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PROJECT FINAL REPORT

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Project acronym: **SUSANA**

Project title: **Support to Safety Analysis of Hydrogen and Fuel Cell Technologies**

Funding Scheme: **Coordination and Support Action**

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[1] Usually the contact person of the coordinator as specified in Art. 8.1. of the Grant Agreement.

4.1 Final publishable summary report

4.1.1 An Executive Summary

The main objective of the project with the acronym SUSANA was to develop a "CFD model evaluation protocol" regarding modelling and simulation by computational fluid dynamics, adapted for a wide range of exigencies induced by the continuous development and complexity of hydrogen and fuel cell technologies. The small project consortium consists out of experts who decreed of long expertise in using CFD applied to solve very different complex and also specific problems. Seven European partners worked in direct collaboration to execute an ambitious work program during a three years' time period, started in September 2013 and ended in August 2016. The academic European partners within the project consortium were Karlsruher Institute of Technology (Germany), which took over the coordinators position, the University of Ulster (UK), National Centre Scientific Research Demokritos (Greece), the Joint Research Centre of European Commission Petten (The Netherlands), the Health and Safety Laboratory (UK) and the industrial partners Element Energy LTD (UK) and AREVA Stockage d'Energie SAS (France), former HELION SAS.

The development of the CFD model evaluation protocol based on very different project activities and fundamentals which became organized and structured by seven work packages. As important project activities, to support the development of the CFD model evaluation protocol directly, can get referred the expert work shop done in Athens including the knowledge and participation of various external experts on high and international level, the development of a validation and verification database compiling numerous datasets of results received from nearly hundred related experiments, published papers and further information dedicated to validation and verification problems, two benchmarking exercises which also including external participation and last but not least, two webinars, a series of publications and presentations to conferences were done, in accordance to fulfil the responsibility of disseminating the project activities and achievements to a preferably broad range of stakeholders.

The fundamentals, on which the development of CFD model evaluation protocol relies, were condensed out of expert's knowledge, research and investigations to the state-of-the-art in physical and mathematical modelling of phenomena and scenarios relevant to hydrogen safety. Guidance to best practices in use of CFD applied to safety analysis of fuel cell systems and infrastructures complement the list of documents.

The project database, which is separated into a model validation database, providing a set of nearly hundred reported and documented primary experimental data sets, and a verification database which includes twenty-seven different instances of verification problems, is available through the project website as open access. The fundamental project achievements as there are the CFD model evaluation protocol, the guidance to best practice or state-of-the-art in physical and mathematical modelling of phenomena as well as reports to the benchmarking exercises are also provided as open access through the project website.

4.1.2 Summary description of project context and objectives

Strategic documents on European energy policies set fuel cell and hydrogen technologies as a vector for efficient and flexible energy conversion. This attitude became manifested by Joint Technology Initiatives FCH-JU 1.0 and meanwhile also by the FCH-JU 2.0, in which hydrogen plays the leading part as energy carrier. But all energy carriers need to get produced or treated technically somehow, before getting used by related technology e.g. combustion engines, turbines and in case of hydrogen also by fuel cells. Hydrogen itself can be recognized as an uncritical energy carrier in principal as well as safe and harmless. However, failures in the technology chain e.g. through devices and/or application technologies, could lead to accidences due to exceeding chemo-physical effects especially based on the reaction with chlorine or oxygen. It is difficult to prohibit the complete and complex technology chain in all details and lifetime from failures and thus probable accidents; so the technology must get developed to its best quality and safety use and handling, to guarantee safe and harmful applications.

The outgrowth of FCH technology, systems and infrastructure from industry-only applications to public domain and wider access of population to FCH facilities pose serious concerns about level of safety that can affect public acceptance of the technologies. Growing number of FCH early market projects triggers even higher demand for professional safety analysis and design. This boost of demand requires the increasing number of hydrogen safety experts able to use efficiently the contemporary tools for safety engineering design like Computational Fluid Dynamics. Numerical simulations using CFD technique are complimentary to costly experimental studies and testing of FCH system, and often it is the only affordable way to develop safety strategy and/or engineering solutions. However, CFD users could come from outside of the hydrogen industry and/or be novice to use of numerical simulations for safety of FCH systems. In spite of ever growing computing power and user friendly interface of CFD tools, the knowledge of the state-of-the-art in physical and numerical aspects, as well as best practices in application of CFD for safety engineering design of FCH systems is very limited among growing number of involved stakeholders. Sometimes users fail to apply this powerful technique properly that could have dramatic consequences for life safety and future of the technologies.

The project was arranged to support CFD technology users in accordance to apply it correctly. The project established on the complementarities of expertise and knowledge of leading European experts in the field of CFD use for provision of hydrogen safety in order to achieve synergy and consolidate the CFD excellence in application to safety design of complete FCH systems and infrastructure. In particular, the project outcomes equip all stakeholders and interested parties with a methodology to evaluate credibility of CFD simulations supporting safety analysis. The documents and database developed can inform regulators and public safety authorities, industry players and practicing CFD specialists in industry, consultancy, academia and research organisations about the state-of-the-art in the phenomena characteristics for safety FCH applications, advanced models and tools, and best practices to carry out safety design by CFD. The project created for the first time a unique database separated into two categories, one for verification and one for validation of CFD models and codes. All public documents and database are available through the project website via open access. The developed CFD Model Evaluation Protocol can significantly contribute to the establishment of new safety culture for inherently safer engineering design of FCH systems and infrastructure.

The project outcomes can support the use of CFD tools in efficient and reliable way as well as the assessment of CFD result, e.g. by permitting authorities, during and beyond the project. The developed CFD Model Evaluation Protocol can now assist relevant stakeholders in carrying out hydrogen safety engineering by CFD tools in a clear and systematic way, supports the advice to decision making to permitting authorities and eliminates errors associated with non-professional application of CFD tools.

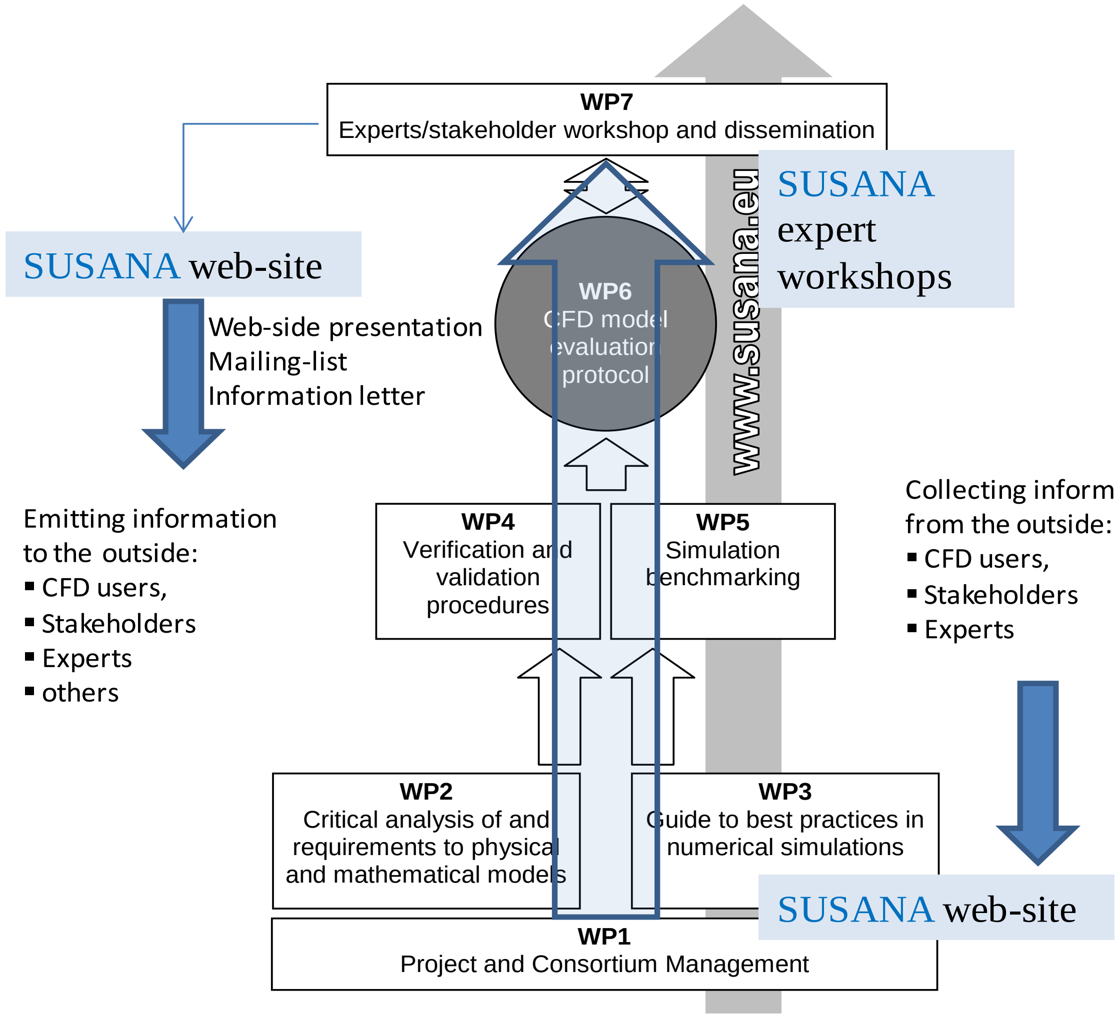
In the above concern, the scientific and technology project objective were:

- To review the state-of-the-art in CFD physical and numerical modelling and simulations being applied to safety analysis in hydrogen technologies
- To update and enhance verification and validation procedures for CFD models, codes and simulations
- To compile the best practices guide in numerical simulations of problems specific to safety of fuel cells and hydrogen technologies
- To develop a CFD model evaluation protocol for assessment of the capability of the CFD models, accurately describing the relevant physical phenomena and needed capability of CFD users to follow a consequent modelling strategy in applying correctly the CFD safety analysis of hydrogen and fuel cell technologies
- To create the infrastructure and all support needed for implementation of the CFD model evaluation protocol, which includes:
    - Database of problems regarding verification of codes and models against analytical solutions, designed to demonstrate capability of CFD codes to solve numerically the governing equations
    - Model evaluation database of experiments for validation of simulations covering a range of relevant phenomena
    - Reports about the performed benchmarking exercises according codes and models
    - Project website to support CFD stakeholders and experts' by providing open access to the databases, reports and documents through the public access domain

The specific feature of the project was generating synergies on complementarities of not only project partners yet experts beyond the consortium. Due to that, the participation of external experts became issued through different routes, including direct connections to the International Association for Hydrogen Safety (IA HySafe), International Energy Agency Hydrogen Implementation Agreement Task 31 "Hydrogen Safety" (IEA HIA Task 31), the H_2FC European Infrastructure project and its developed Cyber-Laboratory and least but not least, by direct personal contacts.

The project context and incorporated project objectives can be demonstrated pictorially by the figure reflecting the overall project structure [fig.1.0]. As can be recognized by the figure, the project objectives fixed in the work plan got structured and organized by seven work packages to guarantee unobstructed activities in parallel, transparency regarding the addressed issues and to evaporate fruitful synergies. While WP1 focused on the overall administrative execution of the project and monitoring alongside the general planning as well as organising of specific project events, all other work packages were dedicated to the scientific objectives apart from WP7, which was generally aligned to the dissemination and exploitation activities. In details, the specific objectives of the single work packages can be described and reported as follows:

WP1 “Management” consisted of two main tasks, the administrative project management and monitoring and the development and maintenance of the project website, which included also the development of the verification and validation databases. A management committee became composed including one representative from each project partner. The project website was used as a repository to support the internal project activities (monitoring of reports, milestones and deliverables) and as a powerful tool for outreach and integration of stakeholders for implementation and use of the project outcomes during and beyond the project duration.



[fig.1.0] Project structure reflecting the components (work packages) and interconnections

The objectives of WP2 “Critical analysis of and requirements to physical and mathematical models” was the review of the state-of-the-art situation concerning CFD used for physical and numerical modelling and simulation applied to safety analysis in all kind of fuel cells and hydrogen technologies. A series of objectives was incorporated as such were the review of exiting CFD models applicable for engineering simulations, a description of mathematical formulation for CFD models including relevant source terms, to set the requirements to CFD model performance based on critical analysis to support the development of guidance document of best practice and the major project outcome namely the CFD model evaluation protocol.

