IMCA

Information Note

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Diving Division

IMCA D 02/06

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January 2006

The Evaluation and Testing of the Environment Control of Hyperbaric Evacuation Systems

Background

In 1999, IMCA produced a protocol to provide information for its members on the thermal testing of hyperbaric evacuation systems (HESs). This was issued as information note IMCA D 24/99, with an extensive technical note, available on request, which provided the technical details for those responsible for testing and assessing HESs.

In the light of experience, the protocol was fully reviewed and updated as appropriate and issued in 2004 as information note IMCA D 09/04.

The text in D 09/04 provided revised figures for metabolic heat output from a diver to be used in the tests, which were agreed after extensive discussion on the issue.

An issue also addressed in the revised protocol was the carbon dioxide (CO_2) injection rate to be used during the 24-hour test. Initial validation testing suggested that the revised figure contained in IMCA D 09/04 was too high. IMCA subsequently sought the advice of an expert on respiratory physiology to determine whether the CO_2 injection rate proposed in IMCA D 09/04 was realistic or not. Professor Mike Tipton of Portsmouth University has now undertaken trials to obtain an estimation of the metabolic production of carbon dioxide in hyperbaric evacuation chambers. That work has now been completed and concluded that the CO_2 injection rate used in the tests should be 490 ml per diver per minute.

This new information note updates D 09/04, which has now been withdrawn.

The Testing Protocol

The International Maritime Organization (IMO) Code of Safety for Diving Systems 1995 requires that:

*An evacuation system should be provided having sufficient capacity to evacuate all divers under pressure, in the event of the ship having to be abandoned, and should be in accordance with the provisions of this Code. **

** IMO Assembly Resolution A.692 (17) "Guidelines and Specifications for Hyperbaric Evacuation Systems"*

Typically on dynamically positioned diving support vessels (DP DSVs) compliance with the requirement is through provision of a davit launched self-propelled hyperbaric lifeboat, often referred to as a SPHL, HRL or HLB. For mobile or temporary saturation diving spreads evacuation of divers under pressure may be by a specially modified hyperbaric rescue chamber (HRC), the diving bell or some other suitable means. Generically, all these systems are collectively referred to as hyperbaric evacuation systems (HES) or hyperbaric rescue systems (HRS).

IMCA has developed the attached information note (IMCA D 02/06) to address the thermal testing of hyperbaric evacuation systems. All hyperbaric evacuation systems should be designed to protect the occupants from hypothermia and hyperthermia.

Without adequate control over chamber temperature the ability of an HES to provide autonomous life support is significantly reduced in certain circumstances.

This information note has been developed to provide guidance on:

- establishing a thermal testing baseline for the HES from which extrapolations can be made for its use in different ambient conditions;
- thermal testing without the need for manned intervention;
- undertaking trials on mixed gas;
- addressing the capability of the HES to cope with the increased heat load in tropical climates;
- providing suitable equipment for accurate environmental measurement;
- addressing the duration that habitable conditions can be maintained in the event of failure of the environmental control systems;
- development of specific hyperbaric emergency response procedures.

This information note does not seek to set performance standards for an HES, but to enable accurate assessment of the integral HES environmental control system performance.

The resulting information will play a crucial part in developing emergency response plans following evacuation of divers using the HES including, where necessary, the early recovery of the HES to a safe place and connection to life support systems capable of effectively controlling a chamber environment.

Status of Information Note

This information note updates the previous information notes (IMCA D 24/99 and D 09/04) on the evaluation and testing of the environmental control of hyperbaric evacuation systems. Since some of the information contained in this note is new to members, it is not realistic for IMCA members to be able to meet the requirements set out in this note immediately. The intention is that IMCA members can use the information in the attached information note (IMCA D 02/06) and accompanying technical note to help them develop appropriate test procedures for testing their hyperbaric evacuation systems and to subsequently undertake these tests during a two-year period from the issue of this note. As the thermal evaluation of a hyperbaric evacuation system is complex, feedback on the applicability of these documents is sought by IMCA so that any necessary changes or improvements can be made.

The International Marine Contractors Association

Information Note

The Evaluation and Testing of the Environmental Control of Hyperbaric Evacuation Systems

IMCA D 02/06
January 2006

The International Marine Contractors Association (IMCA) is the international trade association representing offshore, marine and underwater engineering companies.

IMCA promotes improvements in quality, health, safety, environmental and technical standards through the publication of information notes, codes of practice and by other appropriate means.

Members are self-regulating through the adoption of IMCA guidelines as appropriate. They commit to act as responsible members by following relevant guidelines and being willing to be audited against compliance with them by their clients.

There are two core activities that relate to all members:

- Safety, Environment & Legislation
- Training, Certification & Personnel Competence

The Association is organised through four distinct divisions, each covering a specific area of members' interests: Diving, Marine, Offshore Survey, Remote Systems & ROV.

There are also four regional sections which facilitate work on issues affecting members in their local geographic area – Americas Deepwater, Asia-Pacific, Europe & Africa and Middle East & India.

IMCA D 02/06

This information note and associated technical note were originally developed were subsequently been updated for IMCA under the direction of its Diving Division Management Committee by Geoffrey Crockford. The information note has been updated following work undertaken by Prof. Mike Tipton of Portsmouth University.

These documents supersede information notes IMCA D 24/99 and D 09/04 and the associated technical notes, which are now withdrawn.

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The Evaluation and Testing of the Environmental Control of Hyperbaric Evacuation Systems

IMCA D 02/06 – January 2006

1 Introduction

This Information Note is for those involved in the testing of hyperbaric evacuation systems (HESs) such as hyperbaric lifeboats (HLB) and hyperbaric rescue chambers (HRC). It is based on the IMCA technical note '*The Evaluation and Testing of the Environmental Control of Hyperbaric Evacuation Systems*', which accompanies this information note issue dated January 2006 (ref. 1), which should be referred to for details and background by those responsible for testing and assessing the HES.

Information note IMCA D 09/04, produced in September 2004, revised IMCA's previous test protocol, updating it in light of experience and providing additional guidance on how to evaluate the HES and undertake the environmental assessment of the system. The revised text provided revised figures for the metabolic heat output from a diver to be used in the tests, which were agreed after much discussion on the issue.

