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STC-2 & -3 Shrouds Technical Requirements Definition

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1 Introduction

RAL Space is seeking to procure thermal shrouds for integration into its two 5m Space Test Chambers, known as STC-2 and STC-3. The test chambers consist of a horizontal cylindrical section (5m internal diameter), with dome-shaped doors at both ends. There are two rails running along the bottom of the cylindrical section of the chambers to support items under test.

The shroud for each chamber will cover the internal surfaces of the cylindrical section and both doors, whilst also allowing test items to be positioned on the rails and allowing the doors to be opened and closed. The shrouds are used to provide a thermal environment within the vacuum test chambers that can be adjusted during testing. The shroud temperature is controlled using LN₂ and/or electrical heating as required. As certain tests require different parts of the shroud to be set at different temperatures, each shroud is divided into a number of thermal “zones”. Given these requirements, the shroud is expected to consist of a number of separate components (“panels”).

Each chamber is situated between two cleanrooms, with a door at each end of the chamber to provide access from each cleanroom (see AD 5). One cleanroom for each chamber is configured as a “dark room”, providing a suitable optical environment for test equipment to be set up outside the chamber. This set up activity is often complicated and time-consuming and once underway, the door at that end of the chamber must remain closed. Therefore test preparations within the chamber are designed to be performed with access only from the other end of the chamber.

The two chambers have already been assembled. The shrouds therefore need to be compatible with the existing interfaces and specifications of the chambers (weight, volume envelope, mounting, electrical etc.). The shrouds shall be supplied with mounting components to interface to the chambers.

The two chambers are largely identical; hence the shroud designs shall be suitable for either chamber. The common requirements are defined in Section 2.1. There are some differences however, and requirements derived from these differences are highlighted in Section 2.2.

The requirements for the shrouds are set out in Section 2. Each requirement is given a requirement number followed by all of the verification method(s) applicable to that requirement, as follows:-

- R Review of Design
- A Analysis
- I Inspection
- T Test
- S Similarity

The text for each requirement is formatted in italic font. Any additional explanatory text is formatted in normal font.

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1.1 Document Scope

This document defines the technical requirements for the shrouds for the STC-2 and STC-3 vacuum chambers.

1.2 Applicable Documents

AD 1.	AIV-STC2_3-SOW-1003	STC-2 &-3 Statement of Work
AD 2.	KE-0266-111	STC-2 Drawing Shroud Interface Drawing
AD 3.	KE-0288-111	STC-3 Drawing Shroud Interface Drawing
AD 4.	KE-0266-030 & KE-0288-060	STC2 &3 chamber allowable volumes
AD 5.	ISO DD R100 STC 0005	STC-5m Number 1 Suite Description
AD 6.	ISO DD R100 STC 0008 1.0	STC-5m Number 1 Vacuum System PID - version 3
AD 7.	SC33	“Pressure and Vacuum Systems” STFC Safety Code
AD 8.	Directive 2014/68/EU	Pressure Equipment Directive
AD 9.	PER	Pressure Equipment Regulations 1999
AD 10.	PSSR 2000	The Pressure Systems Safety Regulations
AD 11.	EN 13445	Unfired Pressure Vessels
AD 12.	ECSS-Q-ST-70-02C	Thermal Vacuum Outgassing Test for the Screening of Space Materials
AD 13.	MIL-STD-1246C	Product Cleanliness Levels & Contamination Control Program

1.3 Reference Documents

RD 1.	ECSS-Q-ST-70-02C	Thermal vacuum outgassing test for the screening of space materials
RD 2.	P4436.01.5.00.001 & 02	Structural Analysis of Space Test Chamber
RD 3.	ECSS Q-ST-70-01C	Cleanliness and Contamination Control
RD 4.	TEC-QT-2014-344	Analysis of Bake-out monitoring
RD 5.	P4436	Technical File and manual for STC-2 vessel

Applicable documents and reference documents can be found on the following ftp site

FTP Site: <ftp://rsftp.stfc.ac.uk>

Username: PR18122 STC2_3

Password: BH76_Yhn*(

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2 Requirements

2.1 Common Requirements

2.1.1 Design

R-1 [R] *All parts of the shroud subjected to internal or external pressure shall conform to the applicable requirements of EN 13445(AD 11).*

The Contractor may use another recognisable pressure vessel design code, but must state clearly at the time of tender which code will be used.

