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Appendix 12 Leak Testing

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ITER Vacuum Handbook
Appendix 12

Guide to Leak Testing of Components for the ITER Project

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12 Vacuum Leak Tightness and Testing

12.1 Scope and Status

As an Appendix to the ITER Vacuum Handbook, the status of this document is advisory and not mandatory on the supplier of any component. Nevertheless, it is strongly advised that the requirements of this document are adhered to for the supply of vacuum components to ITER.

The purpose of this Appendix is to define the criteria for the leak tightness of vacuum related components supplied to ITER. It is applicable to equipment destined for use on the ITER facility and any other area on site, which utilises items and assemblies with a vacuum boundary. It defines the test criteria and gives general instruction and guidelines to those persons, be they on site at the supplier, on site at ITER, or as part of an off site organisation which is called upon to perform vacuum helium leak detection.

12.2 General

Tests shall be performed both at ambient temperature and at the maximum and minimum working temperatures of the component, with the pressure differential in the same direction as for operation of the component. Where possible, component parts shall be tested before assembly. However, final assemblies must also be tested.

Where it is not envisaged that leak tests will be performed at cryogenic temperatures on vacuum components which are for use on cryogenic systems, a method of “thermal shocking” of welded connections shall be agreed in advance.

The supplier is responsible for all jigs, seals and equipment to allow the leak tightness to be proven across all vacuum boundaries, unless otherwise stated in the contract. Where pressure testing is required, this must always be performed prior to final vacuum leak testing. Acceptance tests shall wherever possible use the same type of seal which shall be used after installation of the component.

The supplier is responsible for the supply of tooling and methodologies for the subsequent removal of jigs, seals, temporary closure plates, etc., which have been fitted to components to facilitate the leak testing of such components.

The leak test method shall be agreed in advance with ITER. This will involve the submission for approval of a procedure as part of an external supply contract. The procedure should describe how the leak test will be performed, and include configuration diagrams and full details of the equipment to be used etc.

The ITER Vacuum Responsible Officer (RO) will nominate a Vacuum Specialist to witness the acceptance leak tests and any other leak test deemed necessary as part of a manufacturing process.

In no circumstance shall ***any*** vacuum equipment be installed without an *accepted* pre-installation leak check being performed at the ITER site, without the express permission of the ITER Vacuum Responsible Officer. This applies to ***all*** Vacuum Quality Classifications.

12.3 Leak testing Methodologies

This Appendix describes recommended procedures for carrying out the most widely used methods of helium leak testing; it does not consider all available methods. Other methods may be used, but only with the prior approval of the ITER Vacuum RO

12.3.1 Over Pressure Methods

Over-pressure methods enable thin-walled vacuum chambers to be leak tested which might otherwise collapse under vacuum. This method is also useful when the equipment to be tested is already filled with a gas which can be used as the test gas. However the test gas which flows out through any leaks always mixes with contaminants present in the air, and this might reduce sensitivity.

12.3.1.1 Mass Spectrometer Sniffing Probe

Helium, or some other suitable gas, is used to slightly pressurise the component to be tested and a sampling probe “sniffs” for leaks. Helium passing through the leak is sampled from the surrounding atmosphere through a long narrow flexible tube which is connected to a mechanical pump to give a drop in pressure from atmosphere to about 10^{-2} Pa at the ion source of a mass spectrometer detector. Traces of helium or halogen in the environment can also be detected, which may lead to errors in the measured leak rate.

The helium content of atmospheric air limits the sensitivity of the sampling probe, and the detection limit is typically ~1 x 10^{-7} Pam^3s^{-1} if the volume is filled with pure helium (or the tracer gas appropriate for the detector used such as argon).

The sampling tube should be as short as possible to reduce the response time of the gas flow of the air-helium mixture from the entrance of the tube to the detector. The flow rate may also be limited by the available pumping throughput.

12.3.1.2 Probe Leak Testing (vacuum box or suction cup method)

Open objects can be tested using the vacuum box or suction cup method. A partial enclosure which can be evacuated by a leak detector is tightly pressed against the wall of the component being tested. The enclosure is evacuated and helium tracer gas applied to the opposite surface of the wall by a spray gun or other means. Helium leaking through the wall can pass to the detector via the vacuum box. This method of leak detection is widely used for the testing of welds on incomplete enclosures. The sensitivity is usually limited by diffusion of helium through the seal between the evacuated enclosure and the component wall.

