EUROTUNNEL'S SPECIFICATION FOR HALON 1301 REPLACEMENT

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INTRODUCTION

The Channel Tunnel project comprises a three bore tunnel construction which joins the UK and France and is the longest underwater tunnel in the world. It runs from Folkestone in the UK to Calais in France and has a total length of 50 kilometres (approx. 31.1 miles). It is basically a rail tunnel transport system and enables Eurotunnel to provide a "drive-on" shuttle service for road vehicles between the two terminals at Folkestone and Calais. Additionally passenger and freight trains from the national railways in Europe can and will use the tunnel system as a link between the British Rail network and that of France and the remainder of Europe.(9)*

The terminals are situated on the motorway networks and all types of traffic will drive onto the shuttle trains, be transported through the tunnel system and then drive off at their destination terminal.

Lorry or heavy goods vehicles will use one type of shuttle while passenger vehicles such as cars (automobiles) and coaches will use a different type of shuttle - a tourist/passenger shuttle. It is the latter type of shuttle wagons which will use Halon 1301 as an extinguishing agent.

SAFETY AUTHORITY

The UK and French Governments have appointed an Intergovernmental Commission (IGC) to administer the tunnel Concession(2). The IGC in turn have appointed a Safety Authority to examine the design and procedures proposed by Eurotunnel and grant an operating certificate for the operational phase(1).

Because of the unusual features of the Channel Tunnel system, it has not been possible to use well tried and tested safety standards for some of the areas of design. Considerable research has therefore been undertaken to obtain the necessary scientific evidence to prove the feasibility and safety aspects of design. This paper addresses one part of design process - the use of Halon 1301 as the extinguishing media in the passenger shuttle wagons.

PASSENGER SHUTTLES

The first half of a passenger shuttle comprises; a locomotive, a loader wagon, twelve single deck wagons for coaches and an offloader wagon. The other half is of a similar composition but has twelve double deck (two tier) wagons for cars. Each single deck wagon will carry a coach and the double deck wagons can carry up to 5 cars per deck, i.e., 10 in total per wagon.

Passengers will remain in their cars and coaches for the journey through the tunnel system. It is the perceived risk of passengers remaining with their vehicles that is the reason for the Channel Tunnel Safety Authority requiring a high standard of safety.

CONCEPTUAL STAGE OF SHUTTLE WAGON DESIGN

The shuttle wagons were designed as enclosures for passenger vehicles with a minimum fire resistance of 30 minutes. The reason for this basic concept was that the journey through the tunnel takes about 30 minutes. If therefore a fire started at the time the shuttle entered the tunnel, even without all the fire detection and suppression equipment, the fire would be contained until the shuttle reached its destination. The policy of whenever possible keeping the passenger shuttle running until it reached the terminal site enables the residual incident to be dealt with in the specially designed "Emergency Siding".

Fire Shutters

The need to have a drive on and off system required unrestricted access through the entire length of the 12 wagons units (rakes) during loading and unloading. This design concept also requires each wagon to be a self-contained fire resisting enclosure for the journey and this factor made it essential to have fire shutters at the end of each wagon.

The design parameters were a challenge and in practice had to ensure minimum protrusion into the wagon, the incorporation of pass doors through which passengers could pass to evacuate in the case of fire, have a minimum of 30 minutes fire resistance and withstand the pressure régime of a shuttle passing along the tunnel. Finally the shutters had to have a minimum leakage rate in order to maintain the minimum fire extinguishing concentration of Halon within the Wagon.

Shuttle Wagon Features

The safety features in the final wagon design proposals were a combination of Eurotunnel's original proposals and those required by the Safety Authority following their consideration of the results of full scale fire tests. They include the following:

- A Series of fire detectors interfaced with
- An AFFF spray system at deck level, and
- A Halon 1301 extinguishing system.
- A central drainage system at the centre point of the deck to remove spilled fuel.
- A hydrocarbon detector system interlinked with the AFFF spray system.
- A fire and evacuation alarm system which operates automatically once fire has been detected.
- An interface with the wagon ventilation system which either closes down in the case of a fire or increases in the case of fuel spills.
- An interface with the central control on the shuttle and the shuttle patrol staff.

Design Safety Philosophy Logic

The design safety logic was based on the fact that stationary cars with their engines switched off are safe and are ten times less likely to be involved in fire than when being driven. Cars and their passengers in a wagon protected by a sophisticated detection and suppression system for a short journey of 30 minutes were not being placed at risk. However the Safety Authority required each of the design assumptions to be proven to their satisfaction(3)-(8) inclusive.

