Health and Safety

Executive

Using ATEX and industry best practice to manage the risk from hydrogen in conventional and nuclear workplaces

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Presentation overview

- The ATEX Directives
- Risk management strategy
- Applying the risk control hierarchy
- Managing the risk from H_2 in the nuclear sector
- Sources of advice and guidance
- Questions

ATEX directives

- ATEX 95 (94/9/EC) – product directive
- ATEX 137 (1999/92/EC) – user directive

ATEX User Directive philosophy

- Are flammable substances present?
- Can sufficient dispersal occur to give an explosive mixture?
- Is the formation of an explosive mixture possible?
- Is the formation of explosive atmospheres reliably prevented?

Risk management strategy

- Recognise, understand and prioritize the hazards
- Assess the risks, i.e.
- Identify those scenarios that generate the big risks
- Demonstrate you have a plan to manage the risks
- Show your plan follows a suitable (ATEX) hierarchy
- Don’t forget the boring, old fashioned risks!

ATEX risk management hierarchy

HSE

- Eliminate the risk, e.g. replace the dangerous substances
- Control the risk
  - Reduce the inventory of dangerous substances
  - Avoid/control releases
  - Prevent flammable atmospheres forming
  - Avoid ignition sources
  - Control access
- Mitigate the risk
  - Reduce the number of people at risk
  - Provide explosion relief, suppression or containment

Strategies for avoiding flammable mixtures

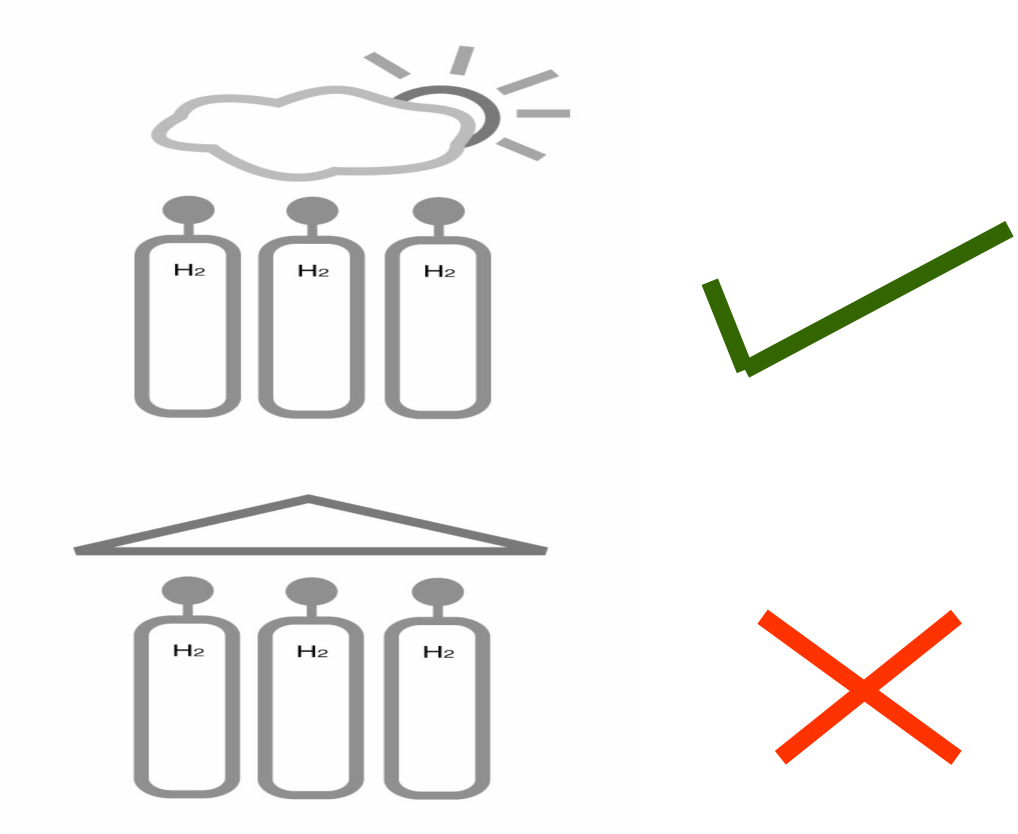
- Suitable containment
- Appropriate location/orientation of equipment
- Effective ventilation

