EUROPEAN INTEGRATED HYDROGEN PROJECT (EIHP)

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ABSTRACT

A main objective of the EIHP was the development of draft regulations for hydrogen vehicles. These documents will be presented to WP29 of the Economic Commission for Europe (ECE), a UN organisation in Geneva, in the first half of 2000.

The EIHP [1] aims at creating the basis for the harmonisation of the necessary legislation in Europe for the use of hydrogen in road vehicles. The work has been undertaken by the partners in close co-operation with the licensing authorities and is based on a dual strategy: analysis of existing hydrogen related legislation in Europe, Japan and the USA, and analyses of existing hydrogen vehicles and infrastructure in Europe complemented by safety studies. Proposals for improved safety concepts were developed as well as concepts for standardised vehicle components, infrastructure components and pre-normative regulations, and where necessary the proposal of further investigations. Open questions of hydrogen fuelled vehicles were addressed and approval authorities were familiarised with hydrogen technology. In a project related public mid-term workshop [2], held in Brussels in March of 1999, project partners and interested European authorities and specialists exchanged views on the approach of the project and on safety, licensing and approval issues.

The work is jointly funded by the partners and by the European Commission to a maximum of 50% of the total budget of 2.5 MEuro [3].

KEYWORDS: Approval procedure, Hydrogen, Regulation, Road vehicle, Safety, Storage

1. MOTIVATION FOR THE PROJECT AND PROJECT OBJECTIVES

1.1 Status of Standards, Regulations, Approval Procedures for Components, Systems and Road Vehicles in Europe

GENERAL: Products such as components, systems, or road vehicles in almost all regions and countries have to comply with regulatory requirements and approval procedures. For products manufactured in series, typically two approval procedures can be distinguished: the type approval procedure and the self-certification procedure. Both procedures are based on vehicle related legal requirements which the manufacturer of the product has to comply with.

For the type approval procedure an independent institution ascertains the compliance of the type presented with the applicable legal requirements. The proof of compliance is assessed by the type approval procedure which may be granted by the responsible authority (approval administration). With the existence of a valid type approval the requirements for bringing a product into the market are met.

A Whole Vehicle Type Approval (WVTA) is done on the basis of an EEC directive (mandatory for type approval of passenger cars since 1996). Approvals for components or systems are done either on the basis of EEC directives or on the basis of ECE regulations and either can be used to obtain a WVTA.

In the case of the self-certification procedure the manufacturer at his own risk ascertains the compliance of each single unit of a product with the applicable legal requirements and confirms this by a respective labelling of the product, e.g. a sticker or a label. With this labelling, the requirements for bringing a product into the market are met.

Depending on the region, country and technical scope both procedures can exist in combinations. For small numbers or single units abridged and/ or simplified approval procedures exist (single approval). In all cases the manufacturer has to take care that both construction and production are in compliance with legal requirements.

For specific regulations/ directives, e.g. emissions, additional requirements exist which cover the behaviour of the vehicle in the customer's use, e.g. wear, and with which the manufacturer also has to guarantee compliance.

Standards such as ASTM, DIN, CEN or ISO are not legal requirements. Standards achieve a legal status only if there is a reference to a standard in a legal requirement.

In Europe there are 2 different sets of harmonized legal requirements:

- EEC directives of the European Community
- ECE Regulations of the Economic Commission for Europe, a United Nations organization

The ECE is also the platform for a global harmonisation of legal requirements for road vehicles. The European Union and its member states are members of the ECE.

1.2 Objectives of the Project

In order to create a well defined basis for discussion with relevant authorities the main objectives of the EIHP were to create a pan-European database of existing regulations and codes of practice relevant to the use of hydrogen in road vehicles, to contact other pertinent authorities outside Europe, to identify deficiencies impeding the harmonisation of guidelines and regulations, to identify weak spots in today's technology, to define the areas requiring regulation, to develop concepts for standardised vehicle and infrastructure components and to co-ordinate harmonisation in the approaches to standardisation, to integrate ECE guidelines, and create a draft of an ECE regulation for the use of compressed and liquid hydrogen in road vehicles replacing national legislation/ regulations.

