometry, thermal hydraulics, aerosol particle and structural surface properties. The scoping aerosol wash-down test shall also provide the basis for more extensive investigations on aerosol wash-down and contribute to experience on related experimental methods, and outline the conditions for mechanistic transport modelling. In addition to the scoping test in the THAI vessel, laboratory-scale tests were undertaken to investigate specific details.

3. EXPERIMENTAL FACILITY

Described here is the basic configuration, including the basic instrumentation, of the test facility. Additional instrumentation was installed specifically for each test group.

3.1 Basic configuration

The tests have been performed in the THAI containment test facility which is operated by Becker Technologies GmbH at Eschborn, Germany, under the sponsorship of the German Federal Ministry of Economics and Technology. Main component of the facility is a cylindrical stainless steel vessel of 9.2 m height and 3.2 m diameter with a total volume of 60 m³ (Fig. 3-1). The maximum admissible overpressure is 14 bar at 180°C.

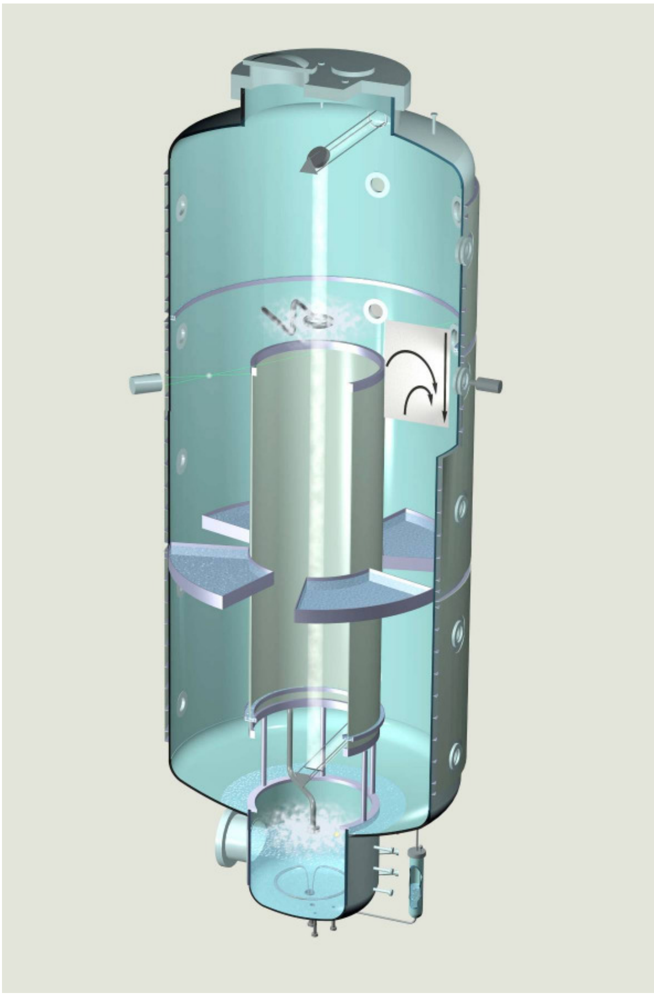


Fig. 3-1: **THAI test vessel**

The vessel size allows to establish natural convection driven flow to study heat and mass transport processes in sufficiently large scale, also in a multi-compartment geometry.

The vessel structures are made of stainless steel and are completely enveloped by a 120-mm rockwool thermal insulation. The cylindrical part of the THAI vessel wall is double-walled and accommodates the wall heating/cooling system. The cylindrical part of the inner vessel wall has a thickness of 22 mm. The outer wall is made from 6-mm stainless steel; its outside is thermally insulated. At each of the five levels at H = 2.1 m, 3.5 m, 4.9 m, 6.3 m and 7.7 m, four block flanges of 150 mm nominal width and one 200-mm block flange are integrated into the cylindrical vessel wall.

3.2 Supply systems

The vessel is equipped with supply systems for steam, gases (hydrogen, helium, air, nitrogen, oxygen), aerosols (soluble, non-soluble, droplets), and iodine as described briefly in the following.

Steam supply

Steam is provided by a local 110-kW steam generator (8 bars, 170°C saturated steam). Once the predetermined temperature and steam partial pressure has been achieved, steam feeding is stopped (or markedly reduced to compensate for condensation), and the vessel temperature is maintained by the vessel wall heating system which is used also for adjusting steam conditions either at saturation or at superheated state.

Gas supply

Hydrogen gas is taken from gas bottles, its pressure is reduced to a constant level of e.g. 6.5 bar; its mass flow (e.g. 6 Nm^3/h) is adjusted by a needle valve, measured by a float-type (rotameter) gauge, and fed into the test vessel at various locations, depending on the test configuration. The same system is used for helium injection.

Nitrogen and oxygen is also taken from gas bottles and injected into the vessel at various, test dependant locations. Air is taken from the local compressed air supply system.

Aerosol injection

Non-soluble SnO_2 aerosol is produced by means of a brushing device, in which SnO_2 particles are brushed in sufficiently small size from a solid SnO_2 pellet, transported by nitrogen as carrier gas into the vessel, and injected via a nozzle from top of the vessel. Soluble aerosol is injected as $LiNO_3$ solution or as CsI solution, both together with nitrogen via nozzles as two-fluid jets

Iodine injection

The injection of gaseous molecular iodine (I_2) into the THAI vessel consists of two steps, (1) the production of I_2 labelled with radioactive I-123 within a specially designed pressure vessel, the “iodine reactor”, and (2) the transfer of gaseous I_2 from the iodine reactor into the THAI vessel with a carrier gas (either nitrogen or air) within a short period of time. The injection location varies with the test configuration.

3.3 Instrumentation

The standard instrumentation encompasses thermal hydraulic and gas composition instrumentation. It is supplemented by special instrumentation depending on the specific test design and test objectives.

Feed mass flow measurements

Steam mass flow as well as compressed air mass flow is measured by a float-type gauge (Rotameter)

The mass flow of the gases hydrogen, helium, nitrogen and oxygen taken from gas bottles is measured by float-type gauges. For test data evaluation, the integral of the gas mass flow measured with this device is compared with the injected gas mass determined from the start and the end pressure of the gas bottles and compared with the pressure increase in the vessel.