Avoiding the formation of flammable mixtures

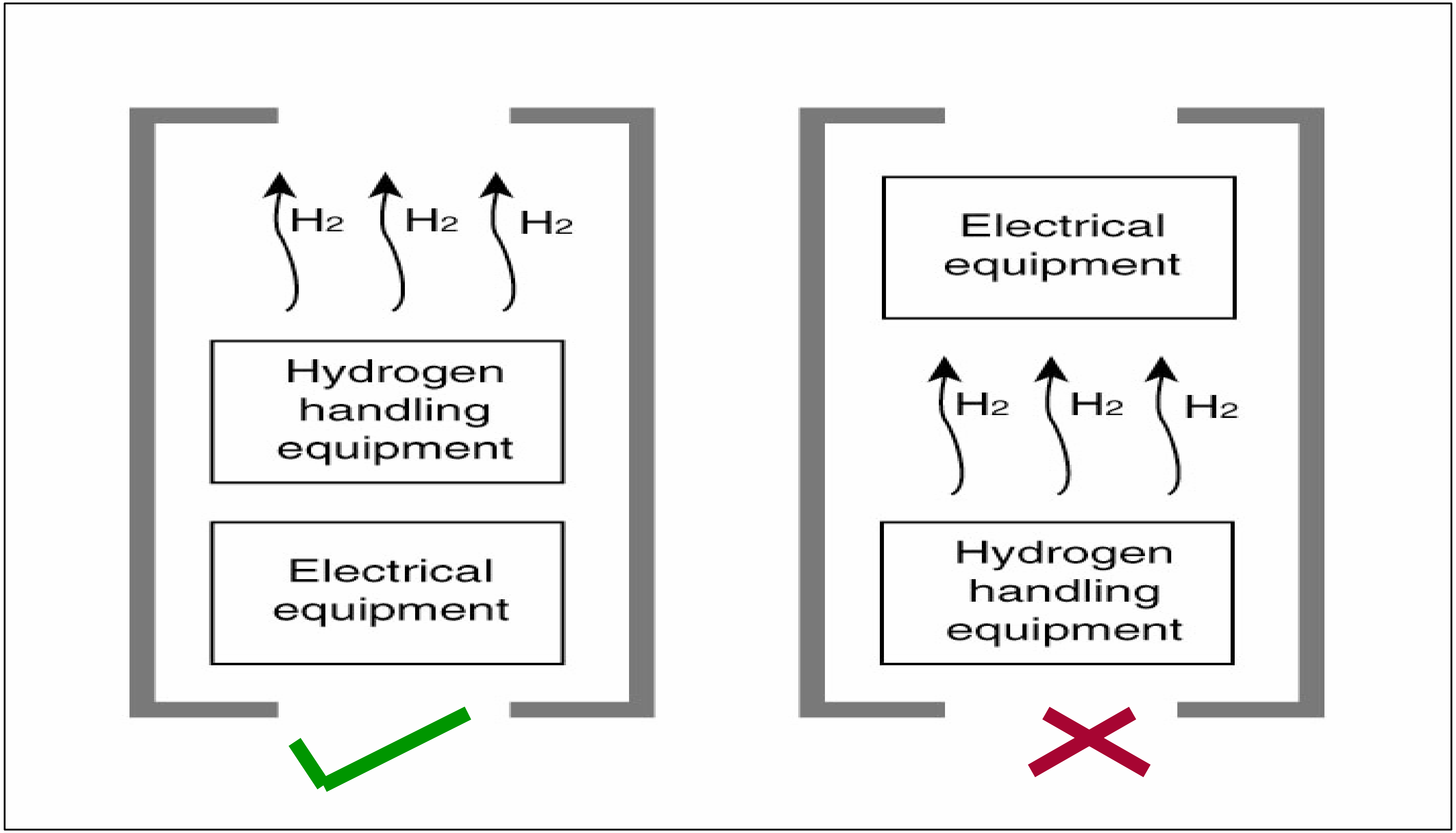
- Containment :
  - Design to an appropriate standard
  - Fabricate using suitable technicians
  - Maintain appropriately
  - Review performance

Location, location, location

- Locate H_2 storage/handling equipment outside
- Beware of ceilings, covers, canopies and roofs



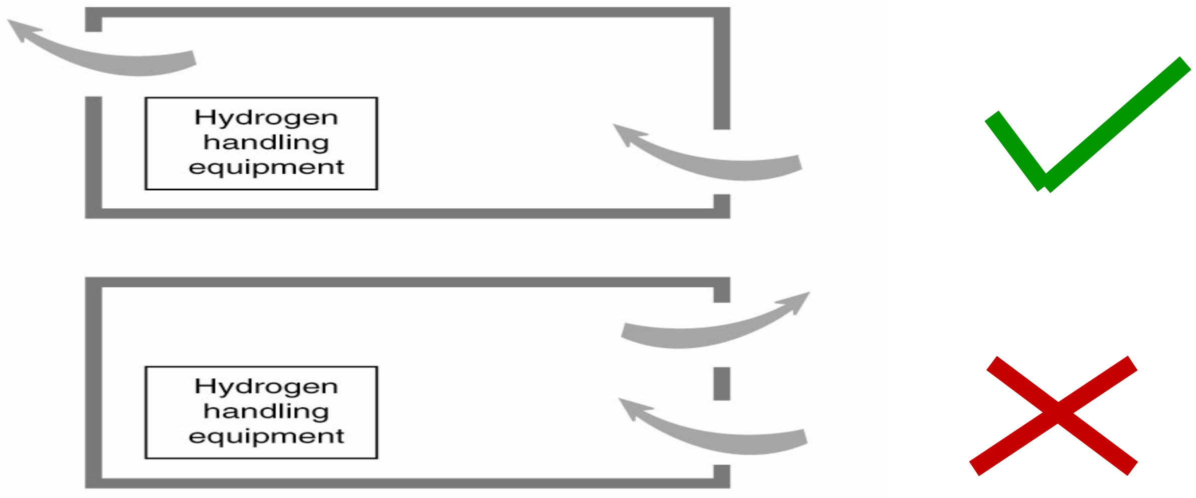
Equipment orientation



Let the buoyancy of hydrogen work for you!