WP3 “Guide to best practice in numerical simulations” focused on the development of a guidance document so called guide of best practice. To achieve this specific objective in high quality, a survey and review of the state-of-the-art knowledge of models to simulate particular phenomena was envisaged as well as a critical analysis concerning the effectiveness of calculations. The guidance document complements the physical and mathematical survey done under WP2 and addresses also the main project outcome, the model evaluation protocol, because it gets incorporated as a reference document as a unique knowledge base useable for all CFD users. A direct and continuous exchange of knowledge and expertise in developing the guide of best practice was crucial to draft the guide of best practice document on stakeholder demands and in sustaining high quality.

WP4 “Verification and validation procedures” was originated to develop the organisational and technical frameworks for demonstration of the credibility of models and codes and to ensure the provision of correct results from the perspective of their intended use. One major objective of the work package was the specification of processes to ensure that the models identified by WP2 and the best user practices outlined in WP3 provide meaningful results. Another major objective was the compilation of a series of data to get included in the project database of verification problems specific to FCH technologies. Therefore a comprehensive analysis of simulation uncertainties, arising due to our lack in understanding of physical phenomena, was performed to get referenced also by the CFD model evaluation protocol.

WP5 “Simulation benchmarking” had two major objectives, the execution of benchmarking exercises and the collection of meaningful reviewed papers for the database, both to support at least the CFD model evaluation protocol. The benchmarking exercise became separated into two exercises and includes also the participation of external experts, based on their willingness of participation. The benchmarking exercises were an essential part of the implementation of the CFD model evaluation protocol. It put in action validation procedures identified by WP4.

The Database of experiments for different relevant phenomena was the second major objective within this work package. Partners’ codes became assessed across a series of benchmarks for each selected phenomena, i.e. releases and dispersion, ignition and jet fires, deflagrations and detonations, etc. Partners’ simulation results for a series of benchmarks were analysed against experimental data to quantify predictive capabilities of models/codes and got included in the database to be available for future references. The results available through the project website under open access to anyone wishing to benchmark own code, e.g. a CFD consulting engineer, or seeking example of typical model and code evaluation.

WP6 “The CFD model evaluation protocol” was the paramount of the project and includes the compilation of outputs received from WP2 - WP5. The development of the protocol structure and drafting of a detailed table of content starts early in the project allowed the adjustment of the content developed in each specific work package WP2 - WP5, and the involvement of external experts and the experts group incorporated in WP7. Draft versions of the Protocol became presented to the experts group through different channels, including the workshop “Computational Hydrogen Safety”, to obtain critical and constructive feedback. The final protocol prepared at the end of the project was presented and discussed at the dissemination seminar for stakeholders, which was executed as a webinar to get most stakeholders included as possible.

WP7 “Experts group and outreach” was designed to make the project outputs available to all interested stakeholders, including hydrogen safety community and wider public using various dissemination routes and gather feedback. Communications with the stakeholders to form a group of experts started at early stages of the project. Also the work shop with CFD experts, invited from locations in Europe and around the globe, was in organised in light to have lively discussions on the various aspects of the project, project tasks and interim results, to get at least incorporated in the CFD Model evaluation protocol structure, etc. The experts got free access to the database of validation experiments and were also invited to participate in benchmarking exercise and other project activities beneficial to them. The dedicated dissemination seminar was organised at the end of the project in closed collaboration with FABIG to present the project outcomes in its entirety to the fuel cell and hydrogen safety community. Additionally the dissemination of interim results and single reports took place through journal publications, conference presentations, inclusion of the project results into educational, e.g. MSc course in Hydrogen Safety Engineering and training programmes.

4.1.3 Description of the main S&T results

As mentioned chapter before, the project objectives fixed in the work plan got structured and organized by seven work packages to guarantee unobstructed activities in parallel, transparency regarding the addressed issues and evaporation of fruitful synergies. While WP1 focused on the overall administrative execution of the project and monitoring alongside the general planning as well as developing the web-portal including share point, databases and project website, all other work packages were dedicated to the scientific objectives apart from WP7, which was generally aligned to the dissemination and exploitation activities. In this concern, also the S&T results arising specifically to the objectives of each single work packages can be described and reported as followed by the next subchapters.

4.1.3.1 Management (WP1)

The management to the project was structured that way, to follow different major tasks in conventional manner for the project management of small research project. Contractual, administrative and financial issues run as planned without notable occurrences. Internal project standards of internal communication and continuous project monitoring were set in alignment with the project consortium and got fixed in a project management handbook. A lean administrative system was established capable to monitor the progress of individual work packages as well as the progress of the whole project. To support all project partners an IT-based system was installed including an early warning system that allows timely interactions of coordinator at first stage concerning significant deviations from the general project schedule and planning.

A best practice handbook defined informal project rules apart from the consortium agreement and informed about organisational infrastructure (share point) to distribute all relevant information and knowledge among the project partners in order to ensure the general principles of project operation. It lists those major regulations concerning IPR management, exploitation and dissemination strategy as well as confidentiality which were set in the consortium agreement and that is obviously relevant to the day-to-day interaction of the participating scientist with either users or with each other. The project management handbook basically collects all templates and rules necessary for reporting and documentation of project results, milestones, deliverables and reports at a web portal. As such it exploits existing quality standards at the part sites. The project management handbook serves as a code of conduct that covers internal networking and research processes and became regular updated.

A web-portal was developed as a main entry point for internal project partners and external experts and/or stakeholders. The web-portal runs as a virtual entry point for the external experts to get free access to the project database via access code (verification and validation database) as well as public deliverables and specific results of the project via a public domain. For internal participants the web-portal had the further option to get connected to the share point, a restricted domain for project partners and Commission service only. Additionally, beside the database and share-point also the conventional project website was developed to provide all information about the project to the public and public documents (public deliverables) for free. As such, the web-portal integrates and provides the gateway to the project supports activities and collects the demands of the CFD community (open problem discussion via blog). Thus it also serves as an internal project platform for exchange and storage of knowledge and information. The project website will run beyond the project for the next years to provide open access to the documents and database and will get interconnected with other specific websites, to enhance visibility. The project website runs actually under the following link: http://www.support-cfd.eu/

Deliverables achieved within the 1st work package can get listed as:

D1.1	1st periodic project report
D1.2	1st interim project report
D1.3	2nd interim project report
D1.4	2rd periodic project report (final)
D1.5	Kick-Off Meeting (minutes)
D1.6	Mid-term Meeting (minutes)
D1.7	Share point (exchange of all documents and internal webpage communication)
D1.8	Project Management Handbook
D1.9	Update D1.8

4.1.3.2 Critical analysis and requirements to the physical and mathematical models

The main output of WP2 is an establishment of foundation for the “guide to best practices” document which gets subsequently developed under WP3. Two main deliverables were finalised and delivered according to the project schedule, the deliverable D2.1 “state of the art review concerning FCH technologies” and deliverable D2.2 “critical analysis and requirements to models”.

The deliverable D2.1 has been developed as planned and includes comprehensive list of existing CFD models and their mathematical formulation (including source terms, physical property coefficients, specific initial and boundary conditions etc.) covering all physical phenomena mentioned in the work plan. Conceptual models, based on analysis of the physical systems and including corresponding conservation equations (partial differential equations for mass, momentum, energy, specie conservation etc.), were formulated for each relevant phenomena. This list comprise of models which are applicable for engineering simulations and relevant to safety analysis in the field of fuel cell and hydrogen technology. As one of the main important deliverables to the project the document were reviewed by partners and have been composed into the final document, which consist of 321 pages and counts 795 references.

The second deliverable D2.2 based on deliverable D2.1 and includes condensed information about analysis and requirements to simulation of different phenomena (i.e. releases, ignition, fires, deflagration and detonation). The document gives critical evaluation of the models in the context of hydrogen safety engineering; it provides recommendation for selection and utilization of the models identified within deliverable D2.1 and indicates the bottlenecks and deficiencies in the set of existing

CFD models. Also this document became cross-reviewed among the partners to get final agreement on a final version consisting of 73 pages and 203 references.

Delivery of both documents fulfills all of WP2 objectives outlined in description of work. Because WP 2 is closely linked to other work packages through the specific mentioned deliverables, the results obtained during its preparation supplied the work packages WP3 - WP6. Models identified during compilation of deliverables D2.1 and D2.2 are fed into WP3 which deals with details of the problem(s) setup and best practices of their implementation. Physical models described during preparation of deliverable D2.1 are provided to WP4 and WP5 to ensure that validation and verification database covers the complete range of relevant phenomena. They are also used within WP5 in order to select representative problems and numerical methods for benchmark simulations. The results of internal reviews of the deliverables D2.1 and D2.2 are the reference documents supporting “CFD model evaluation protocol”, which is the principal project output, and laying foundation for WP3 “guide to best practices in numerical simulations”.

Deliverables achieved within the 2nd work package are:

D2.1	Review "The state-of-the-art in physical and mathematical modelling of safety phenomena relevant to FCH technologies"
D2.2	Report “Critical analysis and requirements to physical and mathematical models"

4.1.3.3 Guide to best practices in numerical simulation

Work package WP 3 dealt with the “guide of best practice in numerical simulations” and reflects the major output of this work package, which became reported in deliverable D3.2. According to the project plan and schedule, an intermediate report on “best practice in numerical simulations”, deliverable D3.1 was prepared first, to structure and review the final document and thus builds the basis for the final document of “guide of best practice in numerical simulations”.

The purpose of the “guide to best practice in numerical simulations” is to develop comprehensive guidelines in numerical simulations for fuel cells and hydrogen applications. The best practice guidelines constitute a foundation for the main output of the project, which is the model evaluation protocol which gets addressed in WP6. The best practice guidelines focus on the practical needs of engineers in consultancies and industry faced with undertaking computational fluid dynamics (CFD) simulations in supporting hazard/risk assessments of hydrogen facilities, but also the needs of regulatory authorities. The guidelines have been drawn together by team with extensive experience in relevant FCH simulations. The reader of the document can refresh or improve their knowledge in the field and boost the quality of their hydrogen-safety simulations. The reader is introduced to the appropriate practice (modelling approach) and by following this, improves the accuracy and fidelity of the modelling.

The best practice guide covers the whole range of hydrogen safety relative phenomena such as: release and dispersion, ignition and jet fires, deflagration and detonation. Moreover, it includes aspects of CFD user education and training. All issues of CFD simulations are discussed: physical models (release, turbulence and combustion models), problem setup (domain and mesh design and boundary and initial conditions), numerical options (solver type, spatial and temporal discretization schemes, convergence criteria) and analysis of the simulation results (validation, sensitivity and interpretation of the results). The document is organized and structured in five chapters, one for each hydrogen safety related phenomenon and one for CFD user education and training. The best practice guidelines get completed by an appendix which reflects sample cases. The sample cases are representative examples taken from real CFD simulations for each hydrogen application. The “guide of best practice in numerical simulations” became thoroughly reviewed by the project partners according their experience, in doing so each section became reviewed by two separate project partners. The final document consists of 235 pages and incorporates 268 references.