Fuel Spills

One of the potentially most serious, but unlikely dangers was a leak of petrol and this was counteracted by

- Having a central drainage system which would ensure leaks were drained away to an underfloor tank thus minimising the potential fire size.
- Incorporating hydrocarbon vapour detectors which would identify a fuel leak before reaching a dangerous level.
- The detection of a threshold level of vapour would trigger the AFFF spray system installed at floor level and this would prevent further vapour formation in the wagon, thus minimising the possibility of a fire.
- The ventilation system increased its output to lower vapour levels.

Fires

The fire detection system was a combination of ionic detectors, flame detectors and opacimeters measuring smoke density. These were capable (in conjunction with the vapour detector mentioned earlier) of assessing the environmental conditions and discharging Halon 1301 if the fire reached a potentially dangerous level.

The fire detection system was integrated with other equipment as outlined previously (Shuttle Wagon Features).

THE USE OF HALON 1301

When the design phase was commenced in 1987/8 there was a strong reaction against the use of Halon 1301 in an area where members of the public were present. The concept did not sit comfortably and a programme of work was commenced to prove:

- Halon 1301 was the most effective fire extinguishing agent.
- There was no other agent available which was as effective on fires and had relatively no toxicological properties at low concentrations or limited in decomposition products following its use on fires.
- Halon 1301 could be used at low concentrations without any short or long-term ill effects on passengers.
- The decomposition products of the fire or Halon 1301 in the fire were safe for passengers in the short time they were evacuating from a wagon on fire.
- Halon discharge would not seriously impair visibility.
- The noise of a Halon discharge could be reduced to a tolerable level.

While the above parameters dealt with the use of Halon on a fire there were additional engineering parameters which also needed to be addressed:

- The concentration of Halon had to be maintained. This involved assessing any leaks that took place through the shutter pass doors during evacuation and subsequently because of leakage from the wagon itself, due to porosity and aerodynamic farces.
- Weight constraints meant that the storage and discharge systems had to be as light as possible.
- The drive-through dimension parameters of the wagons meant that storage had to be considered on the underside of the wagon. The resmcted space under the floor of the wagon was limited and vertical storage almost impossible to achieve.
- The temperature variations 25 °C in the tunnel and sub zero freezing conditions in winter had to be considered.

In addition to the items at 5.1 - 5.10 there were an additional range of classical safety considerations:

- Proving Halon was effective on all types of fire - fuel spill, engine fires, passenger compartment fiis, luggage compartment etc.
- Designing in a reserve Halon "shot" in case of failure of the primary system or a need to "top up" the first Halon discharge.
- The need to have a manual operation.
- Designing the software to ensure the interfaces between each of the safety and engineering systems worked effectively.

THE REASON FOR INCLUDING THIS COMPREHENSIVE LIST IS TO SHOW WHY EUROTUNNEL HAS HAD TO INCORPORATE SOME OF THESE FACTORS INTO ITS HALON ALTERNATIVES SPECIFICATION.

TEST AND RESEARCH PROGRAMME

The tests and research programme for any aspect of Emtunnel design was discussed with the Channel Tunnel Safety Authority (SA) before its implementation. SA representatives and their advisors were present at the tests and they were supplied with a final report and experimental data for consideration before making their comments known.

For sound commercial reasons, the **data** has not been made public by Eurotunnel until that part of the design process has been completed and approved. There are some of the safety considerations which have yet to be fmalised and as a consequence, considerable **areas** of research have not been released to the public. However confidential briefing sessions have been given to professional organisations and this has enabled them to endorse much of the safety logic and design parameters chosen.

The parts **of** the research programme which are pertinent to Halon are as follows

- Considerations of toxicological aspects of Halon 1301 and their effect on the general public (young, old, healthy and infirm).
- The miscibility of Halon discharges in shuttle wagons with the ventilation system turned off.
- A range of fire tests to prove:
  - -- Effectiveness of Halon **1301** on all types of fire
  - -- The decomposition products of the fire
  - -- Decomposition products of Halon on vehicle fires
  - -- Rate of development of fires and effectiveness of fire detection systems
  - -- No spread of fire between vehicles
- **A** range of evacuation tests to ascertain
  - -- the time taken for passengers to evacuate
  - -- behavioural patterns and reaction to evacuation alarms
  - -- the pass door opening and closing pattern to assess Halon loss
- Halon discharge noise levels
- Any misting or fogging of the Halon discharge which occurred in temperature and humidity conditions *similar* to those experienced in the tunnel system.

TEST RESULTS AND CRITERIAL LEVELS

Before the tests and research was commenced it was necessary to consider the acceptable levels of the range of criteria that were being measured. Various nationally accepted levels were considered and particular emphasis was given to standards which were interlinked with Health and Safety at Work regulations. In some cases no national or international criteria were available and in those cases a well argued set of proposals had to be produced.

Halon Concentration

The percentage of Halon used had to satisfy a number of criteria. Firstly it had to be sufficiently high to extinguish fires rapidly, secondly it had to be low enough to have no effect on passengers and thirdly the percentage chosen had to be satisfactory for the minimum and maximum vehicle capacity of the wagon.