12.3.1.3 Pressurisation – Evacuation (“bombing”) Test

Hermetically sealed objects which cannot be pumped out can be leak tested using the so-called “bombing” method. The component to be tested is subjected to a high pressure of tracer gas, usually helium, to force gas into the component through any leaks present. After flushing to remove adsorbed tracer gas from the surface of the component, it is placed in a vacuum chamber which is connected to a leak detector. This can then detect any tracer gas passing out of the sealed volume through the leaks. This method is usually employed as a “go/no go” test since it is very difficult to locate the position of any leaks on such components.

12.3.2 Vacuum Leak Detection Methods

12.3.2.1 Pressure Rise Test

A pressure rise test is a useful way of determining the overall magnitude of any leaks present in a component.

A vessel to be tested of volume V is evacuated and sealed off. The pressure rise ΔP is measured over a time interval Δt and the leak rate q_L (at constant temperature) is evaluated from:

$$q_L = V \cdot \frac{\Delta P}{\Delta t}$$

This calculated leak rate also includes contributions from any other gas sources such as virtual leak and outgassing.

Real leaks may be distinguished from other sources of pressure rise since a real leak gives a pressure rise which is strictly proportional to time, while virtual leaks and outgassing result in an initially rapid pressure rise which tends to level off after some time

12.3.2.2 Helium Leak Detectors

These are based on a mass spectrometer, usually a small magnetic sector device. Leak detection can begin only when high vacuum conditions are obtained in the mass spectrometer. Due to its high sensitivity this method is the most frequently used method of leak detection for vacuum applications. The inlet pressure at the entrance to the leak detector depends on the design of the unit, but can range from atmosphere down to about 10^{-4} Pa.

Helium is usually used as the tracer gas, but other gases such as argon, neon, krypton, hydrogen and mixed gases may be used with the mass analyser suitably tuned. Modern helium leak detectors are usually supplied with the capability of detecting H_2, He^3, and He^4.

To increase the helium detection sensitivity and improve detector stability, the mass analyser in helium leak detection systems is often de-tuned to give lower mass resolution. This can lead to a contribution to the measured mass 4 intensity from mass 2 and mass 3, thus giving a higher leak detector background signal at mass 4. For large component leak testing at high sensitivity, it may be necessary to reduce the partial pressure of hydrogen at the analyser by selectively pumping it with a getter in series with the leak detector input. It may also be necessary to selectively pump condensable gasses at the leak detector inlet. This can be achieved by the addition of a cold (e.g. liquid nitrogen) trap in series with the inlet.

12.4 Procedure for Helium Leak Tightness and Testing

12.4.1 Equipment

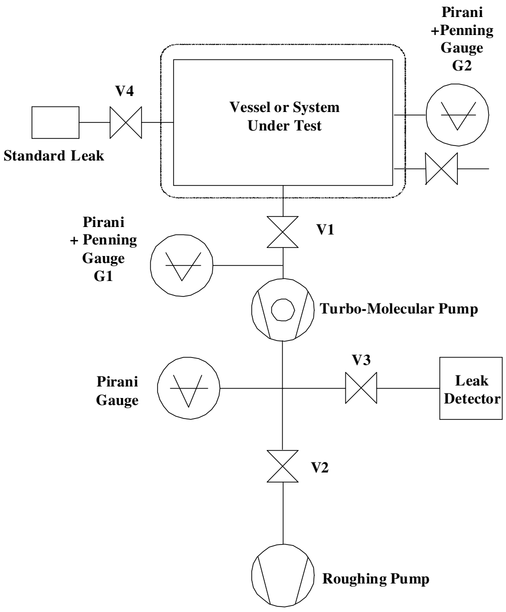

Figure 12-1 Typical Leak Detection Equipment

12.4.2 Pumping System

An indication of the basic elements of a pumping system, which could be used for leak detection, is illustrated in Figure 12-1. In this form it consists of the following items: -

1. A turbo-molecular pump isolated by a valve V1 and backed by a roughing pump via a valve V2, of enough pumping capacity to pump the system under test down to a suitable pressure at the inlet of the leak detector. Ideally all fittings and seals (at least those on the high vacuum side) should be all-metal to alleviate the problem of helium permeation.