2. TECHNICAL APPROACH

The project is based on a dual strategy:

One part of the project - a top-down-approach - focused on the existing hydrogen related vehicle legislation in European countries. Adequate legislation does not exist today in the field of licensing procedures for hydrogen vehicles. Correspondingly, a structured survey and analysis of existing relevant rules, regulations and licensing procedures in Belgium, France, Germany, Japan, Spain, Sweden and the USA was conducted. The aim of the survey was not only identifying deficiencies but also regulations which are already sufficiently comprehensive to facilitate harmonisation throughout Europe. The regulations were categorised in accordance with their degree of obligation. From these regulations the most essential and demanding aspects were extracted and integrated into the draft hydrogen regulations.

The other part of the project - a bottom-up-approach - focused on hydrogen vehicles and technology in Europe including safety issues and infrastructure supply technology. Systematic analyses were conducted and complemented by detailed safety studies and analyses of worst-case accident scenarios. This improved the knowledge of hydrogen technology and related safety issues, thus creating a more solid basis for discussion with relevant licensing authorities. This approach was chosen as practically all regulations presently in use were not applicable to hydrogen. The partnership's practical experience with hydrogen technologies enabled the partnership to formulate the draft hydrogen regulations.

3. PROGRESS AND RESULTS ACHIEVED IN THE PROJECT

3.1 Public Mid-Term Workshop

A public workshop [2] on the dissemination of goals, preliminary results and validation of methodology of the EIHP was held in Brussels on March 11th, 1999. The workshop covered *Standards, Regulations and Codes of Practice*, *Safety Concepts and Technologies*, and *Co-ordination with ISO and ECE.* The workshop was used to collect comments and suggestions on the methodology adopted by EIHP and was open to specialists interested in the field, such as representatives from automotive industry, gas and electric utilities, oil companies, vehicle operators, materials testing institutions, licensing and approval organisations, and government administrators. In general, the approach chosen by the EIHP was approved by the participating experts.

3.2 Present Approval Practice

Today, for example, individual test vehicles are approved in Germany following acceptance testing of the pressure tank system as well as of the overall vehicle by a state-authorised agency, e.g. TÜV. Exceptional provisions may also be laid down which, while maintaining safety standards, deviate from existing technical codes. On the other hand, e.g. in France

individual test vehicles may receive a special approval from authorities after a precise safety study on this individual test vehicle defining all the different test that have to be done (fire, crash, gun shot, etc.). This safety study shall be accepted by the ministry of transport. Therefore at present, the operation of vehicles with propulsion systems/ fuels for which specific regulations do not exist, e.g. LNG, H_2, is very difficult and very costly on public roads in France. A similar situation existed for CNG some years ago and the CNG draft document is due to be approved by ECE WP29 shortly.

3.3 Analysis of Existing and Planned Hydrogen Safety Concepts and Technologies

A number of safety studies were undertaken by various partners for hydrogen fuelled vehicles investigating the hazards relating to hydrogen, high pressure equipment and the use of cryogenic hydrogen. Safety analyses of existing hydrogen vehicles, e.g. BMW 7-series, Renault Laguna FEVER and MAN city bus, permitted the identification of weak points in today's technology. Requirements for components and systems, their integration into vehicles, maintenance, vandalism and for parking vehicles in enclosed spaces were formulated. Among the activities undertaken were functional and preliminary risk analyses, failure mode and effect analyses (FMEA), and fault and event tree analysis.

A complete FMEA concerning the hydrogen technology onboard liquid hydrogen driven passenger cars was conducted by one of the vehicle manufacturers. FMEA is a systematic approach (see fig.) 2 to identify possible failures so that they can be avoided. The desired reduction of development time of new technologies, e.g. components and their integration in a hydrogen drive train system for vehicles, requires development of accompanying failure analyses. A FMEA was integrated in the five product development phases (definition, concept, series development, production, utilisation). It is a living document reflecting the actual product development phases. The structural format serves as a basis for discussion and documentation. Most of the possible failures can be discovered and avoided through this systematic approach.

