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NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

OECD/NEA PRISME Project Application Report

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Application of the OECD PRISME results to investigate heat and smoke propagation mechanism in multi-compartment fire scenarios

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The mission of the NEA is:

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- 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 Committee on the Safety of Nuclear Installations (CSNI) shall be responsible for the activities of the Agency that support maintaining and advancing the scientific and technical knowledge base of the safety of nuclear installations, with the aim of implementing the NEA Strategic Plan for 2011-2016 and the Joint CSNI/CNRA Strategic Plan and Mandates for 2011-2016 in its field of competence.

The Committee shall constitute a forum for the exchange of technical information and for collaboration between organisations, which can contribute, from their respective backgrounds in research, development and engineering, to its activities. It shall have regard to the exchange of information between member countries and safety R&D programmes of various sizes in order to keep all member countries involved in and abreast of developments in technical safety matters.

The Committee shall review the state of knowledge on important topics of nuclear safety science and techniques and of safety assessments, and ensure that operating experience is appropriately accounted for in its activities. It shall initiate and conduct programmes identified by these reviews and assessments in order to overcome discrepancies, develop improvements and reach consensus on technical issues of common interest. It shall promote the co-ordination of work in different member countries that serve to maintain and enhance competence in nuclear safety matters, including the establishment of joint undertakings, and shall assist in the feedback of the results to participating organisations. The Committee shall ensure that valuable end-products of the technical reviews and analyses are produced and available to members in a timely manner.

The Committee shall focus primarily on the safety aspects of existing power reactors, other nuclear installations and the construction of new power reactors; it shall also consider the safety implications of scientific and technical developments of future reactor designs.

The Committee shall organise its own activities. Furthermore, it shall examine any other matters referred to it by the Steering Committee. It may sponsor specialist meetings and technical working groups to further its objectives. In implementing its programme the Committee shall establish co-operative mechanisms with the Committee on Nuclear Regulatory Activities in order to work with that Committee on matters of common interest, avoiding unnecessary duplications.

The Committee shall also co-operate with the Committee on Radiation Protection and Public Health, the Radioactive Waste Management Committee, the Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle and the Nuclear Science Committee on matters of common interest.

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Fire in nuclear power plants remains a significant contributor to the overall risk with respect to the operation of these facilities. In fact, fire safety analysis studies supplemented by international operating experience demonstrate that fire contributes significantly to the overall core damage frequency (CDF) recognised within the safety cases for both existing and new plants. The actual contribution of fire to the overall CDF requires further precision given the large uncertainties resulting from the lack of precise knowledge on different fire specific phenomena. Furthermore, challenges exist internationally in the use of validated fire models that can reasonably predict the consequences of a fire in a nuclear installation. Following the work carried out in support of *NEA/CSNI/R(99)27 (State of the Art Report on Fire Risk Analysis, Fire Simulation, Fire Spreading and Impact of Smoke and Heat on Instrumentation Electronics, February 2000)*, the international nuclear safety community realised that it was important to both further experimentally study specific phenomena in fire propagation as well to improve the predictive capabilities of fire models and codes.

A number of OECD member countries expressed their interest in participating in an OECD-NEA joint international research project on the topic of fire propagation. The PRISME project (PRISME is the French acronym which stands for “Fire Propagation in Elementary Multi-Room Scenarios”) was proposed by IRSN in France with their specially designed facilities in Cadarache to be used to carry out the various fire test scenarios. The three major research areas addressed by the PRISME project included: propagation of heat and smoke from the fire room to adjacent rooms, impact of heat and smoke on safety critical systems and the impact of the ventilation network on limiting heat and smoke propagation. In all, five experimental campaigns consisting of more than 35 large scale fire tests were carried out using the facilities at Cadarache. Coincident with the conduct of these experimental campaigns, PRISME partners evaluated the capabilities of various fire modelling codes to simulate fire scenarios based on the PRISME data results. A number of benchmark exercises were conducted within the analytical working group of PRISME which further advanced the knowledge on the predictive capabilities of the various fire codes being used.

The project was formally launched in January 2006 and was intended to conclude by December 2010 (subsequently extended to June 2011 by the PRISME partners in order to carry out additional experimental tests). Eventually a total of 12 countries signed the agreement to become PRISME members: Belgium (GDF Suez and the future Bel V), Canada (AECL), Finland (VTT), France (IRSN as operating agent and EDF), Germany (GRS), Japan (JNES), Republic of Korea (KINS), Netherlands (VROM-KFD), Spain (CSN), Sweden (the future SSM), United Kingdom (the future HSE/ONR) and the United States (NRC) (see Appendix 4 for the list of participating members).

A key accomplishment of the PRISME project is the improved understanding gained of the phenomena occurring during a fire in a confined mechanically ventilated installation. Important issues to be considered in safety analysis such as the position of leaks on walls and their effect on smoke and heat propagation in neighbouring compartments have been studied. The second global accomplishment of the PRISME project has been the improvements realised in the use of fire simulation codes to more accurately model fire behaviour. Furthermore, the benchmark exercises conducted by partners have also highlighted for users the inherent limitations of the models used to predict smoke and heat propagation in certain complex scenarios. In general, the PRISME project has resulted in an improved understanding of heat and smoke propagation from the fire compartment to an adjacent compartment, the effects of under-ventilated conditions on the fire source, the behaviour of electrical cables submitted to high thermal stress, the creation of a significant database of experimental data and finally the establishment of an international network on these important topics.

A number of recommendations have been produced by the PRISME project team to address some further phenomena not studied in the current project. Based on the discussion with PRISME partners, three main topics need further work:

- Smoke and hot gas propagation through a horizontal opening between two superposed compartments. This type of smoke flow is poorly studied experimentally in large-scale facilities controlled by ventilation systems and remains a challenging task for computer code validation and modelling;

- Fire spreading on real fire source such as cable trays and electrical cabinet and fire propagation from one fire source to another. These scenarios are identified by most partners, because they currently concern control panel and switchgear rooms of nuclear power plants;

- Fire extinguishing including studying the performance of various extinguishing systems. Modelling the fire suppression system is still a great challenge and an experimental database of full-scale fire tests representative of typical scenarios in nuclear power plants is needed.

Based on these topics, the PRISME 2 project has been defined. This new project will answer some of issues but others will remain open.

During the PRISME 2 project, the improvement of the heat release rate prediction is still particularly important. Based on experimental results, code guidelines to simulate complex fires, such as cable trays or electrical cabinets, will be another important objective as there is a lack of knowledge on these types of fire sources and, following the assumptions of simulation, the discrepancy in the results is important.

However, the PRISME 2 project will not cover the following items:

- For electrical cabinet fires, the study of the influence of the construction characteristics (open doors, internal partitions, etc.) in the evolution of fires;

- The determination the ignition temperature of equipment typically found in industrial installations (electrical cabinets, charcoal filters, cable trays, etc.);

- The study of the fire propagation phenomena through cable tray penetrations through walls or floor slabs;

- The study of heat spreading phenomena to adjacent areas through metal elements through the enclosure;

- The study of fires in large volumes or atriums, performing small-scale experiments and extrapolating the results to large-scale fires, thereby determining the smoke movement and heat propagation to structural elements;

- The study of the influence of fixed fire extinguishing systems actuation on the evolution of the most influential fire parameters; in addition, a comparative study of the effect of using different fire protection systems (extinguishing systems with different extinguishing agents such as water (sprinklers, spraywater deluge systems), water based foam, water mist or inert gases) and detection devices such as spot or linear thermal detectors and spot or aspirating smoke detectors;

- The study of the shape and position of retention heat or smoke canopy for detection at intermediate levels.

This final project report describes the programme of work, high level results and outcomes of the PRISME project following five years of experimental research. In addition, it provides some insights into future areas of research that could further advance the collective understanding of fire propagation scenarios important to safety analysis for NPP facilities. In all, the PRISME project has provided unique and invaluable information to its members to assist them in better understanding fire phenomena, to improve their predictive capabilities of fire simulations and ultimately to advance system design considerations to reduce overall fire risk to the plants.

2. SAFETY ISSUES AND BACKGROUND

Fires in nuclear installation (NI) are a significant regulatory concern due to their potential to affect the safety of the NI. Fire safety assessments and operational experience gained from fire events have shown that fire contributes significantly to the overall fuel damage frequency for both existing and new build plant designs [NEA/CSNI/R(99)27].

Fire occurrence frequencies are in the order of 10^{-2} per reactor year. The fire related core damage frequency in nuclear power plants is typically in the same order as that of the internal events PSA. These estimates include considerable uncertainties resulting from the lack of knowledge on different fire specific phenomena.

Fire modelling is generally used in a number of fire safety assessment studies and to support regulatory decision making. However, fire modelling also presents challenges such as the availability of verified and validated fire models that can reliably predict the consequences of fires in nuclear installation. Validation and verification studies for fire models of a nuclear installation have shown areas where the fire models can be improved, but they also highlight areas where engineers should be confident or concerned when using the current generation of fire models. Several questions remain open to improve fire model prediction:

- Propagation of heat and smoke from the fire room to other rooms;
- Impact of heat and smoke on systems relevant for nuclear safety;
- Ventilation network driving for limiting smoke and heat propagation.

As stated in NEA/CSNI/R(99)27, it is important to reduce uncertainties in the treatment of the above mentioned aspects. For that reason, validated codes able to simulate the relevant steps of the fire scenario are needed.

Therefore, one of the main technical issues in fire safety assessment is related to smoke and hot gaspropagation in a nuclear plant through the possible ways of taking into account the disturbance of the ventilation network and of the room depression levels due to the fire itself and to the behaviour of active fire barrier elements, such as fire dampers, fire break doors, etc. The design of nuclear plants makes the study of fire development and propagation complex since there is a strong correlation between fire and ventilation conditions.