An issue also addressed in the revised protocol was the carbon dioxide (CO_2) injection rate to be used during the 24 hour test. Initial validation testing suggested that the revised figure contained in IMCA D 09/04 was too high. IMCA subsequently sought the advice of an expert on respiratory physiology to determine whether the CO_2 injection rate proposed in IMCA D 09/04 was realistic or not. Prof Mike Tipton of Portsmouth University has now undertaken trials to obtain an estimation of the metabolic production of carbon dioxide in hyperbaric evacuation chambers. This work has now been completed and concluded that the CO_2 injection rate used in the tests should be 490 ml per diver per minute.

To demonstrate that an HES can effectively maintain the hyperbaric chamber within temperature guidelines at the extremes of thermal climate and numbers of divers, the following tests have been developed. The tests can be conducted onboard a ship or on land unless being in the water is required for engineering reasons, e.g. cooling water. The climatic conditions and the thermal load on the HES at the time of the test may not simulate fully the extreme conditions that may be met on location. Therefore, the tests need to provide adequate information on the maximum rate at which heat can be supplied to or extracted from the chamber by the heating and cooling systems. The tests should be under the supervision of somebody with adequate knowledge of thermal environment measurement and who is sufficiently experienced to assess the risks to the diver's safety posed by the thermal environments that will be met at the diver's location. The wide range of HES designs will mean that the test supervisor may have to adapt procedures to the HES being tested. The test supervisor should consult appropriate experts if in any doubt about test procedures and risk evaluation.

The HES should be tested using it's inbuilt life support system as the basic test. This should provide sufficient data to ensure that any back-up life support package (LSP) has sufficient capacity to maintain HSE environment. In the case of a system which has no built –in life support system, then it should be tested using the proposed LSP. The protocol is intended, in part, to build up knowledge of the thermal characteristics of the HES, and from this any proposed LSP can be assessed for suitability.

The tests outlined in this information note provide the minimal core information required for HES assessment.

Prior to conducting the thermal evaluation and tests the hyperbaric evacuation system should be subjected to an engineering assessment (see the IMCA technical note). This is to ensure the HES is in good repair and well maintained and that the heating and cooling systems have been assessed as having the required capacity for the intended climatic zone. The assessment should also have shown that the control systems can maintain the chamber temperature at a given target value.

It may be necessary to use a specialist company to set up the measuring and recording equipment (see Annex 5).

As thermal testing is complex, it needs to be carefully planned and proper preparation is essential prior to the test proceeding. The HES should also have received an ergonomic assessment and operational problems identified and rectified (see section 4 of the technical note). Any defects relating to engineering, ergonomics and operational aspects of environmental control can then be made good prior to testing the HES.

The following checklist is to confirm that the engineering assessment has addressed the main relevant aspects of environmental control:

Checklist – confirm that:

- all mechanical systems, e.g. mechanical transmissions, are in good repair and have been maintained;
- all electrical systems have been checked and maintained, e.g. lighting, battery charging;

- the meters, control panel displays, lights, glass and reflectors are clean;
- labelling and panel displays are clean and clear;
- control valves are accessible, labelled and easy to operate;
- access hatches and latches are in good repair and easy to operate;
- all closed systems/cold pipe work, both feed and return, have been insulated with closed cell material to minimise environmental heat load on chilling units;
- all pumps have been checked and are in good working order;
- all metering is effective and accurate e.g. flow rates, voltages etc;
- the chamber thermometer, to be used during the testing, reads gas temperature and is accurate to ± 0.2°C;
- the chamber humidity sensor is working;
- the CO_2 analyser reads mixed chamber gas CO_2;
- the gas movement in the chamber has been checked and chamber fans are adequate;
- the design of the scrubbers has been checked and gas flow determined at pressure either from technical data or by direct measurements;
- the design of the heat exchangers has been checked for condensation drainage and gas volume flow;
- the cold gas is released, if possible, high in the chamber and mixed with chamber gas so that no thermal stratification occurs;
- fittings, seat covers etc are in place;
- the chamber temperature can be controlled by the cooling and heating system to ± 0.5°C;
- the estimated cooling and heating capacity is more than the predicted capacity required;
- if sea water is used for cooling, the system must be able to work with spare capacity available in the climatic zone in which it is going to be used;
- the data from the baseline test should show that the chamber's thermal insulation is suitable for the climatic zone in which it is to be used.

2 Basic Measurements Required

The testing of a hyperbaric evacuation system is required to last 24 hours. The 24 hour test period is intended to check the operational performance of the HES during the daily extremes in environmental conditions which may be encountered during that period. During the 24 hour period, the individual tests can be conducted. In any individual test, holding the conditions constant for ninety minutes demonstrates that the engineering and control systems are adequate. The climatic conditions in which the test takes place and those in which the HES is to be used should be stated in the test report.

The following core measurements need to be made.

1 The climatic conditions during the test - wind speed, air temperature, cloud cover, black globe temperature, relative or absolute humidity or the ventilated wet bulb temperature, i.e. psychrometric wet bulb. Measurements are to be made at least every hour (see figure 1).