One of the other vehicle manufacturers undertook a preliminary risk analysis executed on functions allowing the determination of Undesirable functional Events (UE), and a preliminary risk analysis executed on components which allowed the determination of UE for components. In this frame also a double analysis was performed on the LH_2 storage tank and the fuel cell system in the vehicle [8]. By the establishment of technical trees, e.g. the LH_2 tank was subdivided into subsystems and then into basic components. Innovative components were identified and compared to existing technology such as LPG and CNG systems. By the establishment of failure trees, different failures associated with each UE were identified and categorised. The resulting dependability approach is given in fig. 6.

Another vehicle manufacturer undertook a wide ranging safety study based on a passenger car powered by fuel cells with hydrogen carried on board in the form of a compressed gas at pressures of up to 700bar. The study investigated the safety of vehicle systems related to the use of hydrogen, and the use of the vehicle in various operational environments, including the vehicle in traffic, refuelling, maintenance and vandalism. The main focus of the study was to identify various accident scenarios and estimate the consequences in order to assess the risks involved and provide input to the drafting of the proposed regulations. The approach taken in the study is shown in fig. 4 Where possible a comparison was made with existing fuels, i.e. petrol and CNG. Likely accident scenarios were identified from hazards relating to hydrogen, the vehicle systems related to the use of hydrogen and the operation of the vehicle. Various systematic techniques were used including failure mode and effect analysis, fault tree analysis and event tree analysis. The consequences of selected accidents were assessed in terms of the effects on people and property. Where possible the results of the worst-case accident scenario analyses undertaken by other partners were used in the study.

3.4 Identification of Deficits in Safety Concepts and Technologies

Typical malfunctions identified for hydrogen related components under the conditions found onboard a road vehicle are: Disconnection of screwed couplings, e.g. because of vibrations; corrosion because of de-icing salt; low reproducibility of the opening and closing process of valves is not independent from the temperature of the ambient air and the H_2 flux. Possible consequences of these malfunctions could be a leakage of hydrogen.

The improvement of the hydrogen related systems started with the critical components of the vehicle. The valves of the fuel system were identified as one of the most critical components. The valves represent an important interface between the fuel system and the environment. Two different types of valves should be distinguished: safety/ overflow valves and solenoid valves. The results of the FMEA and the experience with the operation of LH_2-vehicles the leakage of such valves represent one of the main failure reasons. As an example from practical experience, safety valves can malfunction if contaminated, e.g. by particles. Such contaminants found in the gas flow can cause obstruction and thus prevent the valves from closing again, resulting in leaks. Scratches in the sealing surface of the valve produced from the particles can contribute to the leakage rate.

The protection of the LH_2 fuel-tank against over-pressurisation has been identified by the EIHP partners as an important matter in the daily use of hydrogen driven vehicles. Consequently the existing safety valve, type approved for cryogenic gases, has been investigated. Its behaviour for the release of cryogenic gases is well known. For safety valves on mobile cryogenic fuel tanks that may be involved in various accidents or incidents, it cannot be ruled out that there are situations where two-phase flow conditions prevail, e.g. car turned on its roof. Therefore an experimental test of the valve under two-phase flow conditions (see fig. 5 process flow sheet) was performed and compared with the results of theoretical calculations.

An analysis of maintenance issues affecting hydrogen vehicles identified the leakage of hydrogen as a major problem, primarily in relation to connections between different components including issues such as the re-use/ contamination of screwed connections, accessibility for re-fitting and leak testing, and system depressurisation. Maintenance issues partially related to human error were identified, e.g. installing a component with an incorrect working pressure. For vandalism the study identified issues such as the blockage of vent lines and fire, e.g. arson.