Effective ventilation

- Estimate the maximum foreseeable leak rate (MFLR)
- Provide adequate high and low level ventilation
- Ventilation must dilute MFLR below 10% LEL
- Use CFD for complex ventilation requirements



Avoid sources of ignition

- Carry out a hazardous area classification
- Aim to locate electrics in non-hazardous zones
- Use appropriate electrics in hazardous zones
- Control hot work, smoking, mobile phones etc
- Use bonding, earthing and anti-static clothing
- Consider protection against lightning

Security and access control

- Security provisions should be appropriate to location
- Appropriate balance between ventilation & security
- Perception of Regulator is likely to exceed the real risk
- “Precautionary principle” should be used

Explosion mitigation

- Relief
- Containment
- Suppression

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Managing the risk from hydrogen in nuclear workplaces

The plants

Large plants with significant inventories of material
Variety of conditions
Variable operating histories

Sources Of Hydrogen

Radiolysis :-

Radiation + $H_2O \rightarrow H_2 + \frac{1}{2}O_2$

Reactive Metals:- typically Corrosion

$M + xH_2O \rightarrow M(OH)_x + xH_2$

Are they really a problem?

Radiolysis - Brunsbuettel BWR

- Occurred 14th Dec 2001
- Investigated February 2002
- Reactor pressure vessel spray head pipeline within secondary containment
- 100 mm diameter pipe.

Radiolysis - Brunsbuettel BWR

3m long section lost.
Plant out of action for 12 months.
No activity released.

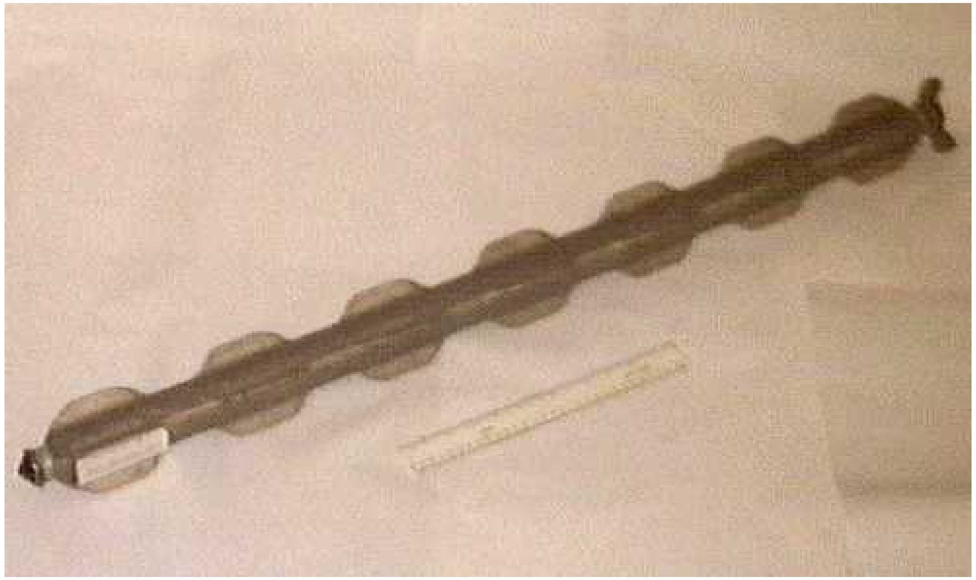
Corrosion issues

- Reactive metals are an issue

(Mg, Al, U, Na and K)

- The most significant of these is Mg.
- Mg is a significant component of Magnox fuel cladding.

Corrosion Issues



Dungeness Magnox

Bradwell Magnox

Corrosion issues

Magnox corrodes

$Mg + 2\ H_2O \rightarrow Mg(OH)_2 + H_2 + energy$

Corrosion issues

Active
Sludge

Corrosion Issues

Energy released by corrosion in the form of heat.

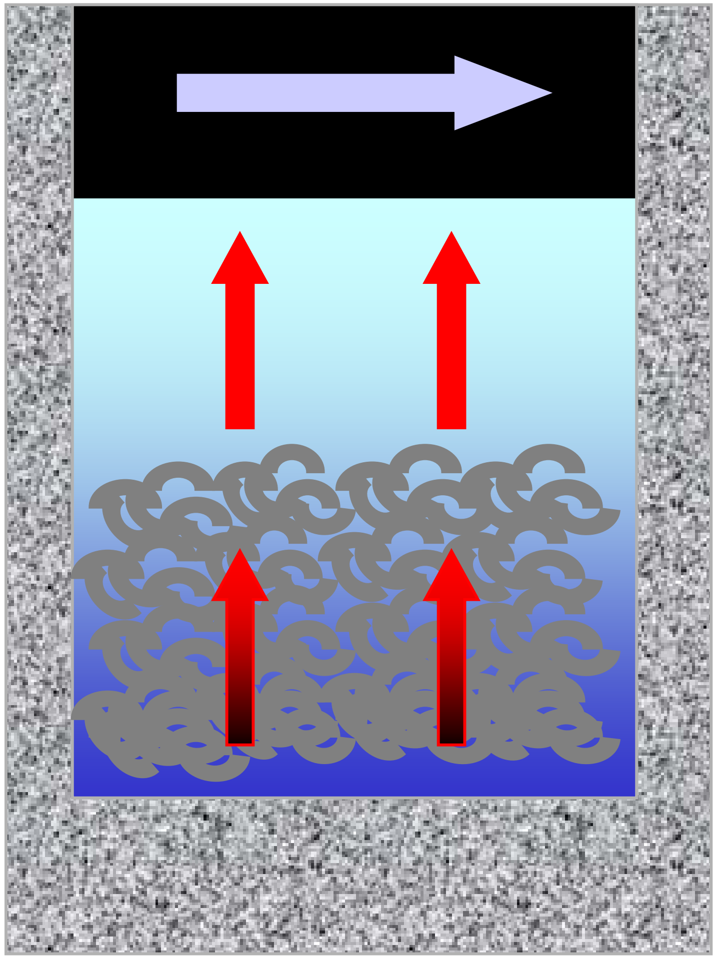
Corrosion of Magnox is temperature dependant – Rate doubles per 8-10°C increase above 22°C.