2.1.2 Interface Requirements

R-2 [R] *The shroud shall fit within the allowed accommodation volume as defined in the interface drawings AD 2 and AD 3. Shroud proposed interface shall take into consideration Vessel wall material and CTE.*

R-3 [R] *The shroud shall incorporate apertures for various ports within the chamber, as shown in AD 2 and AD 3.*

R-4 [R] *The shroud shall be attached to the chamber using the existing mounting features within the chamber, as shown in AD 2 and AD 3.*

The shroud design may use some or all of the mounting points that exist within the chamber. Not all mounting points need to be used, provided the contractor can demonstrate that the mounting scheme permits the shroud design to meet all requirements. The contractor shall supply whatever additional hardware is required to attach between the shroud and the chamber walls.

R-5 [R, A] *The shroud shall impart loads compatible with the loading specification of the interface points within the chamber.*

Figure 7 in RD 2 details the shroud induced loads used for the structural analysis of the chamber.

The body load specifications are as follows (consult RD 2 for additional information):-

Panel Force for all 28 existing Body Panels (based on Shroud Panel weight of 75Kg)	736N in vertical direction
--	----------------------------

R-6 [R] *The LN₂ connections for the shroud shall be attached to the existing LN₂ connections within the chamber, as shown in AD 2 and AD 3. The LN₂ connection fittings shall be ½" VCR male.*

The shroud design may use some or all of the existing LN₂ connections within the chamber. Not all connections need to be used, provided the contractor can demonstrate that the connection scheme permits the shroud design to meet all requirements, including the control of panels by zones.

R-7 [R] *The electrical connections for the shroud shall be attached to the existing electrical connections within the chamber, positioned within 100mm of the LN₂ connections, as shown in AD 2 and AD 3. Heater harnesses to be terminated with 5W5 Male DSub connectors.*

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The shroud design may use some or all of the existing electrical connections within the chamber. Not all connections need to be used, provided the contractor can demonstrate that the connection scheme permits the shroud design to meet all requirements.

R-8 [R] The temperature sensor connections for the shroud shall be attached to the existing temperature connections within the chamber, as shown in AD 2 and AD 3. Temperature sensor connectors to be 25Way DSub (male) using compensating contacts appropriate to the thermocouple type.

R-9 [R] The shroud shall be electrically connected to grounding points which are to be incorporated into the mechanical mounting points for the shroud, with a resistance of less than 0.1Ω. The grounding solution shall be compatible with a supply current of 2 x 6A Class C Miniature Circuit Breakers, one for each heater circuit.

The shroud design may use some or all of the existing grounding points within the chamber. Not all grounding points need to be used, provided the contractor can demonstrate that the grounding scheme permits the shroud design to meet all requirements.

2.1.3 Mechanical Requirements

R-10 [R, A, T] Each panel shall be capable of supporting its own weight without plastic deformation during manufacture, transport, handling, installation, operation and maintenance operations. The shroud shall fit within the allowed accommodation volume as defined in the interface drawings AD 2 and AD 3.

The contractor shall specify the support points and orientation of the shroud during all operations, and demonstrate, through analysis, that at the relevant temperature the design has positive margins of safety. The margin of safety is defined as follows:-

$$\text{Margin of Safety (MoS)} = \left(\frac{\text{Allowable Stress}}{\text{Peak Stress} \times \text{FOS}} \right) - 1$$

Where:-

Allowable Stress: Yield Stress or Ultimate Tensile Strength (UTS). A basis value shall be considered.

Peak Stress: Maximum Von Mises Stress (for ductile materials)

FOS: Factor of Safety = 1.5 (for Yield Stress), 2 (for UTS) (for ductile materials)

The MoS shall be calculated for both yield and UTS, and shall be positive for both cases. FOS for non-ductile materials shall be agreed with the customer.