Gas concentration measurement

Fifteen gas sampling lines continuously take gas samples from the PAR and from the vessel atmosphere at different locations. The sampled gas is fed to a 15-channel gas concentration analyzer which determines the concentration of hydrogen or helium in dry air by heat conductivity measurement. Steam is removed by coolers and condensate traps upstream of the analyzers. Since in most of the experiments the steam in the vessel atmosphere was at saturation state, the real concentrations of hydrogen and oxygen in the vessel atmosphere could be determined by use of the steam table for the partial pressure of steam at the temperature measured in the vessel.

Two channels of the measuring system are additionally equipped with oxygen concentration analyzers.

Temperature measurement

Calibrated 1.5-mm thermocouples for temperature measurement are positioned at each of the gas sampling sites in the vessel and at other locations in the vessel atmosphere.

In addition, another 200 thermocouples are installed to measure the vessel wall temperature, the data of which are provided in the Excel sheets of the respective test group.

Pressure measurement

The initial vessel pressure and the pressure increase due to gas injection is determined by two absolute-pressure transducer and two high precision manometers.

3.4 Additional instrumentation

Additional instrumentation used in the respective tests is:

- Gas flow velocity by vane wheels.
- Flow velocity and velocity profile of He/H_2-jet by Laser-Doppler Anemometry (LDA).
- flow field by Particle Image Velocimetry (PIV).
- A grid of “fast” sheathed thermocouples (outer diameter 0.25 mm), installed at 13 different elevations in the test vessel to monitor flame propagation (“flame front arrival”) and flame temperature during hydrogen combustion.
- The transient deflagration pressure is monitored by four “fast” pressure transducers of the strain gauge type.
- Aerosol filter stations for aerosol concentration measurement.
- Laser light extinction for on-line aerosol concentration measurement.
- Cascade impactors for aerosol particle size distribution measurement.
- Gas scrubbers for gaseous iodine concentration measurement.
- Two Maypack filter stations for the discrimination of the iodine species in the vessel atmosphere.
- CsI concentration in the condensate by electrical conductivity sensors (on-line and off-line measurement).
- CsI aerosol and gaseous iodine deposition on surfaces by means of coupons.

4. PERFORMED EXPERIMENTS

In this chapter, the specified tests of the experimental programme with their test parameters and test conditions are compiled.

Table 2 shows the test parameters of the two HM-tests (hydrogen/helium mixing).

Additional tests HM-3, HM-4 and HM-5 have been performed with test conditions different to those of HM-1 and HM-2 in order to measure flow field parameters by use of particle image velocimetry (PIV). The results of these tests are described in detail in [Kan08a, Kano8b].

Table 3 shows the test parameters of the HD-tests.

The test matrix of the HR experiments is compiled in Table 4.

The metal iodide/PAR interaction experiment (HR 31) encompasses three tests, since two tests could not be completed as planned due to unexpected, but important results: In the first test, an unintended ignition occurred, in the second test the outlet grid of the PAR was blocked by aerosols. The test parameters of the three tests are compiled in Table 5.

Table 6 shows the test parameters for test HR 32.

Table 7 shows the test procedure, test parameters and test conditions of the aerosol wash-down test.

Table2: **Test parameters of HM experiments (hydrogen/helium material scaling)**

Test parameter/test no.	**light gas injected**	**Temperature initial**	**Temperature end (mean)**	**Pressure initial**	**Pressure end**	**Steam injection**
HM-1	He	22°C	50°C	1.01 bar	1.43 bar	25 g/s
HM-2	H_2	22°C	50°C	1.01 bar	1.44 bar	24 g/s

Table 3: **Test HD-experiments (hydrogen deflagration)**

Vertical flame propagation as function of temperature, hydrogen and steam content, and burn direction

Variation of fluid and wall temperature and Hydrogen concentration (premixed)

Po = 1 bar, 25°C, no steam		6% H_2: HD-4	7.5% H_2, 1.14 bar: HD-5						11 tests
Po = 1.5 bar, no steam									
t = 25°C	upwards	6% H_2: HD-1R	7% H_2: HD-6	8% H_2: HD-2R, HD-12	9% H_2: HD-3	10% H_2: HD-7			
t = 25°C	downwards			ignition limit: HD-13/-14	9% H_2: HD-11	10% H_2: HD-8	11% H_2: HD-9	12% H_2: HD-10	
t = 140°C	upwards	6% H_2: HD-20				10% H_2: HD-17			
t = 140°C	downwards				9% H_2: HD-21	10% H_2: HD-18		12% H_2: HD-19	

Variation of steam concentration (pre-mixed)

Po = 1.5 bar, t = 90°C

upwards	10% H_2	no steam: HD-15	25% steam: HD-22 (74°C dewpoint) P_{steam} = 0.375 bar	47% steam: HD-24 (saturation) P_{steam} = 0.7 bar	5 tests
downwards	12% H_2	no steam: HD-16	25% steam: HD-23 (74°C dewpoint) P_{steam} = 0.375 bar		

Vertical flame propagation in a stratified atmosphere

Po = 1.5 bar top 90°C/saturation (47% steam)
bottom 30°C/saturation (3% steam)

upwards	top 10% H_2 bottom 10% H_2 HD-26	top 12% H_2 bottom 6% H_2 HD-27	top 6% H_2 bottom 12% H_2 HD-28	5 tests
downwards	top 12% H_2* bottom 10% H_2 HD-25	top 12% H_2 bottom 6% H_2 HD-29		

* = originally specified to be 10% H_2; this mixture, however, turned out too lean for downward combustion.