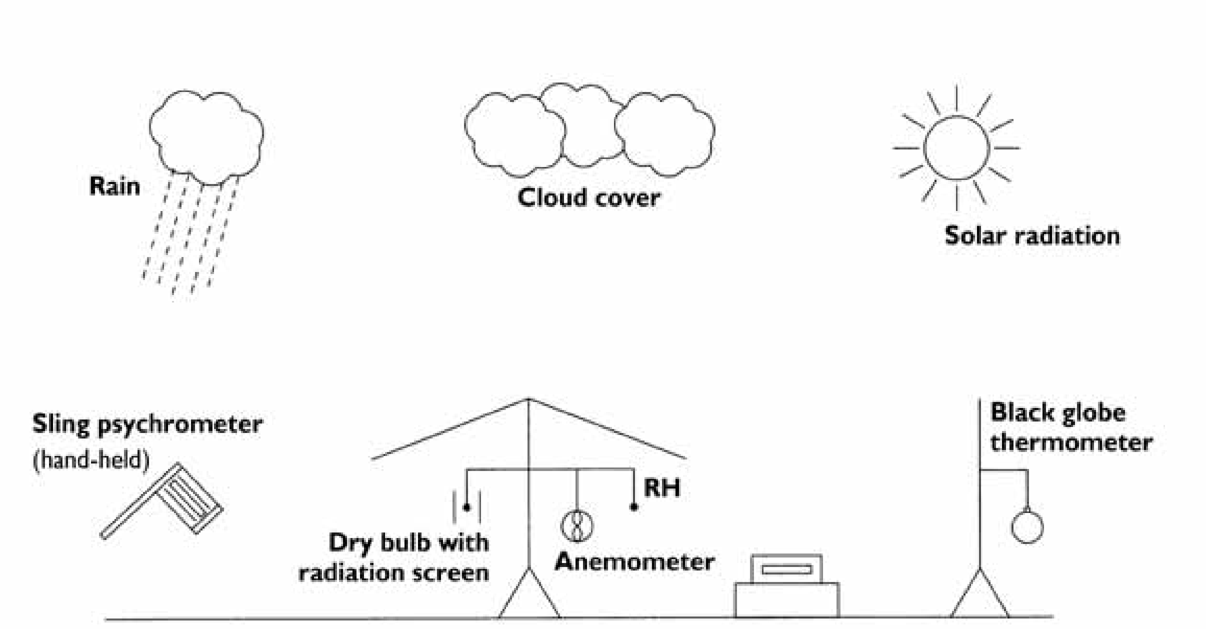

Figure 1 – The monitoring of weather conditions

2 The air temperature and humidity is to be measured in the cockpit if applicable at 1 hour intervals (see figure 2).

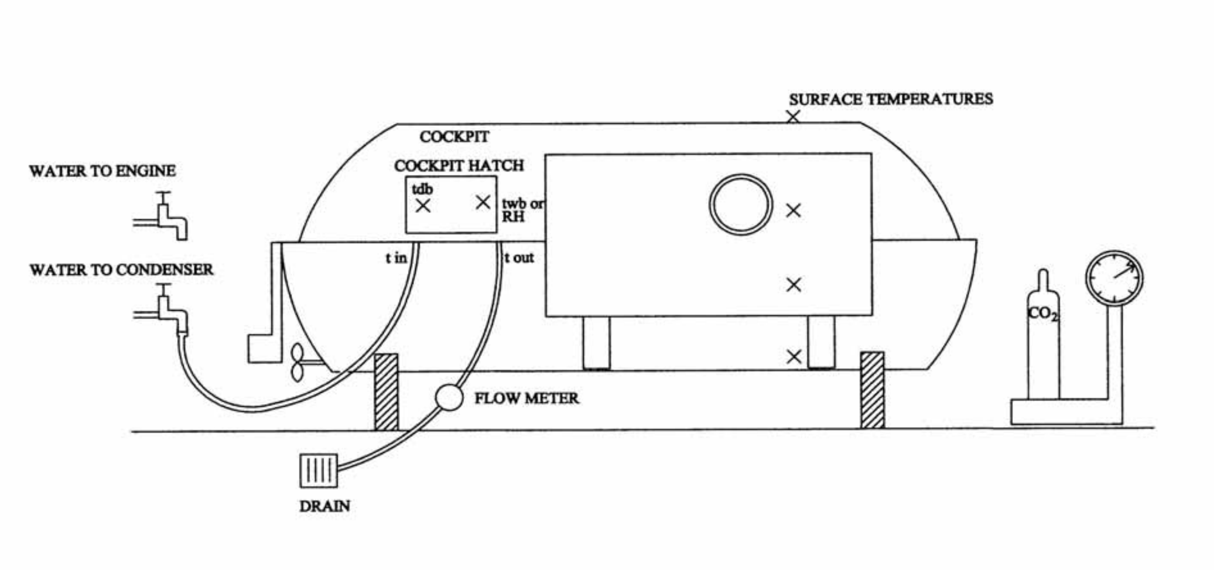

Figure 2 – The external measurements to be made on a HES (see page 18 for abbreviations)

3 Within the chamber the gas temperature is to be measured at five points – at ¼, ½ and ¾ along the long axis of the chamber and at the halfway point 225 mm from the deck and 225 mm from the deckhead/ceiling (see figure 3). The precise number of temperature measurements taken could vary depending on the size of the chamber and standards such as Australian Standard AS2853 (1986) '*Enclosures – Temperature Controlled – Performance Testing and Grading*' (ref. 2) do exist for measuring thermal conditions in enclosed environments and may be consulted.

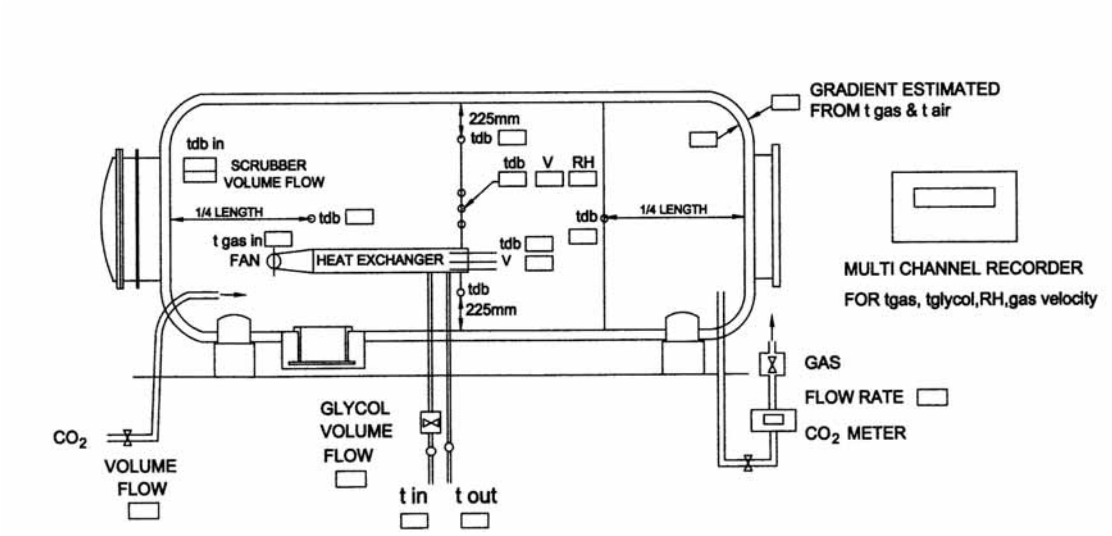

Figure 3 – The measuring points in the Chamber

4 The humidity of the chamber gas at the midpoint of the chamber.

5 The gas movement at the midpoint of the chamber.

6 The temperature of the gas entering and emerging from the coolers. The volume flow through the unit should be determined from the manufacturer's data and measured directly.