The most difficult aspect was the medical consideration and Professor Dayan(11) was engaged to examine the case. The S.A. concluded that it would be safe to allow passengers to remain in a 6% concentration of Halon for up to 10 minutes. As the evacuation times of a complete wagon was rarely in excess of 3 minutes this gave a sufficient margin for any unusual circumstances.

As 6% and lower concentrations were proved to be effective on fires there was sufficient leeway to take into account the loss through pass doors during evacuation of passengers and subsequent leakage through the wagon.

Effectiveness on Fires

The full scale tests involving both cars and coaches were conducted in three sets of tests. In these tests the complete range of types of fire were used; fires in passenger compartments, in baggage holds and boots, leaks of petrol, engine fires etc.

The results were very good and in all but the luggage hold the fire was extinguished in under 20 seconds. In the luggage hold fire, the rate of development was slow and the Halon discharged controlled but did not extinguish the fire due to this type of fire being deep-seated and to the difficulty of Halon reaching the relatively well sealed compartment.

As a result of rapid detection and suppression of the test fires no spread between cars occurred even when the suppression was purposely delayed.

Toxic products from fires

The toxic products from the test fires must be considered by examining those that were caused by the fire and those which were the decomposition products of the suppressant gas Halon 1301 in the fire.

It was therefore decided to test for the levels of Oxygen depletion, Carbon Monoxide, Carbon Dioxide, Oxides of Nitrogen, Hydrogen Chloride, Hydrogen Cyanide, Sulphur Dioxide and Flourine and Bromine acid gases as a result of the use of Halon. Additionally ET tested for acroline as representative of irritant gases.

It was necessary to assess the levels in various parts of the wagon of the toxic gases which would be considered as acceptable for the evacuation phase and after considering a wide range of standards it was decided to adopt the following parameters - over a 5-minute period.

Oxygen not less than	10%
Carbon Dioxide	6%
Carbon Monoxide	5000 ppm
Hydrogen Chloride	200 ppm
Hydrogen Bromide	50 ppm
Hydrogen Flouride	20 ppm
Oxides of Nitrogen	80 ppm
Hydrogen Cyanide	120 ppm
Sulphur Dioxide	50 ppm

Although not of direct application for consideration in this paper smoke density and air temperatures were also considered.

Measurements were taken for the pre-fire phase, ignition until Halon discharge, immediate post Halon discharge and then subsequently.

The test results were satisfactory and the toxic gases were below the level determined safe for passenger evacuation. Even without respiratory protection passengers who were unable to exit the affected wagon would not be faced with a life-threatening environment for the duration of the journey.

Miscibility

A further factor that had to be examined was the mixing of Halon in the air in order to ensure that; the mixing was complete, there were no pockets of Halon in which there was a higher concentration likely to be a danger to passengers and the Halon *air* mixture distributed itself in areas such as the inside of coaches where fires could start.

Prior to the first full size fire tests, scale model miscibility tests were conducted at the Institute of Fluid Mechanics at Marseilles, France. The results included a simulation of the pressure régime, leakage from the shuttle wagon, a fire and the evacuation sequence of opening and closing pass doors.

The results proved that complete mixing did occur but also indicated that coach doors, roof vents and car windows needed to be open in order to ensure the Halon air mixture enters the coach and car passenger areas.

Noise Levels and Fogging

The effect of a high level of noise on passengers in the stress conditions of a fire were identified as a parameter which needed consideration. In addition to the noise the possibility of Halon affecting the visibility of the wagon criteria also had to be assessed.

Noise levels in the tests reached an average of 117 Decibels and as a result, studies are being carried out to ascertain if modifications are needed to reduce the level.

The effect of the Halon discharge on visibility was considered to be well within the obscuration that was acceptable in fire conditions i.e., 0.1 optical density which is an equivalent of 10 metre visibility.

Effect of Halon on equipment and co

The use of a Halon system on a fire may have consequential effects on equipment and components in the wagon, particularly electrical equipment. It will be necessary to carry out a thorough check of all the components before the wagon is put back into commission.

HALON ALTERNATIVE CHARACTERISTICS

In 1991 the Department of the Environment commissioned C.S. Todd Associates to compile a report on the use of Halon in the U.K.(10). This report was considered by the U.K. government in early 1992 and noted the recommendations concerning Eurotunnel being included in the list of "Essential Uses". Eurotunnel considered the report but did not change its policy of looking for a suitable alternative. The following paragraphs indicate the criteria which Eurotunnel may need to incorporate in order to continue to satisfy the Safety Authority.

Ozone Depletion and Global Warming factors

Any replacement will need to conform to the standards accepted for Ozone depletion and global warming.