The contractor shall also highlight any reasonably foreseeable conditions (supports, orientation, and temperature) which would cause yielding of the shroud.

R-11 [R, A, T] The shroud shall be capable of supporting its own weight plus the weight of any contained LN₂, without deflecting outside the allowed accommodation volume during operation.

R-12 [A] The shroud design shall be verified by stress analysis using industry standard

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analysis software.

- R-13 [A] *Fasteners shall also be analysed using industry standard analysis software, to ensure that thermoelastic effects do not lead to fasteners degradation over continuous thermal cycling.*
- R-14 [R, A] *The shroud shall be designed for 4000 thermal cycles (between maximum and minimum shroud operating temperature) and 1000 vacuum cycles over a 20 year lifetime.*
- R-15 [R] *The shroud shall be designed to operate continuously for up to 250 days without damage or degradation in performance.*
- R-16 [R, A, I, T] *The shroud shall be designed in accordance with standards applicable to the design of pressure vessels (AD 11).*
- R-17 [A, T] *Panels must be tested with nitrogen gas or dry compressed air to at least 1.5 times the maximum operating differential pressure of 4.5 bar.*

A Liquid Nitrogen Phase Separator is mounted above each chamber to provide LN₂ to each chamber. The normal working pressure of the Phase Separator is 1bar.g, with an outlet 6m above the floor on which the chamber is mounted. The Phase Separator includes a relief valve with a set pressure of 3.5bar.g. Adequate safety margins (during operation and during testing) shall be applied to the design of the shroud, as per referenced standards (AD 11). See Section 3.3 for additional information.

2.1.4 Thermal Requirements

- R-18 [A, T] *The shroud shall operate at any temperature between 80K and 400K.*
- R-19 [A, T] *The thermal performance of the shrouds shall be achieved assuming the surrounding chamber provides a radiative and conductive environment between 280K and 300K. The thermal performance of the shrouds shall be achieved with a conductive heat load from each mounting point of 20W (see Appendix 3.1).*
- R-20 [R, A, T] *The shroud shall be designed to cool down and warm up at a controlled rate of between 60K/hr and 10K/hr with no thermal load from the test item.*
- R-21 [R, A, T] *The shroud temperature (over 95% of individual shroud panel area) shall be uniform to $\pm 5K$ of the set-point at any temperature between 80K and 400K, when subjected to a thermal load from the test item of 18kW uniformly distributed over the shroud inner surface.*
- R-22 [R, A, T] *The shroud temperature (over 100% of the shroud area) shall be uniform to $\pm 10K$ of the set-point at any temperature between 80K and 400K, when subjected to a thermal load from the test item of 18kW uniformly distributed over the shroud inner surface.*
- R-23 [A, T] *The shroud temperature for each individual panel shall be uniform to $\pm 10K$ of the set-point at any temperature between 80K and 400K, when subjected to a thermal load from the test item of 2.5kW.*
- R-24 [A, T] *The thermal performance of the entire shroud shall be achieved with a maximum LN₂ flowrate of 959kg/hr.*

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- R-25 [R, A, T] *Temperature gradient and stability requirements are applicable to covers attached over apertures in the shroud.*
- R-26 [R] *The shrouds shall not require single- or multi-layer insulation blankets to achieve the required thermal performance.*
- R-27 [A, T] *The shroud temperature (calculated from the average of all shroud thermal sensor measurements) under steady-state conditions shall vary by less than 1K/hr.*
- R-28 [R] *The shroud shall consist of no less than ten independently controllable zones, as shown in AD 2 and AD 3.*
- R-29 [A] *Each shroud zone shall be able to operate at a temperature which is 50K above or below any other zone without affecting the stability or gradient requirements.*
- R-30 [A, T] *Each shroud zone shall be controllable to $\pm 1K$ of its set-point.*
- R-31 [R] *Each shroud panel should have a minimum of 7 and not to exceed 10 sensors per panel (total number of shroud sensors is limited to 436 which is equivalent to number of sensors the chamber shroud data acquisition system can read). Sensors should be installed on the side of panel facing the chamber wall and should be homogeneously distributed.*
- R-32 [R, S] *The location and mounting method of the temperature sensors shall enable repeatable and representative shroud temperature measurements to be made.*
- R-33 [R] *The shroud shall have no gaps or views to the vessel walls from any point on the centreline of the chamber, except where feedthroughs are required.*
- R-34 [R, S] *The surface facing into the chamber shall have a hemispherical emissivity of greater than 0.8 at 80K (e.g. Aeroglaze 306 or coating with similar absorption and outgassing performance). Coating application shall be tested by peel off test. The surface coating shall withstand 50C above shroud operational temperatures*
- R-35 [A] *The shroud design shall be verified by thermal analysis using industry standard analysis software. The model shall be delivered to RAL Space in a format compatible with ESATAN-TMS 2016.*
- R-36 [R, A] *The contractor shall propose the scheme to combine the information from the temperature sensors to control the heating/cooling of the LN₂ shroud. The shroud temperature sensor assemblies will need to be terminated to 25 way DSUB (Male) and the sensors need to be Type T Thermocouple (Copper/Constantan).*