7 The temperature and volume flow of the coolant and heating fluid, e.g. glycol, sea water as it enters and leaves the chamber. The specific heat should be noted.

8 If feasible the outer surface temperature of the chamber or lifeboat at a number of points at one hour intervals (see figure 2).

9 The rated cooling capacity (kW) of the chilling or cooling unit and the heating capacity of any heating system should be recorded.

10 The drop in efficiency or the loss of capacity of a heating or cooling unit arising if heat exchangers, for example for cooling glycol, are placed between the heating or cooling units and the chamber should be estimated and recorded.

This can be done by comparing the heat being moved by the glycol system with the noted cooling power of the chiller unit.

11 Record the wattage of the electrical systems and the heaters that are simulating the diver's heat input using calibrated instruments. Total power input needs to be known.

12 CO_2, 490 ml/min per diver (ref. 3), should be added to the chamber and the scrubbers run during the hyperthermia test. The total CO_2 supplied to the chamber should be recorded.

13 Records need to identify in watts the cooling and heat input into the chamber and any variation over time (see Annex 3 for cooling power).

14 At atmospheric pressure investigate the inside of the chamber for air movement with all systems running. Any areas of high or low air movement which are identified may cause discomfort when the chamber is at a high gas pressure and should be assessed.

15 Cooling water to the chiller condenser – measure the temperature in and out and the volume flow. Calculate heat transfer.

3 Instrumentation and Equipment Required

As mercury is highly toxic and corrosive to metals, no mercury containing instruments should be used. Temperature measurements should be based on thermocouples or thermistors and humidity on electronic instruments using capacitance sensors.

Recommended equipment is as follows:

1 Climatic conditions

- ♦ Dry bulb thermometer, shaded *
- ♦ Psychrometric wet bulb thermometer or humidity meter, shaded *

* Instead of using dry bulb thermometer, shaded and psychrometric wet bulb thermometer, thermocouples with a data logger and humidity transmitter can be used

- ♦ Black globe thermometer, not shaded
- ♦ Suitable anemometer
- ♦ Note sun/rain/cloud

For measuring the temperature of the outer surface of a HES such as a HLB exposed to the sun and weather and the outer surface of the hyperbaric chamber when it is accessible,

- ♦ Contact surface temperature meter

or a

- ♦ Radiation thermometer

2 Control or crew area (cockpit), if applicable

- ♦ Dry bulb thermometer
- ♦ Wet bulb thermometer

3 Chamber – internal

- ♦ Humidity meter
- ♦ Temperature sensor for the gas cooler outlet and inlet and scrubber inlet
- ♦ 5 dry bulb thermometers for gas temperature stations *

* Instead of using dry bulb thermometers to measure the gas temperature stations, thermocouples with a data logger can be used

- ♦ Anemometer for gas movement.

4 Coolant/hot water flow to the chamber

Thermometers (or linked thermocouples to a data logger) for the inlet and outlet streams, volume flow from the pump rating or a flow meter. Note specific heat of fluid.

5 Calibrated volt and ammeter (Watt meter) for determining electrical power inputs. The wires carrying the current need to be accessible so that current can be measured.

6 An anemometer suitable for measuring low air or gas movements (0.05 m/s to 1 m/s) within the chamber and control area, such as the cockpit of a HLB.

7 Cooling water to the condenser. Measure inlet and outlet temperature and the volume flow of water over a period of time.

4 Guideline For Testing Hyperbaric Evacuation Systems

An outline of the HES chamber test programme is provided in Annex 1.

TEMPERATE ZONE OPERATIONS

4.1 Test 1: Hypothermia – 2 Divers (or minimum number of divers)

This test is to be carried out to prove that the HES has the necessary heating capacity to keep the minimum number of divers who will be in the chamber at a comfortable temperature. The following can be used as a guideline for the test. In testing the HES it is important that all equipment is being operated as it would be in a real situation; that is with the engine running if applicable and supplying power and heating. If seawater* is used for cooling the chamber and engine then seawater should be used during the test. Testing on the quay side will enable the tests to be done with greater care and accuracy.

1 The chamber should be unmanned but fitted with heaters to provide the metabolic heat equivalent of the minimum and maximum number of divers. This is 150W per diver for hypothermia tests and 200W per diver for hyperthermia tests.

2 The chamber is to be pressurised to 4 bar absolute on 93/7 helium-oxygen gas mixture.

3 The required heating and scrubbers are to be activated. (See the technical note on how to introduce heat into the chamber).

4 CO_2 is to be injected, using a flow meter, equivalent to the number of divers inside the chamber, that is 490 ml/min. times the number of divers. (This can be omitted from the hypothermia test if it is to be done in a hyperthermia test).

5 Measure the air/gas temperature (t_{db}) and if possible the humidity and air movement at the prescribed positions – see figure 3.

If it is not possible to measure and assess gas movement at pressure, determine the air movements in the chamber at atmospheric pressure. This can be done using an anemometer and soap bubbles.

Equipment in the chamber may make it difficult to make measurements at all recommended locations. Those in the middle of the chamber are the most important and should be done.

6 Analyse the chamber CO_2 level, which should be maintained at less that 1000 ppm.

For any set of conditions, e.g. number of divers, the test should run until the temperature inside the chamber has stabilised for a period of 90 minutes and is at the target temperature ± 1°C and within the Norwegian Petroleum Directorate Guidelines – see figure 4.