Although modelling many aspects of propagation phenomena exists in current numerical tools for fire simulation, few of them take into account coupling with the ventilation network behaviour, including active fire barrier elements such as fire dampers and high efficiency filters. Moreover, even in a simple case that uses both natural and mechanical ventilation there is a lack of experimental data suitable for code validation. Tests with fire damper-closure or filter-plugging carried out in representative scale facilities do not exist.

With regard to multi-room fires, several tests have addressed fire and smoke propagation in different occupancies, including verification and testing of detection and/or extinguishing systems. Small scale multi-room tests have been conducted at VTT in Finland, mainly to produce guidelines on how to implement positive-pressure ventilation measures.

Full-scale multi-room fire tests have been performed in some countries (e.g. Japan, Australia, USA), with regard to specific civil applications. For nuclear applications, tests on fire propagation in an experimental reactor were performed in Germany from 1984 to 1991 (HRD experiments). However, there is a lack of experimental data on confined and mechanically ventilated rooms. There is a need to understand under which conditions heat and smoke propagation can be simulated by zone models and/or three-dimensional CFD (computational fluid dynamics) codes, so-called field models. This understanding necessitates a well-qualified database obtained in full-scale and representative experimental conditions.

3. OVERVIEW OF THE PRISME PROJECT

3.1 Purpose of the PRISME Project

The objectives of the OECD PRISME[1] Project are to investigate different modes and mechanisms involved in the spread of hot gases and smoke from the fire compartment towards adjacent rooms (from 1 to 3 rooms) via the following elements:

- Open door(s);
- Leakages (through openings, narrow slot and a certified firebreak door;
- Ventilation network (for example, reverse flow due to the effects of pressure, effect of forced vs. natural flow rate in the doorways);
- Ventilation duct(s) crossing the fire compartment and blowing out an adjacent room.

The fire sources are liquid pool fire and typical real fire sources such as PVC cables and electrical cabinets. The heat release is in the range of approximately 200 kW to several MW depending on the fuel nature, the fuel surface, the wall material(s) and the ventilation airflow rate. The fire may be self-extinguished by lack of fuel or lack of oxygen in the fire room.

The large-scale experiments are carried out in a multi-room facility (named DIVA) for the confined and ventilated fire tests and in a calorimeter facility (named SATURNE) for open atmosphere. These experimental installations are located both at Cadarache (France). All compartments of DIVA are representative of nuclear power plants with confined rooms connected to a ventilation network. During the PRISME project, five experimental campaigns (more than 35 large-scale fire tests) were performed from early 2006 up to mid-2011:

- PRISME Source fire tests devoted to characterise the fire source and to investigate fire behaviour in a single compartment;
- PRISME Door fire tests devoted to study the smoke and gas propagation between two or three rooms through doorway and the effects of thermal stress on PVC insulated electrical cables (surrogate and real cables);
- PRISME Leak fire tests devoted to investigate the smoke and gas propagation between two rooms through leakages (via two openings, a narrow vertical slot, a firebreak door and a duct crossing the fire compartment) and the effects of thermal stress on real electrical cables for which the electrical malfunction is measured;

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[1] In French, PRISME means “PRopagation d’un Incendie pour des Scénarios Multi-locaux Élémentaires”, which in English stands for « Fire propagation in elementary multi-room scenarios »

- PRISME Integral fire tests devoted to study the heat and mass transfer of hot gases and smoke through doorways considering three and four rooms, with a special focus on smoke and heat propagation due to a real fire source (electrical cabinet and cable fire sources) on ventilation driving on heat and smoke propagation (ventilation and damper effect), and on the effects of a water deluge extinguishing system (sprinkler);

- PRISME Support: around ten tests were conducted to characterise the fire sources in open atmosphere conditions.

3.2 Description of the experimental facilities and instrumentation

3.2.1 The DIVA facility

The DIVA facility, representative of nuclear installations, is in a large-scale multi-room facility (Figure 1) including four compartments (tagged from 1 to 4) and a corridor. All the walls are 0.3 m thick and were built with reinforced concrete allowing them to withstand a gas pressure range from 100 hPa to 520 hPa. Room 4 is not used during this project and would allow the study of vertical hot gas propagation from a lower (room 3) to an upper room (room 4). All the rooms (length × width × height = 6 × 5 × 4 m^3, see Figure 2) are connected via a mechanical ventilation system by means of inlet and outlet ducts. The corridor (length × width × height = 15 × 2.5 × 4 m^3) is located along rooms 1 to 3. Each compartment is equipped with one inlet and one exhaust duct of the ventilation network. The latter can be located in the upper or the lower part of each room depending on the fire scenarios. The rooms can be connected through a single doorway (0.7 m × 2.1 m) or different types of elements (simple openings, firebreak door…). The possibilities offered by DIVA allow researchers to investigate complex scenarios, as encountered in real situations, involving, for instance, electrical cabinets and cables as targets to study malfunction and failure of such equipments.

Figure 1: Scheme of the DIVA facility and its ventilation network

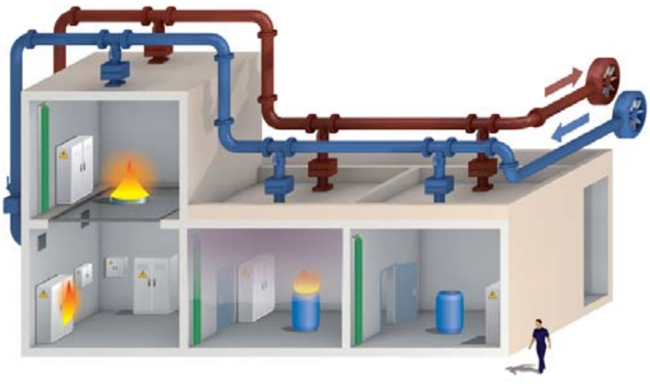
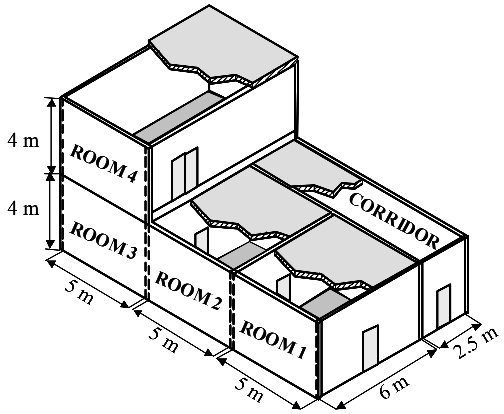


Figure 2: Main geometrical dimensions of the DIVA facility



The DIVA facility is highly instrumented (up to 800 possible measurement channels on the data acquisition system). Its ventilation network allows the simulation of ventilation configurations representative of power plants as well as nuclear laboratories.

3.2.2 The SATURNE facility (calorimeter)

The SATURNE facility (see Figure 3) is a large enclosure of 2,000 m^3 (length × width × height = 10 x 10 x 20 m^3), where a large-scale calorimeter is located.

The fire tests, carried out under the calorimeter hood (see Figure 3 and Figure 4) are devoted to determining the fire behaviour in an open atmosphere for simple and complex fuels such as liquid pools, electrical cabinets and cable trays. They are included in the PRISME Support tests (especially, characterisation of HTP pool fire and of cable fire) as described in tAppendix 3. The main characteristics of the calorimeter are:

- Hood: 3 m in diameter,
- Height from floor: for these tests, the height between the floor and the bottom rim of the hood is approximately 4 m,
- The smoke exhaust system is connected to a ventilation network. Its exhaust flow rate can be varied from 10,000 to 25,000 m^3/h,
- This facility is designed to study fire sources up to nearly 1.5 MW.

Figure 3: Hood of the SATURNE facility (large-scale calorimeter)

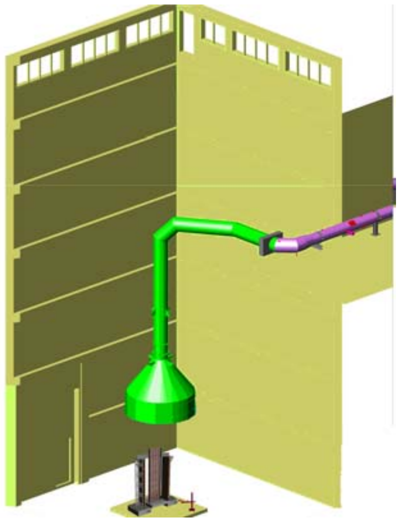
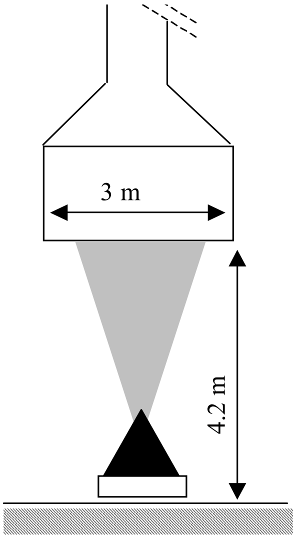


Figure 4: Main geometrical dimensions of the SATURNE facility



3.2.3 Instrumentation

For most of the PRISME fire tests, more than 500 measurements are performed in order to fully describe the fire scenarios and to propose a high quality database for code validation. The measurements focus on the following variables: fuel mass loss rate, gas and wall temperatures (or others such as inside cables), gas species concentrations (CO, CO_2, O_2 and total hydrocarbons), soot concentrations, radiative and total heat fluxes received by the walls or various targets, pressures and flow rates in all compartments and in the ventilation network.