Deliverables achieved within the 3rd work package are:

D3.1	Intermediate report "Best practices in numerical simulations"
D3.2	Guide to best practices in numerical simulations

4.1.3.4 Verification and validation procedures

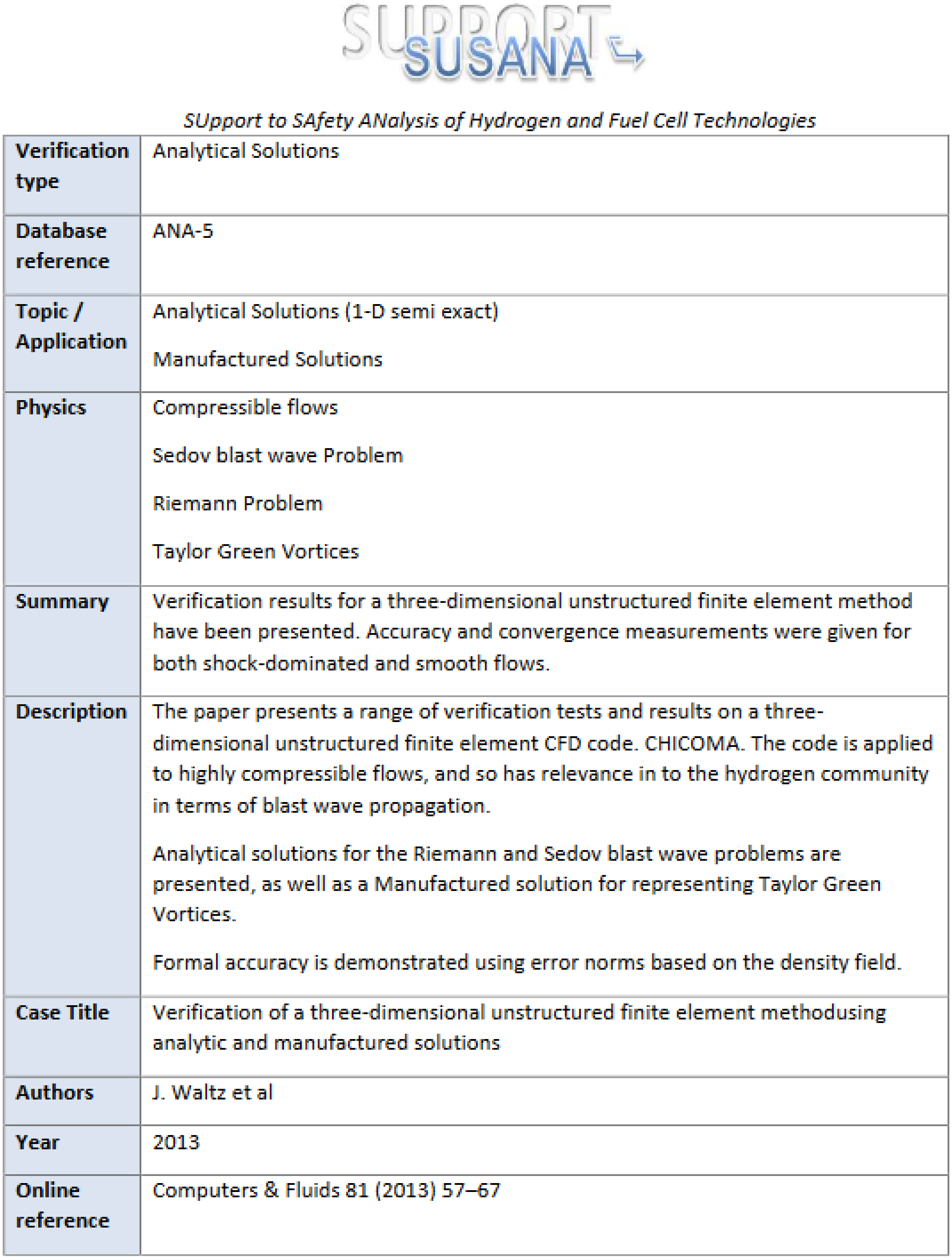
The main output arising from WP 4 is the deliverable D4.1 “database of verification problems”. The deliverable persists of a comprehensive series of datasets and references concerning verification procedures which get incorporated in the project database described specifically as “database of verification problems”. While the development of the technical structures and incorporation of references and datasets were relevant to WP 5, the collection, review and compilation were relevant within this work package. The specific database builds now a comprehensive database on verification procedures and cases, relevant to hydrogen safety simulation. The original form of the database, though comprehensive, needed to be revised in future to make it more accessible and web-searchable. The verification database is running under open access and available here: www.support-cfd.eu/index.php/verification-database

In sum, the database reflects ca, 50 different cases, separated by six distinct headings, with key topics and physics defined. A standard template was used to present the information across all references. The general problem and obstruction of this work package was that there are very few verification databases available worldwide, and (to our knowledge) there are none which appears as comprehensive as the actual project database. Furthermore, this database is the first (to our knowledge) to determine a verification database structure upon which to group cases. This structure of: Analytical Solutions, Code verification, Manufactured Solutions, Methodology Numerical Solutions, and Sensitivity Studies, is in our view unique in determining a set of topics that are mutually exclusive but collectively exhaustive. The database is a valuable resource for hydrogen safety practitioners, by helping them delineate between verification and validation tasks, and providing them with examples and resources to undertake their own verification cases.

Clicking on the Database Reference will open a page with that reference case

Primary Verification type	Database reference	Topic / Application	Physics	Short description
Analytical Solutions	ANA-1	Sod's Shock Tube Laminar Premixed Flame DNS LES	Compressible reactive flows. Combustion Detonations Supersonic	Extensive case verification of a highly accurate solver with applications in compressible flows with combustion.
Analytical Solution	ANA-2	Hydrogen LES	Detonation	Authors use LES to simulate hydrogen-air detonation. The solution is verified against a simplified /analytical model (ZND).
Analytical Solution	ANA-3	Discretisation scale Length Scale	Laminar Premixed Hydrogen-Air Flames	The Paper identifies the spatial discretization required to capture all detailed continuum physics in the reaction zone for one-dimensional steady laminar premixed hydrogen-air flames.
Analytical Solution	ANA-4	Analytical Solutions Manufactured Solutions Numerical Solutions Validation	Compartment Fires Taylor Green Vortices Beltrami Flows Laminar Flow around circular obstacle	This paper contains a comprehensive set of references for analytical solutions to flowfields of relevance to fires and internal flows. MMS and Numerical solutions are also used on more complex flows.

[fig.2.0] Example section of project database to verification problems with cross links included

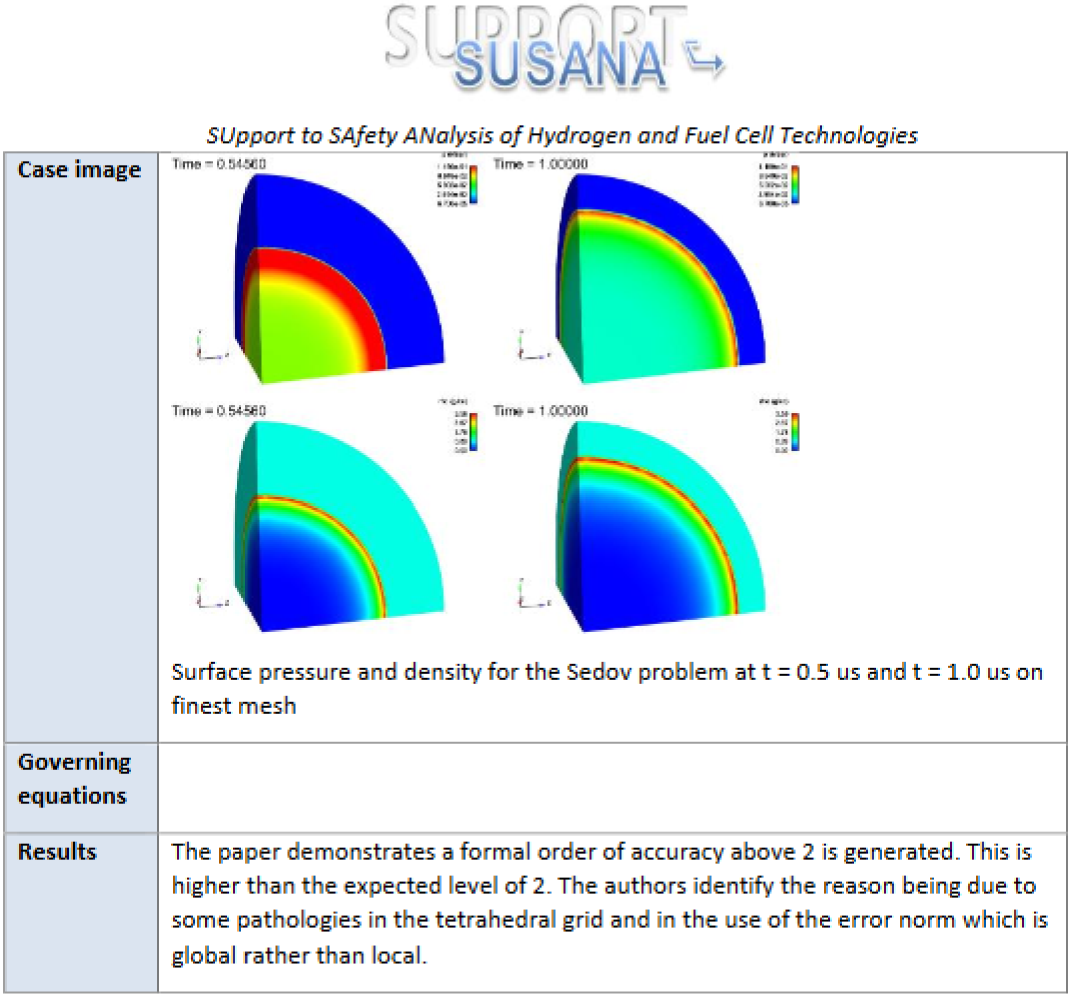


SUPPORT SUSANA

SUpport to SAfety ANalysis of Hydrogen and Fuel Cell Technologies

Verification type	Analytical Solutions
Database reference	ANA-5
Topic / Application	Analytical Solutions (1-D semi exact) Manufactured Solutions
Physics	Compressible flows Sedov blast wave Problem Riemann Problem Taylor Green Vortices
Summary	Verification results for a three-dimensional unstructured finite element method have been presented. Accuracy and convergence measurements were given for both shock-dominated and smooth flows.
Description	The paper presents a range of verification tests and results on a three-dimensional unstructured finite element CFD code. CHICOMA. The code is applied to highly compressible flows, and so has relevance in to the hydrogen community in terms of blast wave propagation. Analytical solutions for the Riemann and Sedov blast wave problems are presented, as well as a Manufactured solution for representing Taylor Green Vortices. Formal accuracy is demonstrated using error norms based on the density field.
Case Title	Verification of a three-dimensional unstructured finite element methodusing analytic and manufactured solutions
Authors	J. Waltz et al
Year	2013
Online reference	Computers & Fluids 81 (2013) 57–67

[fig.3.0] Cross link section as example representing a so called database reference ANA-5



SUpport to SAfety ANalysis of Hydrogen and Fuel Cell Technologies

Case image	Surface pressure and density for the Sedov problem at t = 0.5 us and t = 1.0 us on finest mesh
Governing equations	
Results	The paper demonstrates a formal order of accuracy above 2 is generated. This is higher than the expected level of 2. The authors identify the reason being due to some pathologies in the tetrahedral grid and in the use of the error norm which is global rather than local.

[fig.3.1] Continuation of the cross link section as example representing a so called database reference ANA-5

Deliverable D4.2 “final report on verification and validation procedures” consists of a number of reviewed publications of verification procedures. In reviewing the published data on verification and validation, it gets noted that many publications were not sufficiently clear in their delineation of verification from validation; and where this occurs, verification was nearly always omitted in favour of validation. Thus the deliverable D4.2 serves to fill an important gap by clarifying the distinct need for both verification and subsequent validation, and how these need to be addressed and undertaken sequentially to confirm the validity of the numerical procedures. It also supports the database in providing a clear description of verification procedures, as distinct from validation procedures. Though such delineation is not novel, however we believe the way it is presented in deliverable D4.2, combined with a hydrogen-safety focus to the work, means that practitioners are more likely to understand the need for verification and actually follow the procedures given.

The deliverable covers the need for verification and validation, verification procedures and types, validation procedures, worked examples, data analysis, and inclusion of uncertainty. The report is one of the four resource “pillars” of the project, which supports the model evaluation protocol by providing details and examples of specific aspects mentioned in the model evaluation protocol. We believe the combination of a high-level model evaluation protocol process document, with the detailed documentation underneath to support this (including deliverable D4.2) is novel and can support the industry efficiently in adopting better practices and ultimately improving quality of hydrogen safety simulations.