Effectiveness on Fires

The safe conditions within an ET passenger shuttle depends on a set of interlinking detection, suppression and evacuation equipment of which the Halon 1301 gas plays a fundamental part. Any replacement must exhibit very similar fire extinction properties.

Toxicological Consideration

The extensive tests and convincing evidence which has had to be compiled to permit the use of Halon 1301 will need to be applied to any Halon Alternatives which are proposed. The percentage required for extinction will also have to be safe for passengers who are evacuating from a fire and the 10 minute exposure criteria will be a good guide as a standard.

The more problematical aspect is testing the alternatives on fires because each application will present fires of differing development characteristics and intensities. The cost of proving the Halon alternatives as satisfactory from a decomposition in fire aspect will be astronomical if an international standard cannot be formulated. The standards adopted currently for the ET project may give a good guide to the range of parameter that will have to be considered.

CHARACTERISTICS IN 8.1 - 8.3 ARE ESSENTIAL CRITERIA AND THOSE LISTED BELOW CONSIDER OTHER ENGINEERING AND DESIGN CHARACTERISTICS

Discharge Characteristics

The discharge characteristic regarding miscibility noise levels and fogging need to be considered and lie within acceptable parameters.

Weight Factors

In the ET application. weight is an important consideration. There are two elements to the weight problem. The first is the weight of the extinguishing media in which the percentage of gas required for fire extinction and the molecular weights are of paramount importance. The second factor concerns the total weight of the storage cylinders, pipe work and discharge system. The total weight of the replacement gas and system must not be greater than the proposed Halon installation.

The importance of this factor is soon recognised once a calculation is made of some of the Halon Alternatives which are being considered.

Storage criteria

The restriction of space on the shuttles and the need to install cylinders in a position which is fairly near horizontal and under the wagon floor must be considered to ensure replacement storage conditions will permit this configuration.

Temporary Variations

Temperatures are likely to vary from 30 °C to sub zero temperatures and the effect of these variations on the Halon Alternative may identify specific problem of temperature maintenance, pipework insulation, and requirements for discharge gases. All or any of these factors could affect the weight or reliability of the total system.

Reliability and maintainability

In the specific conditions applying to the ET case a great deal of emphasis was placed on the method of actually discharging the gas from the storage cylinders and having a reserve cylinder to ensure that failure on the primary unit could be rectified by utilising the reserve part of the installation. The reserve capacity also permitted a second injection into the fire if it was necessary.

The maintainability of the system must be considered both from the day-to-day routine maintenance as well as easy rectification of faults in order to minimise down time.

Effects of Halon replacement on Wagon Components

The effect of the alternative suppression media on the equipment and internal component of the wagon must be considered. If the existing pipework is not suitable for the Halon replacement, the estimated period for rem-fitting the wagons with the replacement system is an important commercial factor.

CONCLUSIONS

While elements of the criteria listed in this paper are found in other fire engineering applications, their combination sets a rigorous set of demands which must be met in any effective Halon alternative.

It is hoped that the discussion of the safety demands placed on safety aspects of the Channel Tunnel project by the regulatory body - the Safety Authority - will illustrate the extent of research and studies undertaken by ET and will give a guide to any manufacturers of Halon Alternatives, the criteria that must be met in the Eurotunnel Project

ANNEXE I

DOCUMENT REFERENCE LIST FOR HALON ALTERNATIVES CONFERENCE PAPER

No.	AUTHOR	TITLE	SOURCE
1.	Cmnd. 9745	The Channel Tunnel Treaty Canterbury, 12 February 1986	H.M.S.O.
2.	Cmnd. 9769	The Channel Fixed Link - Concession Agreement - April 1986	H.M.S.O.
3.	Channel Tunnel Safety Authority	Non-Segregation of Drivers and Passengers from their Vehicles - March 1990	H.M.S.O.
4.	Channel Tunnel	Annual Report 1988 - 89 Safety Authority	H.M.S.O.
5.	Channel Tunnel Safety Authority	Annual Report 1989 - 90	H.M.S.O.
6.	Channel Tunnel Safety Authority	Annual Report 1990 - 91	H.M.S.O.
7.	House of Commons Home Affairs committee	First Report - Fire Safety and Policing of the Channel Tunnel - Volume I 17 December 1991	H.M.S.O.
8.	House of Commons Home Affairs Committee	First Report - Fire Safety and Policing of the Channel Tunnel - Volume II 17 December 1991	H.M.S.O.
9.	Eurotunnel	The Channel Tunnel - A 21st Century Transport System - 1990	Eurotunnel
10.	C.S. Todd & Associates	The Use of Halons in the United Kingdom and the Scope for Substitution	H.M.S.O.
11.	Prof. A.D. Dayan	Professor of Toxicology St. Bartholomews Hospital Medical College, University of London	