For the SATURNE hood, the measurements available in the exhaust duct are mainly those typically available in calorimeter system such as pressures, gas flow rates, temperatures, gas concentrations of O_2, CO, CO_2 and soot concentration.

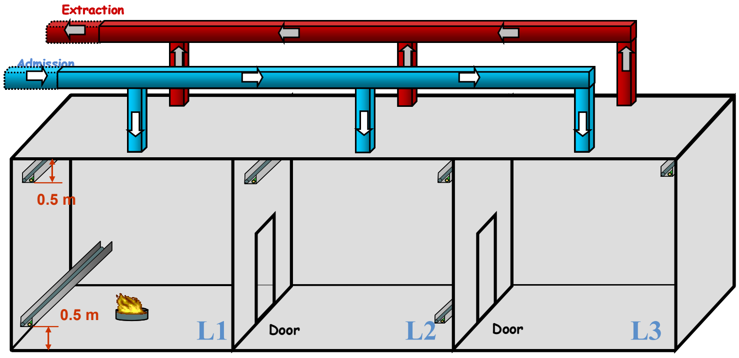
Additional values are also determined nearby the fire source such as the fuel mass, temperatures, radiative and total heat fluxes (nearby and far from fire source), and video camera recordings.

3.3 Description of experiments carried out in the OECD PRISME Project

3.3.1 PRISME Source and Door

As a first stage, the PRISME Source fire tests aim to study the fire behaviour of HTP pool fire (HTP=Hydrogenated Tetra-Propylene, $C_{12}H_{26}$) used as fire source in the PRISME Source and Door experimental campaigns. This liquid fuel is tested first in an open atmosphere (SATURNE calorimeter) for several fuel surfaces and then in confined and ventilated conditions (single room) in order to investigate the effect of oxygen depletion on the fire source. An example of this study will be presented later in the paper. In the following phases of the PRISME project, the same experimental strategy is used, i.e., studying the fire source in open atmosphere (calorimeter), before studying it in confined and ventilated compartments (DIVA facility), which involve oxygen depletion in the fire compartment. The experimental matrix of the PRISME Source tests including the main parameters of fire tests (pool area, initial fuel mass, and ventilation flow rate in DIVA) is described in Appendix 1 for the confined and ventilated fires and in Appendix 3 for fires in open atmosphere. The PRISME Source fire tests in the DIVA facility have been carried out in room 2 (see Figure 5).

Figure 5: DIVA configurations for PRS Source and Door fire tests (front view)



Source: 1 room (L2) - Door: 2 (L1/L2) or 3 rooms (L1/L2/L3)

The PRISME Door campaign specifically investigates the spread of smoke and hot gases through open doors for two and three room configurations and also the heat transfer to surrogate and real cables. The previous PRISME Source experiment results are used to select the fire test parameters (such as the pool area). In Appendix 1, the experimental matrix of the PRISME Door tests is described showing the main parameters of the fire tests such as the pool area, the initial fuel mass, the ventilation flow rate, the number of compartments and the location of the air inlet. The PRISME Door fire tests have been carried out in the rooms 1 and 2 for the two-room scenarios and in the rooms 1 to 3 for the three-room scenarios (see Figure 5).

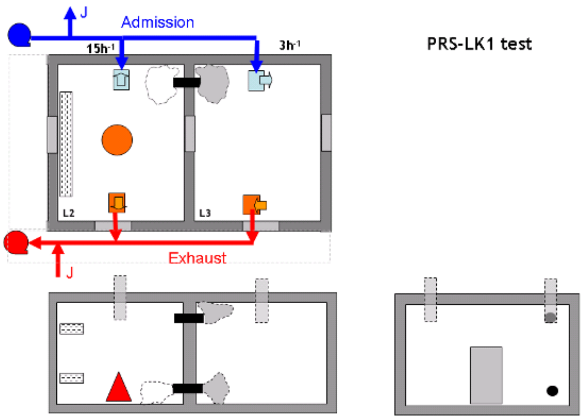
3.3.2 PRISME Leak

The third campaign, PRISME Leak, concerns the propagation of smoke and hot gases through leakages (two openings, narrow slot andfirebreak door) between the fire compartment and the neighbouring room (Leak 1 to 3, see Figure 6) and the study of the heat transfer coming from a duct crossing the fire compartment and flowing into the adjacent room (Leak 4, see Figure 7).

More precisely, PRS_LK1 test concerns the propagation of smoke through two circular holes located in the upper and lower part of the wall separating the source room (fire compartment) and the adjacent room. PRS_LK2 test concerns the propagation of smoke through a vertical slot opening. PRS_LK3 test concerns the propagation of smoke through a real firebreak door. PRS_LK4 test concerns the propagation of smoke through a real firebreak door as well as the propagation of heat through a ventilation duct exposed directly to the fire and blowing heated air into the adjacent room. The experimental matrix of PRISME Leak is described in Appendix 2.

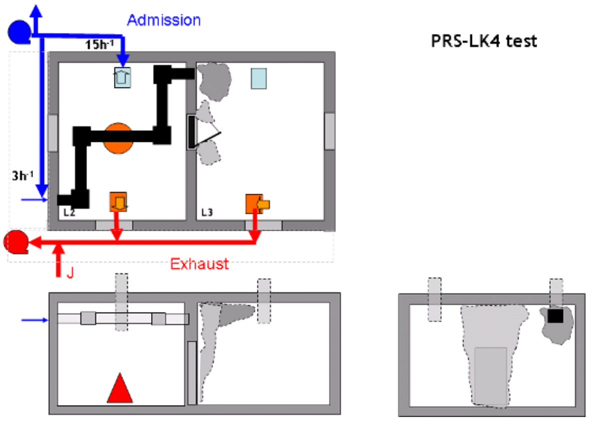
A second objective is the cable performance testing (as found in an NPP) in order to provide additional data to supplement the knowledge based on cable fire induced failure modes and effects. This study was carried out with the technical support of Sandia National Laboratories (SNL) and sponsored by the United States Nuclear Regulatory Commission (NRC) Office of Nuclear Regulatory Research. The equipment and methods used in the PRISME cable performance tests were based directly on those tests used to support the CAROLFIRE program [22].

Figure 6: PRS_LK1 fire test (similar for LK2 & 3)



(2 rooms; top, front and side views)

Figure 7: PRS_LK4 fire test



(2 rooms; top, front and side views)

3.3.3 PRISME Integral

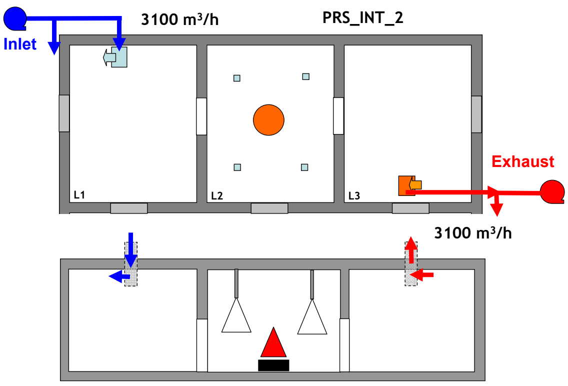
The last stage, PRISME Integral, aims at studying practical configurations (see Figure 8 and Figure 9) involving various fuels, 3 or 4 rooms connected by doorways, a fire barrier element such as fire dampers and a water deluge extinguishing system such as sprinklers. In these experiments, the air inlet flow goes from room 1 (and corridor) to the exhaust duct in room 3 via forced vs. natural air flows through doorways. This last experimental campaign involves six fire tests as specified in Appendix 2. The main objectives of this last campaign are to investigate:

- the propagation of smoke and hot gases through doorways in confined and ventilated rooms;

- the effect of the number of adjacent rooms on the propagation through doorways;
- the effect of sprinkler activation on a fire scenario;
- the effect of fire damper closure on a fire scenario;
- the behaviour of a cable fire in a confined and ventilated fire scenario;
- the behaviour of an electrical cabinet fire in a confined and ventilated fire scenario.

In Appendix 2, the experimental matrix of the PRISME Integral tests is described showing the main parameters of the fire tests such as the fire source, the number of compartments and others (fire dampers, sprinkler activation). To determine the fire behaviour of cables in an open atmosphere, the PRISME Support tests (see Appendix 3) are carried out under the SATURNE calorimeter before the fire test (PRS-INT3) inside the DIVA facility.

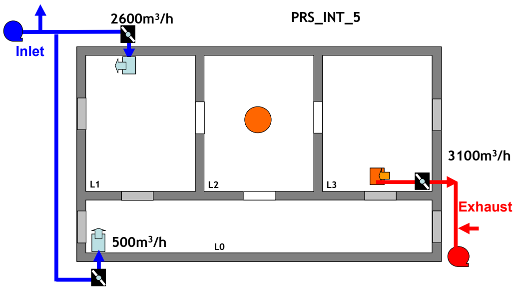
Figure 8: PRS_INT2 fire test



(similar for tests 1 and 3)

(3 rooms; top and front views)

Figure 9: PRS_INT5



(similar for tests 4 and 6)

(4 rooms; top view)

4. MAJOR FINDINGS FROM THE PRISME PROJECT

The main experimental results of the PRISME project are on the following topics:

- Smoke and hot gas propagation through vertical openings (doorways) between the fire room to neighbouring rooms and for two modes of convective flows (natural and natural/forced flows);
- Smoke and hot gas propagation through leakages (two openings, narrow slot, fire door) between the fire compartment and an adjacent one;
- Study of the heat transfer coming from a duct crossing the fire compartment and blowing into the adjacent room;
- Effect of sprinkler activation on the fire scenario;
- Effect of fire damper closure on the fire scenario;
- Behaviour of cable fire and electrical cabinet fire sources in confined and ventilated fire scenarios.