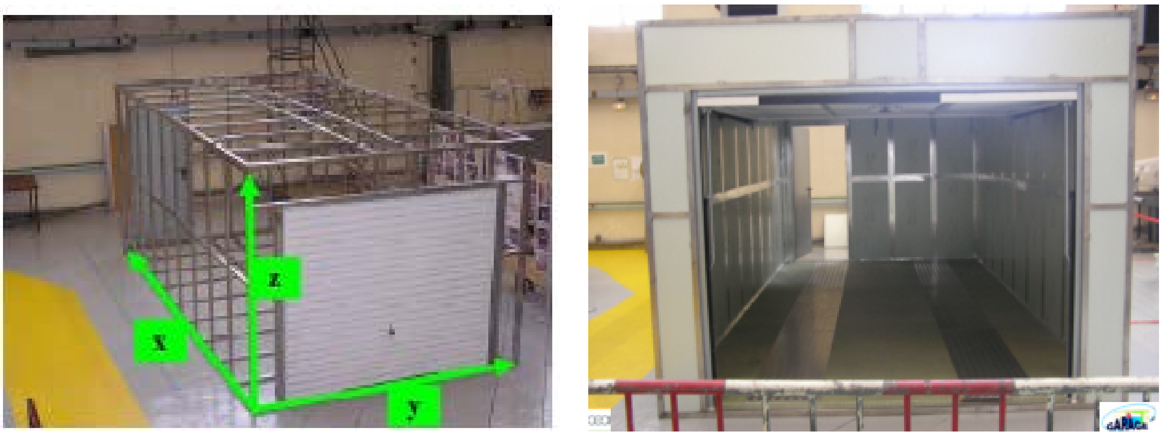
Deliverables achieved within the 4th work package are:

D4.1	Database of verification problems
D4.2	Final report on verification and validation procedures

4.1.3.5 Simulation benchmarking

Work package WP 5 addressed the benchmarking exercise and the development of the content to the model validation database. Also the work package title does not indicate the validation database, the content to the validation database became collected, prepared, developed and at least reviewed under this work package, while the technical development and installation was developed under the work package WP 1 as part of the web-portal. The work package was apportioned into two major activities, the benchmarking exercise and the development of the content of validation database, of which each activity has its own deliverables, a first version as a draft and second version as a final reviewed one.

The main objective of benchmarking exercise was to perform the various CFD software packages available to the project partners, based on several experiments involving hydrogen release and dispersion, hydrogen deflagration and hydrogen detonation. The detailed description of the experiments and computational results are presented in the deliverable D5.2 and D5.3. As a main exercise was chosen a GARAGE facility, which appears situated indoor to avoid the uncertainty based on meteorological conditions. It is of rectangular shape with interior dimensions of 5.76 m (length) x 2.96 m (width) x 2.42 m (height). The internal volume of GARAGE is 40.92 m^3. The maximum uncertainty in GARAGE volume calculation was of the order of ± 0.5 %. The garage appeared as equipped with a door for technical access in the back, and a tilting door on the front side [fig.4.0].



[fig.4.0] Description of GARAGE set-up as can be found at CEA Saclay (Paris). GARAGE structure showing front and service door (left) and GARAGE structure equipped with isolation sheets (right)

In the framework of the project the benchmarking exercise has been performed by five partners. For the benchmarking exercise the GARAGE experiment was used involving helium release inside a garage like facility. The facility has a small vent placed in the lower part of one wall. Helium is released vertically upwards and the injection point is placed in the middle of the floor and 220 mm above it. Each partner used different CFD codes and several turbulent models to simulate the experiment. Several sensitivity studies were conducted by all partners, such as grid, domain and time step sensitivity studies, as deliverable D3.1 "best practice in guidelines in numerical simulations" suggested. The partners used different approaches and models. AREVA used the low Reynolds k-ω model; JRC used the laminar model, the SST transitional and the DES turbulence model. NCSRD used the laminar model, the k-ε and the RNG-LES turbulence model, UU used the LES Dynamic S-L and the RNG-LES turbulence model, and EE used the LES model.

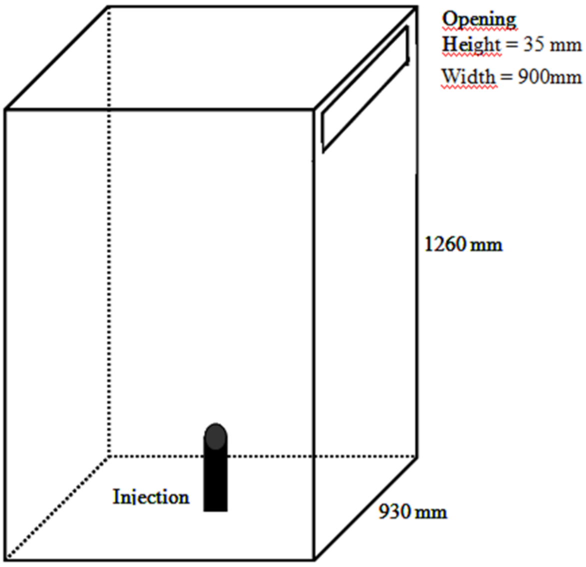
The final independent predictions are compared with the measurements using the time series at several sensors. Comparing the predictions with the same models performed by different partners, it is shown that JRC-laminar model using hexahedral mesh and NCSRD-laminar model (also with hexahedral mesh) are almost identical at most of the sensors. Based on the performance of the laminar model it can be concluded that in the examined case the flow is turbulent (though the low Reynolds number at the pipe exit) and therefore the laminar model cannot capture the real physical behavior. However, when a hybrid mesh is used the artificial numerical diffusion that the tetrahedral cells produce acts like turbulent diffusion and improves the prediction considerably. This can lead to false conclusion that the laminar model performs well in the examined case. The significance to compare the grid independent results with the measurement before making any conclusions is highlighted.

To evaluate the models' performance a statistical analysis has also been performed in accordance with "best practice guidelines in numerical simulations". Four statistical performance measures were used, FB, NMSE, MG and VG. According to these measures the peak concentration appears slightly under-predict it by all models except for NCSRD-laminar and UU-RNG-LES. All models except from laminar model performed overall very well as far as the concentrations at both 7000 and 20000 s. The best performance overall is exhibited by NCSRD-RNG-LES model with k-ε model to follow very close.

As a second benchmarking exercise GAMELON was used. The experimental set up (Cariteau & Tkatschenko, 2013) is a parallelepiped enclosure with a square base of 0.93m width and 1.26m height. The examined case has an opening of total area 32400 mm^2 (vent c: 930 x 35 mm) [fig.4.1]. The exercise describes two physical situations that are frequently encountered in accidents appearing on fuel cell systems:

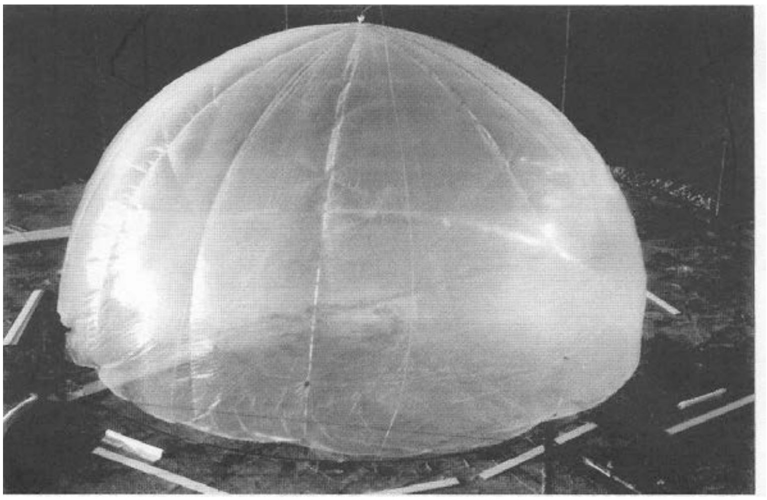
- The flows dominated by buoyancy, encountered on small leaks supposed statistically more frequent and acceptable (or close to the acceptability) from a security point of view
- Rapid flows, for which the convection is dominant. These cases correspond to accidental situations encountered during breaks or pitting of pipes

The numerical simulations give good results (compared to the experimental results) which is a consequence of the solidity of the methodology adopted. It is interesting to underline that this level of approximation has been obtained after many works which consisted in finding the system of equations, the turbulence models, the discretization schemes and the mesh the most adapted to realize this case.



[fig.4.1] Experimental environment of GAMELAN (open box with a vent in the upper part)

A third benchmarking exercise focused on an experiment, which contained hydrogen-air stoichiometric mixture in a thin hemispherical polyethylene balloons of diameter D= 20.0 m. Ignition of the hydrogen-air mixture was given at the centre of the balloon of the ground level. [fig.4.2] shows experimental setup. The exercise addressed the deflagration to detonation transition.

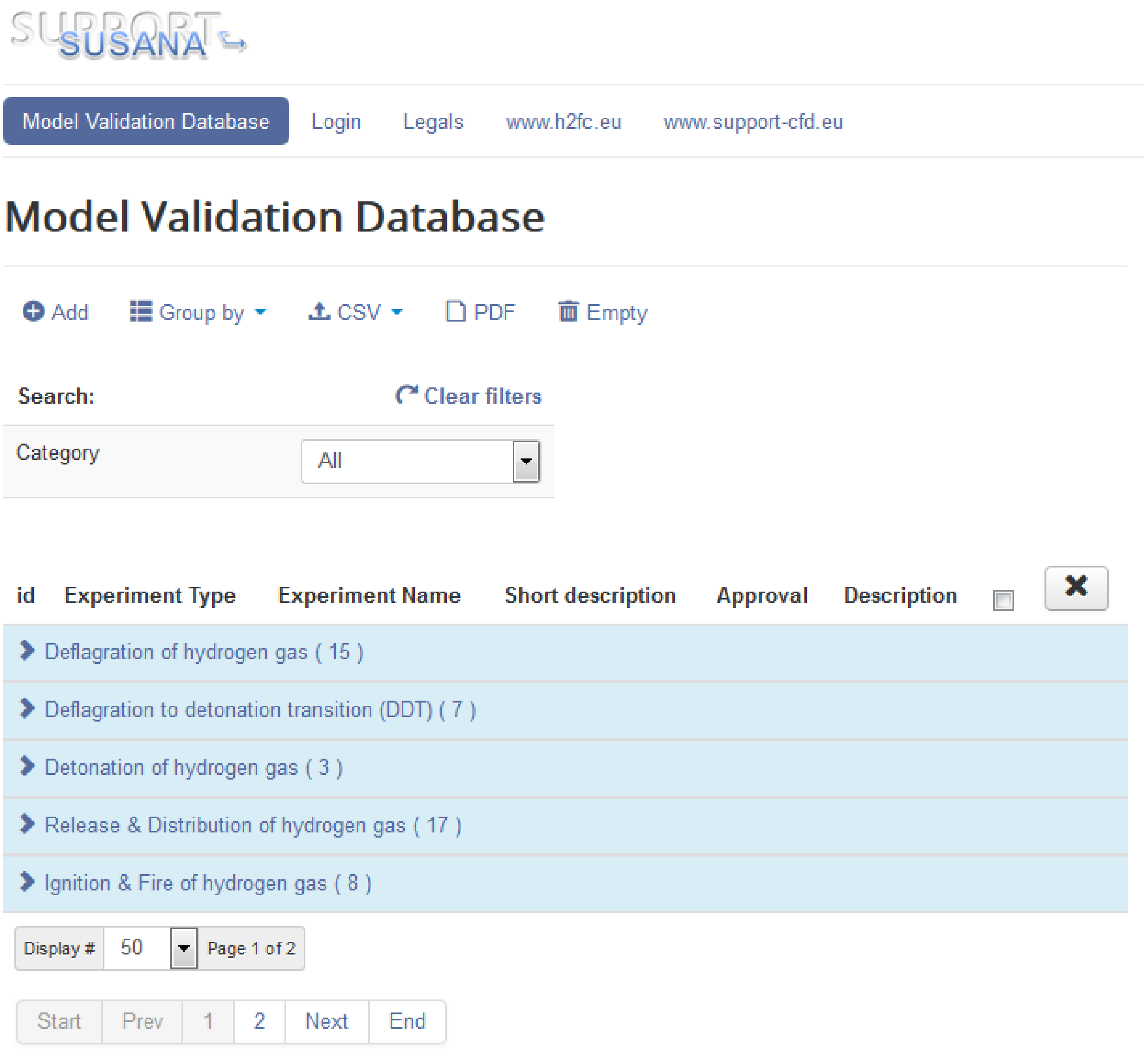


[fig.4.2] Experimental setup of open deflagration

In numerical simulation the deflagration transits to detonation around the last obstacle of the obstructed channel. In the following part, comparison will be focused on the comparison of pressure result, R-t diagram of pressure result and the R-v diagram to show that the numerical simulation reproduce the experiment successfully.