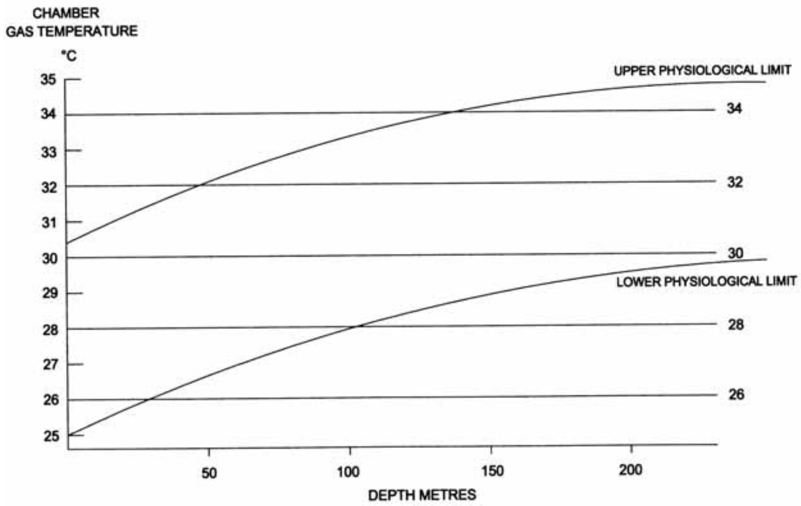

Figure 4 – Chamber Temperature Limits against depth (Norwegian Petroleum Directorate)
Reproduced from "NPD Guidelines for testing of hyperbaric evacuation units for "hyperthermia and hypothermia" to which reference should be made for specific information on temperature (ref. 4)

* Note that the NPD guidelines set a minimum seawater temperature of 12°C

From the data collected estimate the thermal transmittance of the chamber and the heating required for the minimum number of divers at the maximum temperature gradient i.e. winter conditions, also the number of divers required to maintain the chamber at 32°C without heating (see Annex 4).

A chamber temperature of 32°C has been selected as a working figure as it is the mid range and the comfort temperature at a depth of 200m. As depth decreases this temperature comes down and for a particular situation a lower temperature may have to be selected.

4.2 Test 2: Hyperthermia – Full Diving Complement – Summer Conditions

This test is to determine if the chamber has the necessary cooling capacity to keep the maximum number of divers comfortable during the summer.

Repeat test 1 with the heat load set for the maximum number of divers. Wait for equilibrium and hold on target for 90 minutes. The chamber temperature is then lowered so that the temperature gradient across the chamber wall is at a value that might be reached under summer conditions. For example, this could be a chamber temperature of 32°C and an outer wall temperature of 25°C giving a Δt of 7°C. If the outer wall of the chamber at the time of the test is at 5°C the chamber temperature should be set to 12°C so limiting heat flow to the environment to that anticipated under warm conditions.

This places the full thermal load on the cooling system. However, it is possible that if sea water is being used to cool the chamber its temperature may be such that it is impossible to reach 12°C and a higher chamber temperature will have to be used. This is acceptable provided it can be shown that the system can remove the required amount of heat when it is using summer temperature sea water at the dive site.

Note that in reducing the chamber temperature there is going to be a lag whilst heat is extracted from the gas, contents and structure of the chamber before the system comes into equilibrium. The heat from the divers can be switched on once the chamber and contents have cooled and gas temperature is on target.

The target temperature ±1°C should be maintained for 90 minutes. If this cannot be achieved, the chamber has to remain at a stable temperature within the limits set by the Norwegian Petroleum Directorate. The heat removed by the cooling system should be accurately measured and calculated (see Annex 3) and the thermal transmittance of the chamber estimated (see Annex 4). In evaluating the HES, a safety factor for the cooling system should be determined based on foreseeable increases in heat load from divers and the environment. For example, the cooling system could have an excess cooling capacity to enable it to deal with 10 year extremes of summer air and water temperatures.

TROPICAL ZONE

4.3 Test 3: Hyperthermia – Full Diving Complement

This test is to prove that the HES has sufficient cooling capacity to keep the divers at a comfortable temperature in foreseeable tropical conditions. The following can be used as a guideline for the test.

1. The HES should be out of the water to avoid any uncontrolled cooling effect from the water. This will also be the position of the HES in the standby situation before launching.
2. The chamber should be fitted with heating units of 200W per diver for the maximum number of divers that may be under pressure during the diving operation, or the maximum number of divers that the unit is designed for (see the technical note on how to introduce the heat).
3. The chamber should be pressurised to 4 bar absolute on 93/7 helium-oxygen.
4. The scrubbers are to be running and CO_2 injected, using a flow meter, equivalent to the maximum number of divers. (490 ml/min per diver).
5. CO_2 measurements are to be taken and the level should be less than 1000 ppm.
6. The chamber humidity will need to be recorded.
7. The chamber temperatures are to be measured as described for test 1.

8 For any set of conditions, e.g. number of divers, the test needs to run until the temperature has stabilised for a period of 90 minutes and is at the target temperature ±1°C or within the limits set by the NPD.

The HES's own systems are to be used during these tests, and the unit's engine* (if any) is to be running if used in the cooling process. To save time, the chamber may be heated to 32°C or to the temperature of the living complex before the tests start.

From the data collected the heat removed by the cooling system is to be determined as accurately as possible (see Annex 3) and the thermal transmittance value of the chamber estimated (see Annex 4). A safety factor for the cooling system is to be calculated based on foreseeable increases in heat load from the divers and environment.

4.4 Test 4: Assessment of the Maximum Cooling Capacity Available

In test 3, after the chamber temperature has remained stable for a period of 90 minutes, test for the maximum cooling capacity available. Proceed by increasing the heat input into the chamber by increments of about 400W whilst maintaining the chamber at its target temperature of 32°C. The cooling capacity will have to be increased by the same amount. This is done either by increasing the volume flow of sea water through the chamber heat exchanger, by reducing the glycol temperature, by increasing glycol volume flow or a through combination of both (see Annex 3). The compressor or sea water pump should not be overloaded.