Table 4: **Test matrix HR experiments (hydrogen recombiner)**

Test objectives / Test parameters		Number of Tests	Onset of recombination	Recombination rate	Oxygen starvation	Ignition potential
p = 1.0 bar	25°C, dry	**3**	**x**	**X**		**x**
			x	**X**		**x**
			x	**X**		**x**
	86°C, 60% steam	**1**	**x**	**X**	**x**	
p = 1.5 bar	25°C, dry	**5**	**x**	**X**		**x**
			x	**X**		**x**
			x	**X**		**x**
			x	**X**		**x**
			x	**X**		**x**
	74°C, 25% steam	**7**	**x**	**X**		**x**
			x	**X**		**x**
			x	**X**		**x**
			x	**X**		**x**
			x	**X**		**x**
			x	**X**		**x**
			x	**X**	**x**	
	90°C, 47% steam	**3**	**x**	**X**		**x**
			x	**X**		**x**
			x	**X**	**x**	
	97°C, 60% steam	**3**	**x**	**X**		**x**
			x	**X**	**x**	
			x	**X**	**x**	
p = 2.2 bar	25°C, dry	**4**	**x**	**X**		**x**
			x	**X**		**x**
			x	**X**		**x**
			x	**X**		**x**
	108°C, 34% steam	**1**	**x**	**X**	**x**	
p = 3.0 bar	25°C, dry	**1**	**x**	**X**		
	117°C, 60% steam	**2**	**x**	**X**	**x**	
			x	**X**		**x**

Table 5: **Initial test conditions of HR 31 experiment (metal iodide/PAR interaction)**

Test	**Pressure** bar		**Steam concentration** vol %		**Temperature** °C	
	specified	measured	specified	Measured	specified	measured
HR-31	1.34	1.376	70	71	135	140

Table 6: **Test parameters of test HR 32 (PAR poisoning)**

	Duration		**Release rate**	
	specified	achieved	specified	achieved
Phase 1: Pre-condioning (≙ pre core damage)	3-5 h	5 h		
Phase 2: Release phase (≙ core damage phase)				
step 1: H_2-release	1000 s	1000 s	0.17 g/s	0.17 g/s
step 2: H_2-release	2600 s	2600 s	0.24 g/s	0.26 g/s
Aerosol release SnO_2	2600 s	2600 s	not spec.	0.26 g/s
$LiNO_3$ w/o water	2600 s	2600 s	not spec.	0.34 g/s
Phase 3: PAR operation continuing (≙ post core damage phase	> 1 h	4.7 h		

Table 7: **Test conditions of Aerosol Wash Down test**

	Duration		**Temp. gas**		**Temp. wall**		**horiz. surface loading**	
	specif.	achiev.	specif.	achiev.	specif.	achiev	specif.	achiev.
Phase 1 Precond.	24 h	25.3 h	130°C	133°C	135°C	138°C		
Phase 2 Aerosol injection	49 min	50 min h	130°C	133°C	135°C	138°C		
Phase 3 Aerosol depos.	20 h	24.3 h	130°C	133°C	135°C	138°C	< 150 g/m^2	80 g/m^2
Phase 4 Coupon removal	3 h	4.5 h	transient	transient	transient	transient		
Phase 5 Wash-down	23 h	22.9 h	90°C	90°C	90°C	85°C		

5. ESSENTIAL RESULTS

This chapter gives an overview about the most important results of the OECD-THAI experimental programme. Diagrams are of illustration character only; quantitative data can be found in the respective Quick-Look Reports and Technical Reports listed in Appendix A.

5.1 Helium/Hydrogen Material scaling (HM) tests

In the Helium/Hydrogen Material scaling (HM) test series, two identical tests (with respect to initial conditions and parameters) were run – one with helium, one with hydrogen – in order to investigate in which way helium can be used as a replacement for hydrogen in experimental studies on containment thermal hydraulics. It was shown in the experiments that comparable atmospheric distributions, pressure and temperature levels can be obtained if the volumetric concentrations of hydrogen and helium are comparable. This conclusion is based on volumetric light gas concentrations up to 40% according to the experimental parameter ranges. The thermal-hydraulic processes in the containment atmosphere, in particular the stratification and mixing phenomena are primarily governed by the density differences in the atmosphere. Since both hydrogen and helium have much smaller molecular weights as compared to air or steam, the differences in the molecular weights of these light gases give only very small contributions to the atmospheric density differences, provided that similar volumetric concentrations are established. Other differences in physical properties, like diffusivity, thermal conductivity or heat capacity, are of little influence. From this observation it can be concluded that experiments on containment atmosphere flow dynamics using helium instead of hydrogen can provide meaningful data for identification of flow phenomena and code validation.

Fig. 5-1 gives as example the light gas concentration distribution history during the experiment, demonstrating the development of the concentration stratification as well as the erosion and mixing process.

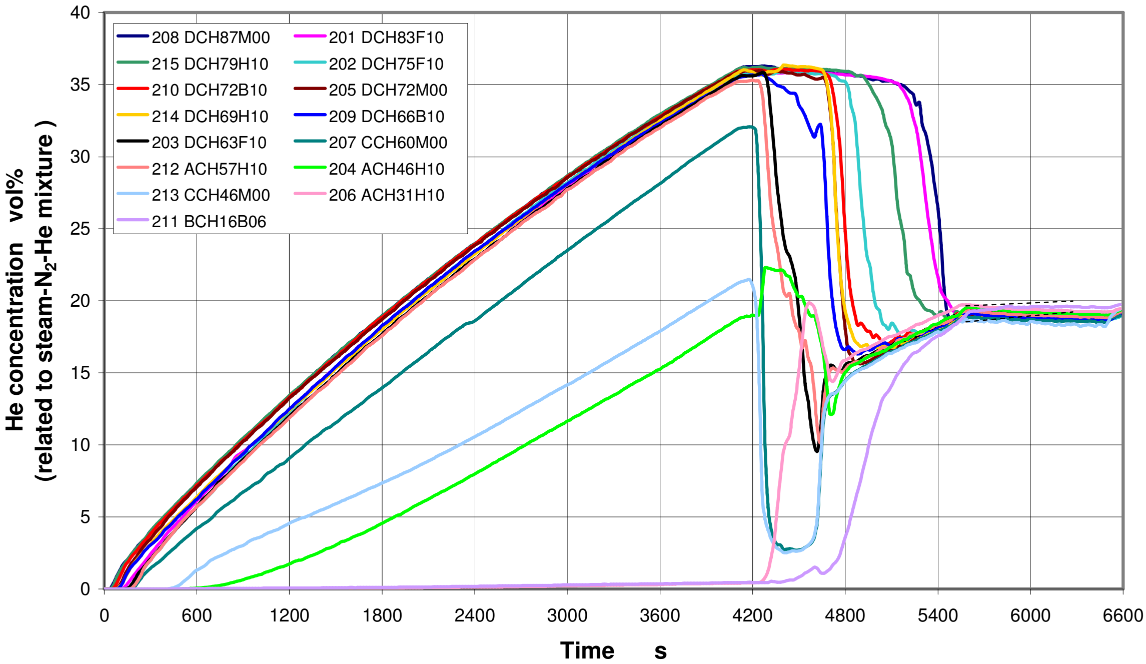


Fig. 5-1: **Helium concentration transients at different elevations of the test vessel**

The HM tests were also used to more deeply investigate atmospheric stratification and mixing processes similar to those previously observed in connection with the NEA/CSNI International Standard Problem ISP-47 on Containment Thermal Hydraulics [All07]. The most important process was the erosion of a light gas stratification layer by means of a buoyant steam plume rising from below. More detailed measurements near the stratification interface, including PIV velocity measurements, confirm the experimental findings of ISP-47. In the frame of the benchmark exercise, intense analytical work in connection with the HM tests was done, which resulted in significantly improved test simulations by means of Lumped-Parameter and CFD codes. Technical details of the analytical work are presented in [Sch08, Sch09, Sch10].