Magnox is a good conductor of heat away from corrosion point.

Magnesium Hydroxide is a good insulator.

Hotspots possible in the waste. - EXCURSIONS!

Excursions – Normal corrosion

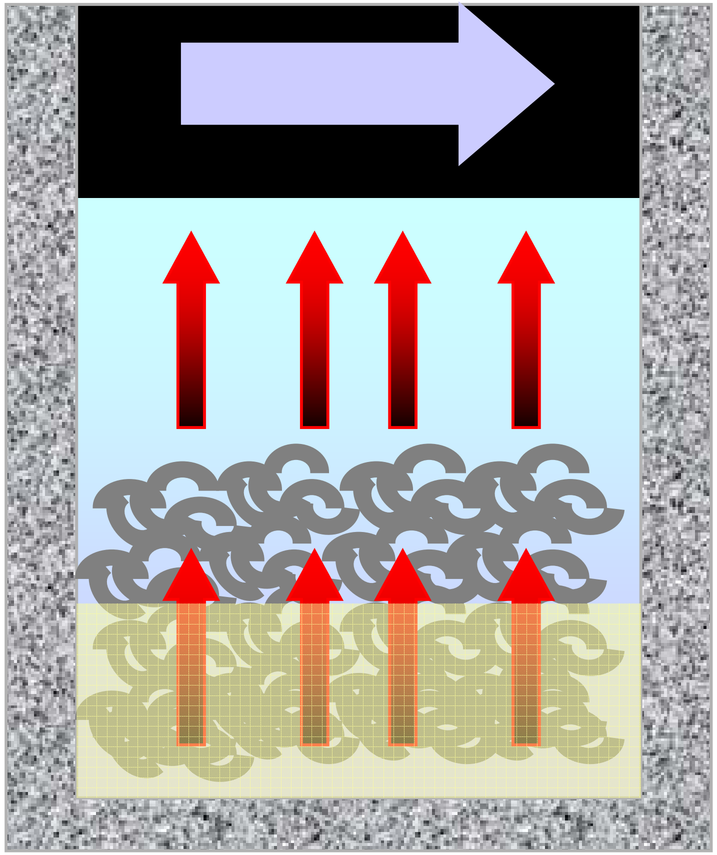


Heat removed by evaporation

Heat dissipated through cover water

Reaction produces heat

Excursions – corrosion progresses

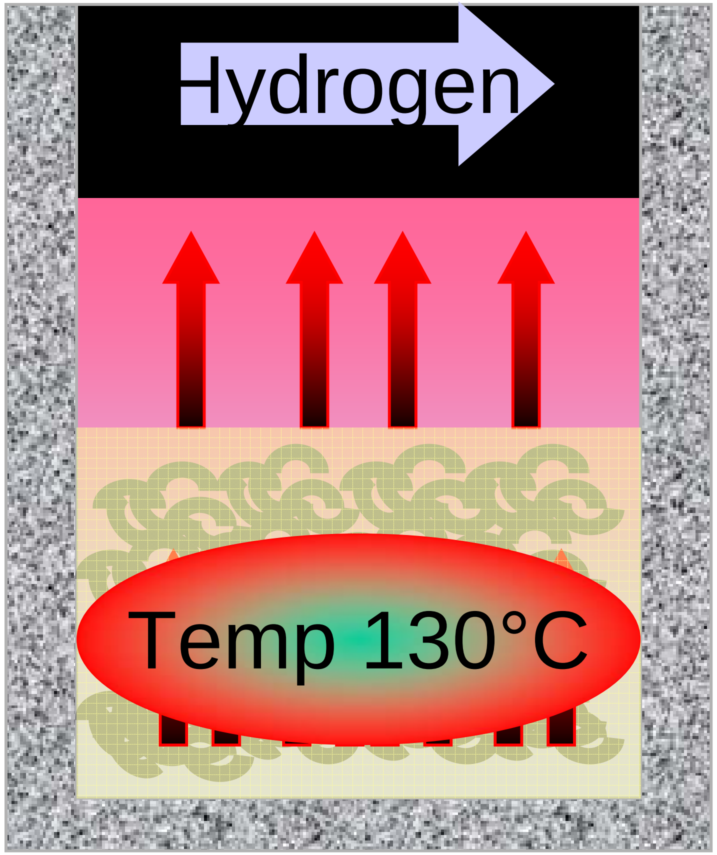


Heat output rises

Temperature rises

Sludge build up restricts heat loss

Excusions – the limit



High hydrogen concentration

Water reaches boiling point at depth

Sludge builds up further. Heat loss less than heat generated

Managing the issues

- Set Operational and Design Limits

Typically:

