

**EIHP 2**  
**WP4.4**  
**Validation of EIHP Draft**  
**FINAL TASK REPORT**

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# Index

<b>1. INTRODUCTION</b>	<b>5</b>
<b>2. REPORTING ISSUES</b>	<b>5</b>
2.1 EXECUTIVE PUBLISHABLE SUMMARY	5
2.2 MANAGEMENT AND COORDINATION ASPECTS	5
2.3 DEVIATION FROM PLANNING	5
<b>3. TANK SPECIFICATIONS</b>	<b>5</b>
3.1 INTRODUCTION	5
3.2 REFUELLING	6
3.3 STORAGE	6
3.4 FUEL SUPPLY	7
<b>4. TANK DESIGN</b>	<b>7</b>
4.1 SAFETY	7
4.2 TANK DESIGN	7
4.3 COMPONENT TRADE OFF	8
4.3.1 <i>Material</i>	8
4.3.2 <i>Seals</i>	9
4.3.3 <i>Insulation</i>	10
4.3.4 <i>Conclusions</i>	10
<b>5. MAIN COMMENTS ON EIHP DRAFT</b>	<b>11</b>
5.1 GENERAL	11
5.2 SHOCK RESISTANCE	12
5.3 INSULATION	13
5.4 ISOLATION DEVICES	16
5.5 FILTERS	16
<b>6. TANK MANUFACTURING</b>	<b>17</b>
<b>7. TESTS</b>	<b>19</b>
7.1 INTRODUCTION	19
7.2 OVERFILL TEST	19
7.3 BOIL OFF AND AUTONOMY TESTS WITH LH2	21
<b>8. APPROVAL</b>	<b>21</b>
<b>9. SPECIFIC SAFETY STUDY (FRENCH)</b>	<b>28</b>
9.1 METHODOLOGIE	28
9.2 ENTITES & RISQUES ASSOCIES	29
9.2.1 <i>Energies mises en OEUVRE</i>	29
9.2.2 <i>Evénements redoutés</i>	30
9.3 SYNTHESE DES RECOMMANDATIONS	30
9.3.1 <i>Domaine sécurité</i>	30
9.4 TABLEAU RISQUES	30

## Figures

Figure 1 : Shock resistance paradox .....	12
Figure 2 : Approval of insulation according to EN1797 (self approval).....	15
Figure 3 : tank under fabrication (1).....	17
Figure 4 : tank under fabrication (2).....	18
Figure 5 : Detail of insulation.....	18
Figure 6 : EIHP tank test results- Stabilization .....	20
Figure 7 : EIHP tank name plate with TUV approval stamp .....	21

## Tables

## 1. INTRODUCTION

AIR LIQUIDE has proposed during the execution of the EIHP 2 project to realize a liquid Hydrogen tank based on BMW specifications in order to validate the EIHP draft for regulation mostly developed during the frame of the EIHP 1 project.

This report describes the publishable work which has been done during the execution of the project and represent part of the deliverable of WP4.4. The hardware part (ie the liquid Hydrogen tank which was built) was delivered during the project execution to BMW Partner Energie Technology for further tests campaign.

Confidential data will not be published, as other partners of the EIHP project have similar commercial activities and interest than Air Liquide.

## 2. REPORTING ISSUES

### 2.1 EXECUTIVE PUBLISHABLE SUMMARY

See coordinator report.

### 2.2 MANAGEMENT AND COORDINATION ASPECTS

See coordinator report.

### 2.3 DEVIATION FROM PLANNING

The EIHP type tank has been delivered 6 months late from the original planning as specific components had to be developed. This delay has not endangered the other project work packages.

## 3. TANK SPECIFICATIONS

### 3.1 INTRODUCTION

The tank was design and built according to the BMW “E68” package. It was delivered to BMW during the project.

This tank has been designed with the highest level of safety. When performances and safety were not compatible during the design phase, Safety has been given the first priority.

This chapter summarizes the different specification of the tank system.

### 3.2 REFUELLING

The refuelling connection or receptacle shall be designed according to the results/regulations/standards achieved through EIHP Work Package WP3 - Refuelling Interface.

Independent of the chosen refuelling connection the following requirements shall be fulfilled:

- The LH<sub>2</sub> tank system shall be evacuable , to remove all contamination of gases or water before the LH<sub>2</sub> tank system is filled for the first time.
- The time for conditioning and first filling with liquid hydrogen shall not exceed 1 hour
- Subsequent refuelling incl. connection to and disconnection from the filling station shall last no longer than 5 minutes .
- The loss of fuel during refuelling shall be minimized .
- Refuelling shall be possible at a declination of the vehicle of 5° in all directions
- Refuelling shall stop automatically when the maximum filling level is achieved .

### 3.3 STORAGE

The filling capacity (maximum quantity of hydrogen that may be contained in the LH<sub>2</sub> tank system) of the LH<sub>2</sub> tank system shall be at least 9 kg LH<sub>2</sub>.

The working pressure shall be minimized according to the requirements of fuel supply

There shall be no loss of hydrogen at any time during operation of the hydrogen

If there is a boil off system installed the boil off rate at any fuel level shall be lower than 2% per day of the maximum quantity of hydrogen that may be contained in the LH<sub>2</sub> tank system .

Furthermore the time elapsed until the pressure rises from working pressure to the set pressure of the boil off system or boil off management system (hold time) shall be at least 3 days .

Thus the following requirements result:

filling capacity	> 9	kg LH <sub>2</sub>
working pressure	3	bar abs
maximum working pressure	7	bar abs
boil off rate	< 2	% per day
hold time	> 3	days

**Table 1 : Performances**

### 3.4 FUEL SUPPLY

The LH<sub>2</sub> tank system shall supply gaseous hydrogen to the combustion engine according to the following conditions:

Pressure :	> 1,0	barg
Temperature :	-40 / +80	°C
Mass flow rate	0 to 20	kg per hour
Dynamics:	minimal to maximum flow within 1 second	

**Table 2 : Fuel supply**

## 4. TANK DESIGN

### 4.1 SAFETY

The tank has been designed according to the highest level of safety.