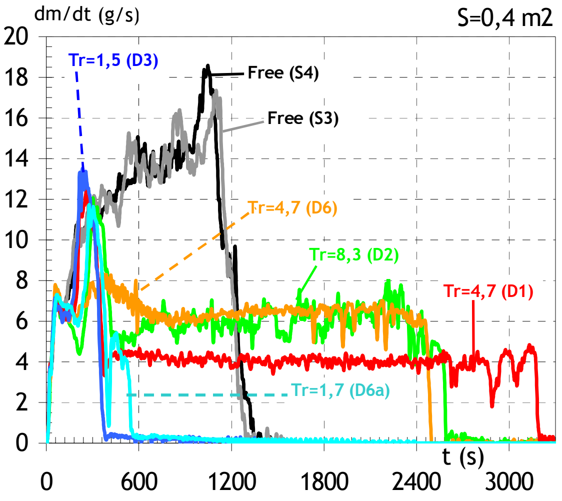
To illustrate the work carried out in this project, some outstanding results from the PRISME experimental campaigns are highlighted:

- the effect of oxygen depletion on fuel mass loss rate (from PRISME Source and PRISME Door fire tests);
- the relative effects of heat and mass transfers from the fire compartment to an adjacent room (from PRISME Door and PRISME Leak fire tests);
- the smoke propagation from the fire compartment to adjacent compartments (from PRISME Door, Leak, Integral and Support fire tests);
- the cable performance testing (from PRISME Leak tests);
- the effect of damper closure on the fire scenario (from one PRISME Integral tests);
- the activation of the sprinkler system (from one PRISME Integral test);
- the behaviour of cable fires in confined and ventilated fire scenarios (from PRISME Integral and Support fire tests);
- the behaviour of an electrical cabinet fire in confined and ventilated fire scenarios (from PRISME Integral and Support fire tests).

4.1 Effect of oxygen depletion on fuel mass loss rate

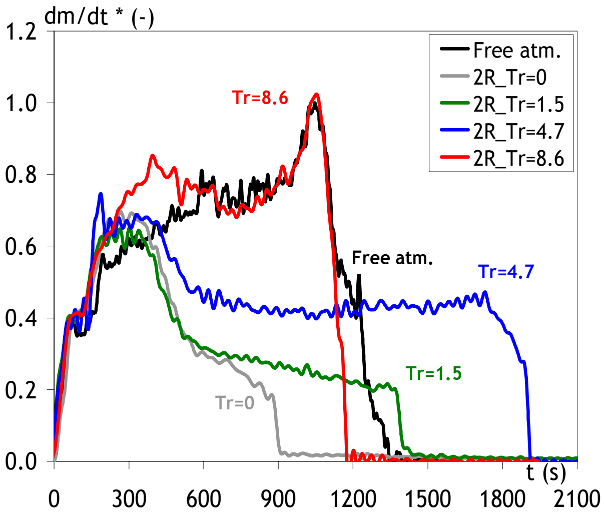
In the case of confined and ventilated fires, the ventilation flow rate might not be high enough to release the combustion products from the fire compartment (depending, of course, on the heat release rate of the fire source). Consequently, these products quickly fill up the fire compartment contributing to oxygen depletion therein ([8], [9], [10], [16], [23], [30]). As a result, the mass loss rate (MLR) of the fire source is significantly reduced until the fire self-extinguishes due to lack of fuel or of oxygen. In fact, the fire duration may be either shorter because of short-term self-extinguishing by lack of oxygen, or drastically longer because of the MLR decrease under steady state conditions (i.e. without the flame extinction) involving more time to burn all the mass of fuel available in the pan. For example, in the PRISME Source experiments, the fire duration for a renewal rate of Tr = 4.7 is around 2.5 times longer compared to the same pool fire in a free atmosphere (see Figure 10 in PRISME Source, similar results also observed in the PRISME Door tests, see Figure 11). Knowledge of the fire duration is of course of major interest for the analysis of fire hazard and the assessment of fire consequences in nuclear power plants.

Figure 10: PRISME Source



(one room; S = 0.4 m²) (0; 0)

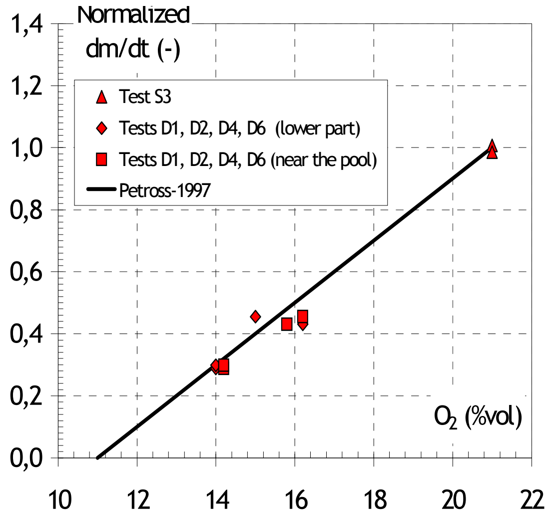
Figure 11: PRISME Door (D1 to D4)



(2 rooms; S = 0.4 m²) (0; 0)

The effect of the air flow rate on the mass loss rate is closely dependent on the oxygen concentration within the fire compartment. From the PRISME Source data, Figure 12 shows a linear relationship of the fuel mass loss rate versus the oxygen concentration near the pool fire. Moreover, the experimental results fit well with the Peatross et al. correlation ([1], [12]). The same behaviour is observed in the PRISME Door test as described in [9].

Figure 12: PRISME Source data compared to Peatross et al. correlation (0, 0, 0)



$$\boxed{\frac{\dot{m}_c}{\dot{m}_c^O} = 0,1\,X_{O_2} - 1,1}$$

The PRISME LEAK and INTEGRAL tests show situations where the external heat fluxes are significant, especially because of the wall compartment thermal insulation, and compensate for the effect of oxygen depletion. For such fire tests, the fire power is very similar to the power expected in an open atmosphere, although the level of oxygen is very low. This type of fire is similar to flashover behaviour where the flame moves all over the volume of the compartment. Consequently, the Peatross et al. correlation is no longer valid and a new modelling [23] has been proposed to take into account the effect of oxygen depletion and the radiative heat flux from surrounding gases.

4.2 Hot gas propagation from fire room to neighbouring room

In order to assess the relative effect of heat and mass transfers in PRISME Door and PRISME Leak campaigns, Figure 13 and Figure 14 present the Mass Flow Rate (MFR) and the Convective Heat Flux (CHF) between the fire compartment and the adjacent compartment. The propagation of hot gases is obviously larger through doorways than through leakages showing a ratio of nearly 5 to 10 times for MFR and of nearly 3 to 10 times for CHF. This result strengthens the fact that a high level of confinement remains the best way to limit the propagation of hot gases in a nuclear facility and its consequences due to fire (ignition of target, malfunction of electrical components, etc.). It has to be noticed that such a high level of confinement could enhance the pressure effects particularly during the fire ignition (over-pressure peak) and fire extinguishing (under-pressure peak) transient periods that can lead to possible damage of confinement equipment.

As expected from PRISME Leak fire experiments, the CHF decreases from PRS-LK1 to PRS-LK3 corresponding to openings, narrow slot and firebreak door. Nevertheless, the MFR from the fire compartment to the adjacent room is similar for these three fire tests indicating that the mass transfer of gas depends weakly on the type of leakages in the fire scenarios studied.

Figure 13: Mass Flow Rate (MFR) from the fire compartment to the adjacent room

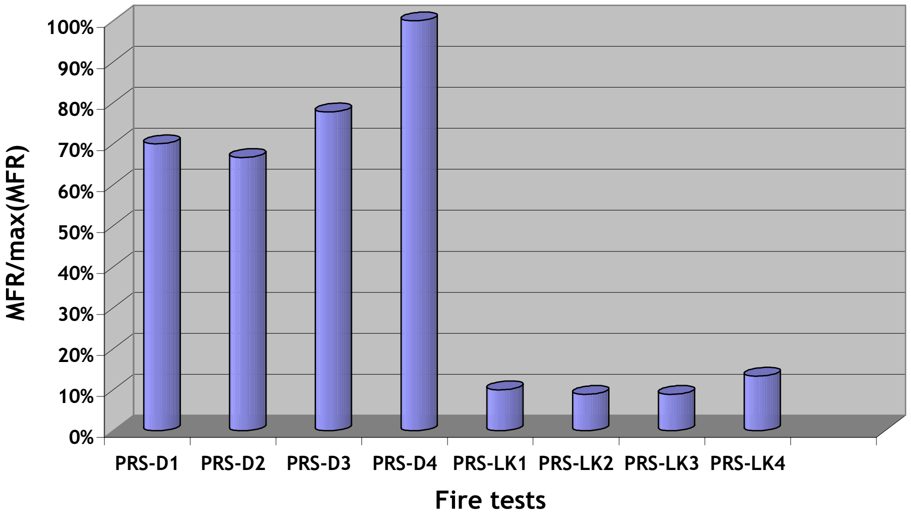
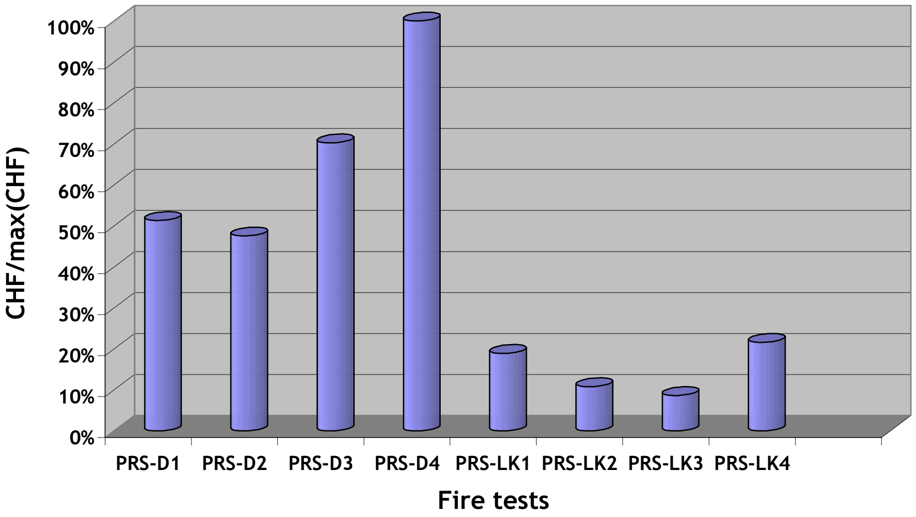