Table 8 shows the participants of the benchmark.

Table 8: **Participants of the HM-2 Benchmark**

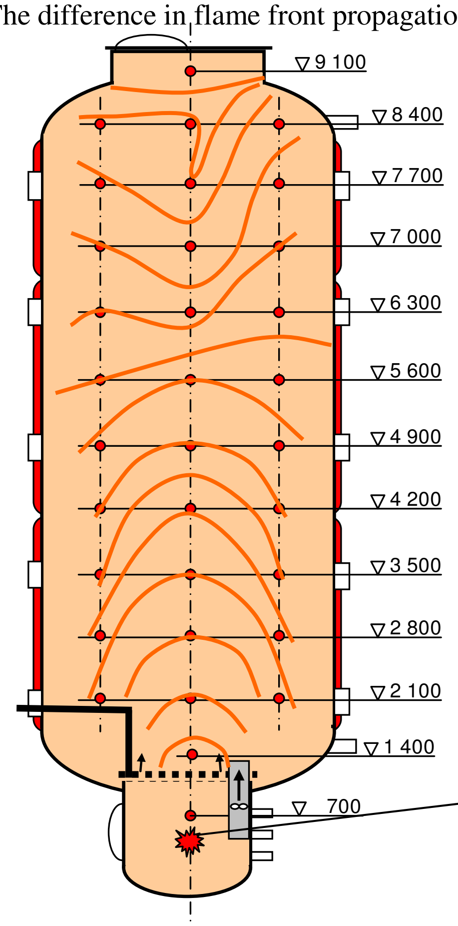
Participant	Affiliation	Programme	Type
Bentaib	IRSN Institut de Radioprotection et de Sûreté Nucléaire	ASTEC	LP
Burkhardt	RUB Ruhr-University Bochum	COCOSYS	LP
Schwarz	GRS Gesellschaft für Anlagen- und Reaktorsicherheit mbH	COCOSYS	LP
Lee	KINS Korea Institute of Nuclear Safety	MELCOR	LP
Duspiva	NRI Nuclear Research Institute Rez plc	MELCOR	LP
Visser	NRG Nuclear Research and Consultancy Group, Petten	FLUENT	CFD
Kyttälä	VTT Technical Research Centre of Finland	FLUENT	CFD
Royl	FZK Forschungszentrum Karlsruhe	GASFLOW	CFD
Kim	KAERI Korea Atomic Energy Research Institute	GASFLOW	CFD
Kostka	NUBIKI Institute for Electric Power Research	GASFLOW	CFD
Liang	AECL Atomic Energy of Canada Ltd	GOTHIC	CFD

5.2 Hydrogen Deflagration (HD) tests

In the Hydrogen Deflagration (HD) test series, the upward and downward propagation of flames in premixed or stratified air-steam-hydrogen atmospheres was investigated. In the tests, by systematic variation of initial pressure, initial temperature, steam content, burn direction and spatial gas distribution, their influence on pressure build-up, temperature development, flame front propagation and completeness of combustion was quantified.

Higher initial temperatures (up to 140°C), which are more typical for severe accidents conditions, lead to lower peak pressures (because of the lower density/energy inventory in the gas mixture) and also give rise to more steady flame front propagation and a more complete combustion. They cause slower upward and faster downward flame propagation because of changes in buoyancy forces. Upward flame propagation is supported by buoyancy; it proceeds at comparatively low hydrogen concentration with higher velocity and shows convex flame surfaces; downward flame propagation shows lower velocities and more flat flame surfaces and does not occur below a hydrogen concentration of 8.7 vol% even in this large facility.

A high steam content (48 vol %, at saturation state) in the combustible gas mixture leads to an irregular ("erratic") combustion both for upward and downward burn direction with lower flame velocities and lower peak pressures as compared to "dry" mixtures. Fig. 5-2 shows as an example the contours of a propagating flame in a premixed atmosphere without steam, Fig. 5-3 shows those of a comparable test (same initial conditions) with high steam concentration (48 vol %, at saturation state). The difference in flame front propagation – steady vs. erratic – is clearly visible.



igniter

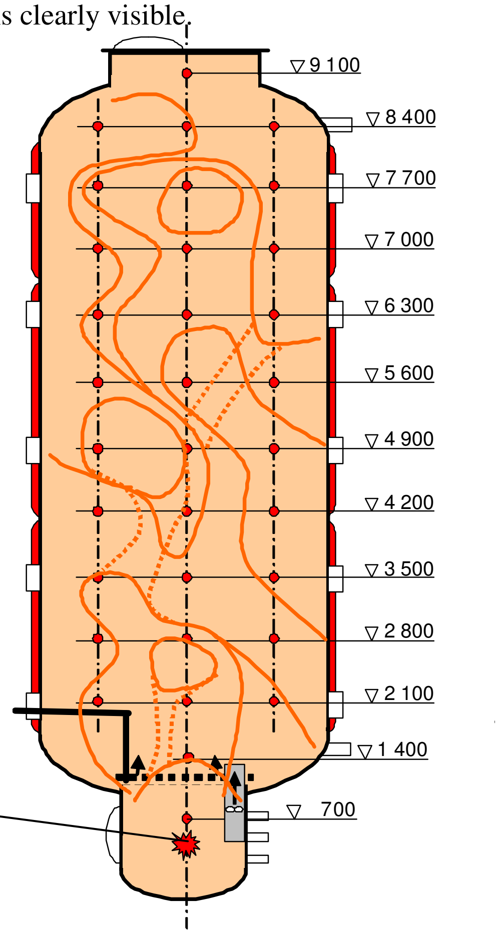


Fig. 5-2: **Test without steam: Flame front propagation as isochrones**

Fig. 5-3: **Test with 48 vol % steam: Flame front propagation as isochrones**

In the tests with initially stratified atmosphere and upward burn direction, after the initiation of the combustion process a large scale convection was generated, which displaces hydrogen-rich mixture into hydrogen-lean, originally non-burnable mixture, which then becomes burnable.