All benchmarking results and comparisons are reported in the deliverable D5.2 “report on the benchmarking exercise I” and deliverable D5.3 “report on the benchmarking exercise II”, which consists of around 100 pages including graphs, tables, formulas and images from simulation.

The second part of work package WP5 was dedicated to the development of the content to the validation database. Also this part was separated into two blocks as done with the benchmarking exercise. The development of templates to collect data from published pares was important to guarantee a harmonized and well-structured collection of data from project partners and external experts. Templates and first compilation of datasets are reported within the deliverable D5.1 “model validation database part I”. A full compilation of datasets (close to hundred dataset) concerning useable validation experiments were collected in the second half of the project and reported within the deliverable D5.4 “model validation database part II”. An impression to the entry to the validation database on project website is given by [fig.5.0].



Model Validation Database

Search:

Category: All

id	Experiment Type	Experiment Name	Short description	Approval	Description	☐	✖

Deflagration of hydrogen gas (15)

Deflagration to detonation transition (DDT) (7)

Detonation of hydrogen gas (3)

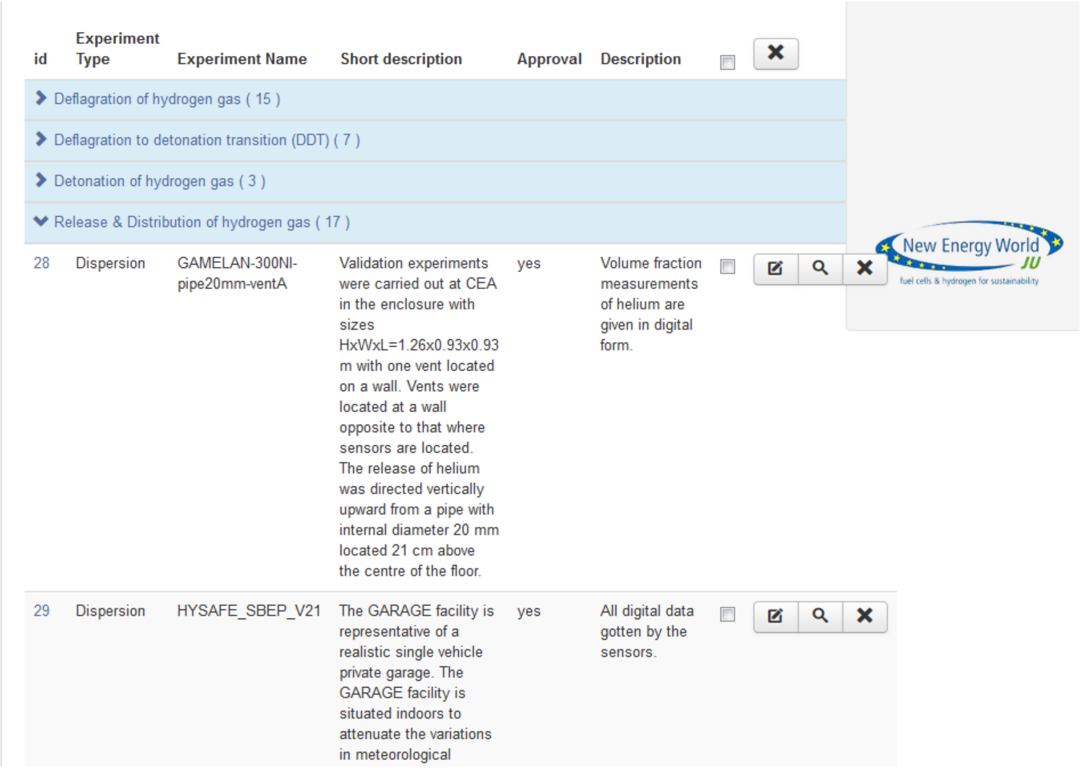
Release & Distribution of hydrogen gas (17)

Ignition & Fire of hydrogen gas (8)

Display # 50 Page 1 of 2

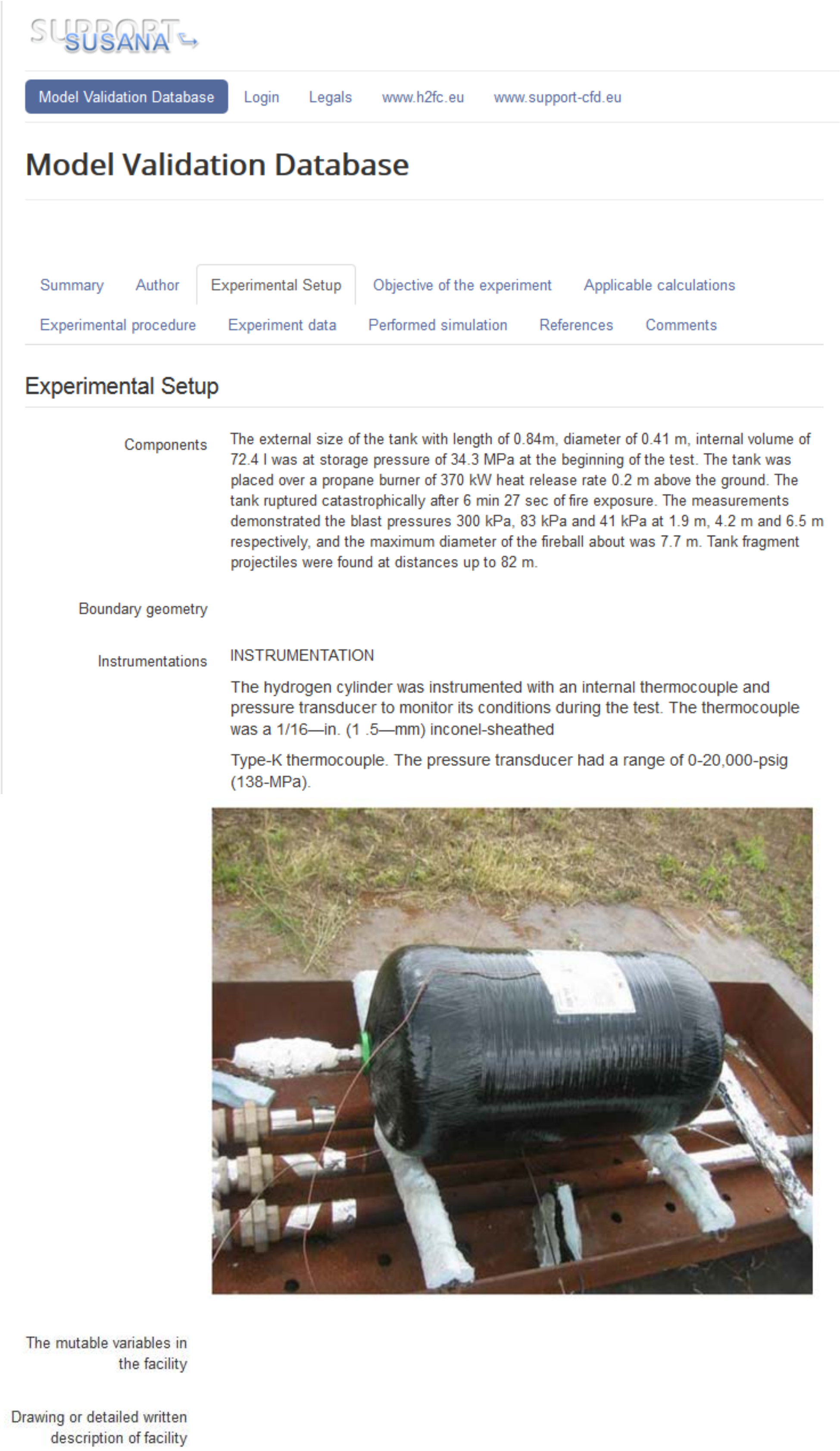
[fig.5.0] direct entry page to the validation database on the project website, accessible for free but only by individual access code due to necessary data-protection

Under this light, data from respectiv papers presenting experiments done and results useable for validation procedure were extracted, edited to the templates as well as to separate excel sheets as far as series of experimental and measured data were available within published papers. From the entry page of the database somene can chose the type of experiment. This follows to further separated and cross-linked tables, which lists the respective experiments [fig.5.1] and further by linking to the experimental data set [fig.5.2][fig.5.3].



id	Experiment Type	Experiment Name	Short description	Approval	Description	☐	✖
› Deflagration of hydrogen gas (15)							
› Deflagration to detonation transition (DDT) (7)							
› Detonation of hydrogen gas (3)							
˅ Release & Distribution of hydrogen gas (17)							
28	Dispersion	GAMELAN-300NI-pipe20mm-ventA	Validation experiments were carried out at CEA in the enclosure with sizes HxWxL=1.26x0.93x0.93 m with one vent located on a wall. Vents were located at a wall opposite to that where sensors are located. The release of helium was directed vertically upward from a pipe with internal diameter 20 mm located 21 cm above the centre of the floor.	yes	Volume fraction measurements of helium are given in digital form.	☐	✎ 🔍 ✖
29	Dispersion	HYSAFE_SBEP_V21	The GARAGE facility is representative of a realistic single vehicle private garage. The GARAGE facility is situated indoors to attenuate the variations in meteorological	yes	All digital data gotten by the sensors.	☐	✎ 🔍 ✖

[fig.5.1] Type of experiments available by entering the entry page of database. (chosen for instance “Release and Distribution of hydrogen gas”). The table is cross-linked to more detailed information and data about the experiment.