A generic safety study (FMEA) has been done on the tank. This safety study contains confidential information and is not published. A specific safety study has been prepared and is attached to this report. (see chapter 9)

### 4.2 TANK DESIGN

Each component of the tank has undergone specific tests to be type-validated according to the EIHP draft. All tests have not been performed, especially destructive tests.

Some key components of the LH<sub>2</sub> tank system were specifically developed for this application :

- Cryogenic Solenoid valves
- Heat Exchanger
- Level gage

Other components were available off the shelf from different suppliers with their own approvals. Those approvals were not exactly EIHP type but were close to it :

- Safety valves and burst disks (PED 97/23 EC and ATEX 94/9/EC)
- Pressure transmitters (EN50014 and following)
- Pressure vessels (PED 97/23/EC)

## 4.3 COMPONENT TRADE OFF

Optimisation of the components have been a constant concern during the project execution. All components have been optimised in order to reach the EIHP requirements.

For each components, a trade off study was made.

The different components of the system examined in this document are the following :

- Material for inner and outer vessels, tubes, components.
- Inner and outer vessel shape
- Supporting
- Valve box concept

### 4.3.1 MATERIAL

In this part, we have tried to select the materials that are compatible with the use of hydrogen (their essential requirement). Their ability in cryogenic use (low temperature, conductivity) have also been considered and a selection has been made with internal rules.

#### 4.3.1.1 INNER / OUTER TANK

##### Stainless Austenitic Steel

With good mechanical characteristics even at low temperature, an high elongation at break and a good compatibility with humidity and most of the cryogenic products, stainless austenitic steel is the most commonly used material for cryogenic applications.

With consideration to hydrogen embrittlement and the recommendations of the AD-Merkblatt W10 for pressure vessels at low temperature, the following grades have been selected :

1.4541 (AISI 321)

1.4571 (AISI 316 Ti)

1.4404 (AISI 316L)

1.4429 (AISI 316LN)

##### Aluminium alloys

Aluminium alloys have a good behavior at low temperatures. Unlike steels, they don't have a transition temperature between brittle and ductile fracture at low temperature. Their medium mechanical characteristics (Rm about 300 MPa and RP02 about 250

MPa) but low density (2700 kg/m<sup>3</sup>) make them often a good alternative to steels when mass is a major concern. Aluminium alloys are used by Air Liquide for spacecraft tanks.

For the forming of stiffened plates an extruder die can be used.

The 5000 family is a good choice considering its 'cryogenic' capabilities, a very good suitability for welding and an excellent resistance to corrosion :

EN AW 5086

EN AW 5083 (best characteristics after welding)

### **Other alternative : Titanium**

Titanium has very high mechanical characteristics but its use as pressure vessel is sometimes difficult due to its very low elongation at break. The French regulation requires for example A% > 13% for pressure vessels. The price of this material may be another disadvantage.

#### **4.3.1.2 COMPONENTS**

For hydrogen, and the use with low temperature, most of the components will be made out of **stainless steel**, **copper alloy (brass)**, **bronze** + **teflon, Kelf, Viton** (tightness).

#### **4.3.1.3 TUBES**

In the choice for tubes material, **stainless steel** is the most commonly used material. Another possible choice, is Invar.

### **Invar**

With good mechanical characteristics, an absence of low temperature embrittlement, and particularly a guaranteed coefficient of thermal expansion of  $2.10^{-6}/^{\circ}\text{C}$ , Invar is an excellent alternative to steels for tubes in low space fittings.

The technology of welding is well known by Air Liquid for Invar/Invar and Invar/Stainless steel assemblies.

#### **4.3.2 SEALS**

All seals have to be compatible with low temperature, even if they are located in a high temperature area of the tank.

Viton<sup>®</sup> is the most commonly used polymer for sealing purposes in the industry. Its sealing properties are excellent down to  $-30^{\circ}\text{C}$ .

The problem we face with the design of a seal on a cryogenic tank is the possibility of having cold temperatures on it in case a small leak appears. This leak will cool down the seal material down to eventually liquid hydrogen temperature, below the minimum

operating temperature of  $-30^{\circ}\text{C}$ . the seal material will then become fragile and a major leak can occur.

Fluoro silicone sealing are also available on the market. However, their minimum operating temperature is  $-60^{\circ}\text{C}$ , which is far above the liquid hydrogen temperature.

Teflon® PTFE is the only sealing material which keeps good mechanical properties at low temperatures and therefore is the sealing material used for the LH2 tank.

### 4.3.3 INSULATION

The thermal characteristics needed for cryogenic vessels are the main constraints for the design. the 3 main categories for insulation are :

Foams with closed cells, with a conductivity of about  $3.10^{-2}$  W/m/K, that is used on spacecraft tanks and is adapted for high flow rates and short time insulation. This solution, considering the asked for bleed off, is not really adapted.

Multi Layer Insulation, that requires a double wall vacuum super insulated vessel, but reaches conductivity lower than  $10^{-4}$  W/m/K. This solution is very attractive but the required external space is much bigger than the internal vessel itself (at least 20mm between inner and outer vessel).

Porous compounds under vacuums, that is less powerful than MLI. It also requires an external envelope that must be designed with 1 bar external pressure which significantly adds to the weight of the storage tank. Such insulation is not really adapted to vibration because it tends to be packed in these conditions what leads to a deterioration of the thermal characteristics.

These considerations lead us to direct our study on a double wall vacuum vessel.

### 4.3.4 CONCLUSIONS

The trade off study has enable Air Liquide to select the most appropriate technical solutions for the design and construction of the LH2 tank, having in mind both safety, technical and regulatory requirements. The conclusions of the trade off study are summarized here below :

- Material : Use of stainless steel 316L (or 316Ti) is recommended. Aluminium will not involve a major weight reduction.
- No use of composite materials (except for supports and sealing) were envisaged. (lack of experience)
- No use of engineered metallic alloys such as INVAR were envisaged. (lack of experience)
- Heat exchanger : A tubular design was originally chosen (versus plate design) for better pressure resistance, but this design was shown to be very sensitive to

freeze, therefore a plate heat exchanger was selected with increased resistance to leaks and special inner apparatus to reduce water freezing.