Fig. 5-4 shows the flame contours of a test with stratified atmosphere (well-burnable mixture in the upper part of the vessel, non-burnable mixture in the lower part) and downward burn direction. In this experiment, the downward combustion does not produce much displacement of well-burnable mixture ahead of the flame downwards, and combustion stops once the flame enters into the non-burnable mixture.

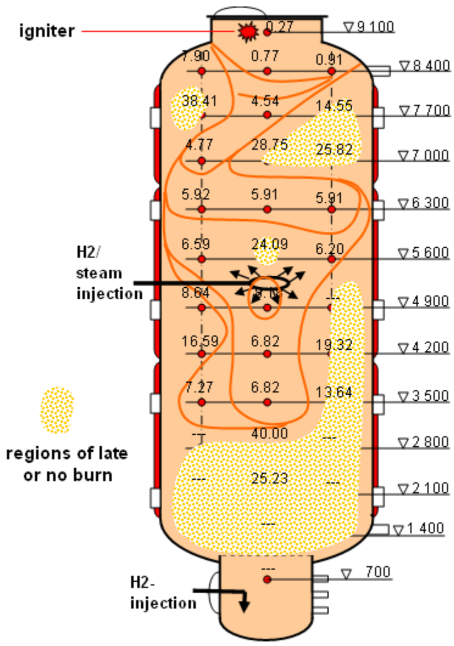


Fig. 5-4: **Flame front propagation as isochrones:**
Test with lean mixture at vessel bottom; downward burn direction

5.3 PAR performance tests

In the Hydrogen Recombination (HR) test series, the performance of three PAR designs has been investigated in a hydrogen-air-steam test atmosphere with free, unrestricted convection. Emphasis has been laid on the following topics: onset of recombination, hydrogen recombination rate, oxygen starvation, and ignition potential.

In total 30 experiments were conducted in the PAR performance test series. These tests (separate effect tests) were dedicated to the investigation of PAR performance under varying parameters including ignition potential by a PAR under certain thermal-hydraulic conditions.

Two special integral tests (PAR-fission products interaction) had been designed to test PAR behaviour under accident typical experimental atmosphere: HR 31 investigated the potential of an operating PAR to convert particulate iodine (CsI) to gaseous iodine, which is of substantial relevance for the radiological source term, and HR 32 investigated the influence of adverse conditions on PAR operation, exposing the PAR to high aerosol concentration and gaseous iodine during the start-up phase. These two tests are described separately in chapter 5.4 and 5.5.

The data obtained for onset of recombination and for hydrogen recombination rate confirm and broaden the existing data base as follows: Saturated steam conditions (in combination with increased temperature) have no significant influence on recombination onset in comparison to dry conditions. Having overcome the onset threshold, hydrogen recombination rate develops almost proportional to hydrogen concentration. Higher pressure results in higher recombination rates (at the same hydrogen concentration); the effect of steam is small.

Significant progress in knowledge has been made in the field of oxygen starvation. A surprisingly high surplus of oxygen (compared to the stoichiometric O_2:H_2 ratio of 1:2) is required for unimpaired PAR performance: A minimum oxygen surplus factor Φ ($2 \bullet c_{O2}/c_{H2}$) between 2 and 3 for unimpaired PAR performance has been determined from the test data. For smaller values of Φ, H_2 recombination rate, PAR efficiency and catalyst temperatures drop drastically. For $\Phi = 1$ (stoichiometric O_2:H_2 ratio) the hydrogen recombination rate falls below 50% of its value for unimpaired PAR operation.

The HR test series markedly improved the level of knowledge on ignition potential by PAR. A PAR loaded by high H_2 concentration (sufficient O_2 surplus provided) ignites the present H_2-air-steam atmosphere in a reproducible way and initiates a hydrogen deflagration which develops from the PAR outlet opening. Ignition is directly correlated with the PAR catalyst material temperature which depends on the H_2 concentration present at the PAR inlet.

Combining the findings on minimum H_2 concentration for ignition by PAR and those on minimum oxygen surplus required for unimpaired PAR performance (and hence for maximum catalyst temperature which, again, is correlated with ignition), a relatively small area in the hydrogen-air-steam ternary diagram can be defined to which ignition by PAR is confined. Reduced O_2 concentration in the air at the PAR inlet (from e.g. PAR operation prior to ignition) further narrows down this "potential ignition area by PAR" in the ternary diagram as indicated in Fig. 5-5. This important finding on ignition by PAR should be introduced into future accident modelling and PSA studies.