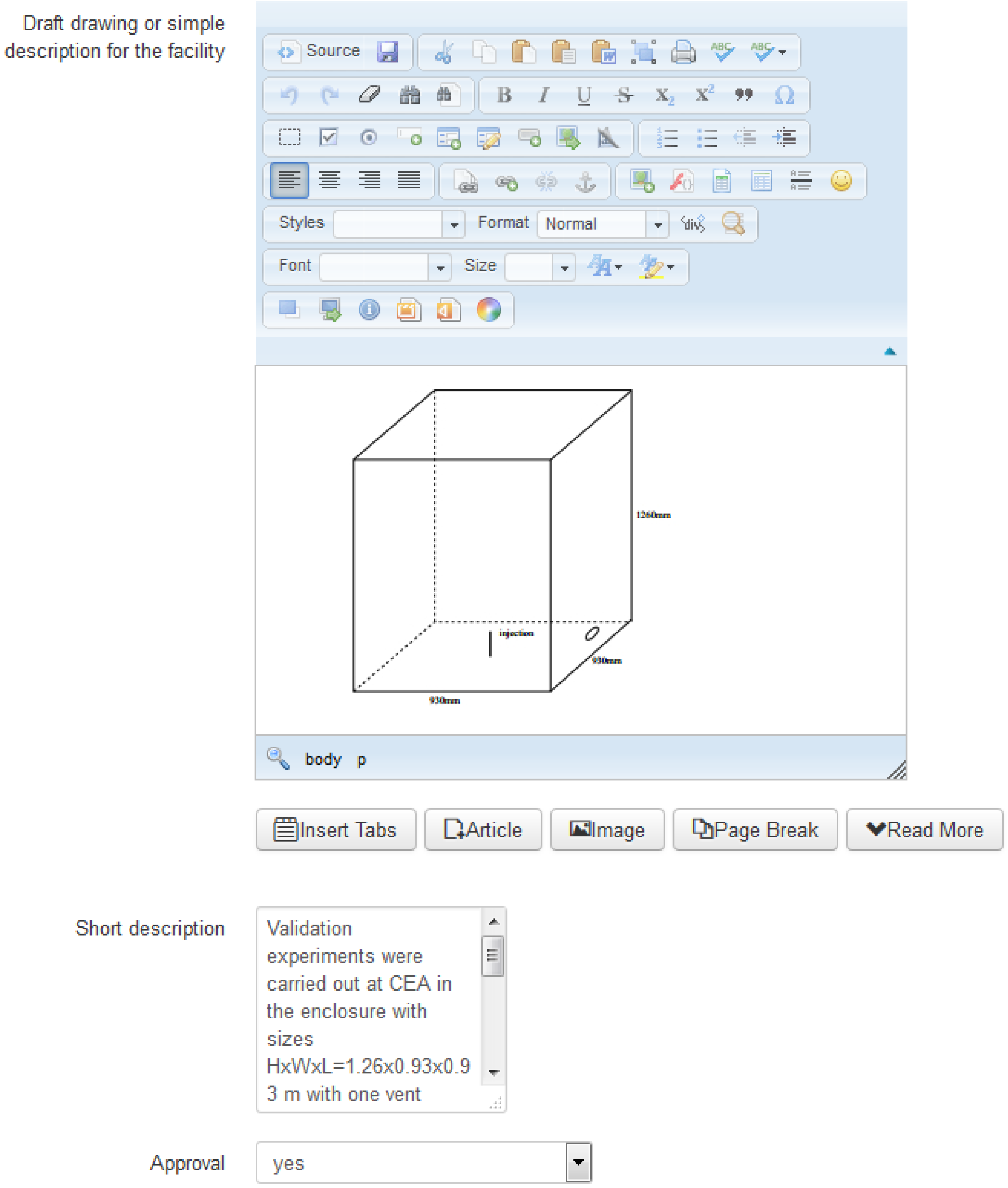


Model Validation Database

Experimental Setup

Components	The external size of the tank with length of 0.84m, diameter of 0.41 m, internal volume of 72.4 l was at storage pressure of 34.3 MPa at the beginning of the test. The tank was placed over a propane burner of 370 kW heat release rate 0.2 m above the ground. The tank ruptured catastrophically after 6 min 27 sec of fire exposure. The measurements demonstrated the blast pressures 300 kPa, 83 kPa and 41 kPa at 1.9 m, 4.2 m and 6.5 m respectively, and the maximum diameter of the fireball about was 7.7 m. Tank fragment projectiles were found at distances up to 82 m.
Boundary geometry	
Instrumentations	INSTRUMENTATION The hydrogen cylinder was instrumented with an internal thermocouple and pressure transducer to monitor its conditions during the test. The thermocouple was a 1/16—in. (1 .5—mm) inconel-sheathed Type-K thermocouple. The pressure transducer had a range of 0-20,000-psig (138-MPa).
The mutable variables in the facility	
Drawing or detailed written description of facility	

[fig.5.2] Available information about the experimental set-up and further details representative as an example for a wider series of documents and data sets



Draft drawing or simple description for the facility

Short description: Validation experiments were carried out at CEA in the enclosure with sizes HxWxL=1.26x0.93x0.93 m with one vent

Approval: yes

[fig.5.3] Details to the chosen experiment including further features and options to collect specific data from database

Deliverables achieved within the 5th work package are:

D5.1	Model Validation Database - part 1
D5.2	Report on benchmarking exercises 1
D5.3	Report on benchmarking exercise 2
D5.4	Model Validation Database - part 2

4.1.3.6 The CFD model evaluation protocol

The main output of WP6 is the “model evaluation protocol of CFD models” for safety analysis of hydrogen and fuel cell technologies. The model evaluation protocol was developed based on outputs from the work packages WP2 - WP5 and absorbs information and feedback received from two dissemination workshops organised within WP7 with the participation of external experts. Moreover a full review of the document was performed by external experts and the protocol was modified taking into account the reviewers’ comments. A constant interaction between WP6 and contributing WPs was arranged at the start of the project and monitored on a permanent basis.

Main chapters of the model evaluation protocol are dedicated to best practice guidelines and recommendations, verification and validation procedures including the model validation matrix/database, evaluation criteria with the definition of the relevant physical parameters and the range of acceptability for the accuracy of those parameters.

The target was to produce a document that aims at being the reference document for the following communities:

- For the CFD code developers (universities, research institutes, R&D departments of industry), the MEP will provide the procedures for the verification and validation both of the old and newly developed models, including the list of experiments that are suitable for validation and the criteria for accuracy assessment.

- For the CFD code users (industry, consultant companies), the model evaluation protocol will provide guidelines, recommendations and modelling strategies for the correct use of the CFD codes for the simulations of the typical physical phenomena that occur in hydrogen related accident scenarios

- For the regulatory/certifying bodies, the model evaluation protocol will be the essential reference tool to assess the accuracy of the results of numerical simulations that are provided as supporting evidence/data in order to ask for the approval/permission for the deployment of hydrogen and fuel cell technologies and infrastructure. The regulatory/certifying bodies may request the organization, which is asking for the permission to show the validation calculations, to demonstrate the compliance of the validation results with the evaluation criteria, and/or to demonstrate the compliance of the user modelling strategy with recommendations contained in the model evaluation protocol.

All partners provided contributions according to the following table of content:

1. Completion schedule, D6.2: “The CFD model evaluation protocol” 12
2. Introduction (JRC) 14
2.1 Context/Background (JRC) 14
2.2 Other protocols: LNG, SMEDIS (JRC/HSL) 14
2.3 HYMEP supporting documents (JRC) 15
2.4 Structure of the Protocol (JRC) 16
2.5 Model Assessment Report (UU) 17
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3.3 Physical problems addressed by the models (UU) 21
3.3.1 Release, mixing and dispersion of gaseous hydrogen, including permeation (UU) 21
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4.1 Introduction 28
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4.3 Summary of Verification procedures 30
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5. Sensitivity study (NCSRD) 33
5.1 Grid independency (NCSRD/JRC) 33
5.2 Time-step/CFL sensitivity (NCSRD/UU) 34
5.3 Numerical scheme (NCSRD/HSL) 34
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Deliverables achieved within the 6th work package are:

D6.1	Draft of the Protocol
D6.2	Final "The CFD model evaluation protocol"

4.1.3.7 Experts and stakeholder work shop and dissemination

The work package WP7 aimed to make the project deliverables available to the hydrogen safety and wider community using various dissemination routes and to gather feedback early in the project to ensure that the outcome would be fit for purpose. The two main activities in WP7 were an expert's workshop early in the project and a dissemination seminar at the end of the project. Other dissemination activities included presentations at conferences and meetings and journal publications.
The experts and stakeholder workshop took place in Athens on the 17th and 18th September 2014 [fig.6.0]. It was arranged as a two day meeting, to cover presentation of the project and to gain the international experts' perspective and views on the project.

[fig.6.0] Participants to the expert workshop in Athens September 2014

Experts were invited personally and to foster communication and discussion on the general topics of the workshop, all participants (external experts and project partners) were accommodated in the same hotel, which also hosted the work shop event. Approximately 20 international external experts were invited, 11 of which participated actively with their presentations to introduce the other participants in their own work and expertise on validation and verification of codes and models used in CFD. The expert workshop was not an isolated activity as one of its outcomes was that contact was maintained with the experts to continue interaction, for example in the form of feedback, possible attendance at the dissemination seminar and participation to the benchmarking.

The final dissemination seminar was held in collaboration with the Fire and Blast Information Group “FABIG” as one of their regular technical meetings on the 22nd and 23rd June 2016. These meetings are held in a specific format; a technical meeting at Aberdeen University (UK), a second technical meeting in London the following day using the same agenda and presentations. The London meeting was also available via webcast to those who registered, therefore increasing the outreach to those based outside the UK and who could not travel to either event. The event, including the webcast, was well attended [fig.7.0] with attendees from a wide variety of backgrounds including academia, companies and consultants from the hydrogen, nuclear and oil and gas sectors and regulators/government bodies. Approximately 180 delegates registered for the meetings and the webcast.

[fig.7.0] Webcast and physical seminar to the project outcome in London June 2016

Deliverables achieved within the 7th work package are:

D7.1	International experts workshop "Computational hydrogen safety"
D7.2	Dissemination seminar for stakeholders
D7.3	List of CFD publications by partners

4.1.4 The potential impact

High priority research directions for the hydrogen economy in Europe and beyond include safety as a technological and sociological issue. FCH JU 1.0 states in their Annual Implementation Plan 2012 a general objective that public awareness and understanding of the technologies should be strengthened, especially in regard to codes and standards and safety matters amongst early adopters. Consequently, the FCH JU 1.0 addressed in their call 2012 the development of a Computational Fluid Dynamics (CFD) model evaluation protocol for safety analysis of hydrogen and fuel cell technologies. The specific topic was assigned under Cross Cutting Research Activities, topic SP1-JTI-FCH.2012.5.2.

The project was composed as a typical coordination and support action. Hence explicit science was excluded, the generation of new knowledge wasn't in focus also some development was mentioned e.g. technical development of database or development of significant documents such as the CFD model evaluation protocol, guidelines of best practice in numerical simulation, the content to the databases named verification and validation problems and also the done benchmarking exercises. However, any measures, development and executed events targeted specifically on the implementation of the CFD model evaluation protocol as a kernel of the project and sustaining document. The CFD model evaluation protocol will influence and support CFD users in an essential manner in regard to practicing modelling and simulation of fuel cells and hydrogen technologies processes and behaviour.

Computational Fluid Dynamics is increasingly used in safety analysis to investigate relevant accident scenarios related to the production, storage, distribution and very different use of hydrogen. Thus, CFD is an extremely powerful numerical tool to support all kind of research and development in case of hydrogen technologies. But it requires also a high level of competence and knowledge in order to be applied in a meaningful way and to reduce or best to eliminate wrong modelling and simulation. By providing first time a CFD model evaluation protocol the project has an impact to the whole range of stakeholders of the FCH industry through increased capability of the CFD models to accurately describe the physical phenomena and the science-informed capability of the CFD users to follow the correct modelling strategy in applying correctly the CFD analysis.

The impacts include the development and implementation of the CFD model evaluation protocol as the reference document for all CFD users, including hydrogen industry, and also for regulatory and certifying bodies that have to provide permission for FCH systems and infrastructure. These bodies, in particular, will now have available a reference document that helps them to evaluate whether the CFD analysis supporting permission requests is scientifically sound or not. Another impact of the project appears to the hydrogen safety community and beyond; the creation of a model validation database is of main interest to the whole community which acts in strong internal connection on international level. In this light, both the CFD model evaluation protocol and verification and validation database appears as a European advancement, developed by European scientists and provide by Europeans scientist. The complete database, a set of supporting documents and at least the CFD model evaluation protocol are publicly available under open access and will achieve the highest possible impact and reputation.

In full agreement with the requirements to the CFD model evaluation protocol the project contains the updated procedures for validation of models/codes/simulations, recommendations to carry out numerical simulations, and the state-of-the-art criteria on how to perform the scientific assessment of the CFD models by means of validation benchmarking exercises based on comparison between simulation results and experimental measurements. In addition, the development of the CFD model evaluation protocol and database gets enriched by other important documents developed and compiled within the project such as the review of physical and mathematical modelling of phenomena relevant to safety of FCH systems, updated verification procedures and best practices guidelines. Last but not least the establishment of a sustaining experts' group and its involvement in the development of the CFD model evaluation protocol and benchmarking exercises during the project lifetime strengthened the commutation of existing knowledge and international collaboration.

As a number of pilot, demonstration and commercial FCH early market projects in public domain started to climb, the role of safety as yet another technical barrier to the wide spread of the technologies raises from a pure academic and research interest to an extremely practical issue. This dictates the growth of a number of qualified professional safety specialists, using CFD as a comprehensive and efficient tool for safety assessment and design, as well as a number of regulators and public safety officials, who are informed on the state-of-the-art in evaluation of safety solutions based on the application of CFD technique. All parties involved in hydrogen safety analysis and assessment with use of CFD, including but not limited to hydrogen safety engineers, regulatory/certifying bodies, technology developers, consultants and researchers, come under pressure to acquire the state-of-the-art knowledge on CFD models capability and on correct CFD modelling strategies in the highly specific multi-disciplinary area of hydrogen safety. Further, the very specific impacts arising from the project shall be described more detailed by the following different paragraphs.