2. A Pirani gauge to measure the pressure in the backing line of the turbo-molecular pump and a pressure gauge system (G1) on the high vacuum side of the turbo-molecular pump (but below valve V1) capable of measuring in the range 0.1 MPa to 10^{-7} Pa.

Possible additional options to this pumping system could include a quadrupole or other type of mass spectrometer to measure the residual gas spectrum. This is essential if system cleanliness is to be assessed. A hydrogen getter and liquid nitrogen trap may be used to lower the detector background signal.

A vent valve on the vessel side of V1 is also advisable for venting the item under test to a clean dry gas such as nitrogen to retain cleanliness.

12.4.2.1 Detection System

This is the system used to detect any vacuum leaks which may be present, thus it is the central part of the system and normally consists of the following items:

1. A helium mass spectrometer leak detector installed such that it can be connected into the backing line of the turbo-molecular pump through valve V3. For maximum leak detection sensitivity, it should provide the necessary backing pressure for the turbo-molecular pump. It therefore should have its own pumping system comprising a turbo-molecular and backing pump combination. It must be able to detect leaks at least one order of magnitude smaller than that required by the specification of the item under test, and up to at least 100 Pam^3s^{-1}.

   It should be noted that with modern leak detectors, it is possible to suppress the background and gain up to 2 orders of magnitude in sensitivity. Although this mode is useful in localising leaks, it shall not be used for the purpose of acceptance testing without prior approval by the ITER Vacuum RO.

   An alternative when the item under test is of relatively small volume of less than 1 m^3, and when only a simple cold leak test is required, is to use the mass spectrometer leak detector on its own. In this case the leak detector is connected directly to the item under test. The separate turbo-molecular and roughing pump system is not required.

   If there is a large leak on the item to be tested or where the pumping system is incapable of pumping the item under test to a sufficiently low pressure for the leak detector to be connected directly to the backing line of the turbo molecular pump, valve V2 may be left open and valve V3 partially opened so that the leak detector samples part of the gas stream to the backing pump. This configuration may be used to locate, but not size, any leaks.

2. A pressure gauge system (G2) on the vessel under test, capable of measuring in the range 0.1 MPa to 10^{-7} Pa.

3. A calibrated helium standard leak of value commensurate with the magnitude of leak rate required by the specification of the item under test, mounted on the system under test, and isolated by valve V4. Traceable calibration certificates shall be kept for this item and these should be readily available.

4. A helium bag or other enclosure fashioned in such a way that the test gas can surround all parts of the item under test with a concentration preferably exceeding 50% in air.

5. A system for continuous recording of the leak test process. This can be achieved by using an analogue recording device such as a paper strip chart recorder connected to the output of the helium mass spectrometer leak detector or by continuous logging (and display) of data on a computer or dedicated data logger.

12.4.2.2 Miscellaneous

The following equipment is optional but experience has shown the items to be of use in helium leak tests.

1. A standard vacuum cleaner to pump the helium enclosure out if it is a sealed collapsible type such as a plastic bag before inflating it with helium, to ensure maximum concentration of the helium in the enclosure.
2. A helium-in-air concentration monitor to ascertain the percentage of helium in the bag or other enclosure during the test.
3. A triggered helium spray gun for subsequent probe testing of the item to localise any leaks found during the global leak test.

12.4.3 Preliminaries

12.4.3.1 Initial Checks on the Leak Detection System

1. With valve V2 open and valves V1 and V3 closed, the roughing pump is started. When the pressure falls to a suitable level, the turbomolecular pump is started and left until the pressure on gauge G1 stabilises.
2. The leak detector is switched on and when it is ready, an internal calibration is carried out as per the manufacturer's instructions.
3. The backing line Pirani gauge pressure reading is noted and valve V3 is carefully opened so that the leak detector does not trip out. (Most modern leak detectors can cope with this.)
4. The roughing pump valve V2 is closed.
5. When a relatively stable reading has been obtained on the leak detector, a leak check is carried out, by using a helium gun to probe with helium gas all joints and welds up to and including the pumped sides of V1 and V3.
6. If any leaks are found of magnitude greater than one decade smaller than the maximum leak rate called for in the specification of the item under test, then these shall be rectified and this sequence repeated until no such leaks are found.