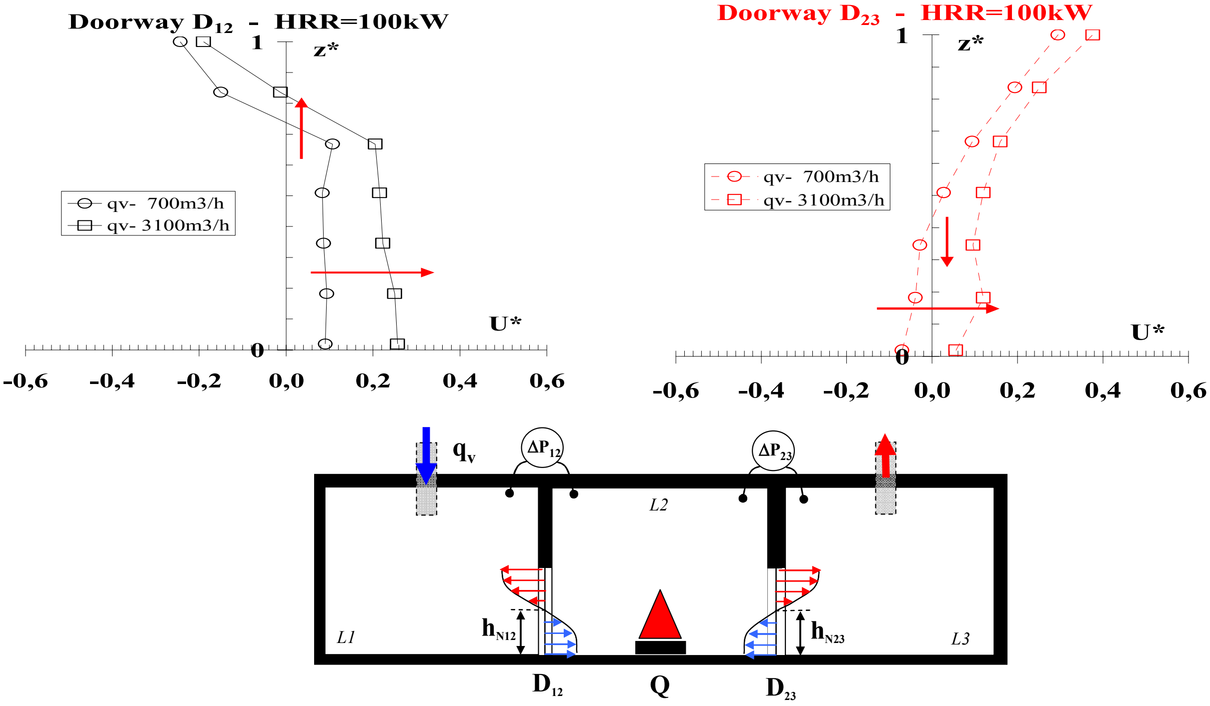
Figure 14: Convective Heat Flux (CHF) from the fire compartment to the adjacent room



4.3 Smoke propagation in ventilated installation

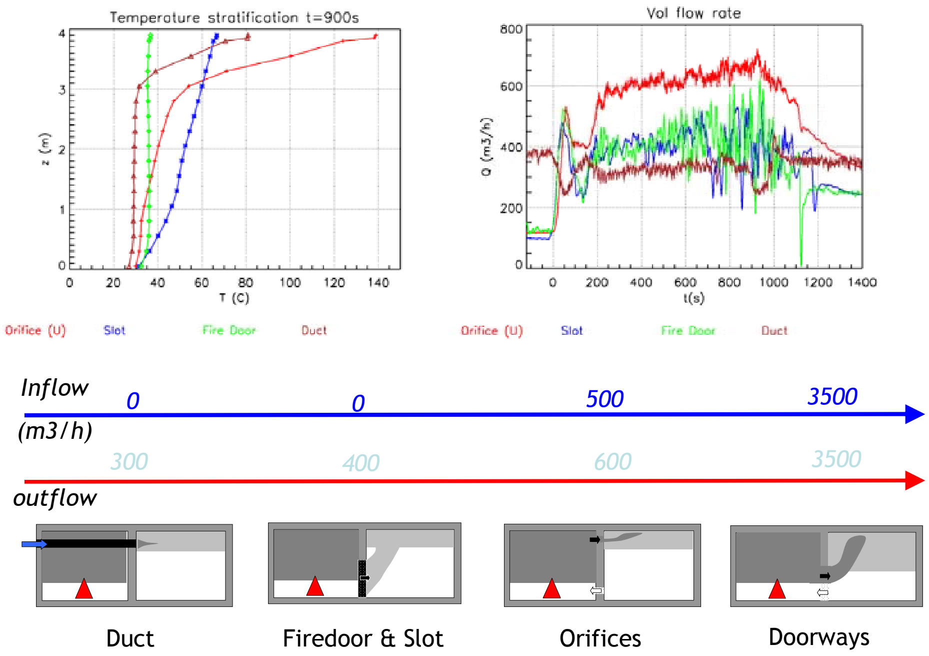
The PRISME Project has pointed out the combined effects of forced and natural convection in the process of smoke propagation in confined and ventilated compartments [18]. The natural convection is induced by the high smoke temperature and forced convection by the effect of the ventilation. The prediction of smoke movement and its propagation required a proper understanding of the coupling between these two physical mechanisms. A typical example of this combined effect is presented in Figure 15: this shows the velocity profiles at two doorways located upstream and downstream the fire compartment. The mechanical ventilation of the fire compartment scenario can significantly modify the typical bi-directional flow at a doorway compared to what is expected in an open atmosphere. It contributes to unbalance within the in- and out-flow rates and to change the position of the neutral plan. For multi-room scenarios, the ventilation layout and the location of the fire compartment have a significant impact on the doorway flow. The effect of the ventilation modifies strongly the natural convection flow induced by the fire. The PRISME Project contributes to improve the knowledge on such flow conditions during a fire scenario.

Figure 15: Velocity profiles at the doorways in the PRISME INTEGRAL configuration



The several modes of smoke propagation tested during the PRISME project can be ranked according to the smoke temperature and flow rate. The smoke propagation through doorways gives the largest rates. For the PRISME configurations, the four other modes give the following ranking according to the temperature and the flow rate of the smoke: orifices, closed fire door, slot and duct. The test results demonstrate the impact of each mode and the way it influences the readings in the adjacent compartment.

Figure 16 : Illustration of the ranking for smoke propagation configuration (PRISME LEAK)



4.4 Cable performance testing

The cable functionality tests were performed during the PRISME Leak campaign. The objective of the cable performance testing was to provide additional data to supplement the available knowledge based on cable fire-induced failure modes and effects. One or more electrical cables routed in open ladder style cable trays were exposed to the fires and monitored for electrical performance using two different electrical monitoring systems. One system, the Insulation Resistance Measurement System (IRMS), monitors conductor-to-conductor and conductor-to-ground insulation resistance for various conductor pairs. The second system, the Surrogate Circuit Diagnostic Unit (SCDU), is nominally configured to simulate a typical motor operated valve (MOV) control circuit, but was also deployed in a more simplistic mode in which specific conductors were electrically energised and various modes of cable failure monitored (e.g., intra-cable short circuits versus shorts to an external ground).

The test results provide the relationship between outside gas temperature and cable electrical failures. These data were in close accordance with those obtained in laboratory tests under controlled radiative heat sources.

4.5 Effect of damper closure on fire scenario

The damper closure (at both air inlet and exhaust ventilation branches) leads to weaken the fire heat release rate. This effect is more pronounced for a liquid pool fire than for an electrical cabinet fire.

For an under-ventilated liquid pool fire, the damper closure is followed by rapid extinction, the level of oxygen being already low at the time of closure. No pressure rise has been noticed, but a significant low-pressure peak (- 46 hPa) results due to the combined effect of the closure of the ventilation and the sudden stop of the fire heat release rate (extinction).

For an under-ventilated electrical cabinet fire, the damper closure is not followed by extinction. The combustion slows down, but still proceeds and a significant increase of pressure is measured (+ 15 hPa). At extinction due to lack of oxygen, there is still a low pressure peak (-6 hPa), which is, however, significantly lower than for a pool fire test.

The effect of the damper closure, therefore, depends on the HRR history and the nature of the fuel. The time of closure, in relation to the HRR history, is also an important parameter.

4.6 Behaviour of activation of sprinkler system in a fire scenario

The PRISME Project aimed on investigating the effect of the activation of a sprinkler system during one representative large-scale fire test.