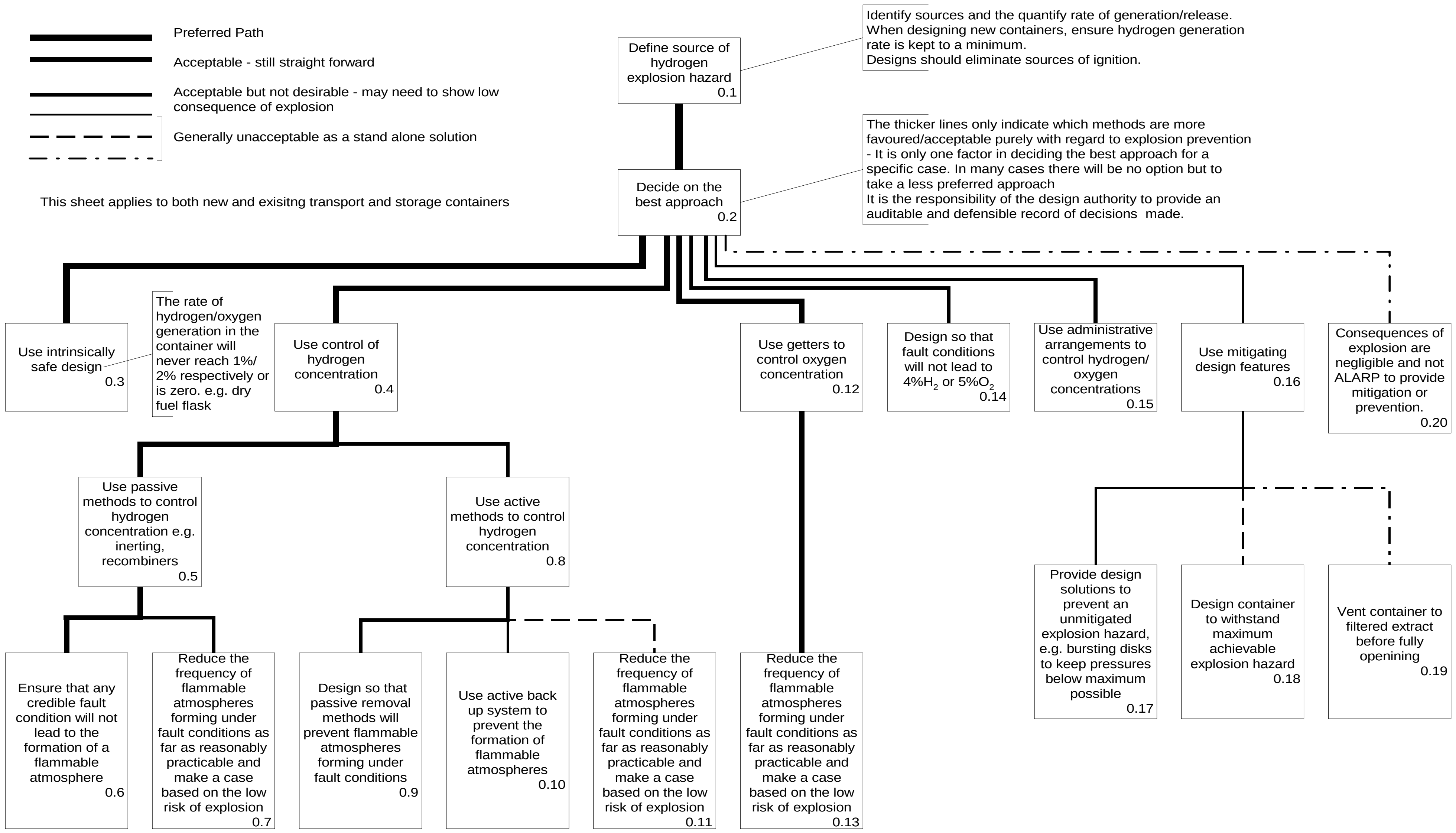
< 1% H_2 Normal Operations

< 4% H_2 Fault Conditions

< 2% limiting O_2

- Manage using a suitable hierarchy and Multiple Layers of Protection

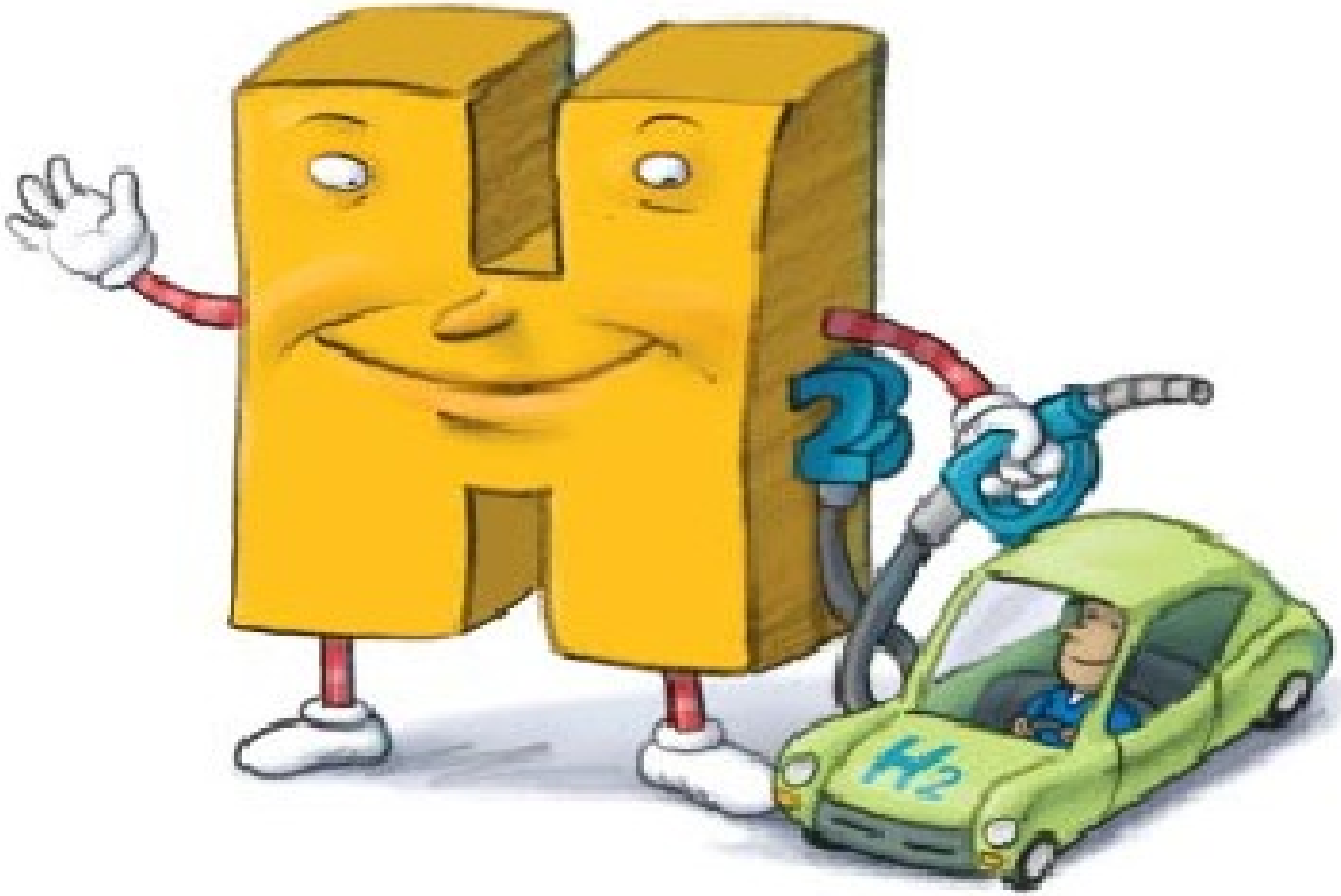
Managing the Issues



Information and guidance

- HSG 243: Fuel cells; understand the hazards, control the risks
- European Industrial Gases Assoc. (IGC Doc 15/05E)
- NASA (Safety std for hydrogen & hydrogen systems)
- ISO/DPAS 15916: Safety of hydrogen systems
- NFPA 50A: Standard for gaseous hydrogen systems
- ATEX (supply) Regs; SI192,1996
- HSE DSEAR ACOPs (L134-138 inc)
- BS EN 60079 Electrical app. for explosive gas atms

That’s all folks!



Questions?

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Peter Donnelly

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- Jem Sullivan: hydrogen man cartoon
- Fuel Cells Canada: selected images
- The Sellafield Ltd Hydrogen Technical Guide
- Mr P Vesey

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Workshop

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Programme

Each team should:

- Select an assignment from those available
- Prepare a 10 - 15 minute PowerPoint presentation
- Ensure that at least 3 presenters are involved

Workshop assignments (1)

Two types of assignment to chose from:

1. Design proposals

   Analyse the brief

   Identify the key safety challenges

   Assess the risks

   Prepare a risk management strategy

   Produce a design

   Identify the operational needs to underpin the design

   Prepare the presentation

Workshop assignments (2)

2. Assessment of an installation

Analyse the description of the installation

Identify the key issues of the design, location etc

Consider whether ‘good practice’ has been used

Assess the risks to safety from the installation

Identify what changes you would suggest/demand