Safety problems related to the release of cryogenic liquid/gas or pressurised gas were investigated with detailed CFD (computed fluid dynamics) calculations and simulations of various worst case accident scenarios for garage and tunnel settings (see fig. 7). The release and dispersion behaviour of hydrogen gas clouds resulting from the discharge of CGH_2 and the evaporation of LH_2 were studied. For tunnels the effects of hydrogen combustion were investigated. From these results recommendations with respect to the necessity of boil-off management systems, ventilation, flow restrictors, shut-off valves, etc. were defined.

3.5 Proposal for Safety Concepts

Studies have been performed concerning the safety concept of recent LH_2 vehicles and CGH_2 concepts. The studies focused on those vehicle systems that differ from the systems of passenger cars powered by conventional fuels. Possible reasons for failures were identified, which may lead to a fire or an explosion endangering passengers and the surrounding environment. A safety system has to prevent such undesired events.

The study of CGH_2 vehicles highlighted the need for primary safety systems to prevent hydrogen leaks, while hydrogen detection and control of ignition sources should be regarded as secondary protection. The studies also identified a wide range of issues to be addressed for the successful introduction of hydrogen vehicles including, for example, components to be clearly labelled with the working pressure for which they were intended, the need to avoid obstructing vent lines in the event of an accident or vandalism, and the retraining of technicians who service hydrogen vehicles.

Among others, the following recommendations were formulated: pressures and flow rates shall be reduced to a minimum just after the LH_2 tank and low cryogenic temperatures should be avoided after the tank outlet; the refuelling receptacle for cryogenic tanks should be standardised; the LH_2 flow in supply lines shall be minimised to a maximum of twice the amount required by the consumer; the remaining LH_2 in supply and interface components shall be minimised; the uncontrolled LH_2 flow from the tank into the refuelling line shall be prevented, and the quick evaporation of cryogenic liquid shall be enabled in order to avoid spills. The risk of explosion can be minimised by avoiding H_2 releases which could lead to an accumulation of 4% H_2 in air (lower ignition limit) and by ensuring sufficient ventilation.

3.6 Outcome of the EIHP Work with Respect to Road Vehicles

As a consequence of the existing inadequate regulatory situation for road vehicles using hydrogen, the application for a Whole Vehicle Type Approval for vehicles using Hydrogen in Europe is almost impossible because:

> Some EEC directives are not yet adapted to Hydrogen vehicles and there are currently no legal requirements for UNIFORM PROVISIONS CONCERNING THE APPROVAL OF:
>
> - Specific components of motor vehicles using Hydrogen
> - Vehicles with regard to the installation of specific components for the use of Hydrogen.

For the harmonisation of regulations the EIHP chose the UN body, the Economic Commission for Europe (ECE) as it is regarded as the platform for global harmonisation of legal requirements for motor vehicles (see fig. 1) and was the drafting body of the CNG regulation [4].

Those organisations now forming the EIHP partnership have come together in order to try, in a joint effort, to develop ECE regulations for UNIFORM PROVISIONS CONCERNING THE APPROVAL OF *"Specific components of motor vehicles using Hy-*

drogen” and “*Vehicles with regard to the installation of specific components for the use of Hydrogen*”. 2 regulations have been developed, one for the use of LH_2 and the other for the use of CGH_2.

The survey of relevant existing European legislation and a systematic evaluation of the existing hydrogen vehicle technology formed the basis upon which the draft regulations were developed. The partners developed the framework for the draft regulations for hydrogen vehicles based on the draft ECE regulation for CNG fuelled vehicles. A primary objective of the regulations was to avoid defining technical solutions by developing performance requirements. In a similar manner efforts were made to avoid limiting the development of future hydrogen technologies, e.g. by avoiding specifying upper limits for CGH_2 storage pressures.

As a result of the EIHP workshop in March 1999, the work of related ISO committees was monitored and further existing EC-directives which have to be adapted to hydrogen were identified.

Existing and planned hydrogen safety concepts and technologies were analysed, deficits in safety concepts and technologies were identified and improved safety concepts were integrated where appropriate into the draft regulations.

In general, the partnership increased and consolidated its knowledge of hydrogen technologies and safety requirements with respect to the realisation of future hydrogen vehicles and vehicle fleets.