- To maximise the project impact on hydrogen safety science and engineering the CFD model evaluation protocol and the model validation database consider a comprehensive range of hydrogen safety related phenomena such as dispersion of permeated hydrogen, gaseous and liquefied hydrogen releases and dispersion in the open atmosphere and indoor, spontaneous ignitions by the diffusion mechanisms in complex geometries, jet fires and micro-flames, deflagrations and detonations, etc. Effects of confinement, obstacles, wind, etc. included where relevant. Specific requirements to CFD tools to simulate different phenomena affected to different extent by diffusion, buoyancy, turbulence, combustion in various modes were formulated and included and open to get used and applied by all stakeholders as mentioned through open access.

- The project brought together partners across Europe with the established track-record in hydrogen safety basic and industry-driven CFD research. The partners came from different pools of stakeholders, including research organisations, universities, industries and regulators. This leads to a proper balance and acceptance of developed documents and database and all practical achievement of the project and ensures that the project results are relevant to achieve the expected impacts on safety of emerging FCH systems and infrastructure. Many of the project partners were involved in international research activities in hydrogen safety, including through other European projects, e.g. the H2FC European Infrastructure project (www.h2fc.eu), HyIndoor, IA HySafe, IEA HIA Task 31, etc. Complementarities of these national and international research activities get fully exploited and expanded through the activities of the experts group. To enhance the impact, provide cross-fertilisation of expertise and advancement in CFD use for safety engineering design the project developed an outreach programme that includes international gatherings. Moreover, safety is a cross-cutting activity and widest possible knowledge and technology transfer in the area of innovative safety strategies and engineering solutions is beneficial for all stakeholders competing on the market. FCH technologies address the pan-European issues of scarcity of fossil fuels and its growing cost, environmental pollution and climate change, and are expected to provide in coming future the independence of energy supply in Europe. Thus, this contribution requires a European rather than a national level.

- Hydrogen production, storage and distribution for energy applications are projected to meet at least 10% of total hydrogen demand by 2015. The general outcomes of project arise timely to make the impact on public acceptance of the technologies, equip developers with the methodology of inherently safer design of FCH systems and infrastructure, and assist regulators in science-informed permitting of the technologies. Creation of the CFD model evaluation protocol together with a supporting infrastructure (including the databases) will radiate an important message to all stakeholders: *CFD technique is a contemporary tool capable to assess safety of hydrogen applications, yet requires knowledge of its predictive accuracy and educated/trained users and permitting authorities*. The concise CFD model evaluation protocol will enable regulators to better understand the application of CFD for safety analysis and evaluate if the analysis is scientifically sound. This in turn will aid the decision making process and reduced time of the permitting process. Hydrogen industry and wider CFD users have since the project started access to the unique model validation database and sample simulation results of chosen validation problems to sharpen their skills to simulate scenarios of potential accidents and decide on mitigation measures. Academia and researchers get informed about the state-of-the-art in hydrogen safety science and engineering, and CFD knowledge gaps which became identified in the course of the project.

- Hydrogen safety engineering will be underpinned by more professional use of the CFD tools. The use of the project results impact public and hydrogen industry at large through inherently safer FCH systems, reduced cost of safety solutions, less conservative safety distances, e.g. based on innovative safety solutions for pressure relief devices, and thus more plausible land planning, easier access to and more conventional user practice for hydrogen-powered facilities. All mentioned above greatly contribute to the public acceptance of FCH technologies.

To summarize the major impacts of the project, the implementation of the CFD model evaluation protocol as the reference document for all CFD users performing simulations relevant to hydrogen safety across all sectors of stakeholders including hydrogen industry, is of general interest due to increasing demands concerning simulation and modelling. The CFD model evaluation protocol is of particular interest to regulatory and certifying bodies that needs to provide permission for FCH systems and infrastructure. These bodies can now revert to a reference document that helps them to evaluate whether the CFD analysis supporting permission requests is scientifically sound and correct or not. To complete the CFD model evaluation protocol and its application the project offers open access to a validation and verification database and further supporting documents publicly available to achieve the highest possible impact. The results of the project will influence also the whole range of stakeholders of the FCH industry through increased capability of the CFD models to accurately describe the physical phenomena and the science-informed capability of the CFD users to follow the correct modelling strategy in applying correctly the CFD analysis. The most recent knowledge about CFD application to phenomena relevant to FCH systems and facilities (available models, their choice, best modelling practices to follow, assessment of results etc.) became summarised and made available in the public deliverables of the project.

The project outcomes were made available to a broad public during the final dissemination workshop “ensuring the adequacy of CFD modelling in safety engineering” organised in partnership with “Fire and Blast Information Group” (FABIG, www.fabig.com). The project consortium makes aware that the all project achievements will consequently contribute also to the public acceptance of FCH technologies via an inherently safer design of hydrogen applications, installations and facilities. To handle safety issues to its best is of genuine magnitude.

4.1.5 The address of the public project website

The consortium has successfully cooperated and all project partners have professionally delivered their input with a high level of engagement and reliability.

[fig.8.0] Project Logo “SUSANA”

Please consult the SUSANA website www.support-cfd.eu and find the deliverables as well as the verification and validation databases.

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"**SU**pport to **SA**fety **AN**alysis of Hydrogen and Fuel Cell Technologies"
Grant Agreement no: 325386 and is funded by the European Commission

SUSANA is built on the complementarities of expertise of leading European experts in the field of Computational Fluid Dynamics (CFD) use for provision of hydrogen safety to achieve the synergy and consolidate the CFD excellence in application to safety design of FCH systems and infrastructure. The project will critically review the state-of-the-art in physical and mathematical modeling of phenomena and scenarios relevant to hydrogen safety, i.e. releases and dispersion, ignitions and fires, deflagrations and detonations, etc.; compile a guide to best practices in use of CFD for safety analysis of FCH systems and infrastructure; update verification and validation procedures; generate database of verification problems; develop model validation database; perform benchmarking; and finally create the CFD model Evaluation Protocol built on these documents and project activities.

4.1.6 List of the project partners including contact persons

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4.2 Use and dissemination of foreground

The project has its major target on computational fluid dynamics applied to fuel cells and hydrogen technologies. In this concern, the project partners developed and compiled a comprehensive set of information on assessment of CFD models, a CFD model evaluation protocol supported by a database as well as practical advice and best practice guidance. Especially the database appears as a further important outcome of the project which includes a significant amount of experimental data in a single location. This data, demonstrated to be “validation quality” will be of value to modellers with a wide range of interests, not only those in the hydrogen safety field. Therefore, a large amount of the project resource was directed at dissemination activities, primarily as a specific part of work package WP 7. The dissemination activities are therefore reported more fully in a separate deliverables D7.2 “Dissemination seminar” and deliverable D7.3 “Publications list”.

4.2.1 Means of dissemination

To make the FCH and wider community aware of the project and achievements, a number of different routes for dissemination were utilised, these were:

- Experts and Stakeholder workshop
- Dissemination seminar
- Project website
- Attendance and presentation at conferences
- Publication of articles in journals
- Other presentations

Table [tab.1] reflects how the project interacted with different groups through two different contact methods; direct contact through invitation by email/letter and indirect contact through presentations/articles i.e. raising awareness of the project.

	Direct contact 🔴					
	Indirect contact ●					
Group	Conference presentations	Journal publications	Website	Expert workshop	Dissemination seminar	Other presentation
Developers	●	●	●	🔴	🔴	
Users	●	●	●	🔴	🔴	
Regulators/public/representative bodies	●	●	●	🔴	🔴	●
Industry/consultants	●	●	●	🔴	🔴	

Academic institutions	●	●	●	🔴	🔴	

[tab.1] Contact means for dissemination routes

As described in chapters before, the experts and stakeholder workshop and dissemination seminar formed the main dissemination outputs apart from conventional publication, presentations and papers to related conferences, workshops and specific journals. Presentations done by experts to the expert work shop and internal presentation used at the dissemination seminar are available on the project website by downloads. All presentations done to the dissemination seminar are additionally available on an open area of the FABIG website (http://www.fabig.com/Files/FABIG/FABIG-TM87-Proceedings-June2016.pdf - accessed 25th October 2016). The webcast of the London event was made available to those who had registered for the event and a summary of the project has been written for circulation in the FABIG newsletter which is sent out to their members.

The SUSANA project website contains much of the information output from the project. It provides an important source of information and instructions and has therefore been mentioned as interesting link where possible. This is not only to promote the existence of the CFD model evaluation protocol and guidelines to best practice in the future, but also to provide a route for interested parties to obtain experimental data and modelling guidance from the verification and validation databases.

4.2.2 Future activities

The project website will be available beyond the project for the next years, but needs to get reorganised and restructured. In this line a decision needs to be done, to transfer the major achievements as essential content to other web-platform and to resign the actual web-address. The reason is that the project website became attacked several times in the past, which led at least to “unavailability” of website. The reasons for the attacks are unclear and cannot get analysed. However, the databases as well as all documents declared as public deliverable will get transferred to the new platform without restrictions and will be provided on a public domain under open access.

Further dissemination activities planned in regard to the International Conference of Hydrogen Safety (ICHS), September 2017, Hamburg, Germany. Further the project achievements will be presented (also not in details) to related conferences to fuel cells and hydrogen technologies. Scientific Journals are still in focus to present the benchmarking exercises and general overview of the project itself. The ongoing with the public deliverables and documents which become actually not published is not yet decided, but the final report shall be available via Research Gate. Same could be done with the other public deliverables but must get decided first by authors and co-authors.

Section A (public)

TEMPLATE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS										
NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers[2] (if available)	Is/Will open access[3] provided to this publication?
1	Development of a Model Evaluation Protocol for CFD Analysis of Hydrogen Safety Issues – The SUSANA Project	Daniele Baraldi	International Journal of Hydrogen Energy				2016			No
2	Release and dispersion modelling of cryogenic under-expanded hydrogen jets	Alexandros Venetsanos	International Journal of Hydrogen Energy				2017			No
3	CFD evaluation against a large scale unconfined hydrogen deflagration	Ilias C Tolias	International Journal of Hydrogen Energy				2017			No

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[2] A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view) or to the final manuscript accepted for publication (link to article in repository).

[3] Open Access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES

NO.	Type of activities[4]	Main leader	Title	Date/Period	Place	Type of audience[5]	Size of audience	Countries addressed
1	Conference, FCH-JU Review Days	O Jedicke, KIT	General Presentation of the Project	11th and 12th November 2013	Brussels	Scientific, other	100s	
2	Workshop	S Slater, EE	SUSANA Experts and stakeholder workshop	17th and 18th September 1014	Athens	Scientific, industry, other	100s	International
3	Conference, FCH-JU Review Days	O Jedicke, KIT	General Presentation of the Project	17th November 2014	Brussels	Scientific, other	100s	
4	Conference, FCH-JU Review Days	O Jedicke, KIT	General Presentation of the Project	18th November 2015	Brussels	Scientific, other	100s	
5	Conference, ICHS-4, International Conference on Hydrogen Safety	O Jedicke, KIT	General Presentation of the Project	11th September 2013	Brussels	Scientific, industry, other	100s	International
6	Conference NAFEMS meeting on quality and reliability of CFD simulations	A Kelsey, HSL	Development and Application of Model Evaluation Protocols	8th April 2014	Warwick	Scientific, industry, other	10s	United Kingdom
7	Conference, IChemE Hazards 25	S Coldrick, HSL	A model evaluation protocol for Computational Fluid Dynamics (CFD) models used in safety analyses for hydrogen and fuel cell technologies	13th – 15th May 2015	Edinburgh	Scientific, industry, other	100s	International
8	Conference, ICHS-6, International Conference on Hydrogen Safety	D Baraldi, JRC	Development of a Model Evaluation Protocol for CFD Analysis of Hydrogen Safety Issues – The SUSANA	21st October 2015	Japan	Scientific, industry, other	100s	International

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[4] A drop down list allows choosing the dissemination activity: publications, conferences, workshops, web, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, Other.

[5] A drop down list allows choosing the type of public: Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias, Other ('multiple choices' is possible).