Prepare the presentation

Design proposal assignment 1

HSE

Hydrogen powered canal boat

Commercial sight-seeing canal boat

The client would like the design to include:

- The H_2 fuel cell should be visible to the passengers
- A large all-weather sight-seeing salon
- Facilities for providing light refreshments
- Infrequent refuelling
- City/town centre overnight berthing

Design proposal assignment 2

The installation will provide domestic electricity base load (5 kW) and will include:

- Wind powered electricity generator
- Hydrogen storage
- <u>Underground</u> fuel cell, electrolyser, controls etc.

Design proposal assignment 3

A store for reactive metal radioactive Waste to include the following features:

- Store filled relatively quickly
- Waste retained for a significant time
- Waste to be retrieved for further processing
- Material must be handled remotely
- Issues with environmental discharges

Installation assessment assignment

UPS system based on hydrogen fuel:

- Fuel cell and control located in large open plan office
- High pressure hydrogen storage located outside
- Hydrogen cylinders located in dedicated cabinet

DESIGN PROPOSAL ASSIGNMENTS

These assignments will provide you with the opportunity to use the technical knowledge that you have recently gained in a typical ‘real world’ situation. Each of the project briefs outlined below is based upon actual projects.

The backdrop to each of these assignments is that you, as a well respected hydrogen safety engineer, have been commissioned to propose a design that addresses the key elements of project brief. Where it is not practicable, on safety etc grounds, to fulfil all the client's desires, then the reasons why this is not possible should be identified and suitable, hopefully minor, changes should be made and the design progressed.