- The tank surrounding is a hazardous area with possible H2 leak (Zone I according to IEC 60079-10). §14.8.2 stipulates that valve are either compatible with this area (explosion proof Eex -d, intrinsically safe Eex -ia, or increased safety Eex -e-m). Explosion proof concepts are not easily compatible with the space requirements of a vehicle. Valve with no protection require additional hardware (H2 detectors) and the reliability of the entire system will be limited to the reliability of the H2 detector.
- No good cryogenic valve was available on the market, therefore a specific valve has been developed (Eex -e-m)
- Insulation : Tank is double walled, vacuum insulated.
- On the fuel supply line, and the gas return line, an isolating device has to be placed between the tank and the fuelling coupling. This isolation device can be a check valve (§14.4.1.2). This point has to be discussed as check valve are usually not considered as isolation devices.
- TEFLON<sup>®</sup> sealing were selected for cold and hot sealing

## **5. MAIN COMMENTS ON EIHP DRAFT**

### **5.1 GENERAL**

Most of the comments of Air Liquide on the EIHP draft for regulation were addressed before or during the WP4 working meetings.

A general comment was issued on the draft for regulation : As far as possible, references to applicable documents should be made when dealing an issue not specific to the LH2 tanks for vehicle application. For instance on pressure vessel definition, reference should be made to the latest revision of the corresponding European regulation. This would decrease the risk of misunderstanding and misinterpretation of the standards, and would enable to update the regulation as efficiently as possible while reducing by far the size of the specific regulation.

## 5.2 SHOCK RESISTANCE

- 14.3.4. The hydrogen container(s) including the safety devices affixed at it must be mounted and fixed so that the following accelerations can be absorbed (without damage of the safety related parts) when the hydrogen containers are full. No uncontrolled release of hydrogen is allowed.

Vehicle of categories M1 and N1:

- (a) 20 g in the direction of travel
- (b) 8 g horizontally perpendicular to the direction of travel

Vehicles of categories M2 and N2:

- (a) 10 g in the direction of travel
- (b) 5 g horizontally perpendicular to the direction of travel

Vehicles of categories M3 and N3:

- (a) 6.6 g in the direction of travel
- (b) 5 g horizontally perpendicular to the direction of travel

There is an important difference between these requirements and the requirement of TPED 99/36/EC where the shock requirements are 2 g in all directions for road transportation and 4 g for rail transportation, in all directions.

The 20 g requirement is not consistent with the autonomy and boil off requirements which are usually 3 days or more.

This requirement specifies that after a 20g shock, there should be no release of hydrogen, but it does not specify what is the maximum shock allowable in normal use.

Figure 1 summarizes the “shock resistance paradox” where a H<sub>2</sub> powered train could transport a hydrogen car with a trailer filled with hydrogen. The train tank should resist 4 g, the LH2 trailer towed by the car should resist to 2 g and the LH2 tank vehicle should resist to 20g...

“Normal acceleration resistance” specification should be added in the norm (to have non vehicle specific design) Tank would have to sustain without damage these accelerations.

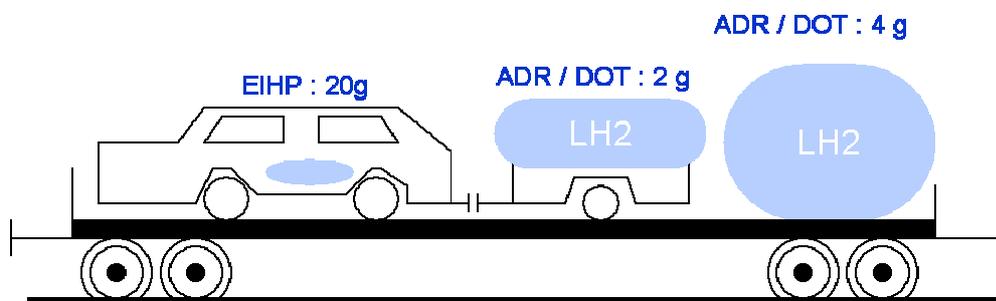


Figure 1 : Shock resistance paradox

## 5.3 INSULATION

LH2 tanks are double wall - vacuum insulated. Multi Layer Insulation, a succession of heat reflective material and low thermal conductivity material is installed to make as many shields against radiation as there are layers.

For example, multi layer insulation can be Aluminum as reflective and Paper of fiber glass as insulation, 30-70 layers, 15-25 layers / cm or Mylar™ / paper, 40 layers/cm

Extract of EIHP Draf v14 :

- 6.3.3. The insulation of the components shall prevent liquefaction of the air in contact with the outer surfaces, unless a system is provided for collecting and vaporizing the liquefied air. Then the materials of the components nearby shall be compatible with an atmosphere enriched with oxygen according to EN 1797:2001.

In case vacuum is lost, LOX can concentrate in the insulation because LH2 temp is lower than O2 liquefaction temperature if a shock occurs then the system can catch on fire

As per EN 1797-2001 : insulation material must withstand fire O2 compatibility test : one sample of insulation is installed in a shelter with 50% wt LN2, 50% wt LOX => no deflagration when a 15mm\*15mm sample is submitted to an energy of 100J

As per ISO 13985-3: test is much less strict (refers to corresponding ISO statement)

At least two accidents with fatalities in the gas industry on tank insulated as per ISO standards.

As per EIHP (EN1797-2001), tank must be insulated with :

- Reflective material : Aluminum thickness > 15µm
- fiber glass (non combustible) as spacer

The following problems are faced while isolating small cryogenic tanks with this type of multi-layer insulation :

- Aluminum has a high thermal conductivity => layers at different temperature levels should not get in contact one from the other and should not touch cold parts, as tubes when they cross the insulation as shown in Figure 5.
- Fiber glass is hydrophilic and has no mechanical resistance. Therefore the installation of such a material is extremely delicate, and the pumping of the tank insulation is very long as humidity needs to be evacuated.