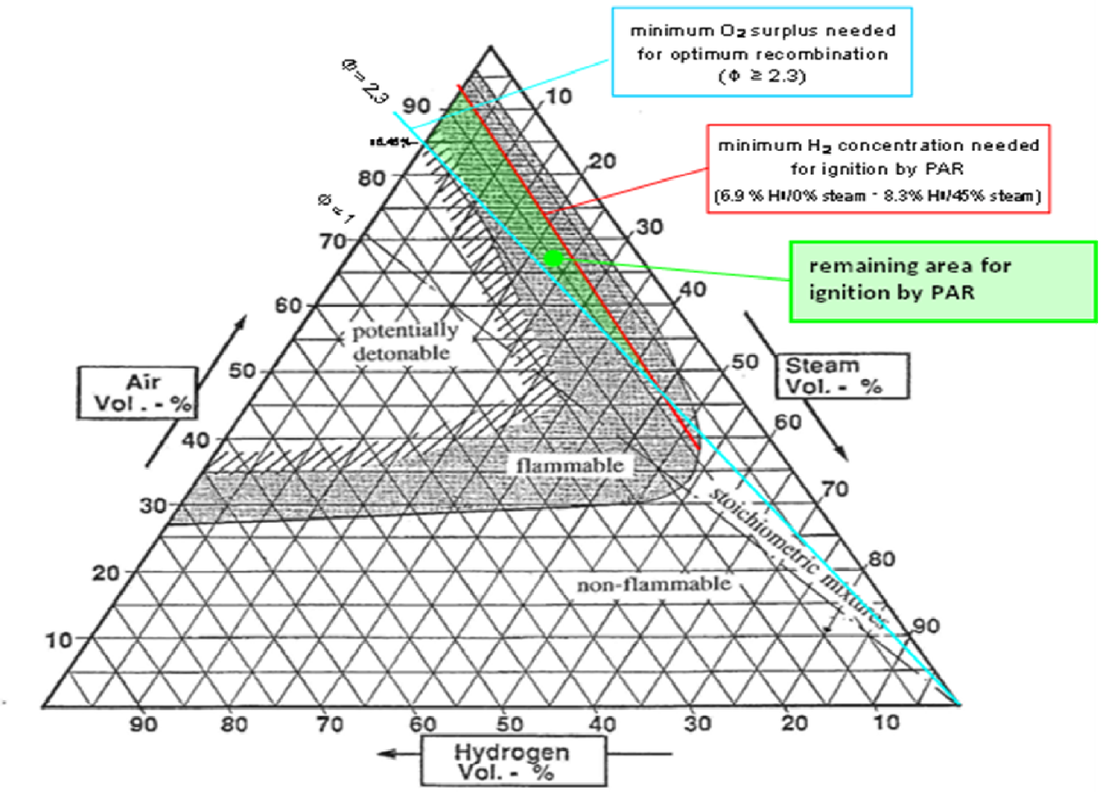


Fig. 5-5: **Ternary diagram (example):**
Area of possible ignition by PAR (green shaded), resulting from HR test findings

5.4 PAR test concerning metal iodides/PAR interaction (HR 31)

The test HR 31 considers a phase in the accident in which steam and hydrogen release has already occurred and PAR units are working. Locally in the containment, high hydrogen concentrations (8 to 9 Vol %) and a steam inerted atmosphere may prevail. The removal of hydrogen under these conditions results in temperature levels at the catalytic surfaces higher than 800°C and produces high temperatures in the gas volume of a PAR unit. Under such operating conditions, suspended CsI and other iodide particles are transported with the convective gas flow through PARs and can be converted into volatile iodine. Even low conversion rates of a few percent can increase the concentration of gaseous iodine and may influence the iodine source term into the containment.

The RECI laboratory experiments carried out by IRSN in France [Sab05]. showed that conversion rates of up to 60% can be achieved under conditions favourable for the decomposition of metal iodides (e.g. temperature > 900°C, fine particles < 1 µm, residence time > 0.5 s). A test with more accident-typical thermal hydraulic conditions has been designed performed in the THAI facility with a commercial PAR.
Test specifications and boundary conditions, in particular high temperatures (which require high hydrogen concentrations and, hence, steam inertisation) of the catalytic foils have been chosen for this experiment to maximise CsI conversion.

PAR inlet hydrogen and steam concentrations have been set to approximately 8 vol % and 60% respectively, hence limiting the catalyst plate temperatures to approximately 800°C, in order to avoid ignition. Particle sizes (Sauter diameter) between 0.5 and 0.7 µm and residence times in the range of 0.15 s were achieved. Conversion rates in the range of 1 to 3% were found in the experiment. For similar test conditions with respect to particle size, temperature of catalyst foils and residence time, in the RECI experiments conversion rates in the order of 5% were found.

5.5 PAR poisoning test (HR 32)

Test HR 32 considers an early phase of an reactor accident where PAR units are exposed to saturated steam environment favouring formation of a condensate layer and deposition of aerosol mixture (inert + hygroscopic) on catalyst foils along with exposure of catalyst foils to gaseous iodine flowing through the PAR unit. In such a situation, the efficiency of a surface to act as a catalyst will be subject to a competition between the rate of decrease of the free catalytic surface and the hydrogen and oxygen recombination reaction.

In the experiment, two different aerosols were injected separately: solid SnO_2 particles were injected (together with nitrogen) from top of the vessel, a $LiNO_3$ solution was injected via two nozzles (together with nitrogen) as small droplets near the vessel bottom into the inner cylinder. The resulting aerosol-concentration, i.e. the sum of the solid SnO_2 particles and the hygroscopic $LiNO_3$ particles was relatively high in the range of 1.5 g/m^3 to 2.5 g/m^3 during the main PAR operating phase.

Hydrogen injection started at a release rate of 0.17 g/s for 16 min; at this time, aerosol and iodine injections were started and the hydrogen release rate was increased to 0.26 g/s for another 44 min. Recombination onset was observed 25 min after start of hydrogen injection.

The injection of gaseous iodine (catalyst poison) resulted in a mean iodine concentration in the vessel atmosphere of about 0.5 10^{-3} g/m^3 during the main PAR operating phase.

Under these challenging test conditions, PAR recombination efficiency remained in the range of 50 – 70 %, which is comparable to other tests of the HR series with the same thermal-hydraulic conditions, but without aerosols and iodine and an artificially slightly increased oxygen concentration (recombination efficiency 60–70%). Also, the onset of recombination occurred at the same PAR inlet hydrogen concentration as for the comparable HR tests, Fig. 5-6. Apparently, the effect of aerosols and iodine on PAR performance is not significant.