The activation of the sprinkler system during a pool fire scenario in confined and ventilated compartment leads to rapid extinction. For the only test performed, the water spray system activation induces no over-pressure peak, but a low-pressure peak, which is the result of the combined effects of gas cooling by water and fire extinguishing.

4.7 Behaviour of cable fire in confined and ventilated fire scenario

The cable fire shows two very different behaviours, depending on if it occurs in an open atmosphere (maximum 800 kW and 1 h duration, see Appendix 3) or in confined and ventilated rooms (maximum 200 kW and 20 min duration, see Appendix 2). The ignition and flame spreading process is modified by the environment and especially by the flow induced by the doorways. For solid materials, such as cables, the ignition and spreading process is very sensitive to the flows around the combustible material and to the ignition conditions (location and HRR of the igniter, cable arrangement); both can annihilate the flame propagation process. In addition, the thermo-physical properties of cables have a very important effect on the fire spread.

4.8 Behaviour of electrical cabinet fire in confined and ventilated fire scenario

The electrical cabinet fire leads to an under-ventilated combustion regime inducing self-extinguishing of the fire by lack of oxygen. The HRR time history shows a period of slow propagation phase (incubation phase) followed by a large peak at nearly 1 MW. This behaviour is very different from the pool fire, which generally shows a steady phase. The electrical cabinet fire is an unsteady fire typical of a fire involving solid materials.

5. MAJOR FINDINGS FROM THE PRISME BENCHMARKING GROUP

At the same time as the experimental tests were conducted, the partners of the OECD PRISME project evaluated the capabilities of various fire codes to simulate fire scenarios based on the PRISME tests.

5.1 Improvements of fire models and of fire codes validation

The experimental outcome obtained during the OECD PRISME Project provides a better understanding and an increase of knowledge in the fire development in confined and ventilated large-scale compartments representative of nuclear plants. In particular, the PRISME tests highlighted the interaction between fire and mechanical ventilation. Moreover, the experimental results are used to improve fire modelling and form a huge experimental database useful in validating fire simulation codes (zone models or lumped parameter codes or CFD codes).

The results of the PRISME tests have been used by developers to improve the ventilation models of fire codes (e.g., MAGIC and FDS) and to validate the calculation of the pressure for mechanically ventilated fires. For example, the main outcome for MAGIC V4.1.3 is the confidence and quality of the MAGIC pressure calculations for confined fires as a supplement to the previous validation files for natural fires that had demonstrated the code ability to predict gas and wall temperatures, concentrations, heat fluxes and target features.

Based on the PRISME tests, some developers improved the predictability of their codes, e.g. COCOSYS, SYLVIA or ISIS. Predictive pyrolysis models, based on the Peatross et al's correlation [12] or developed by partners [23], had been implemented in the fire codes and validated on the PRISME tests.

The PRISME Benchmarking Group has, from the users' point of view, helped in better understanding the fire simulation codes outputs as well as in analysing their strengths and weaknesses. This complements the analysis performed in the Validation and Verification document presented in NUREG 1824 [11] with respect to later versions of fire codes. Therefore, the PRISME Benchmarking Group has made it possible to carry out a comparative analysis of results obtained with different fire codes.

The benchmark exercises also highlight some significant user-effects. Discussions between users allow the identification of the differences in input, geometry and post-processing methods.

5.2 Benchmark exercises

The PRISME Benchmarking Group is composed by developers and users of fire simulation codes. In order to facilitate effective exchanges on the use of fire codes, benchmark exercises are proposed to PRISME partners and managed by IRSN.

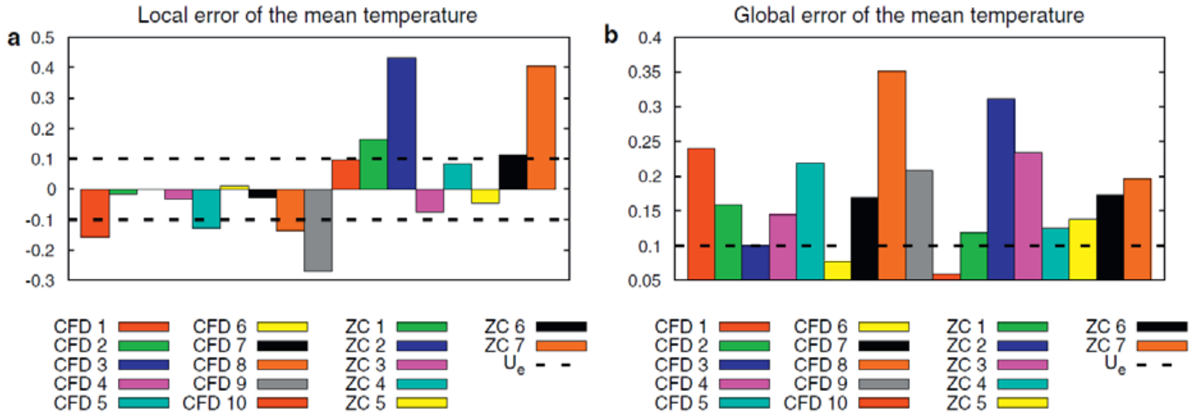
5.2.1 Benchmark exercise #1

The major goal of the first exercise is to provide a more quantitative process to compare fire models with experimental data ([1], [29]).

The use of metrics to assess the level of agreement between experimental data and fire code results is not very widespread in the fire safety community. The analysts often have to evaluate some single-point comparisons (minimum/maximum of curves, values in stationary conditions), which are relatively easy to calculate and to analyse. In the case of time-dependent curves (unsteady conditions), the estimate of the agreement between two curves is more difficult to calculate (need to use the functional analysis with vector operations) and sometimes more difficult to get a straightforward interpretation of the values obtained from this calculation. Usually, the metric operators are built on the relative difference (often normalised) between model predictions and experimental measurements, on which some mathematical norms (e.g., Euclidean and Hellinger norms, for example) from functional analysis are applied. These norms permit the measurement of average curve separation or of curve shapes.

The work in the PRISME Benchmarking Group is to investigate different metric operators to compare experimental data with numerical results and to evaluate their use in the validation process of fire codes.

Figure 17: Local (a) and global (b) errors for the mean gas temperature, from [1].



This benchmark exercise involves 17 participants using eight fire simulation codes (three CFD or field codes and five zone codes). The calculation was qualified as “open” (as opposed to “blind”), therefore, wall and fuel properties were specified as well as the fuel burning rate, the ventilation conditions and the test data. Despite this guidance, the so-called “user-effect” was important for both field and zone models. The main objective of this work was, however, to investigate the possibility of using metrics in a validation process of a real large scale fire scenario involving several participants with different fire simulation tools. For the validation process, six quantities were compared during the whole fire duration: the gas temperature, the oxygen concentration, a wall temperature, the total heat flux to a wall, the compartment pressure and the ventilation flow rate at the inlet branch. Compared to the proposals of the literature, two metrics are used for quantifying the evaluation of the models. The first metric, also used by the USNRC and EPRI in the validation work of fire models [11], considers the relative difference of numerical and experimental results expressed in terms of the difference between an extreme value and its baseline. This metric considers only instantaneous values and behaves as a measurement of a local error. The second metric, called the normalised Euclidean distance, considers the differences between computational results and measurements during the entire fire duration. This metric behaves as a global error and gives an overview of code capabilities. To be able to define criteria for acceptance of simulation results, the interpretation of differences must be possible. As it was shown on simple exemplary model results, several other metrics, tested for this benchmark, could not be used due to these difficulties.

However, it appears that it is important to consider more than one metric for the validation process of computer codes. The definition of the purpose of the validation process is also a critical issue in assessing numerical models. Obviously, the compared quantities and the metrics selected in a validation process directly depend on its intended use. In this work, the assessment of metric capabilities in case of fire in a confined compartment has shown that the unsteady behaviour of the phenomenon is as significant as peak values.

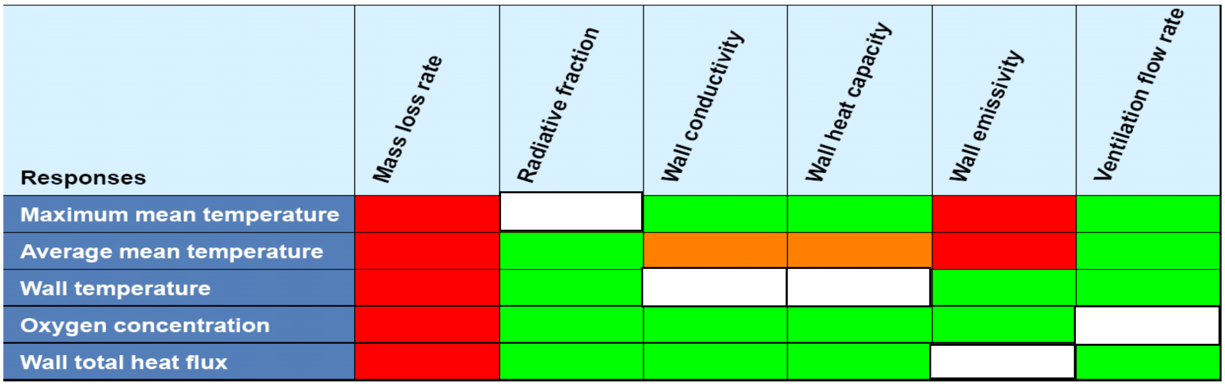
5.2.2 Benchmark exercise #2

A sensitivity analysis was performed on several fire models using a fractional experimental design. The computer codes involved are: FDS, CFAST, MAGIC, OEIL, SYLVIA and COCOSYS. The influence of six factors was tested on nine responses including gas and wall temperature, oxygen concentration, wall heat flux and over or under pressure peak in the fire compartment. These responses were selected due to their importance in fire safety studies. The factors considered are as follows: the fuel mass loss rate and radiative fraction, thermo-physical properties of the compartment (conductivity, heat capacity and emissivity of concrete walls) and the air mass flow rate through the ventilation network.