The partnership presented the draft regulations to the relevant authorities in five EU states for a preliminary evaluation and comments. The comments by the authorities were integrated into the draft regulations. The draft proposals for ECE regulations for the licensing and approval of hydrogen vehicles will be presented to WP 29 of the ECE during 2000 (see fig. 3).

3.7 Outcome of the EIHP Work with Respect to Infrastructure Installations

Infrastructure components or plants are usually manufactured and installed in much smaller numbers than vehicles. Furthermore, as they are stationary they have to be licensed and approved locally, which is normally done under existing national legislation. As infrastructure equipment is applied in numbers of only several hundred or a few thousand annually the need for international harmonisation seems not as evident as for vehicles and vehicle related components, with the important exception of refuelling interfaces, e.g. such as nozzles/ receptacles and related operating procedures. A suitable platform for the Europe-wide harmonisation of licensing and approval processes for infrastructure components and installations, such as ECE WP29 was identified as being relevant for vehicles, but still has to be defined. An intensified initiative in this direction with additional partners having infrastructure competency is one target of a second phase of the EIHP.

4. PROJECT DURATION AND FUNDING

The duration of the project has been over two years (02/1998 to 04/2000). The EIHP has received cost-shared funding under the European Commission's 4th Framework Program within the JOULE program. At least 50% of the total project budget amounting to approx. 2.5 MECU was provided up by the EIHP partners. The co-sponsor European Commission contributed a maximum of 50% of the project budget.

5. OUTLOOK

The majority of the partners are considering the continuation of the EIHP into a second phase, possibly together with some additional new partners. The second phase will focus primarily on questions related to infrastructure, interface compatibility and risk evaluation. The slightly modified and extended partnership will very likely apply for support by the European Commission.

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FIGURES

Figure 1: Procedure of ECE Harmonization [provided by BMW**]**

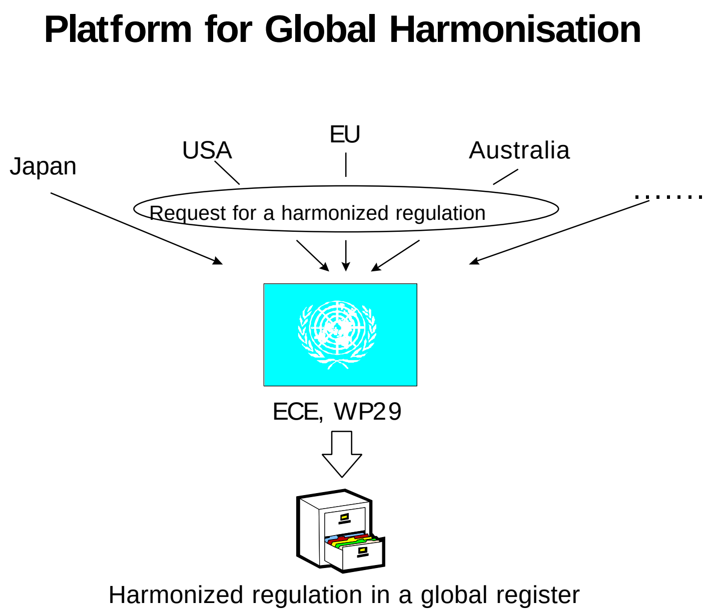

Figure 2: **Quality Management – Five steps to set up a System-FMEA [**provided by BMW**]**