When a rise in the temperature of the chamber occurs it will indicate that the cooling system is no longer able to handle the heat load imposed on it. When this happens reduce heat input by one or two increments and maintain gas temperature at the target value for 90 minutes. Earlier signs of the system reaching its limit may be maximum glycol flow rates having to be used, glycol temperature increasing, the compressor not cutting out at intervals. Note that the maximum cooling capacity of the system is what it can maintain in the long term not what it can reach for a short period of time. Because of inefficiencies and heat pickup outside the chamber the actual cooling capacity is going to be lower than the manufacturer's value for the chilling unit. This test should indicate what this cooling capacity is.

4.5 Test 5: Cooling System Failure

A foreseeable risk is the failure of the cooling system and a back up system and procedures will have to be in place to enable the crew to deal with the emergency. The crew will need to know the time course of the rise in chamber temperature following on failure of the cooling system.

As it is not possible to simulate the thermal mass and inertia of the divers' bodies the test results are only an estimate of the time course of the rise in chamber temperature.

To determine the time taken for the chamber temperature to rise 3°C turn off the primary cooling system and record the change in temperature. Where a secondary cooling system or other contingency measures are available they should be tested by turning off the primary system only and the chamber temperature followed until it is established as stable over 90 minutes or the time it has taken to rise 3° C recorded.

For interpretation of this test see 6.4 of the technical note.

The complete evaluation test should cover day and night conditions and last a minimum of 24 hours.

* This may mean that the HES has to be in the water or cooling provided for the engine.

5 Reporting

A test report (see Annex 2 for a draft report format) should be written, giving the results of the measurements and an assessment of the HES's likely performance in extreme conditions. Further details of the tests and their justification are given in the IMCA technical note.

These are recommended procedures for determining if an HES will protect the divers in thermal extremes and for an indefinite period of time. There are other ways by which it can be done but expert advice should be obtained to develop alternative methods.

Annex 1 – Outline of a HES Chamber Test Programme

The testing of a HES involves complex procedures and a number of personnel including outside contractors. A test programme should be drawn up to ensure adequate liaison and co-ordination and the smooth running of tests.

Planning stage

- Collect relevant documents and data including climatic data.
- Identify who is in charge of the tests and responsible for reporting.
- Confirm that the engineering assessment and checks of the HES have been completed.
- Confirm that the ergonomic and operational procedures assessments have been completed.
- Complete maintenance and upgrades as required for the thermal testing.
- Complete the baseline test on the HES (technical note Box 1).
- Set up site services for tests on the HES.
- Engage a contract company to complete instrumentation of the HES and set up a meteorological station.
- Plan air, gas and liquid flow measurements.
- Prepare data recording sheets for climate, and HES test results.

Test 1: Hypothermia

- Bring the chamber to 32°C. Ensure the chamber is in equilibrium, i.e. heat input is constant.
- Add the heat load to represent two divers or the minimum number of divers (150W/diver).
- Adjust chamber heating to keep the chamber at 32°C. Maintain at 32°C for 90 minutes.
- Check temperature gradient across the chamber wall, i.e. gas to ambient air temperature.
- Identify the new chamber temperature from dive site climatic data, i.e. extreme low temperature, which is required to impose extreme heat loss conditions.
- Increase chamber heat input to bring the chamber to the new target temperature. Wait for equilibrium then control for 90 minutes at the new target gas temperature.
- Return chamber gas to 32°C.

Test 2: Hyperthermia

- Increase diver heat load (200W/diver) to full diver complement. No chamber heating. Start scrubber and inject CO_2 at 490 ml per minute per diver equivalent.
- Bring in cooling to maintain chamber gas temperature at 32°C, wait for equilibrium to be established, i.e. constant cooling load.
- Keep at 32°C for 90 minutes.
- Check temperature gradient across the chamber wall (t gas to t air).
- Identify the new gradient which is required to simulate extreme conditions from climatic data.
- Remove diver heat load.
- Increase cooling to bring the gas temperature down to the new temperature and wait for equilibrium.
- Turn on diver heat load.
- Hold target temperature for 90 minutes.

For the Tropics – Test 3: Hyperthermia

- This test is as for test 2 but under tropical conditions there will be a greater load on the cooling system.

Test 4: Assessment of the Maximum Cooling Capacity of the HES

- After test 2 or 3 proceed by increasing the heat input into the chamber by suitable increments e.g. 300W. Maintain the chamber gas at the target temperature, 32°C. When this is no longer possible, drop the heat input by one or two increments and maintain chamber temperature on target for 90 minutes.
- Return heat input to that for maximum number of divers.

Test 5: Cooling system failure

- Cut the cooling to the chamber.
- Monitor temperature rise until it reaches 3°C above target. A warming curve is required. If the data is not sufficiently good allow gas temperature to rise by another degree or two.
- Return the chamber to 32°C and complete a 24 hour run.

Annex 2 – Draft Report Format

The aim of the tests is to demonstrate that the hyperbaric evacuation system has the heating and cooling capacity to protect the divers in the chamber from hypothermia and hyperthermia in the climatic conditions at the dive location.

The heating and cooling capacity as determined by the tests should be given in the report. Any restrictions that might apply should also be stated, for example the limiting sea water temperature if it is being used for cooling the chamber or condenser. If it has not been possible to determine the maximum cooling capacity available the manufacturers figure can be used as the basis for an estimate. If the engineers doing the testing identify weaknesses in the design and engineering of the environmental control system (ECS) or the HES this should be stated. For example, a top entry to the chamber which is uninsulated and could allow heat to enter the chamber if not protected from the sun.

The following outline report form is not intended to be used as an actual report or certificate. The safety manager needs to ensure that the report contains the necessary information to meet company and local legal requirements. Restrictions on where the HES can be used may have to be given.

Chamber Test Report

Chamber type and designation: ....
Maximum diver capacity: ....
Operational area e.g. North Sea ....
Test location: ....
Date of test: ....

The following tests have been done:

☐ Hypothermia
☐ Hyperthermia
☐ Hyperthermia tropics
☐ Maximum cooling capacity
☐ Cooling system failure

Test Site Designation: ....