Globally, the ranking factor is identical for most numerical tools. This major result helps to quantify the importance of the different factors for each response with a high level of confidence. For this purpose, a qualitative three-color coding scheme is used to highlight the most important factors for the responses considered and Table 1 gives an overview of the performed analysis. The results show that the main factor for each response is the fuel mass loss rate. The oxygen concentration seems to be affected by the ventilation mass flow rate whereas the thermo-physical quantities such as temperature, heat flux or pressure in the room are primarily affected by the wall emissivity and by the fuel radiative fraction. These results are both original and very important for the fire community in that they provide us with clear orientations for future research of high relevance and, thus, contribute to the improvement of databases, mandatory for fire models.

Initially, different methods to generate samples were compared. The effects of factors are studied in the case of a Monte Carlo method, a full and a fractional factorial design. For each response, the methods used give similar results with the same ranking factor. This result is also important not only for experimental studies but also for numerical simulations performed with fire field models, given the fact that fractional FD with eight runs provides the same information as a Monte Carlo method with 200 runs or a full FD with 64 runs. Since it drastically reduces the number of runs to perform, fractional FD makes sensitivity analysis easier for industrial applications.

Table 1: Qualitative overview of the most important factors for the selected responses.



Responses	Mass loss rate	Radiative fraction	Wall conductivity	Wall heat capacity	Wall emissivity	Ventilation flow rate
Maximum mean temperature	🟥	⬜	🟩	🟩	🟥	🟩
Average mean temperature	🟥	🟩	🟧	🟧	🟥	🟩
Wall temperature	🟥	🟩	⬜	⬜	🟩	🟩
Oxygen concentration	🟥	🟩	🟩	🟩	🟩	⬜
Wall total heat flux	🟥	🟩	🟩	🟩	⬜	🟩

🟥	the factor has a significant influence (> 0.8) for most of the codes;
⬜	the factor has a relative influence (≈ 0.5) for most or for some codes;
🟩	the factor has a small influence (< 0.25) for most of the codes.

5.2.3 Benchmark exercise #3

The aim of the last exercise, based on one PRISME Door test, is to assess the fire model ability to predict thermal stratification in two connected rooms, in particular the behaviour of the flow rate through the door. The experimental results show that the mechanical ventilation of the fire compartment scenarios can significantly modify the typical bi-directional flow at a doorway compared to what is expected in an open atmosphere. It contributes to unbalance the in and out flow rate and to change the position of the neutral plan (cf. § 4.3). These phenomena are difficult to model with CFD codes.

The results of simulations obtained with CFD codes show that the temperature and velocities profiles at the door are quite good in the upper and lower parts. The estimation of the gradient and the range of temperature or velocity are not as good in the intermediate zone, around the neutral plane.

This exercise highlights the need to properly estimate the gradient of pressure between the two connected rooms in a mechanically ventilated configuration.

6. APPLICATION OF THE PRISME PROJECT RESULTS TO FIRE SAFETY ANALYSIS

The main objective in participating in the PRISME project is to improve the capacity to make “blind” simulations of real situations encountered in nuclear facilities for fire safety analysis. To do this, it is necessary that the test configurations are as close as possible to the real configurations, while at the same time allowing the study of certain phenomena.

In order to achieve this goal, the implementation of the PRISME project results under the fire safety analysis can be viewed from two different angles.

The first is to use the tests results and to analyse them in order to improve the understanding of the phenomena occurring during a fire in a confined installation that is mechanically ventilated. In this context, analyses and exchanges with other partners during the PRISME meetings are particularly useful. Even if the rooms we find in nuclear power plants are not necessarily completely identical to those of the DIVA installation, in which the PRISME tests are performed, some phenomena for which additional studies are needed have been highlighted and important issues to be considered in safety analysis have been addressed. In particular, the PRISME LEAK campaign showed the influence of the position of leaks in the walls connecting two neighbouring rooms. So, leaks located near the ceiling will be more detrimental for the propagation of heat in an adjacent room that leaks at the bottom of the wall. The test of this LEAK campaign concerning the propagation of heat through a pipe crossing the fire compartment has also highlighted the possible impact that this configuration might have on equipment located in the adjacent compartment to the fire compartment. These particular points observed during test campaigns of the PRISME project are now considered by some partners in their fire safety analysis. Another point is that the cable functionality testing during the PRISME tests has given some insights for fire safety analysis on the critical cable temperature and on the failure modes for I&C cables used.

The second way the PRISME project has added value to the safety analysis is the improvement of mastering and use of fire simulation computer codes. The exercises conducted as part of the Benchmarking Group helped in highlighting some important aspects which have been shared with the PRISME project partners. In particular, participation in such exercises allowed to better identify the limitations of the models used. Several fire codes (zone models or lumped parameter codes or CFD codes) are now validated on the PRISME tests. These validations highlight the limits of some codes to simulate the interaction between fire and mechanical ventilation. In particular, the simulation of the PRISME tests shows that the prediction of gas pressure in the fire compartment is not so easy for some models. The work performed by partners allowed enlarging the validation domain of several fire codes. This point leads to some Technical Safety Organisation (TSO) meanwhile accepting the use by operators of some computer codes in an application domain close to the PRISME validation domain. Exchanges between users highlight some difficulties encountered in simulating fire scenarios. As a result, simulation results used in fire risk analysis have to be considered with caution.

One important aspect, which has also been demonstrated in the PRISME project is the influence of the “Heat Release Rate” used. In case of a “blind simulation”, the real “HRR” is unknown and must be estimated. Given the high sensitivity of this parameter on the results, the use of an “HRR” as close to the real value as possible is crucial for good modelling. This needs to be considered especially for assessments of fire simulations carried out by the operator.

The need to use several metrics to measure quantitatively the agreement between numerical and experimental results, and, therefore, give an evaluation of computer code validation, was also illustrated by the PRISME project. The use of these different metrics should be a new aspect of future requests for a code validation procedure.

A sensitivity analysis of the fire simulation codes in a single-compartment experiment has been performed. The effect was quantified based on the variation of different input parameters on the results analysed. Those quantifications are deemed particularly useful in performing safety analyses.

In order to improve the use and evaluation of fire simulation models, some partners believe that participation in the PRISME project and, in particular to the “benchmarking” exercise, was of paramount importance. This has enabled in particular the launch of R&D activities on the subject at Bel V, the acquisition of new computer codes and the monitoring of several theses by students as part of “Fire Safety Engineering” studies.

In conclusion, the added value of the PRISME project results in safety analysis is considered important to the process of understanding the phenomena of confined fire in under-ventilated compartments as for the development of the use and evaluation of fire simulation codes.

Several “issues” requiring additional research have been highlighted. Extending the study of these issues is needed to further improve the fire safety analysis.

7. RECOMMENDATIONS

The main outcomes of the PRISME Program concern smoke movement from the fire compartment to adjacent rooms, the effects of under-ventilated conditions on the fire source, the electrical cable behaviour submitted to high thermal stress, the building up of a large experimental database and the establishment of an efficient international network on this topic.

Based on the discussion with PRISME partners, three main topics need further work:

- Smoke and hot gases propagation through a horizontal opening between two superposed compartments. This type of smoke flow is poorly studied experimentally in large-scale facilities controlled by ventilation systems and remains a challenging task for computer code validation and modelling;

- Fire spreading on real fire source such as cable trays and electrical cabinet and fire propagation from one fire source to another. These scenarios are identified by most partners, because they currently concern control panel and switchgear rooms of nuclear power plants;

- Fire extinguishing, including studying the performance of various extinguishing systems. Modelling the fire suppression system is still a great challenge and an experimental database of full-scale fire tests representative of typical scenarios in nuclear power plants is needed.

Based on these topics, the PRISME 2 project has been defined. This new project will answer some of issues but others will remain open.

During the PRISME 2 project, the improvement of the heat release rate prediction is still particularly important. Based on experimental results, code guidelines to simulate complex fires, such as cable trays or electrical cabinets, will be another important objective as there is a lack of knowledge on these types of fire sources and, following the assumptions of simulation, the discrepancy of the results is important.

However, the PRISME 2 project will not cover the following items:

- For electrical cabinet fires, the study of the influence of the construction characteristics (open doors, internal partitions, etc.) in the evolution of fires;

- The determination of the ignition temperature of different equipment typically found in industrial installations (electrical cabinets, charcoal filters, cable trays, etc.);

- The study of the fire propagation phenomena through cable tray penetrations through walls or floor slabs;

- The study of heat spreading phenomena to adjacent areas through metal elements through the enclosure;

- The study of fires in large volumes or atriums, performing small-scale experiments and extrapolating the results to large-scale fires, thereby determining the smoke movement and heat propagation to structural elements;

- The study of the influence of fixed fire extinguishing systems actuation on the evolution of the most influential fire parameters; in addition, a comparative study of the effect of using different fire protection systems (extinguishing systems with different extinguishing agents such as water (sprinklers, spraywater deluge systems), water based foam, water mist or inert gases) and detection devices such as spot or linear thermal detectors and spot or aspirating smoke detectors;

- The study of shape and position of retention heat or smoke canopy for detection at intermediate levels.