			Project					
9	Conference, ICHS-6, International Conference on Hydrogen Safety	S G Giannissi, NCSRD	Modelling of cryogenic hydrogen jets	21st October 2015	Japan	Scientific, industry, other	100s	International
10	Conference, ICHS-6, International Conference on Hydrogen Safety	I C Tolias, NCSRD	Comparison of convective schemes in hydrogen impinging jet CFD simulations	21st October 2015	Japan	Scientific, industry, other	100s	International
11	Conference, ICHS-6, International Conference on Hydrogen Safety	I C Tolias, NCSRD	CFD evaluation against a large scale unconfined hydrogen deflagration	21st October 2015	Japan	Scientific, industry, other	100s	International
12	Conference 4th International Conference on Mathematical Modelling in Physical Sciences (IC-MSQUARE)	I C Tolias, NCSRD	Application of CFD to hydrogen deflagration in a vented enclosure	5th -8th June 2015	Greece	Scientific	100s	International
13	Conference 21st World Hydrogen Energy Conference	D Baraldi, JRC	HYMEP The Model Evaluation Protocol for CFD analysis of hydrogen safety issues	13-16th June, 2016	Spain	Scientific, industry, other	100s	International
14	Conference final dissemination seminar	S Coldrick, HSL	Ensuring the Adequacy of CFD Modelling in Safety Engineering	22nd -23rd June 2016	Aberdeen and London, UK	Scientific, industry, other	100s	International
15	Article in Second edition of e-Newsletter within H2FC project	D Makarov, UU	FCH JU project “Support to safety analysis of HFC technologies (SUSANA)”	March, 2015	Web-based	Scientific, industry, other	100s	International
16	Article in Fire and Blast Information Group (FABIG) newsletter (in preparation)	S Coldrick, HSL	Development of a Model Evaluation Protocol for hydrogen applications	November 2016	Web-based	Scientific, industry, other	100s	International
17	Workshop ISO TC197 WG24 (Gaseous H2 Fuelling Stations - General Requirements)	V. Molkov, UU	European SUSANA project and the use of CFD for assessment of hazard distances for hydrogen systems and infrastructure	22nd -26th Feb 2016	Japan	Scientific, industry	10s	International
18	Workshop	A Kelsey, HSL	SUSANA project and its outputs, presented at UK Office of Nuclear Regulation Internal Hazards Fire Workshop	25th October, 2016	UK	Industry, regulator	10s	UK

Section B (Confidential[6] or public: confidential information to be marked clearly)
Part B1

Within the project no applications for patents, trademarks or registered designs are foreseen.

TEMPLATE B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.

Type of IP Rights[7]:	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant (s) (as on the application)

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[6] Note to be confused with the "EU CONFIDENTIAL" classification for some security research projects.

[7] A drop down list allows choosing the type of IP rights: Patents, Trademarks, Registered designs, Utility models, Others.

Part B2

Within the project no exploitable foreground was designed or generated that way, to enter into market.
Please complete the table hereafter:

Type of Exploitable Foreground[8]	**Description of exploitable foreground**	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	**Exploitable product(s) or measure(s)**	**Sector(s) of application**[9]	**Timetable, commercial or any other use**	**Patents or other IPR exploitation (licences)**	**Owner & Other Beneficiary(s) involved**
	Ex: New superconductive Nb-Ti alloy			*MRI equipment*	*1. Medical* *2. Industrial inspection*	*2008* *2010*	*A materials patent is planned for 2006*	*Beneficiary X (owner)* *Beneficiary Y,* *Beneficiary Z, Poss. licensing to equipment manuf. ABC*

In addition to the table, please provide a text to explain the exploitable foreground, in particular:

- Its purpose
- How the foreground might be exploited, when and by whom
- IPR exploitable measures taken or intended
- Further research necessary, if any
- Potential/expected impact (quantify where possible)

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[19] A drop down list allows choosing the type of foreground: General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of R&D results via standards, exploitation of results through EU policies, exploitation of results through (social) innovation.

[9] A drop down list allows choosing the type sector (NACE nomenclature) : http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

3.1 Report on societal implications

Replies to the following questions will assist the Commission to obtain statistics and indicators on societal and socio-economic issues addressed by projects. The questions are arranged in a number of key themes. As well as producing certain statistics, the replies will also help identify those projects that have shown a real engagement with wider societal issues, and thereby identify interesting approaches to these issues and best practices. The replies for individual projects will not be made public.

A General Information *(completed automatically when **Grant Agreement number** is entered.*

Grant Agreement Number:	325386
Title of Project:	**SU**pport to **S**afety **ANA**lysis of Hydrogen and Fuel Cell
Name and Title of Coordinator:	Prof. h.c. DP Olaf Jedicke

B Ethics

1. Did your project undergo an Ethics Review (and/or Screening)? • If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	***No***
2. Please indicate whether your project involved any of the following issues (tick box) :	
RESEARCH ON HUMANS	
• Did the project involve children?	***No***
• Did the project involve patients?	***No***
• Did the project involve persons not able to give consent?	***No***
• Did the project involve adult healthy volunteers?	***No***
• Did the project involve Human genetic material?	***No***
• Did the project involve Human biological samples?	***No***
• Did the project involve Human data collection?	***No***
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	***No***
• Did the project involve Human Foetal Tissue / Cells?	***No***
• Did the project involve Human Embryonic Stem Cells (hESCs)?	***No***
• Did the project on human Embryonic Stem Cells involve cells in culture?	***No***
• Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	***No***
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	***No***
• Did the project involve tracking the location or observation of people?	***No***
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	***No***
• Were those animals transgenic small laboratory animals?	***No***
• Were those animals transgenic farm animals?	***No***
• Were those animals cloned farm animals?	***No***

- Were those animals non-human primates?	***No***
RESEARCH INVOLVING DEVELOPING COUNTRIES	
- Did the project involve the use of local resources (genetic, animal, plant etc)?	***No***
- Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	***No***
DUAL USE	
- Research having direct military use	***No***
- Research having the potential for terrorist abuse	***No***

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	**Number of Women**	**Number of Men**
Scientific Coordinator		1
Work package leaders		7
Experienced researchers (i.e. PhD holders)		11
PhD Students	1	3
Other	3	11

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	**2**
Of which, indicate the number of men:	2

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project?	○ x	Yes No

6. Which of the following actions did you carry out and how effective were they?

		Not at all effective … Very effective
x	Design and implement an equal opportunity policy	○ ○ x ○ ○
x	Set targets to achieve a gender balance in the workforce	○ x ○ ○ ○
☐	Organise conferences and workshops on gender	○ ○ ○ ○ ○
☐	Actions to improve work-life balance	○ ○ ○ ○ ○
○	Other:	

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

○ Yes- please specify

x No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

○ Yes- please specify

x No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

x Yes- please specify (Guidelines of Best Practice and Database)

○ No

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

x Main discipline[10]:

○ Associated discipline[10]: ○ Associated discipline[10]:

G Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)*	○ x	Yes No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

x No
○ Yes- in determining what research should be performed
○ Yes - in implementing the research
○ Yes, in communicating /disseminating / using the results of the project

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[10] Insert number from list below (Frascati Manual).

11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?	○ x	Yes No

12. Did you engage with government / public bodies or policy makers (including international organisations)

x No

○ Yes- in framing the research agenda

○ Yes - in implementing the research agenda

○ Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

○ Yes – as a **primary** objective (please indicate areas below- multiple answers possible)

○ Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)

x No

13b If Yes, in which fields?

Agriculture
Audiovisual and Media
Budget
Competition
Consumers
Culture
Customs
Development Economic and Monetary Affairs
Education, Training, Youth
Employment and Social Affairs

Energy
Enlargement
Enterprise
Environment
External Relations
External Trade
Fisheries and Maritime Affairs
Food Safety
Foreign and Security Policy
Fraud
Humanitarian aid

Human rights
Information Society
Institutional affairs
Internal Market
Justice, freedom and security
Public Health
Regional Policy
Research and Innovation
Space
Taxation
Transport

13c If Yes, at which level?

- ○ Local / regional levels
- ○ National level
- ○ European level
- ○ International level

H Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	5
To how many of these is open access[11] provided?	**0**
How many of these are published in open access journals?	
How many of these are published in open repositories?	
To how many of these is open access not provided?	**5**
Please check all applicable reasons for not providing open access:	
☐ publisher's licensing agreement would not permit publishing in a repository X no suitable repository available X no suitable open access journal available X no funds available to publish in an open access journal ☐ lack of time and resources ☐ lack of information on open access ☐ other[12]: ……………	

15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*	**0**

16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	**0**
	Registered design	**0**
	Other	**0**

17. How many spin-off companies were created / are planned as a direct result of the project?	**0**
Indicate the approximate number of additional jobs in these companies:	

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

- ☐ Increase in employment, or
- ☐ Safeguard employment, or
- ☐ Decrease in employment,
- ☐ Difficult to estimate / not possible to quantify

- ☐ In small & medium-sized enterprises
- ☐ In large companies
- x None of the above / not relevant to the project

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:* *0*

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[11] Open Access is defined as free of charge access for anyone via Internet.

[12] For instance: classification for security project.

Difficult to estimate / not possible to quantify	x

I Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?

○ Yes x No

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

○ Yes x No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

☐ Press Release
☐ Media briefing
☐ TV coverage / report
☐ Radio coverage / report
x Brochures /posters / flyers
☐ DVD /Film /Multimedia

☐ Coverage in specialist press
☐ Coverage in general (non-specialist) press
☐ Coverage in national press
☐ Coverage in international press
x Website for the general public / internet
x Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

☐ Language of the coordinator
☐ Other language(s)

x English

Question F-10: Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES
1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]
1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)
1.3 Chemical sciences (chemistry, other allied subjects)
1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)
1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY
2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)
2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]
2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as

geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. Medical Sciences

3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)
3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)
3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. Agricultural sciences

4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)
4.2 Veterinary medicine

5. Social sciences

5.1 Psychology
5.2 Economics
5.3 Educational sciences (education and training and other allied subjects)
5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. Humanities

6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)
6.2 Languages and literature (ancient and modern)
6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]

2. FINAL REPORT ON THE DISTRIBUTION OF THE EUROPEAN UNION FINANCIAL CONTRIBUTION

Report on the distribution of the European Union financial contribution between beneficiaries

Costs claimed both reporting periods 01/09/2013 to 31/08/2016 (including adjustments to the 1st period)

	Project Partner	Funding rate %	indirect costs	Coordination / Support	Management	Other		Requested EC contribution by Form C all RPs
1	KIT	75%	A	523.766,72 €	255.943,67 €	17.570,39 €	797.280,78 €	438.798,20 €
	cost estimated by KIT			315.334,00 €	234.698,00 €	75.036,00 €	625.068,00 €	376.043,00 €
2	UU	75%	T	336.790,17 €	30.275,83 €	38.113,39 €	405.179,39 €	293.755,07 €
	costs estimated by UU			383.026,80 €	34.660,40 €	0,00 €	417.687,20 €	303.062,00 €
3	NCSRD	75%	S	167.054,87 €	1.300,00 €	9.394,88 €	177.749,75 €	144.508,48 €
	costs estimated by NCSRD			305.198,92 €	2.500,00 €	0,00 €	307.698,92 €	154.249,00 €
4	JRC	75%	T	0,00 €	0,00 €	164.703,70 €	164.703,70 €	119.410,18 €
	costs estimated by JRC			126.024,00 €	0,00 €	0,00 €	126.024,00 €	0,00 €
5	HSL	75%	A	125.244,42 €	1.562,46 €	57.016,94 €	183.823,82 €	67.413,16 €
	costs estimated by HSL			257.620,80 €	2.500,00 €	3.937,00 €	264.057,80 €	94.912,00 €
6	EE	75%	F	177.965,11 €	2.500,00 €	0,00 €	180.465,11 €	131.024,70 €
	costs estimated by EE			159.840,00 €	2.500,00 €	0,00 €	162.340,00 €	117.884,00 €
7	AREVA	50%	A	273.909,36 €	0,00 €	0,00 €	273.909,36 €	79.588,99 €
	costs estimated by AREVA			214.293,98 €	2.500,00 €	0,00 €	216.793,98 €	112.974,00 €
				1.604.730,65 €	**291.581,96 €**	**286.799,30 €**	**2.183.111,91 €**	**1.274.498,78 €**
	estimated project budget			**1.761.338,50 €**	**279.358,40 €**	**78.973,00 €**	**2.119.669,90 €**	**1.159.124,00 €**
	Difference			156.607,85 €	-12.223,56 €	-207.826,30 €	-63.442,01 €	-115.374,78 €