2.1.5 Electrical Requirements

- R-37 [R] *The shroud shall be fitted with electrical heaters which enable the thermal requirements to be met. Panel heating needs to be compatible with existing heating harnesses in the chamber. Panel heating harnesses need to be terminated to 5W5 Male DSUB connector.*
- R-38 [R, T] *The heaters shall operate from the existing electrical supply in the chambers and be in compliance with Electrical safety standards.*

The heater electrical supply harness provides two independently switched heater supplies using four wires.

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The power supply for the heaters is 240V AC and each supply (two per current shroud panel) is designed to allow 3.2A of current without exceeding the permissible operating condition of the wiring and inline connectors.

2.1.6 Cleanliness and Contamination Requirements

R-39 [R, S] *The materials used for the shrouds shall be compatible with the following outgassing requirements: Total Mass Loss (TML) <1%, Volatile Condensable Material (VCM) <0.1% when tested in accordance with AD 12.*

No cadmium, zinc, oil or silicone based products, Polyvinyl chloride (PVC) plastic and potential hazardous materials such as beryllium shall be used. A declared material list for the panels will have to be approved by the customer at the manufacturing readiness review.

R-40 [R] *Any stainless steel parts of the shroud shall be electro-polished, unless exception can be justified.*

R-41 [R] *All aluminium components of the shroud or its pipework must have a surface finish applied such as Surtec/alodine 1200 to ensure no oxide layer is able to form.*

R-42 [R, I] *The shroud shall be cleaned to cleanliness level 250 (AD 13) prior to installation in to the chamber.*

R-43 [T] *In accordance with RD 4, prior to delivery, the shrouds shall be vacuum baked at 400K for a minimum of 72 hours and until the outgassing rate as measured by a Thermoelectric Quartz Crystal Microbalance (TQCM) (set at -20 degC) reaches a significantly reduced and almost steady state, , in order to evaluate this:*

- Record frequency rate at 0.5 hourly intervals minimum frequency

$$\frac{df(t)}{dt} = \frac{(f(t - 0.5hr) - f(t))}{0.5}$$

- Record rate of change over five hourly intervals (for each data point captured)

$$\frac{d^2f(t)}{dt^2} = \frac{\left(\frac{df(t - 5hr)}{dt} - \frac{df(t)}{dt} \right)}{\frac{df(t - 5hr)}{dt}}$$

- Bakeout is complete when rate of change ($d^2f(t)/dt^2$) < 0.05 continuously for a period of more than 3 hours.
- A wipe test and a tape test on the shrouds shall be implemented at the end of the bake-out, as there are paints which continuously generate powder or lose their mechanical integrity.

R-44 [T] *Following bakeout, a full set of the shroud panels shall have an outgassing rate of*

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less than 10 ng / cm² / day when measured with the panels held at +60°C and a Thermoelectric Quartz Crystal Microbalance (TQCM) set at -20°C.

Note that it is expected that this requirement is verified by calculation from a build up of measurements on the panels as they are baked individually or in batches rather than as a single complete set.