12.4.3.2 Pump-down

Before the leak test can be undertaken, the item under test must be pumped down to the requisite pressure. In the case of the system shown in Figure 12-1 which uses a turbo-molecular and roughing pump set, the following actions shall be performed.

1. The roughing pump is started and valves V1 and V2 are opened.

2. When the system Pirani pressure reaches the level given in the manufacturers instructions the turbo-molecular pump is started.
3. The system is ready for initial tests when the pressure reaches 10^{-3} Pa or lower on G1, or such other pressure specified as suitable by the manufacturer of the leak detector. If it does not reach this pressure then there may be a large leak present which must be located and rectified. It should be located using either an overpressure technique as described in Section 12.3.1.1 or the procedures of Section 12.4.5.2 but with valve V3 only partially opened so that the pressure at the inlet of the leak detector remains below the upper pressure limit specified by the manufacturer with the gas flowing to the roughing pump being sampled into the leak detector.

12.4.3.3 Background Determination

After a stable pressure reading has been obtained on gauge G2 with valves V1 and V2 open and the turbomolecular pump set running normally, with the leak detector fully functioning and the data logging device connected and operating, then the roughing valve V2 is closed and the leak detector valve V3 opened.

The leak detector reading is monitored until it has stabilised, without any electronic correction. This should take around 10 minutes, but the time can be longer depending on the size of the system under test.

This reading is recorded as the background level. Any reading above this value during the overall test constitutes a positive indication of a leak.

12.4.4 Leak Detector Calibration

With the system in the state as above for background determination, leak detector calibration shall be performed.

Valve V4 is carefully opened and the reading on the leak detector monitored until it is stable. This should correspond to the value of the standard leak to within ±5% after suitable corrections for the age of the standard leak and its temperature have been applied.

If a response time measurement is not required, then V4 is closed and the reading should then return to the background level.

12.4.4.1 Response and Cleanup Time Measurement

This should be done for a large system or where there is a long path length involving small bore tubes. This ensures that the duration of the overall test will be valid.

1. With the standard leak open to the system and the leak indication stable at the value of the standard leak, suitably corrected for age and temperature, valve V4 is closed.

2. The time taken for the reading on the leak detector to return to the background level is recorded. This is the cleanup time for the system and will depend on the applied pumping speed for helium and the configuration of the system under test.
3. When the background level has been attained, valve V4 is opened and the time taken to return to the level of the standard leak indication, suitably corrected, is recorded. This is the response time for the system.
4. Valve V4 is closed and the system is allowed to return to the background level.
5. This concludes the initial set-up tests and the overall leak test may then be undertaken.

12.4.5 Cold Leak Tests

12.4.5.1 Global Leak Check

If all the preceding conditions have been met with all equipment functioning and ready for use, a global cold leak test may be carried out according to the following procedure.

1. The data recording system is connected to the output of the leak detector and started and the date and time are recorded.
2. Valves V1 and V3 are opened and valves V2 and V4 are closed.
3. When the background reading is stable and is at a level consistent with the leak specification of the item under test, which will be for most purposes at least an order of magnitude lower than the specified maximum leak rate of the component under test and without electronic correction, the global leak check may be started.
4. The component under test is surrounded by a suitable helium enclosure. If the helium enclosure is a flexible type, it should have as small a volume as possible. The enclosure is filled with helium to a concentration of at least 50% in air and the time is recorded in the data log
5. Helium should remain in contact with the item under test for at least 10 minutes or longer, depending on the size of the object and the response time previously measured, or for the time specified in the test specification for the component under test, whichever is longer.

   In the case of components where there might be possible low conductance leak paths, for example porosity, the time required for a sensible test may be significantly longer than the response time measured for the system using the techniques of Section 12.4.4.1. Details of the method and time of duration of helium application shall be included in the leak testing procedure to be *accepted* by the ITER Vacuum Responsible Officer.
6. Where the helium enclosure is not completely sealed, then suitable precautions shall be taken to ensure that helium cannot back-diffuse through the roughing pumps and/or the leak detector pumps into the mass spectrometer detector. In the

case of long-duration global tests, it may be advisable to house these items in a separate enclosure held at a small positive pressure above atmosphere.