The descriptions of the assignment have deliberately been kept short to give you plenty of scope to exercise creativity. The most important element that the presentations of your designs should demonstrate is an understanding of how the risk associated with hydrogen projects can be influenced by intelligent design and an appreciation of when risk has been reduced to an acceptable level and when it has not.

Once you have chosen which design proposal assignment to tackle, you should:

- Analyse the brief
- Identify the key safety challenges
- Assess and prioritise the risks
- Prepare a risk management strategy
- Produce a design that fulfils the client’s requirements (where practicable)
- Identify any operational requirements necessary to underpin the design
- Prepare the presentation

(1) HYDROGEN POWERED CANAL BOAT

An environmentally conscious organisation would like to operate a hydrogen powered narrow boat to carry sight-seers along the canals of a major city.

Normally, around ten passengers will be carried each trip and these will typically last for about four hours. The boat will be operated by a crew of four.

The client would like the design to address the following key elements:

- The boat should be suitable for day/evening trips
- The H_2 fuel cell should be visible to the passengers
- A large all-weather sight-seeing salon must be provided
- Catering facilities for preparing and serving light refreshments should be included
- Refuelling should only be required once a day
- City/town centre overnight berthing

(2) HYDROGEN FUEL CELL/ELECTROLYSER INSTALLATION

A millionaire environmentalist wants to establish an integrated hydrogen project on his estate to provide the electrical power for his home. He already has a wind turbine and wants to use the surplus electricity from this to produce and store hydrogen, so that in calm conditions the stored gas can be used to generate power. Unfortunately, his wife, a keen gardener, does not want the grounds spoiled by ugly buildings. Consequently, the only way he has been able to gain her agreement is if the installation is underground.

Your design should address the following key points:

- The electrical output from the fuel cell must be at least 5 kW
- The fuel cell, electrolyser, controls etc must be underground. The implications of this requirement need to be considered in some detail and clearly explained.
- The hydrogen storage facility may be located above ground.
- The ability to accept delivery of externally produced hydrogen is not required

(3) NUCLEAR WASTE SILO

Mixed radioactive waste (including Magnesium) is to be held in a free standing concrete silo. The internal dimensions of the silo will be nominally 4 m wide, 4 m long and 10 m high. The waste when stored will be roughly 8.5 m in depth with 1 m of water cover and there should be 0.5 m air space. The waste will corrode and produce hydrogen and a partially corroded sludge.

You have been engaged as a hydrogen safety expert to advise the designers of the new silo for the storage of the radioactive waste. The new silo will be filled over a period of 2 years and will then have to store the waste for an indeterminate period, not less than 15 years, after which it will be removed for further processing.

Consider the following:

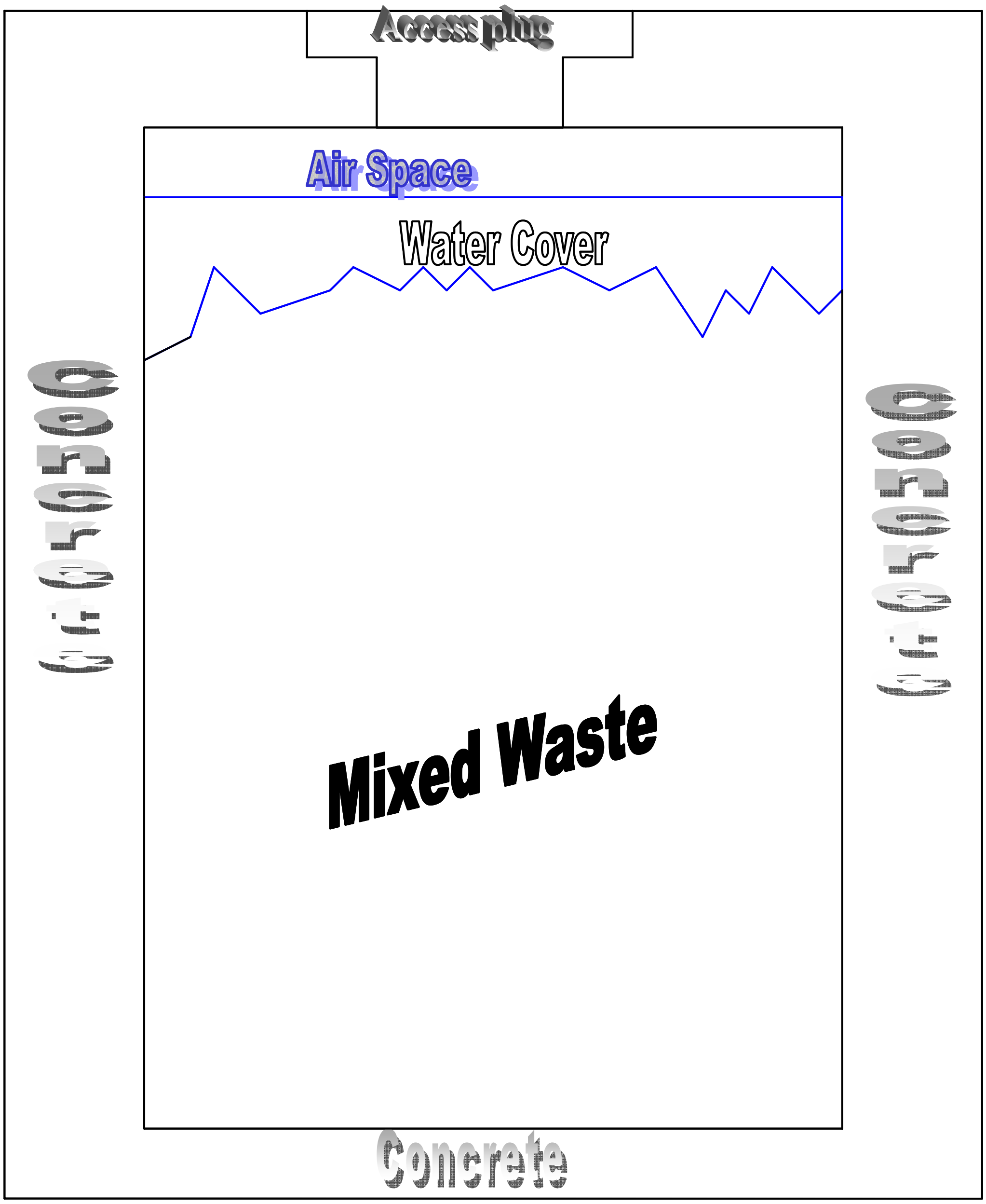
What steps would you take to address the hydrogen hazard generated from the waste if you were building the facility from new, assuming silo dimensions given above?