For instance, the aluminum type insulation of the EIHP tank has been 12 days, with two workers, whereas the insulation of the same tank with other type of multi layer insulation (not approved as per EN1797-2001) takes no more than 5 days, two workers

Air Liquide has therefore developed a unique multi layer insulation (patent pending) in order to meet both the requirements of the EIHP and the necessity of easy installation. The approval report as per EN1797 of this insulation is reported Figure 2.

AIR LIQUIDE D.I.C.I. CENTRE DE TECHNOLOGIE ET D'EXPERTISES LE BLANC MESNIL	ESSAIS DE CHOC MECANIQUE Dans un comburant liquide Selon Norme NF EN 1797 Méthode d'essai: ASTM D 2512	Date: 30/03/1995 Numéro : OC0416 Fluide : N2+O2																																																																																																																																																																																																																																																																											
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Incertitude sur le temps de chute 4- COMMENTAIRES : Mélange 50% N2 50% O2 en poids. 5- RESULTATS DU TEST : <table border="1" style="margin-left: 20px; border-collapse: collapse;"> <tr> <td style="padding: 5px;">Matériau:</td> <td style="padding: 5px; text-align: center;">Compatible</td> </tr> </table> 6- ESSAIS SUPPLEMENTAIRES: Bombe: Indice d'oxygène: Le responsable d'Activité Oxygène : JP Schaeff Opérateur:										Matériau:	Compatible																																																																																																																																																																																																																																																																		
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La remise par Air Liquide de cette fiche à son destinataire ne peut conduire Air Liquide à assumer à quelque degré et à quelque titre que ce soit les risques opérationnels industriels et commerciaux du destinataire. Ce rapport d'essai ne concerne que l'échantillon qui a été soumis aux essais. FR-3-ctrl-indicesf																																																																																																																																																																																																																																																																													

**Figure 2 : Approval of insulation according to EN1797 (self approval)**

## 5.4 ISOLATION DEVICES

page 17

- 14.4.1.2. The **refuelling** line shall be secured by either a manually or an automatically operated shut off valve which shall always be closed except during the refuelling process. If the receptacle is not mounted directly on the container, a second isolating device is needed. This device may be a manual valve, an automatic valve or a non-return valve. One of these two isolating devices shall be mounted directly on or within the container and the other one shall be integrated in the receptacle.

On the fuel supply line, and the gas return line, an isolating device has been placed between the tank and the fuelling coupling (which has an isolating device itself). This second isolation device can be a check valve (§14.4.1.2). Check valves are usually not considered as isolation devices.

## 5.5 FILTERS

Filters are not described in the EIHP draft for regulation. Air Liquide does not recommend the use of filters on Liquid hydrogen lines as solid oxygen particle can concentrate in the filter and explode if a energy source is provided (fluid velocity, shocks, etc...). This recommendation should be mentioned in the regulation.

## 6. TANK MANUFACTURING

The following picture shows the EIHP tank during the fabrication process, in Air Liquide workshops.



**Figure 3 : tank under fabrication (1)**



**Figure 4 : tank under fabrication (2)**



**Figure 5 : Detail of insulation**

## 7. TESTS

### 7.1 INTRODUCTION

The tank has been fully tested with Liquid nitrogen and liquid hydrogen. Separated reports (non publishable) have been issued concerning the LH2 and LN2 tests performed.

Specific behaviours have been witnessed on the tank. Some of them are safety relevant and can be described in this report.

### 7.2 OVERFILL TEST

When the tank is fully filled with no gaseous phase remaining, we consider it as being “overfilled”.

In this case, we witness two consequences :

- 1- the boil of flow at constant pressure is really unsteady as cryogenic liquid is circulating by gravity in the tubing down to a valve (hot point), and flashes immediately, which creates a peak in the boil off flow (see Figure 6 : EIHP tank test results- Stabilization, boil off in blue, ambient temperature in green, boil off temperature in pink, atmospheric pressure).
- 2- The pressure rise of the tank is much faster when there if no gaseous phase, as the compressibility of liquid is much lower than the compressibility of gas.

Points 1- and 2 can have serious consequences which could lead to the opening of the safety devices. Therefore, a second level measurement is mandatory in order to secure the tank from overfilling.

#### 5.4. Maximum filling level

- 5.4.1. A system shall be provided for preventing the container from being overfilled. This system may work in conjunction with the refuelling station.
- 5.4.2. The device shall bear a permanent marking, indicating the container-type for which it has been designed and if applicable the mounting position and orientation. Under all circumstances and regardless of the fuel condition and the maximum operating pressure of the inner tank, the filling volume of the liquid shall not exceed 95 per cent of the water volume of the inner tank.

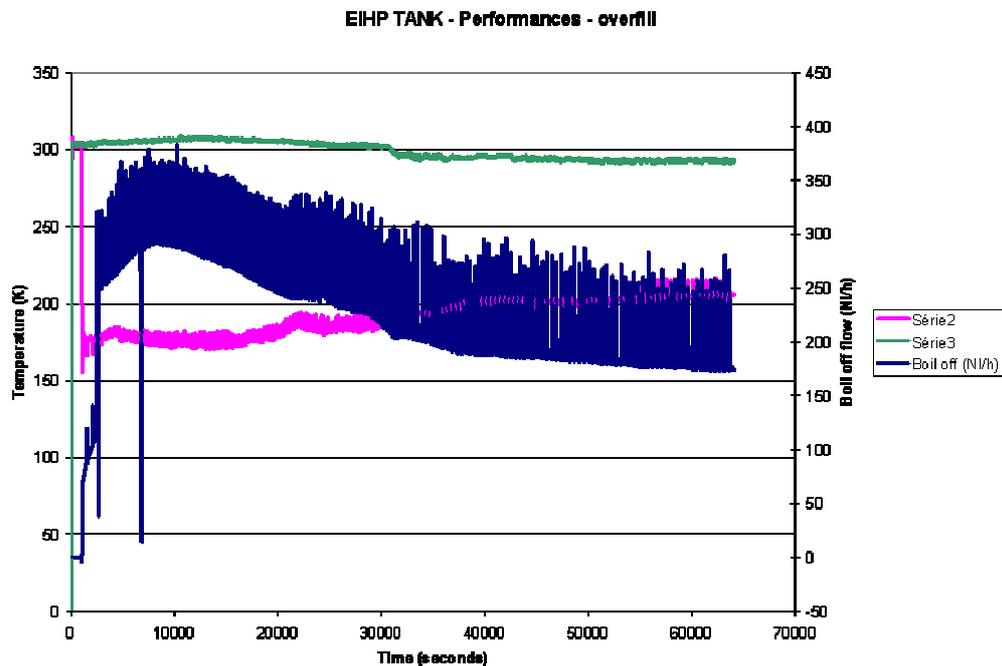
This maximum level criteria means that when the hydrogen is saturated at the set point pressure of the primary safety valve, the remaining gaseous phase must be at least 5%.