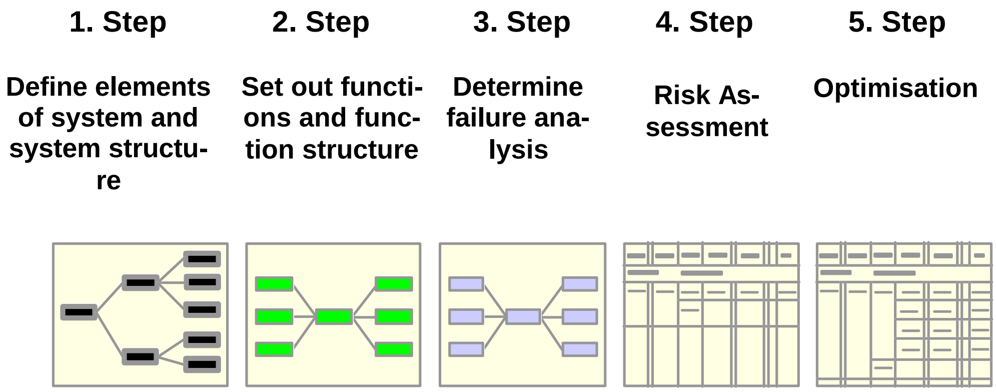

Figure 3: **Application for an ECE Regulation** [provided by BMW]

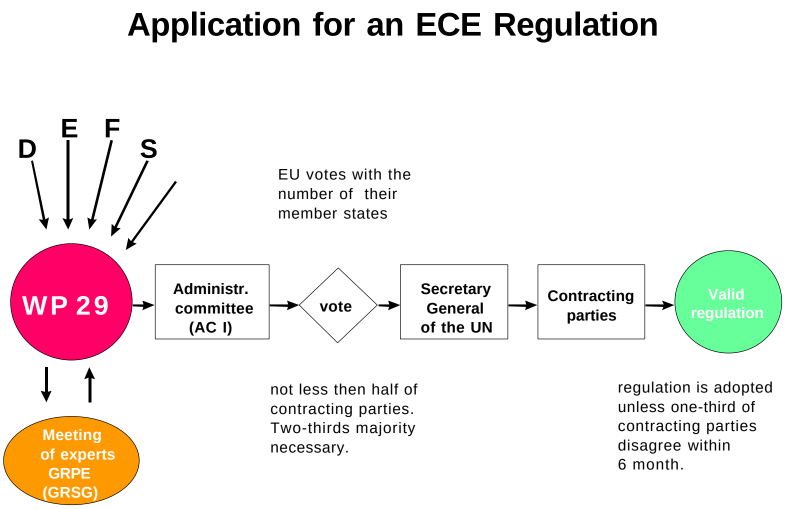

Figure 4: **Concept of Safety Study.** [provided by Volvo]

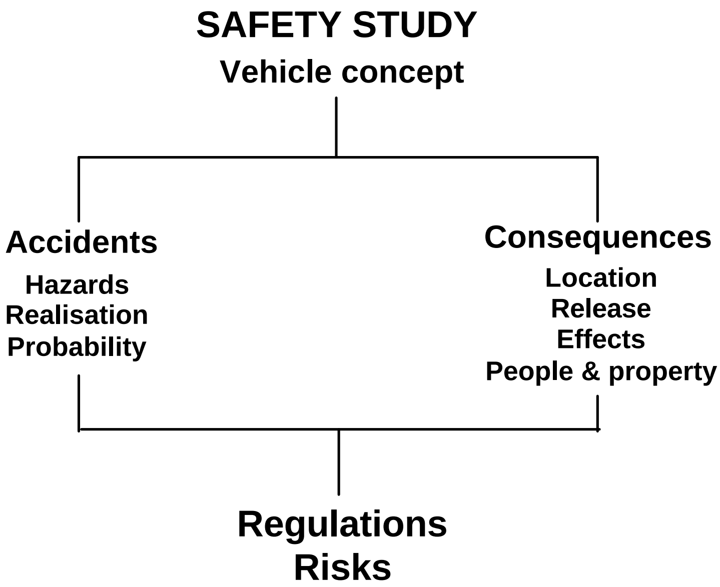

Figure 5: **Process Flow Sheet of the Messer LH_2-Test with the Safety Valve MG 84** [provided by Messer]