Climatic conditions during test:

– Air temperature:	Max :	Min:	Mean:
– Globe temperature mean:	Max:	Min:	Mean:
– Wind speed:	Max:	Min:	Mean:

General conditions: Cloud, rain, wind
Coolant water temperature to engine, etc.:

Test Results:
Chamber target gas temperature: ....
Heating capacity required for 2 divers (or minimum no.): ....
Number of exposure garments required in the chamber:..
Maximum heating capacity available to the chamber: ....
Chamber cooling required for maximum no. of divers : ....
Estimated maximum cooling required: ....
Maximum chamber cooling capacity available: ....
The chamber thermometer is accurate to ± 0.2°C: ....
The chamber thermometer reads to ± 0.2°C: ....
Scrubber life: maximum number of divers: ....
Sodasorb can be replaced by the divers in: ....minutes

The test indicates that the cooling system of chamber No … can operate at … watts for an indefinite period. This is the anticipated maximum thermal load at the dive site.

The cooling system can operate at … watts maximum giving it a spare capacity of … watts.

The written procedures on board are:

Chamber temperature control:	....
Scrubber sorbent replacement:	....

Repairs to:

compressor – drive, cut out, water air cooling:	....
glycol pump:	....
alternator:	....
drench pump:	....

Dive site climatic extremes:

	winter	summer
t_{db}	....	....
t_{wb}	....	....
RH	....	....
Wind	....	....
Solar load	....	....
Sea temperature	....	....

Annex 3 – Chamber Cooling Using Cooled Glycol/Water Mixture

The theory behind calculating the heat removed from a hyperbaric evacuation system by a cooled glycol water mixture is simple*. However, the accuracy of the flow meter and the difficulty of measuring glycol temperature will ensure that the figures obtained are subject to error. They should however be sufficiently reliable for the purposes of the tests. The following tables are to provide an indication of a glycol solution flow rates and temperature rises between inlet and outlet temperatures associated with a range of cooling powers. The specific heat of the glycol water mix will vary according to the mix used and the one used here, 3.9 J/ml, may not apply. The supplier should be able to provide this information for their antifreeze and the water antifreeze mix they recommend.

The figures in tables 1 and 2 are for guidance only.

Table 1 looks at small increments of flow and temperature. Table 2 considers larger increments. The specific heat of water at 5°C is 4.2 J (Kaye & Laby) (ref. 5). Glycol density is taken as1.3g/ml with a specific heat of 2.43 J/g°C, that is 3.16 J/ml°C.

Table 1 – Cooling Power in Watts

Δt°C Glycol Flow (l/min.)	1	2	3	4	5	6	7	8	9	10
0.2	13	26	39	52	65	78	91	104	117	130
0.4	26	52	78	104	130	156	182	208	234	260
0.6	39	78	117	156	195	234	273	312	351	390
0.8	52	104	156	208	260	312	364	416	468	520
1.0	65	130	195	260	325	390	455	520	585	650
1.2	78	156	234	312	390	468	546	624	702	780
1.4	91	182	273	364	455	546	637	728	819	910
1.6	104	208	312	416	520	624	728	832	936	1040
1.8	117	234	351	468	585	702	819	936	1053	1170
2.0	130	260	390	520	650	780	910	1040	1170	1300

Table 2 – Cooling Power in Watts

Δt°C Glycol flow (l/min.)	1°	5°	10°	15°	20°
1	65	325	650	975	1300
2	130	650	1300	1950	2600
3	195	975	1950	2925	3900
4	260	1300	2600	3900	5200
5	325	1625	3250	4875	6500
6	390	1950	3900	5850	7800
7	455	2275	4550	6825	9100
8	520	2600	5200	7800	10400
9	585	2925	5850	8775	11700
10	650	3250	6500	9750	13000

* The cooling power in Joules per min is given by:
Glycol mix volume flow (ml/min)x specific heat (J/ml°C) x glycol mix temperature rise = heat removed (J/min).
Divide by 60 to obtain the cooling power in watts.

Annex 4 – Chamber Thermal Transmittance

MN Young, in his report (ref. 6), states that the measurement of the thermal transmittance of a hyperbaric evacuation chamber is not possible. However, estimates can be made by measuring the heat loss from the chamber and estimating the thermal gradient between the chamber gas and outside air temperature. As Young found out, changes of wind speed affect the heat loss. Also, the chamber and its insulation have to be at a constant temperature – that is no heating or cooling of the thermal mass of the chamber going on. Any value derived is only an estimate but it can be useful when trying to predict how the chamber is going to perform.

For example, in test 1, the heat inputs into the chamber could be:

♦	2 divers	300W
♦	Heat input to control the chamber temperature	600W
♦	Lighting, fans	100W
♦	Gas temperature	32°C
♦	Air temperature	10°C

Therefore, in this example, 1000W of heat would be leaving the chamber down a temperature gradient of 22°C that is 45.5W per °C. It might, therefore, be anticipated that at an air temperature of 5°C a further 230 watts of heating might be required – more if wind speeds are higher than those at the test site. The chamber heating should be able to supply this heat.

When trying to estimate how many divers, in addition to the two present, are required to maintain the temperature of the chamber, the 600W of heating represents 4 divers and under cold conditions the 230W represents about 2 divers. If the heating failed suits for 8 divers may be required. To keep 2 divers comfortable 800 to 900W of heating is needed with perhaps a safety margin of another 200W. These are estimates. One way to check them is to increase the temperature gradient across the chamber wall to what it might be under extreme climatic conditions, say 0°C, giving a gradient of 32°C. With an air temperature of 10°C outside the chamber raising the chamber gas temperature to 42°C would give a Δt of 32°C and confirm that the heating system can hold the chamber temperature on target in the coldest conditions at the dive location.

In test 2, the chamber now has the heat of 10 divers. There will be a flow of heat out of the chamber because the air temperature is low at 10°C but cooling is required.

For example, the heat input into the chamber could be:

♦	10 divers at 200W	2000W
♦	Lighting and fans	100W
♦	Scrubber	unknown
♦	Gas temperature	32°C
♦	Air temperature	10°C
♦	Glycol temperature in	5°C
♦	Glycol temperature out	12°C
♦	Volume flow	2500ml/min
♦	Specific heat	3.9J/ml°C

The heat removed by the cooling system is:

2500 x 3.9 x 7 = 68250 J per min = 1137W.