R-45 [R, T] *During operation the shroud shall not generate particles.*

This requirement shall be verified by placing a particle fallout plate (PFO) in the chamber below the panel under test. Particular care shall be taken to ensure that the results obtained are not influenced by the evacuation or recovery of the vacuum chamber and the shrouds cycled between 80K and 400K five times. The PFO plate shall then be removed and measured. The requirement will be met if the surface cleanliness level of the plate increases by no more than 50ppm

R-46 [R, I] *During installation of the shroud in the chamber particulate debris must be minimized, or any particulates produced must be easily removed.*

The use of protective covers to trap particulates during installation should be considered, but ideally the design of the shrouds shall be such that no material is capable of producing particulates.

2.1.7 Operational Requirements

R-47 [R] *All potentially trapped volumes exposed to vacuum shall be vented.*

R-48 [R, A] *The shrouds shall be designed for 4000 cycles over a 20 year lifetime.*

R-49 [R, T] *The sum of all leaks from the shroud shall not exceed 1x10⁻⁸ mbar.l/s of Helium. (See Appendix 3.4 for testing method).*

R-50 [R] *Panels that can be removed from the inside of the chamber shall be fitted to the shroud to cover the apertures detailed in Section 2.2*

R-51 [R] *These removable panels shall be supplied with the necessary equipment for their removal and refitting.*

R-52 [R] *It shall be possible to remove and reinstall the shroud from the chamber without opening the door at the "dark end" of the chamber.*

2.1.8 Transportation and Storage Requirements

R-53 [R] *The contractor shall provide containers for the shroud to provide adequate protection against damage to the shroud during transportation to the customer.*

R-54 [R] *The shroud containers shall provide adequate protection against damage to the shroud and maintain the required cleanliness levels during storage in ambient indoor conditions at the customer's premises.*

R-55 [R] *The container shall be fitted with a waterproof cover to protect it during movement to and from the storage area.*

R-56 [R] *The transport containers shall be designed for lifting by forklift truck.*

R-57 [R] *The dimensions of the transport containers shall be no greater than 5m in width (this is the size limitation of the loading bay door into R100 where the vacuum*

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chambers are).

R-58 [R, T] The shroud shall be shipped to the customer by the contractor using a means capable of maintaining the cleanliness requirements of the shroud.

2.2 Specific Requirements

R-59 [R] Each panel shall fit within the allowed accommodation volume as defined in the interface drawings listed in Table 1 below:-

KE-0266-030	STC2 CADs showing chamber and allowable volume
KE-0288-060	STC2 CADs showing chamber and allowable volume
KE-0266-111	STC2 LN2 Pipework
KE-0288-111	STC3 LN2 Pipework

Table 1 Interface Drawing Applicability

These interface drawings define:-

- *Accommodation Volumes*
- *Mounting Points*
- *Lifting Points*
- *Cut-Outs*
- *LN₂ Connections*

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3 Appendix

3.1 Specification for Existing Panels (For Information only)

Existing Panels Specification		
Reference KE-0266-410-D (Body panel) KE-0266-431-A (Extrusion)		
Dimensions		
Length	3120	mm
Width	1040	mm
Thickness	3	mm
Material	6061-T6	Aluminium
Flow path	3	double pass extrusions
Pressure drop	6	passes in the extrusions
Calculated mass	43	kg
Emissivity- external face	0.2	
Emissivity-internal face	0.87	
Parasitic Heating		
Heat Flux	55	W/m ²
Thermal radiation	177	W per panel
Supports	20	W per panel
Total	197	W per panel
Thermal radiation	7310	W per chamber
Supports	920	W per chamber
Total	8230	W per chamber
Duty Load - Single panel maximum	2500	W per panel
Duty Load -chamber maximum	18000	W per chamber
Minimum Temperature	-196/77	C/K
Maximum Temperature	120/393	C/K
Internal pipe connection to aluminium friction welded joint on the panel		
OD	12.86	mm
Wall	1.41	mm
ID	10.04	mm
Feed & Return Pipe		
OD	12.7	mm
Wall	0.8	mm

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ID	10.1	mm
Manifold Pipe		
OD	22	mm
ID	18	mm