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9. APPENDICES

Appendix 1: Summary of fire tests (source, door) in the PRISME Programme in DIVA Facility

Test Name	Facility [-]	Fuel [-]	Pool Area $[m^2]$	Initial Fuel [kg]	Fuel Burned [kg]	Fire Extinction [-]	Fire Duration [s]	Air Inlet Location [-]	Ventilation flow rate [m3/h]	Nb of Rooms [-]	Comments
PRS-SI-D1	DIVA	HTP (1)	0.4	15.0	13.2	O2	3190	High	560	1	
PRS-SI-D2	DIVA	HTP	0.4	15.7	15.7	Fuel	2580	High	1020	1	
PRS-SI-D3	DIVA	HTP	0.4	16.0	2.9	O2	360	High	180	1	
PRS-SI-D4	DIVA	HTP	0.4	15.7	13.3	O2	2895	High	565	1	
PRS-SI-D5	DIVA	HTP	0.2	7.2	7.2	Fuel	2552	High	555	1	
PRS-SI-D5a	DIVA	HTP	0.2	7.8	4.5	O2	1978	High	190	1	
PRS-SI-D6	DIVA	HTP	0.4	16.0	12.0	O2	2495	Low	560	1	
PRS-SI-D6a	DIVA	HTP	0.4	15.8	3.4	O_2	575	Low	200	1	
PRS-D1	DIVA	HTP	0.4	14.9	6.8	O_2	883	High	0 m	2	One doorway PVC rods + Cables
PRS-D2	DIVA	HTP	0.4	17.7	9.1	O_2	1410	High	180	2	One doorway PVC rods
PRS-D3	DIVA	HTP	0.4	16.3	16.3	Fuel	1910	High	560	2	One doorway PVC rods
PRS-D4	DIVA	HTP	0.4	15.1	15.1	Fuel	1160	High	1030	2	One doorway PVC rods + Cables
PRS-D5	DIVA	HTP	1.0	15.9	15.9	Fuel	1310	High	560	2	One doorway PVC rods + Cables
PRS-D6 (2)	DIVA	HTP	1.0	25.1	13.0	O_2	420	High	560	3	Two doorways PVC rods + Cables

(1) HTP = Hydrogenated Tetra-Propylene ($C_{12}H_{26}$); (2) PRS-D6: N_2 injection in fire room at 405 s after ignition because of safety reasons.

Appendix 2: Summary of fire tests (Leak, Integral) during the PRISME Programme in DIVA Facility

Test Name	Facility [-]	Fuel [-]	Pool Area [m²]	Initial Fuel [kg]	Fuel Burned [kg]	Fire Extinction [-]	Fire Duration [s]	Air Inlet Location [-]	Ventilation flow rate [m^3/h]	Nb of Rooms [-]	Comments
PRS-LK1	DIVA	HTP	0.6	17.5	17.5	Fuel	1120	High	1760	2	Two circular ducts
PRS-LK2	DIVA	HTP	0.6	18.1	18.1	Fuel	1180	High	1760	2	Narrow vertical slot
PRS-LK3	DIVA	HTP	0.6	17.6	17.6	Fuel	1120	High	1760	2	Real firebreak door
PRS-LK4	DIVA	HTP	0.6	17.7	15.2	O_2	1000	High	1760	2	Real firebreak door + Internal duct
PRS-INT1	DIVA	HTP	1.0	98.9	80.9	O_2	2035	High	3100 (L1)	3	Two doorways
PRS-INT2	DIVA	HTP	1.0	52.3	23.6	O_2	622	High	3100 (L1)	3	Two doorways Sprinkler activation
PRS-INT3	DIVA	Cables	- (1)		4.7	Fuel (2)	1500	High	3100 (L1)	3	Two doorways
PRS-INT4	DIVA	HTP	1.0	52.1	52.1	Fuel	1610	High	2500 (L1) + 600 (L0)	4	Three doorways
PRS-INT5	DIVA	HTP	1.0	53.5	26.0	O_2	750	High	2500 (L1) + 600 (L0)	4	Three doorways Dampers
PRS-INT6	DIVA	Electrical cabinet	- (3)	44.0	35.0	O_2	1950	High	2500 (L1) + 600 (L0)	4	Three doorways Dampers

(1) 4 cable trays of 3 m in length.

(2) Self-extinction of fire (limited flame propagation).

(3) Electrical cabinet dimensions: 1.2 m in width, 2.0 m in height, 0.6 m in depth.

Appendix 3: Summary of Support Fire Tests (Source, Cab) in the PRISME Programme under SATURNE Calorimeter

Test Name	**Facility [-]**	**Fuel [-]**	**Pool Area [m²]**	**Initial Fuel [kg]**	**Fuel Burned [kg]**	**Fire Extinction [-]**	**Fire Duration [s]**	**Air Inlet Location [-]**	**Ventilation flow rate [m^3/h]**	**Nb of Rooms [-]**	**Comments**
PRS-SI-S1	Hood	HTP	0.2	7.8	7.8	Fuel	3190	-	Open	-	
PRS-SI-S2	Hood	HTP	0.2	7.7	7.7	Fuel	1510	-	Open	-	
PRS-SI-S3	Hood	HTP	0.4	14.9	14.9	Fuel	1295	-	Open	-	
PRS-SI-S4	Hood	HTP	0.4	15.1	15.1	Fuel	1350	-	Open	-	
PRS-SI-S5	Hood	HTP	0.1	3.7	3.7	Fuel	1945	-	Open	-	
PRS-SI-S6	Hood	HTP	0.1	3.8	3.8	Fuel	1940	-	Open	-	
PRS-SI-S7	Hood	HTP	0.1	6.1	6.1	Fuel	2928	-	Open	-	
PRS-CAB-1	Hood	Cables	- (1)	≈ 47.0 (2)	19.7	Fuel	4200	-	Open	-	First cable test
PRS-CAB-2	Hood	Cables	- (1)	≈ 47.0 (2)	28.8	Fuel	3300	-	Open	-	Improvement of the fire propagation along the cables
PRS-CAB-3	Hood	Cables	- (1)	≈ 47.0 (2)	27.2	Fuel	3390	-	Open	-	Repeatability of PRS-CAB-2

(1) 4 cable trays of 3 m in length.

(2) In the CAB fire tests, the total mass of PVC power cables was about 173 kg including 104 kg of copper wire and 69 kg of plastic materials. From latter materials, only 47 kg of plastic materials (mainly PVC and Polyethylen including in both additive materials as $CaCO_3$) could be ignited during the fire tests.

In addition to the PRS-INT2 fire test (including activation of sprinklers), a hydrodynamic characterisation of the droplets flow was performed for one sprinkler head. These tests measured the water flow rate spatial distribution on the floor for five heights of sprinkler nozzle (1.0, 1.5, 2.0, 2.5 and 3.0 m) for average flow conditions of 42.6 l/min and 2.65 bars.

During the PRISME campaigns, the whole DIVA facility was checked just before the first fire test by carrying out one or more simple fire experiments by mean of a gas burner (PYROS) or a small liquid pool fire. Some of these additional experiments can be used to investigate some research topics (as the forced vs. natural flow through doorway in the PRISME Integral campaign 0)

Appendix 4: List of participating members in the PRISME Project

Country	Organisation	Name
Belgium	Bel V	Frederick BONTE
	Bel V	Pieter DE GELDER
	Bel V	Nicolas NOTERMAN
	GDF Suez	Enrico GORZA
Canada	AECL	Yu-Shan CHIN
	AECL	Subhash SUTRADHAR
	CNSC	Abderrazzaq BOUNAGUI
Finland	VTT	Simo HOSTIKKA
France	DGA	Christine LALLEMAND
	EDF	Laurent GAY
	EDF	Gerard LABADIE
	IRSN	Thierry ALBIOL
	IRSN	Laurent AUDOUIN
	IRSN	Jean-Michel BONNET
	IRSN	Maria FAURY
	IRSN	Richard GONZALEZ
	IRSN	Pascal GUILLOU
	IRSN	William LE SAUX
	IRSN	Jean-Claude MELIS
	IRSN	Marc PILLER
	IRSN	Hugues PRETREL
	IRSN	Laurence RIGOLLET
	IRSN	Sylvain SUARD
	IRSN	Samuel VAUX
Germany	BFS	Heinz-Peter BERG
	GRS	Patrick BRINGEL
	GRS	Heiko DREIER
	GRS	Walter KLEIN-HESSLING
	GRS	Martin PELZER
	GRS	Marina RÖWEKAMP
	IBMB	Volker HOHM
	IBMB	Shiping LIANG
	IBMB	Olaf RIESE
Japan	JNES	Tomomichi ITO
	JNES	Tadashi MORII
	JNES	Susumu TSUCHINO
Korea	KEPRI	Moon Hak JEE
	KINS	Young Bum BAE
	KINS	Jong Seuk PARK
	KINS	Yong-Ho RYU
	KOPEC	HeeJin KO
	KOPEC	Kju Bok LEE

Country	Organisation	Name
Netherlands	NRG	Laltu CHANDRA
Netherlands	NRG	N.B. (Arne) SICCAMA
Netherlands	NRG	Dirk VISSER
Spain	CSN	Julian PECO
	EA	Victor AMEZCUA
Sweden	LUND	Patrick VAN HEES
	LUND	Jonathan WAHLQVIST
	SSM	Gustaf LOWENHIELM
	SSM	Ralph NYMAN
	VATTENFALL	Tommy MAGNUSSON
United Kingdom	HSL	Stefan LEDIN
	ONR	Steven GREENWOOD
	ONR	Alan WYLIE
United States	NRC	Mark SALLEY
	NRC	Jason DREISBACH
OECD-NEA		Alejandro HUERTA
		Greg LAMARRE
		Carlo VITANZA