As liquid saturated hydrogen expands with the pressure (density at 1.013 bar abs is 70g/l, versus 56 g/l at 7 bar abs), if we fill the tank with saturated liquid hydrogen, we need to stop the filling at the following levels given in Table 3 : Refuelling pressure vs. set pressure of first safety valve in order to get the 5 % (3% in the example below).

In case the refuelling pressure is not the saturated pressure another table must apply.

		Refuelling pressure (Mpa)							
		0.1	0.15	0.2	0.3	0.5	0.7	0.9	0.11
Set Pressure of the first safety Device (Mpa)	0.10	97.0%							
	0.15	94.7%	97.0%						
	0.20	92.7%	95.0%	97.0%					
	0.30	89.2%	91.3%	93.2%	97.0%				
	0.50	83.1%	85.1%	86.8%	90.2%	97.0%			
	0.70	77.3%	79.1%	80.6%	83.7%	89.7%	97.0%		
	0.90	71.1%	72.7%	74.0%	76.6%	81.8%	87.9%	97.0%	
	0.11	63.4%	64.7%	65.7%	67.9%	71.9%	76.6%	83.5%	97.0%

**Table 3 : Refuelling pressure vs. set pressure of first safety valve**



**Figure 6 : EIHP tank test results- Stabilization**

### 7.3 BOIL OFF AND AUTONOMY TESTS WITH LH2

Those tests are described in a separate confidential report.

## 8. APPROVAL

The tank has been submitted to the TUV, with the following results :

- System has been approved (see Figure 7)
- Comments were made on the design with regards to the EIHP requirements. (see tables below, in French)