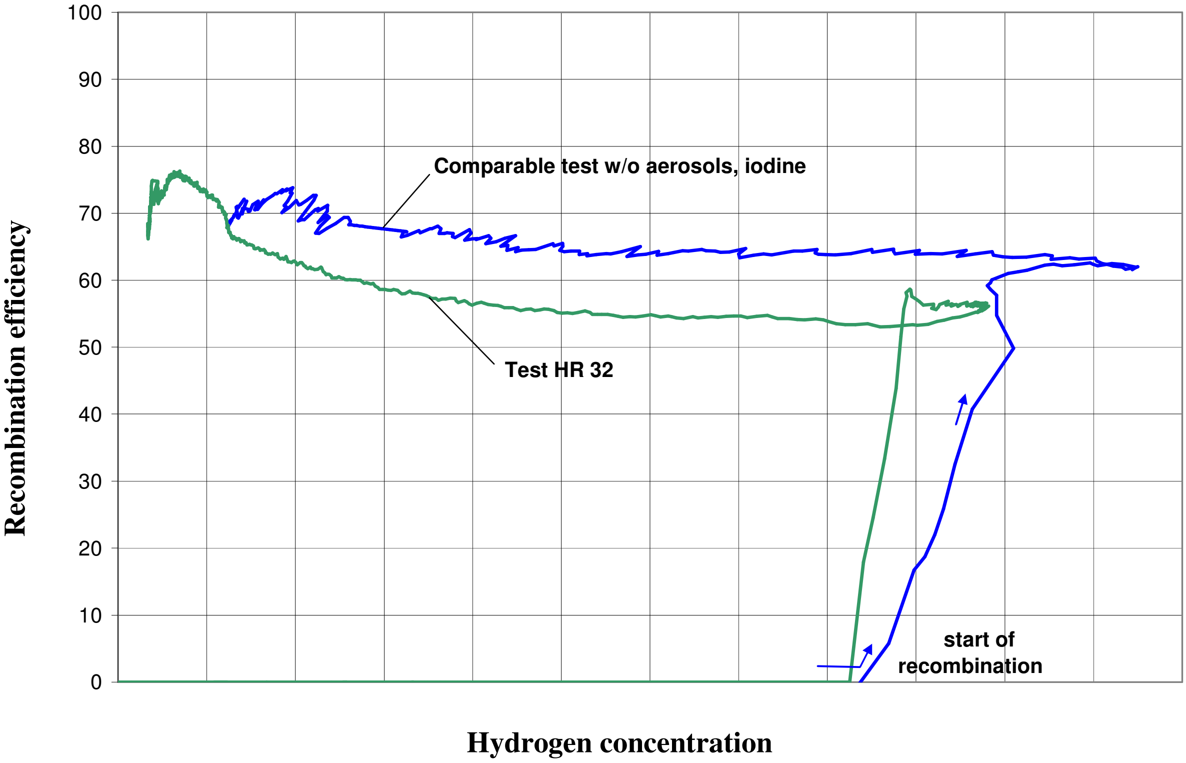


Fig. 5-6: **Test HR-32: Recombination efficiency and onset of recombination for test HR 32 and for a comparable HR test without aerosols and iodine**

5.6 Aerosol Wash-Down test

Fig. 5-7 shows the progression of different phases and the resulting pressure history during the test. The pressure increase from t = −25.1 to t = −24.3 h is due to the injection of CsI-aerosol solution together with air as carrier gas. At time t = −24.3, aerosol injection has been stopped and aerosols are allowed to be deposited on the surfaces in a dry vessel atmosphere.

Steam injection is started (wash-down phase) at time t = 0 h and pressure starts to increase. Before starting the steam injection i.e. between t = −4 h and t =0 h, a flange was opened to remove the deposition coupons. Cooling of the middle and lower vessel walls was started at time t = −2.50 h in order to ensure maximum condensation on the vertical vessel walls. During this wash-down phase, steam mass flow rate was adjusted to 14 g/s (considering cooling power available for the vessel jackets) to achieve vessel wall temperatures of 80°C, which results in complete condensation of the injected steam in a quasi-stationary condition.

The CsI aerosols deposition on the horizontal surface that includes plate sections and the puddle was quantified by means of the coupons The aerosol horizontal surface loading measured with deposition coupons was of the order of 80 g/m^2. The specific surface loading of the vertical walls was 11 %, compared to 89% for the horizontal surfaces.

Slightly inclined surfaces are subject to aerosol wash-down in the time range of minutes to hours. The measurements of CsI concentration in the condensate flow from the plate- and puddle sections show the highest values at the beginning of the water flow. The concentration in the plate runoff water decreases rapidly and reaches low nearly-constant levels after 2.5 hours. The concentration in the puddle runoff water decreases much slower and shows enhanced values even after 23 hours of washing time. The puddle water acts as an intermediate storage of aerosol material, which leads to a considerable delay in the wash-down transport.

Laboratory experiments performed in parallel showed, that the characteristic time of the transport process is shorter and the wash down more complete for high water flow rates on stainless steel surfaces. For identical test conditions (aerosol surface loading, water flow rate), the painted surface exhibited a higher wash down efficiency as compared to the stainless steel surface. The difference of the wash down process on stainless steel and painted surfaces was found to be associated with the formation and dissolution mechanisms of rivulets across the surface.