3.2 RAL Space Liquid Nitrogen Supply information (Outside storage tank)

Liquid Nitrogen Supply (Outside storage tank)		
Capacity	40000	litres
Normal working pressure	3	bar G
Relief Valve set pressure	3	bar G
Burst Disk set pressure	8	bar G
Maximum delivery rate	2	tonnes per hour
Maximum delivery rate - STC2	1	tonnes per hour
Maximum delivery rate - STC3	1	tonnes per hour

3.3 RAL Space Liquid Nitrogen Supply information Phase Separator STC2 &STC3

A phase separator is mounted above each chamber to deliver liquid nitrogen to that chamber. The delivery pressure of liquid nitrogen should consider the hydrostatic head generated.

Phase Separator STC2 &STC3		
Capacity	500	litres
Normal working pressure	1	bar G
Relief Valve set pressure	3.5	bar G
Supply Pipe Foam Length	4	m(estimated)
Supply Pipe vacuum insulated length	82	m(estimated)
Supply Pipe vertical rise	11	m(estimated)
Inlet valve trim Kv	2.6	(m ³ /hr)
Maximum Delivery Rate	959	Kg/hr (by analysis)
Valve opening	100	%

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3.4 Panel LN2 Pipework Leak Testing Methodology

The LN2 pipework proposed (by the contractor) shall be tested to confirm that they do not contain any leaks. The LN2 pipework should also be used by the contractor to cool the completed panel assembly, to demonstrate no problems with differential expansion, buckling etc. that STFC-RAL has reported on existing panels. The two methods below are suggested by RAL as acceptable methods to prove that the panels are leak tight but the contractor can propose alternate methods for RAL space approval.

If the LN2 pipework is separate and to be added to the panel for final assembly, the test sequence shall be;

1. Leak test at ambient temperature
2. Temperature cycle between 77K and 400K
3. Leak test at ambient temperature
4. Leak test after final assembly at ambient temperature

The LN2 pipework must meet the leak rate requirement after temperature cycling before it is fitted to the shroud panel.

The final leak test after assembly is required to demonstrate that during assembly the pipework has not been damaged.

If the LN2 pipework is part of the panel, the test sequence shall be;

1. Leak test at ambient temperature
2. Temperature cycle between 77K and 400K
3. Leak test at ambient temperature

Leak Test Methodology

A leak test shall be performed on the LN2 pipework using a Helium Leak Detector. The LN2 pipework shall be evacuated to a vacuum (provided by the He leak tester) and then Helium gas sprayed over the entirety of the pipework with particular focus on the welds. The leak rate should be less than $1e-8$ mbar.l/s.

If the leak rate exceeds this value, the contractor shall locate all leaks and repair to acceptable quality consistent with the proposed longevity of these panels.

Temperature Cycling

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Each panel LN2 pipework shall be subjected to a thermal cycle test. The test shall subject the LN2 pipework to at least 2 cycles of cooling to -196°C (77k) and warming back to 400K.

There are two possible methods for performing this test.

Method 1

Connect one end of the LN2 pipework to a Dewar full of LN2 and leave the other unconnected. Open the Dewar valve to allow LN2 to enter the LN2 pipework. Monitor the temperature of the welded joints using a temperature sensor, and when all of them have reached 77K close the Dewar valve and allow the pipework to warm up.

Method 2

Immerse the entire LN2 pipework in a shallow bath of LN2. After at least 5 minutes in the bath the LN2 pipework should be removed and allowed to warm-up.

Post Temperature Cycling Leak Testing

After the basic leak test and LN2 stress tests and additional Leak Test should be performed. Each panel should be bagged and the bag filled with helium. This test will look for porosity as well as an instantaneous leak. The manufacturer must document and issue these results.

CAUTION

A thorough risk assessment of the chosen cooling method must be undertaken by the Contractor before any testing is undertaken. The presence of large quantities of LN₂ and cold gaseous N₂ poses serious risk of burns, and suffocation due to the exclusion of oxygen. If the Contractor considers these two test methods to be too hazardous, then they should propose alternative methods or state in their proposal why they cannot perform this test.