This leaves 2100 - 1137 = 963W to pass down a 22° temperature gradient to the outside.

Dividing 963 by 22 gives 43.7W/°C as the transmittance of the chamber. To this must be added the heat produced by the scrubber.

In summer, air temperatures could be 20°C so that the gradient across the chamber wall is not 22° as in the test but 12°. This indicates that over 437W of extra cooling will be required.

If the gas temperature is reduced to 22°C, thereby reducing Δt to 12°C, the ability of the chilling unit to deal with this load can be assessed.

In test 3, for the tropics, the gas temperature is going to be much closer to air temperature. For part of the day the combined air and radiant temperature could cause heat to move into the chamber. For example:

- 10 divers at 200W 2000W
- Lighting and fans 100W
- Scrubber unknown
- Gas temperature 32°C
- Air temperature 30°C
- Glycol temperature in 7°C
- Glycol temperature out 15°C
- Volume flow 4000l/min
- Specific heat 3.9J/ml°C

The heat removed by the cooling system is 4000 x 3.9 x 8 = 124800 J per min. or 2080W so 20W + the heat from the scrubber is lost from the chamber giving a transmittance of 10W + per 1°C.

If it is anticipated that combined air and radiant temperature could be say 5° higher than chamber temperature the test can be repeated with a chamber temperature 5°C below the ambient air temperature, that is at 25°C.

As already described, if the chamber temperature is changed there is a long period during which the chamber contents, wall and insulation are coming into thermal equilibrium. Tests involving changes in heat input while keeping the chamber temperature constant are therefore much quicker. The approach used in test 4 therefore has much to recommend it.

If climatic conditions at the test site change they must be assessed to ensure that the objectives of the tests are still being met. For example if during test 1 the ambient air temperature rises to say 15°C the load on the chamber heating will be reduced and the chamber heating capacity required could be underestimated.

Annex 5 – Engaging a Metrology Company for Temperature and Fluid Flow Measurements

There are companies that specialize in measuring physical parameters. In the UK a business telephone directory can be consulted (try temperature) or the UK Accreditation Service (www.ukas.org). Companies tend to specialise, so one may be needed for temperature and one for fluid and gas flow. The same services will be available in other parts of the world where environmental control system testing of HES is likely to take place. There are companies who are accredited for certification of systems on site to the Australian Standard AS 2853. If measuring equipment is required, consult such companies as York Survey Supply Centre (www.yorksurvey.co.uk).

As with all measurements, accuracy and precision are vitally important when measuring temperature, volume and mass flow. The contracting metrology company must be able to guarantee that both its measuring systems and its procedures on site ensure high standards.

What is often forgotten is that faults can develop on site and a field check should be made after the tests to ensure temperature sensors have been reading correctly. This is most easily done by placing the transducers in a bucket of water. They should all record the same temperature and the print out should show this.

In setting up the temperature sensors they should not be exposed to radiant heat or be in the gas stream from a fan heater. Stem error where heat can be conducted along the wire to or from the sensor should be avoided. If surface temperatures are being measured, sufficient stem needs to be in contact with the surface to protect the transducer from stem errors – normally 50mm. If thermocouples are used it is normal to solder or weld the two wires together and coat with an electrical insulator such as varnish. The temperature sensor in the chamber should be sufficiently secure to prevent movement or dislodgment by the gas stream. When measuring gas temperature the sensor should be 50 mm away from any surface so that it is not in the boundary layer.

When measuring the temperature of glycol or water the stem of the sensor should be in contact with the pipe (50 to 100mm) and the section of pipe insulated so that the linkage is to the fluid and not the environment. Condensation should not be able to penetrate the insulation. The contractor should be asked for a hand held electronic thermometer which will be useful for measuring cooling water temperature in and out and other tasks. A vessel of known capacity, which can also be weighed, is required for measuring volume flows of cooling water.

The climate or metrology station can be on a separate data logger or the temperatures can be read at intervals and recorded. When using flow meters of the variable orifice type it is important that they are vertical and the float is read correctly – across the centre of a ball float and across the top of a cylindrical type float. The floats are normally made to rotate to show that they are free of the walls. Flow meters of this type measuring gas flow are calibrated at a given pressure, for example with the exhaust side at atmospheric pressure or some other stated pressure. In some systems the flow meters are used purely to indicate that a flow of gas is occurring and although the scale indicates relative amounts, e.g. high or low, the meter reading is not necessarily correct unless it has been calibrated for the pressure.

When weighing cylinders for the amount of carbon dioxide used, only the cylinder should be weighed with any supporting harness if required. The harness and cylinder should be dry and kept dry. The capacity of the cylinder should be matched to the anticipated use of CO_2. A suitable weighing system will have to be found as accuracy, ±10g if possible, is important. It is unlikely that a company will deal with both weight measurement and temperature.

References

1 IMCA Technical Note on the Evaluation and Testing of the Environmental Control of Evacuation Systems (2006). This technical note accompanies this information note IMCA D 02/06

2 Australian Standard AS2853 (1986) Enclosures – Temperature Controlled – Performance Testing and Grading

3 The Estimation of the Metabolic Production of Carbon Dioxide in Hyperbaric Evacuation Systems – Mike Tipton et al. University of Portsmouth (2005). Report available from IMCA

4 Norwegian Petroleum Directorate (NPD) Guidelines for testing of hyperbaric evacuation units for hyperthermia and hypothermia

5 Table of Physical and Chemical Constants GWC Kaye and TH Laby, Longmans 1962

6 Thermal balance of an hyperbaric rescue vehicle by MN Young, Houlder Offshore Ltd

Abbreviations

CO_2 carbon dioxide

kW kilowatt

ml millilitre

O_2 oxygen

RH relative humidity

t temperature
t_{in} temperature in
t_{out} temperature out
t_{gas} gas temperature
t_{glycol} glycol temperature
t_{db} temperature – dry bulb
t_{wb} temperature – wet bulb

V gas velocity

W watt