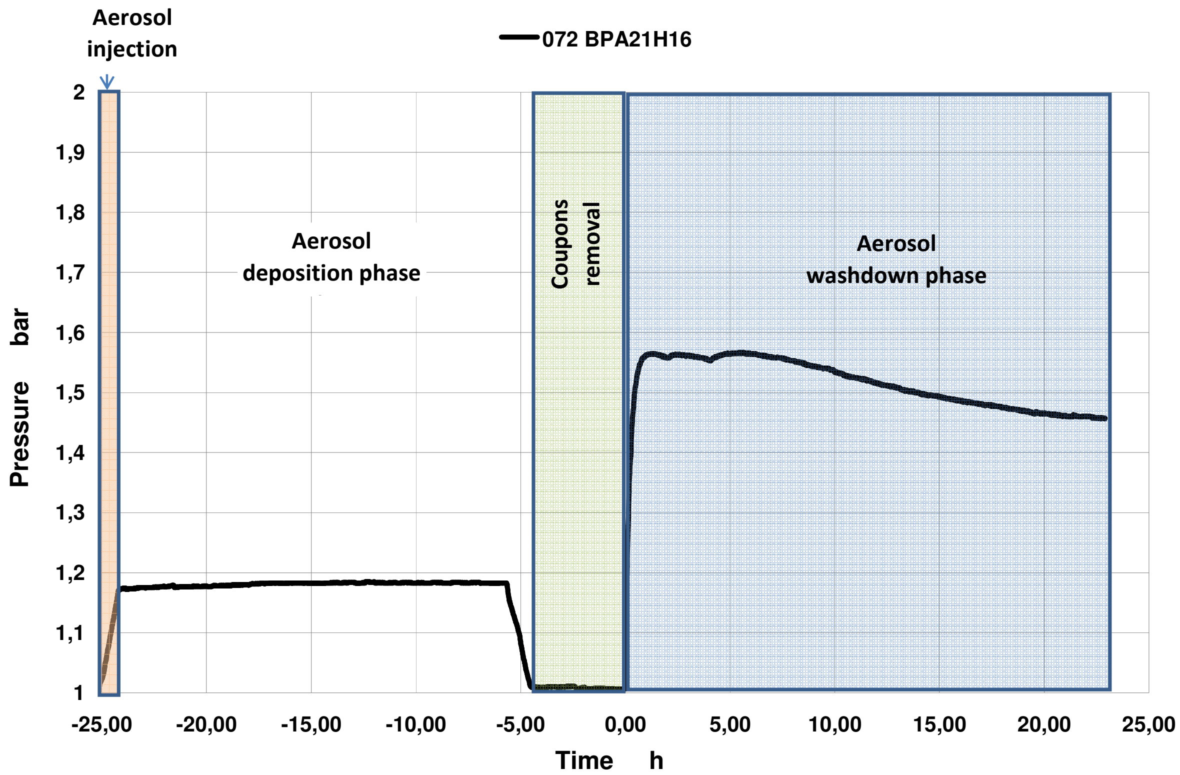


Fig. 5-7: **Aerosol Wash-Down Test: Test phases**

6. CONCLUSIONS

The experimental data obtained from the different series of tests demonstrated the capabilities of the THAI facility in producing high-quality, high-resolution data on gas mixing/stratification issues, slow hydrogen deflagration, Passive Autocatalytic Recombiners and their interaction with fission products, and fission product wash-down in a large-scale geometry. The database developed in the frame of the OECD-THAI project has been and will be extensively used to validate and improve Lumped Parameter and CFD tools available and under development for containment analysis. The analytical activities performed by project partners provided very complete analyses of the experimental data by carrying out pre- and post-test calculations of the test series performed. The enhanced tools validated against experimental data will provide a more reliable approach to safety relevant issues in evaluation of the containment response and the planning of accident management measures.

A broad spectrum of issues has been addressed. The investigations have filled existing knowledge gaps to a large extent. As an example, in case of the PAR investigations, an almost complete picture of their performance under accident typical conditions has been obtained. The results of the experimental program have provided assurances of PAR performance under realistic conditions. However, not all open questions could be resolved; they remain open and have to be addressed in future investigations. Some of these investigations are part of a planned OECD-THAI II project, for which −among others− further experiments about a special hydrogen combustion phenomenon, PAR behaviour, and iodine volatilization and transport are planned to be investigated. This project is envisaged to be commenced in late 2010.

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<u>Notes:</u>
By decision of the THAI Project Management Board the HM series report are available to non signatories without waiting for the non-disclosure deadline.

References to Project Report are listed in Appendix A.

APPENDIX A: LIST OF PROJECT REPORTS

These reports are restricted to the project signatories, however, the Management Board of the THAI Project has agreed that these Quick Look Reports and Technical Reports will be disclosed for non-signatories after 31 December 2012 and can be obtained after this date upon request to the NEA secretariat.

Reports in alphabetical and chronological order

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THAI Test numbers referenced to reports

HM Tests (Hydrogen/Helium Material scaling)			
Test No.	**Documented in**		
	Quick-Look Report	**Technical Report**	**Final Report**
HM 1	1501326 QLR-HM-1/August 2007	1501326-HM-1 TR/January 2008	1501326- FR-1/FR-2, April 2010
HM 2	1501326 QLR-HM-2/February 2008	1501326-HM-2 TR/February 2008	
HM 3		1501326-HM-1 TR/January 2008	
HM 4			
HM 5			

HD Tests (HydrogenDeflagration)			
Test No.	**Documented in**		
	Quick-Look Report	**Technical Report**	**Final Report**
HD 1R	1501326 HD-QLR-2/April 2008	1501326-HD-2 /January 2010 (incl. results of HD 22 and HD 23)	1501326 FR-1/FR-2, April 2010
HD2R	1501326 HD-QLR-1/April 2008		
HD 3	1501326 HD-QLR-5/August 2008		
HD 4	1501326 HD-QLR-2/April 2008		
HD 5	1501326 HD-QLR-5/August 2008		
HD 6	1501326 HD-QLR-5/August 2008		
HD 7	1501326 HD-QLR-2/April 2008		
HD 8	1501326 HD-QLR-2/April 2008		
HD 9	1501326 HD-QLR-5/August 2008		
HD 10	1501326 HD-QLR-2/April 2008		
HD 11	1501326 HD-QLR-5/August 2008		
HD 12	1501326 HD-QLR-1/April 2008		
HD 13	1501326 HD-QLR-5/August 2008		
HD 14	1501326 HD-QLR-5/August 2008		
HD 15	1501326 HD-QLR-3/May 2008		
HD 16	1501326 HD-QLR-3/May 2008		
HD 17	1501326 HD-QLR-3/May 2008		
HD 18	1501326 HD-QLR-3/May 2008		
HD 19	1501326 HD-QLR-3/May 2008		
HD 20	1501326 HD-QLR-3/May 2008		
HD 21	1501326 HD-QLR-5/August 2008		
HD 22	1501326 HD-QLR-6/September 2008		
HD 23	1501326 HD-QLR-6/September 2008		
HD 24	1501326 HD-QLR-3/May 2008		
HD 25	1501326 HD-QLR-4/August 2008		
HD 26	1501326 HD-QLR-4/August 2008		
HD 27	1501326 HD-QLR-4/August 2008		
HD 28	1501326 HD-QLR-4/August 2008		
HD 29	1501326 HD-QLR-4/August 2008		

HR Tests (Hydrogen Recombiner)		
Test No.	Documented in	
	Technical Report	Final Report
HR 1	1501326 HR-QLR-1/February 2009	1501326 FR-1/FR-2, April 2010
HR 2		
HR 3		
HR 4		
HR 5		
HR 6	1501326 HR-QLR-2/August 2009	
HR 7		
HR 8		
HR 9		
HR 10		
HR 11		
HR 12		
HR 13		
HR 14	1501326 HR-QLR-4/October 2009	
HR 15		
HR 16		
HR 17	1501326 HR-QLR-3/October 2009	
HR 18		
HR 19		
HR 20		
HR 21		
HR 22		
HR 23		
HR 24		
HR 25		
HR 26		
HR 27	1501326 HR-QLR-1/February 2009	
HR 28		
HR 29	1501326 HR-QLR-2/August 2009	
HR 30		

HR 31	1501326 HR-QLR-5/September 2009	1501326 FR-1/FR-2, April 2010

HR 32	1501326 HR-QLR-6/October 2009	1501326 FR-1/FR-2, April 2010

AW	1501326 AW-QLR/December 2009	1501326 FR-1/FR-2, April 2010