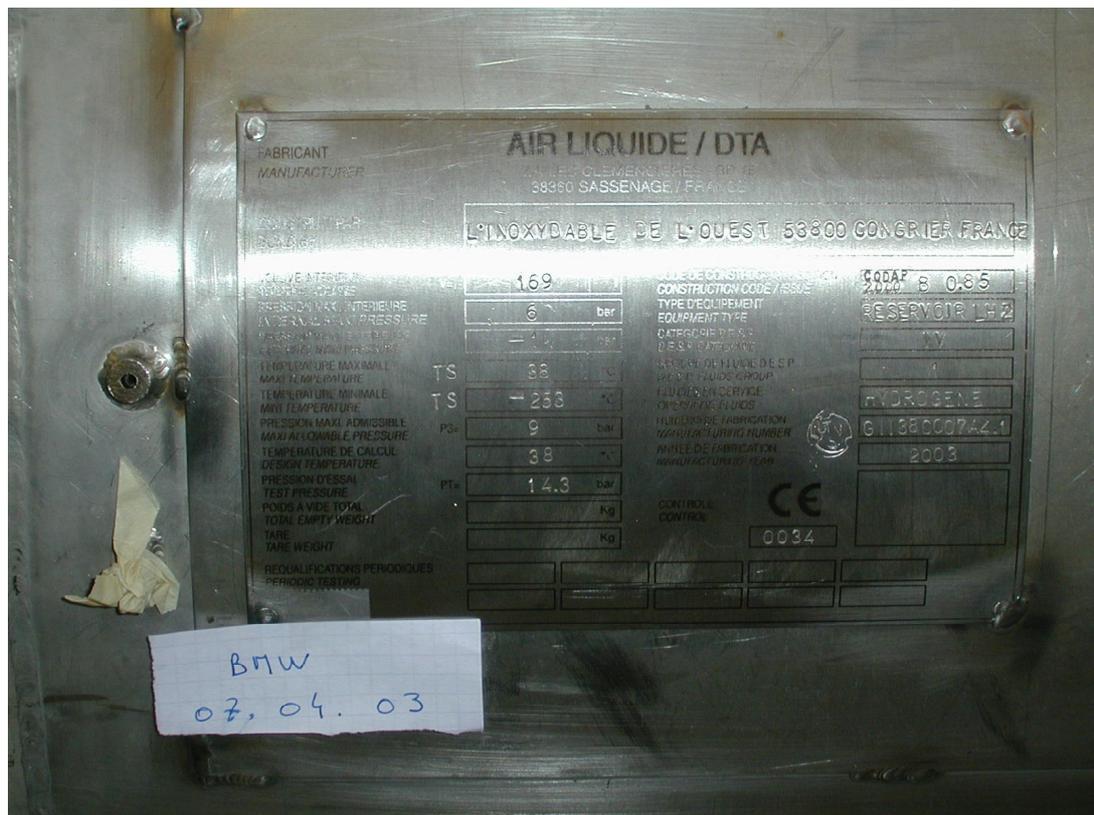


Figure 7 : EIHP tank name plate with TUV approval stamp



pos.	exigence contrôle / inspection	référence	mobile fixe			COMMENTAIRE REUNION DU 21/03/2003
			M	I	F	
	agrément requis (R97/CEOC/CP98 ou ped)	Rxxx, 7A-1-3.1	x	x	x	Inox de l'ouest est ISO9000 et dispose d'un agrément produit
	idem pour transformateurs	Rxxx, 7A-1-3.2	x	x	x	Sous traitement de INOX; A préciser. Préliminaire de la PED
	agrément traçabilité pour débitteurs/usiniers matériaux réservoir extérieur	Rxxx, 7A-1-3.1	x	x	x	Toute l'intégration est faite chez Air Liquide
	A% >= 12% à -106°C	Rxxx, 7A-1-3.4.2	x			Matière de Rext = 316L. Raison du critère à vérifier. Trouver un essai relatif à ce point.
	certificats	Rxxx, 7A-1-3.5.3	x			OK; Nous les avons tous
	31B	Rxxx, 7A-1-3.5.3	x			OK
	traçabilité et identification jusqu'au n° de lot fabricant du réservoir	Rxxx, 7A-1-3.5.8	x			Fabricant du réservoir : Air Liquide. Vérifier si INOX DE L'OUEST est HP0 ou est qualifié EN729-2 ou -3
	agrément requis (R80-81/CEOC/CP91 ou ped et EN729-2 ou 3)	Rxxx, 7A-1-4.1 / 2 / 3	x	x	x	OK
	QMOS / QS	Rxxx, 7A-1-4.4	x			NON. La définition des contrôles dimensionnels est dans le CODAP
	EN 288 / 287	Rxxx, 7A-1-4.4	x			Toutes les soudures doivent être radiographiées, sinon test Hélium
	dimensionnel	Rxxx, 7A-1-3.6.3	x			OK
	cf ISO 2708 (?)	Rxxx, 7A-1-4.8	x			OK
	tuyauteries entre réservoir interne et externe : 100% CND	Rxxx, 7A-1-4.8	x			Non applicable
	pression d'épreuve	Rxxx, 7A-1-6.3.5	x			OK
	Pt = 1,3*(Pdesign + 1) b	Rxxx, 7A-1-6.3.3	x			OK
	Pt = 1,43*(Pdesign + 1) b	Rxxx, 7A-1-6.3.4	x			OK
	contrôles en série	Rxxx, 7A-1-6.3.1	x			OK
	cf aussi EN 1251-2	Rxxx, 7A-1-6.3.2	x			OK
	visuel	Rxxx, 7A-1-6.3.6	x			OK
	dimensionnel	Rxxx, 7A-1-4.11	x			Ok
	vérification CND	Rxxx, §4.3.1	x			Ok
	épreuve		x			Ok
	étanchéité		x			Ok
	marquage		x			Ok
	propreté et séchage		x			Ok
	EN 12300 (point de rosée -40°C)		x			Ok
	marquage réservoir intérieur		x			Ok
	fabricant		x			Ok
	n° série		x			Ok
	volume		x			Ok
	design pressure		x			Ok
	année / mois d'homologation		x			Ok
	sigle d'homologation		x			Ok
			x			Non applicable



pos.	exigence contrôle / inspection	référence	mobile fixe			COMMENTAIRE REUNION DU 21/03/2003
			M	I	F	
	calcul et conception selon EN 13648-1 / 2 cat B selon PID transmis design P : 1,5 design P du réservoir intérieur	Rxxx, 7B1 / 2 Rxxx, 7B3	x			Dans la note de calcul thermique OK
	températures de design : -253°C / +85°C en interne tests : pression étanchéité fonctionnel	Rxxx, 7B5 Rxxx, 7B6 Rxxx, 8B Rxxx, 8B	x	x		-198°C avec validation des matériaux (316L et PTFE) pour une température inférieure à - 198°C, température max : 70°C OK OK
	corrosion cyclage thermique si parties non métalliques homologation requise marquage CE (catégorie IV)	Rxxx, 8B	x			OK. Essais sur OPEL JAPAN. Le test est fait au moment du tarage de la soupape. OK. Soupape à l'intérieure de la boite étanche.
	dispositif de protection réservoir extérieur	Rxxx, 8B Rxxx, 8B Rxxx, §9.4.1.8 ped	x	x		Pas fait. Exclusion Non fait Marquage CE des soupapes
0040	dispositif de protection réservoir extérieur					
	dispositif contre surpression requis	Rxxx, 7A-1-5.1	x			Bouchon pour pompe ALCATEL. Ce n'est pas un équipement de sécurité.
0060	dispositifs de limitation de pression autre que réservoir doit être dispo si risque d'isolement de phase liquide ou gazeuse upstream : <= MIN(120% design P du réservoir ; design P des composants) downstream : <= design P des composants homologation requise	Rxxx, §9.4.2.1 Rxxx, §9.4.2.2 Rxxx, §9.4.2.3 Rxxx, §9.4.2.4	x	x		Non applicable Non applicable Non applicable Non applicable
0080	mesures de niveau système requis avec justesse +/- 10% si flotteur coefficient sécurité de 2 système de détection de remplissage maxi requis, avec marquage spécifique design P : 1,5 design P du réservoir intérieur températures de design : -253°C / +85°C tests : pression étanchéité externe corrosion si parties hors réservoir extérieur	Rxxx, 7A-1-5.3.1 Rxxx, 7A-1-5.3.2 Rxxx, 7A-1-5.4.1 / 2 Rxxx, 7G1 Rxxx, 7G2 Rxxx, 7G3 Rxxx, 7G3 Rxxx, 8B Rxxx, 8B	x	x		+/- 5% Non applicable Oui/Sonde spécifique capacitive C'est du tube T sup 70°C OK Boitier électrique IP 66 Boitier électrique IP 67 Pas de cyclage thermique. Pas de vieillissement O3 Non Pendant le test de remplissage
0070	vannes et accessoires H2 calcul et conception selon EN 1826	Rxxx, 7C1	x			



pos.	exigence contrôle / inspection	référence	mobile fixe		COMMENTAIRE REUNION DU 21/03/2003
			M	F	
	compatibles zone 1 satisfaction exigences Directive CEM, BT	Rxxx, §14.8.2	x	x	La vanne sera ATEX. In process. CEM non effectuée. Il faut un justificatif précisant qu'aucun changement de conception n'a été effectué suite à l'homologation
0110	connections remplissage : exclus du champ				OK
0120	régulateur de pression : exclu du champ				OK
0130	capteurs "specific devices" autres que mesures de niveau : supposé exclu du champ	?			OK
0140	conduite flexibles : exclus du champ				OK
0150	éléments boulonnés : exclus du champ				OK
0160	bruteur H2 : exclu du champ				OK
0170	visites de sondage lors de production en série de l'ensemble	Rxxx, §8	x	x	OK

nb : les éléments notés "exclu du champ" le sont au vu du PID transmis  
 nb : dans le cadre d'une homologation "mobile" tous les points cités en M sont à vérifier par l'organisme d'inspection.  
 nb : sont repérés en colonne "I", variante mobile, les points pour lesquels l'organisme doit être présent lors des essais  
 nb : sont repérés en colonne "F" les points strictement minimaux à réaliser pour la variante fixe  
 nb : tous les accessoires autres que soupape et disque de rupture sont supposés être du type §3.3 ped dans la variante fixe  
 nb : sont repérés en colonne "I", variante fixe, les points pour lesquels l'organisme doit être présent lors des essais