Given that the only significant access is through the access plug on the top of the silo, how would you go about retrieving the waste?

Points to consider are:

Operations near the waste must be carried out remotely owing to the high radiation dose consequences to personnel.

Release of activity to the environment in any form must be As Low As Reasonably Practicable and meet Best Environmental Practice.


Access plug
Air Space
Water Cover
Concrete
Concrete
Mixed Waste
Concrete

HYDROGEN INSTALLATION DESIGN REVIEW

Introduction

You are a highly regarded expert on the safe use of hydrogen. The Managing Director of a small, highly successful manufacturer of uninterruptible power supply (UPS) units has commissioned you to carry out a safety (risk) assessment of their prototype hydrogen-fuelled UPS installation. The unit is centred on a polymer electrolyte membrane (PEM) fuel cell and is capable of supplying 10-20 kWatts of electricity at 240 volts a.c.

The UPS system is designed to remain on standby, with the pipe work up to the final solenoid operated isolation valve (SOV) immediately before the fuel cell pressurised with hydrogen. When the mains electricity supply to the protected equipment, e.g. a computer network, is lost the UPS unit would automatically be brought online. The SOV in the hydrogen supply line would open and allow hydrogen into the fuel cell, which would produce electricity to ensure that the computers continue to operate without upset or interruption.

Your team's assignment is:

1. To study the description and drawings of the installation.
2. Identify the questions you need to ask the designers or duty holder in order to ensure that you have a full understanding of the installation.
3. Prepare and then give a 10-15 minute presentation to the Managing Director of the Company on the findings of your inspection. Your presentation, which should involve at least three members of the team, should cover the following issues:
    - A review of the general design of the installation
        - Good points.
        - Issues of concern, it is very important to identify your level of concern for each issue.
        - Areas where more information, consultation with peers or research is needed.
    - Recommendations, e.g. changes to the design, fabrication, location, operation etc. (Identify 'nice to have' and 'must do now!').
    - Suggested action plan for the Company.

Description of the installation

The UPS unit is located indoors, in a medium-sized ground floor open-plan office in which approximately 8 people work 9 am to 5 pm, Mondays to Fridays. The office has a suspended false ceiling, which contains approximately ten double-tube 240-volt fluorescent light fittings. One of these is conveniently located above the UPS unit and provides good illumination of the equipment.

The UPS unit is contained in a metal cabinet approximately 1.85 m high, 0.75 m wide and 0.75 m deep. The sides of the cabinet are made from sheet steel, which is perforated with many thousands of regularly spaced 2 mm holes over their full area (Fig 1). The cabinet is freestanding and is positioned about 1m from the gable end wall of the office.

The electrical and electronic components associated with converting the d.c. output of the fuel cell into usable 240 a.c. current are located in the top half of the cabinet. The fuel cell and associated hydrogen supply connections and cathode purge pipe work are situated in the lower section. A horizontal metal plate, secured to the perforated sides with four self-tapping screws, divides the upper and lower sections of the cabinet. The centre of this plate contains a 50 mm hole to which is attached the ventilation duct.

The ventilation duct runs from the cabinet to an electrically powered extraction fan, the exhaust from which is carried in 50 mm plastic pipe through the building wall to the outdoor vent. The external ventilation outlet and the cathode purge line vent are located close together at a height of approximately 1.70 m near the cylinder storage cabinet on the outside gable end of the building (Fig. 2). The gable end faces on to open ground containing several large evergreen trees, one of which is very close to the wall and provides shade to the cylinder store and the vents (Fig. 3). An electric floodlight has been fixed to the wall directly above the storage cabinet to provide illumination of the area during cylinder replacement or maintenance.

The hydrogen used by the fuel cell is stored outdoors in two K size cylinders that are located in a dedicated storage cabinet (Fig. 4) that is fixed to the gable end of the office building. The sides of the cylinder storage cabinet contain perforated ventilation panels at high and low level. The hydrogen cylinder pressure (200 barg) is reduced to 5 barg close to the cylinders and is fed to the fuel cell through metal pipes. A flexible hose is used inside the indoor office to connect the fuel cell unit to the end of the metal hydrogen supply pipe work.

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