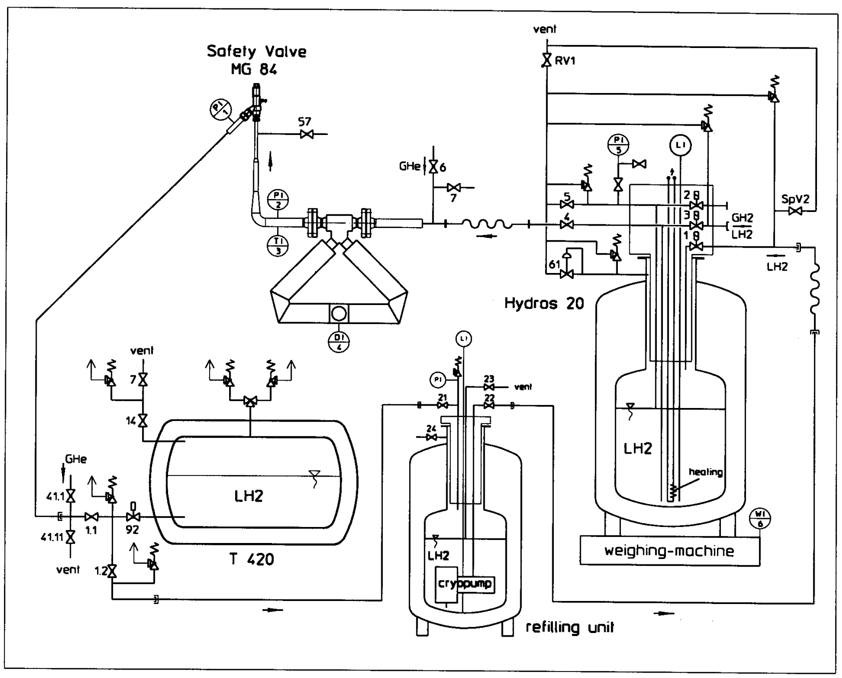

Figure 6: **Dependability approach for analysis of existing and planned H_2 safety concepts and technologies** [provided by Renault]

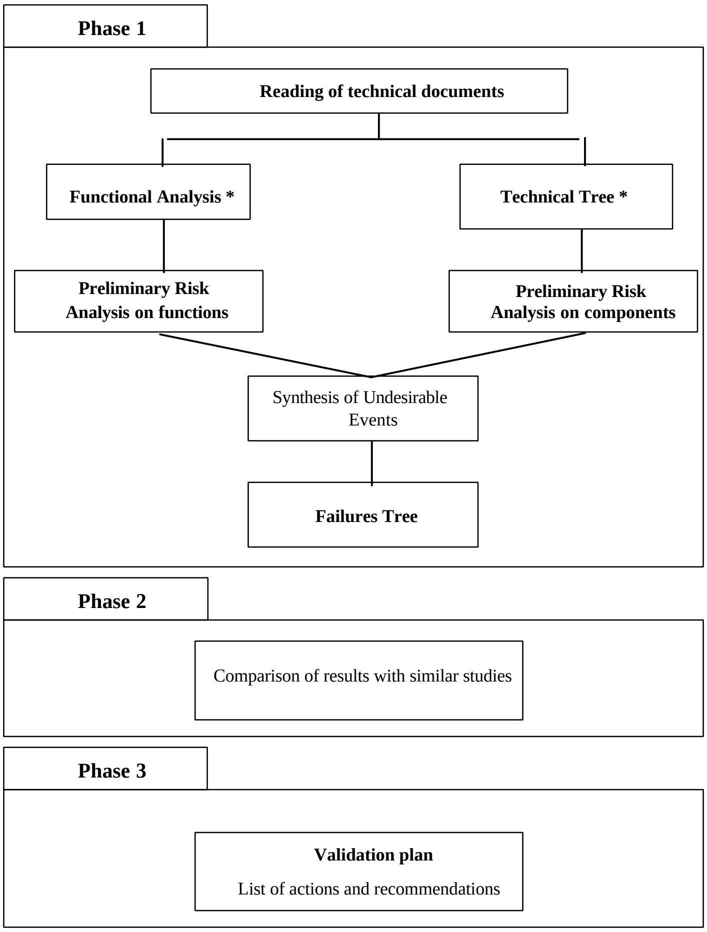

Figure 7: **Simulation of a hydrogen release in a tunnel..** [provided by EC-JRC]