FIN

## 9. SPECIFIC SAFETY STUDY (FRENCH)

### 9.1 METHODOLOGIE

L'étude de sécurité consiste à identifier les risques liés à l'utilisation du réservoir LH2 pour son environnement et les exploitants et à justifier les moyens mis en œuvre pour la suppression, la réduction des risques ou l'information des usagers des risques subsistants.

La démarche de l'étude est la suivante :

- Lister les événements redoutés (type de risques).
- Identifier les risques pris en compte.
- Désigner l'entité à l'origine de l'identification du risque.
- Indiquer, tant au niveau de la conception que de l'utilisation et de l'information, les mesures prises :
  - 1- **pour l'élimination du risque**
  - 2- **pour sa réduction**
  - 3- **pour l'information des utilisateurs concernant les risques subsistants.**

Les tableaux chapitre 9.4 synthétisent les mesures d'élimination, de réduction ou d'information sur les risques subsistants à prendre en compte.

## 9.2 ENTITES & RISQUES ASSOCIES

Entités	Risques associés	Risques en fonctionnement	Risques en phase maintenance
Hydrogène liquide (LH2)	<ul style="list-style-type: none"> <li>• Brûlure cryogénique</li> <li>• Explosion</li> <li>• Mise en pression par réchauffement dans une portion de ligne ou du réservoir</li> </ul>	<ul style="list-style-type: none"> <li>• Déclenchement soupape ou disque de rupture et éjection d'hydrogène sous pression potentiellement froid. Inflammation éventuelle</li> </ul>	Idem risques associés
Pression	Projections	<ul style="list-style-type: none"> <li>• Déclenchement soupape ou disque de rupture et éjection d'hydrogène sous pression potentiellement froid. Inflammation éventuelle</li> </ul>	Idem risques associés

### 9.2.1 ENERGIES MISES EN OEUVRE

- Fluide sous pression
- Fluide à basse température (cryogénique)
- Fluide inflammable

## 9.2.2 EVENEMENTS REDOUTES

- Anoxie
- Feu
- Explosion
- Brûlure cryogénique
- Brûlure suite à incendie / explosion
- Effet de souffle suite à explosion

## 9.3 SYNTHESE DES RECOMMANDATIONS

### 9.3.1 DOMAINE SECURITE

Cet équipement est utilisé par des opérateurs formés.

Les mises à l'air se font hors zone de risque.

## 9.4 TABLEAU RISQUES

Equipement (8) RESERVOIR LH2 BMW		Référence : G 1138 Rév : 0 Date : 03/02/03 Fabricant : AL DTA Pour le fabricant Visa :						
Type de risques (1)	Concerné (2) OUI/ NON	Risques estimés par (3)	Si applicable, le risque a été réduit ou éliminé par : (5)			Evaluation du risque (4)	Explications	
			Conception		Utilisation			
			Moyen de construction	Contrôle de la production	Système de sécurité (6)	Autres précautions	Consigne dans la notice d'utilisation (7)	
Battement de pression	NON							
Opérations d'assemblage	OUI	E	O	O				A
Vibrations agitateurs ou pompes	NON							
Charge mécanique des internes	NON							
Déversoirs/défecteurs	OUI	E	O					A
Cavitations	NON							
Charges dues aux tuyauteries externes	NON							
Charges dues aux supports de fixation	OUI	SU	O			O		A
Contraintes d'installation	OUI	SU	P			P	P	A
Contraintes géotechniques	NON							
Influence de la circulation	OUI	SU				O		A
								Calculs aux éléments finis des supports
								Installation dans un véhicule par client sous la responsabilité du client.
								Réservoir protégé des agressions extérieures dans véhicule

Equipment (8) RESERVOIR LH2 BMW		Référence : G 1138 Rév : 0 Date : 03/02/03 Fabricant : AL DTA Pour le fabricant Visa :					
Type de risques (1) RISQUES DUS A L'INSTALLATION ET SON ENVIRONNEMENT	Concerné (2) OUI/ NON	Risques estimés par (3)	Si applicable, le risque a été réduit ou éliminé par : (5)		Evaluation du risque (4)	Explications	
			Conception				
		Moyen de construction	Contrôle de la production	Système de sécurité (6)	Autres précautions	Consigne dans la notice d'utilisation (7)	
Charges dues au vent	NON						
Séismes / inertie	OUI	SU	O				A Spécification client accélérations
Chocs de mobiles ou chute d'objet	NON						
Accélérations	OUI	SU	O			O	A Spécification client accélérations
Transport manuel	OUI	E					A La notice doit stipuler que le réservoir doit être vidé et assaini avant d'être manutentionné.
Effets de l'humidité du froid, de la chaleur	NON						
Charges dues à la neige et à la glace	NON						
Compatibilité du fluide de test hydro	NON						
Débordement	OUI	E	P	P		P	A double protection anti débordement (2 sondes)
Dispositifs électrostatiques	NON						

Equipment (8) RESERVOIR LH2 BMW		Référence : G 1138 Rév : 0 Date : 03/02/03 Fabricant : AL DTA Pour le fabricant Visa :					
Type de risques (1)	Concerné (2) OUI/ NON	Risques estimés par (3)	Conception (5) Si applicable, le risque a été réduit ou éliminé par :		Utilisation (7) Consigne dans la notice d'utilisation	Evaluation du risque (4)	Explications
			Moyen de construction	Contrôle de la production			
Mise à la terre	OUI	E	O			A	Réservoir connecté à la terre du véhicule
Raccordements temporaires ou supplémentaires	NON						
Dispositifs de chauffage électrique	OUI	E	P		P	A	Le système de chauffe ne doit pas être utilisé réservoir chaud
Forces extérieures	NON						
Décomposition fluides instables	NON						
Combinaisons de charges	NON						
Mauvais fonctionnement des dispositifs de sécurité	OUI	E	p	Disque de rupture et soupape	P	A	Risque de bouchage des événements par malveillance.
Avaries dues à de fausses manœuvres	OUI	SU	P	Système de contrôle commande	P	A	
Chargements inégaux	NON						
Remplissage excessif	OUI	E	P	P	P	A	double protection anti débordement (2 sondes)
Turbulences	NON						

Equipment (8) RESERVOIR LH2 BMW		Référence : G 1138 Rév : 0 Date : 03/02/03 Fabricant : AL DTA Pour le fabricant Visa :					
Type de risques (1)	Concerné (2) OUI/ NON	Risques estimés par (3)	Conception (5) Si applicable, le risque a été réduit ou éliminé par :		Utilisation (7) Consigne dans la notice d'utilisation Autres précautions	Evaluation du risque (4)	Explications
			Moyen de construction	Contrôle de la production			
RISQUES DUS A L'INSTALLATION ET SON ENVIRONNEMENT							
Supression	OUI	E	O			A	Système de contrôle de la surpression par déverseur.
Dépression	OUI	E	P		P	A	Le système ne fonctionne plus si une pression minimale n'est pas présente dans le réservoir.
Haute température	OUI	E	P	Soupapes et disques de ruptures calculés au scénario de feu.		A	Construction en inox 316L, résistant aux températures des scénarios de feu (650°C)
Fluage	OUI	E	O			A	Enceinte extérieure calculée au vide
Basse température	OUI	E	O			A	Matériaux au contact du froid : 316L
Choc thermique	OUI	E	O			A	Choc thermique lors de la fabrication
Corrosion	NON						
Erosion	NON						

Equipement (8) RESERVOIR LH2 BMW		Référence : G 1138 Rév : 0 Date : 03/02/03 Fabricant : AL DTA Pour le fabricant Visa :							
Type de risques (1)	Concerné (2) OUI/ NON	Risques estimés par (3)	Si applicable, le risque a été réduit ou éliminé par : (5)		Evaluation du risque (4)	Explications			
			Conception				Utilisation		
			Moyen de construction	Contrôle de la production	Système de sécurité (6)	Autres précautions	Consigne dans la notice d'utilisation (7)		
Ecoulement, fuite	OUI	E	P		Système de sécurité (6)		P	A	Minimisation des raccords non soudés. Détecteurs de fuite
Echappement (événets)	OUI	SU					P	A	Les évènements doivent être situés en zone saine, et non dirigés vers des personnels.
Inspection/regards de contrôle	NON								
Inadaptation des éléments sécurité	OUI	E	O		Soupape + disque de rupture			A	Voir note de calcul des dispositifs anti surpression
Mancœuvre incorrecte	OUI	E	P				P	A	
Remplissage/vidange	OUI	SU	P				P	A	La procédure de remplissage et son contrôle sont de la responsabilité du client.
Inspection des dispositifs de sécurité	OUI	E			Marquage CE sur soupapes et disques de rupture			A	Certificats de tarage des systèmes de sécurité passifs
Non conformité des pièces de rechange	OUI	E					O	A	La notice doit stipuler que les pièces de rechanges doivent être fournies par le constructeur.
Charges cycliques non prévues	NON								

Equipment (8) RESERVOIR LH2 BMW		Référence : G 1138 Rév : 0 Date : 03/02/03 Fabricant : AL DTA Pour le fabricant Visa :					
Type de risques (1)	Concerné (2) OUI/ NON	Risques estimés par (3)		Si applicable, le risque a été réduit ou éliminé par : (5)		Evaluation du risque (4)	Explications
		Moyen de construction	Contrôle de la production	Conception	Utilisation		
					Consigne dans la notice d'utilisation (7)		
RISQUES DUS A L'INSTALLATION ET SON ENVIRONNEMENT	OUI			Système de sécurité (6)	Autres précautions		
Abrasion érosion	NON						
Usure/dépôt	NON						
Bruit.	NON						
Vibrations	OUI	P				A	???
Sécurité/contrôle démarrage/arrêt/ service	OUI	O		Système de contrôle commande			
Emission de fluides ou particules	NON						
Eblouissement	NON						
Brûlures	OUI	P	E		P	A	La notice doit rappeler les risques liés aux brûlures cryogéniques
Contamination/ asphyxie	NON						
Chutes/glissade	NON						
noyage	NON						

1. Dans le contexte d'une utilisation raisonnablement prévisible, et des erreurs de fonctionnement causé par l'exploitant, dans des conditions normales d'utilisation.
2. Analyse des risques possibles issue d'un raisonnement logique et quand cela est nécessaire, appuyé par une analyse technique.

Répondre par : **OUI** ou **NON**

3. Répondre par :

F : Fabricant

E : Etudes

SU : spécification utilisateur

Dans le cadre de la DESP, le fabricant doit prendre la responsabilité globale de l'analyse des risques, et si tel n'est pas le cas (manque d'informations, par exemple), cela doit être explicitement et clairement identifié dans le résultat de l'analyse des risques.

4. Répondre par :

A : acceptable (si le risque est raisonnablement éliminé)

NA : non acceptable (si le risque n'a pu être éliminé)

5. Répondre par :

O : si le risque est directement réduit à un niveau acceptable

P : si le risque est réduit à un niveau acceptable avec d'autres précautions (plusieurs "P" pour un même type de risque)

6. Il faudra indiquer les références des systèmes de sécurité, de régulation,...

Il sera nécessaire de fournir l'étude (note de calcul) de la capacité du système de sauvegarde

7. Si le risque n'a pu être éliminé, les précautions à prendre doivent être clairement définies dans le manuel d'utilisation.
8. **Identification de l'équipement** : définir l'appareil, la tuyauterie, les accessoires de pression, les accessoires de sécurité inclus dans l'équipement soumis à la pression et étudié dans ce cas.