7. After the appropriate time interval, the helium supply is closed off (where appropriate), and the enclosure vented to atmospheric air and removed. The time is recorded in the data log.
8. If the leak rate indication on the leak detector has not risen by more than the specified maximum leak rate at any time during this test procedure, the item under test shall be deemed to have passed, subject to the requirements of Section 12.4.5.3.
9. It may be advisable to recheck the background reading and leak detector calibration if the global test has been of significant duration. When that has been done according to the procedures of 12.4.3.3 and 12.4.4, then the global leak test is complete.
10. Valves V1 and V3 are closed and valve V2 opened.
11. The item is vented, or left under vacuum for further work as required.
12. If the leak rate reading during the test has at any time exceeded the specification value, then the item has failed the test, and the leaks shall be located using the procedures of Section 12.4.5.2.

12.4.5.2 Probe Tests

These are necessary to locate any leaks greater than the value in the specification of the component being tested which may have been indicated during the global test. They may be required not only at this stage, but may be needed also after the hot global test and the final cold global test, if those two tests are required as part of the contract or other instruction.

The following procedure shall be used, although others are possible and may be used after prior agreement.

1. Any helium enclosure or other covering or obstruction is removed from the item under test wherever possible.
2. If the component under test is at cryogenic temperatures, it may have to be warmed to ambient temperature before probe tests can be carried out.
3. Valves V1 and V3 should be open and valves V2 and V4 should be closed.
4. In the case of a large item, the data logging system shall continuously record the leak detector signal so that any longer term variations in leak rate may be observed.
5. Using a helium gun, helium gas is sprayed over or into all suspect locations and under any non-removable coverings, starting at the top of the item under test and working down as required. The helium spray should be introduced to the area under test for a time period consistent with the response time of the system measured in accordance with Section 12.4.4.1

6. If a leak indication is found, then the point of maximum reading shall be localised. For subsequent testing to localise any other leaks, it is advisable to blanket that point with a physical barrier such as a polythene bag or sheet or with a stream of another gas whilst checking the remainder of the system.
7. When all detectable leaks have been located, then the leak detector is isolated by closing valve V3. Valve V1 is closed and the item under test shall be vented to dry nitrogen or clean dry air admitted through the vent valve. The ITER Vacuum Responsible Officer shall be contacted to agree a procedure to rectify the leak or leaks.
8. When any agreed repair has been successfully accomplished, the process starting from stage 12.4.3.2 and to point 10 at the end of stage 12.4.5.1 is repeated until the item is proved to meet the relevant specification.

12.4.5.3 Acceptance Criteria

If all the stages above have been successfully completed then the item under test may be accepted by the ITER Vacuum Specialist as having met the relevant specification provided that the following conditions have been met.

1. The leak detector has been correctly calibrated and its calibration value is within ±5% of the standard leak rate value as corrected for the ambient temperature and the age of that item and that standard leak rate value is commensurate with the value of the maximum leak rate specified for the item under test.
2. The leak test has been performed by suitably qualified and experienced personnel to the *accepted* procedure, with no significant deviation from that procedure and has been witnessed by the ITER Vacuum Specialist.
3. The leak rate value as measured by the leak detector has not increased in value above the measured background to a value greater than the specified leak rate during the entire duration of the global leak test.

The location and magnitude of <u>all</u> identified leaks shall be recorded. Normally, all practicable efforts shall be made by means agreed with the ITER Vacuum Responsible Officer to reduce any leak discovered during the manufacturing phase to a level lower than the limit of detection of the leak detection method used for the tests.

12.4.6 Hot Leak Check

12.4.6.1 Test Conditions

If it is required as part of the contract or other instruction to perform a hot leak test on an item which during its life may be subject to increased temperature usage, then the following procedure shall be carried out.

1. Before commencing any part of this leak test procedure, the item under test must have completed one or more temperature cycles as specified and be at that point on the cycle where it is specified that the hot leak test shall take place.

2. The leak detector shall be set up using the procedures of Sections 12.4.3.3 and 12.4.4. If the response time of the system has already been determined, or is not required, it need not be re-measured.
3. If the background is elevated when the item under test is at temperature (as may often be found), then the conditions stipulated in 12.4.5.1 Point 3 may not be met. However with judicious choice of scale it may be possible to do a perfectly valid leak check at a raised background level. It may also be necessary to selectively pump hydrogenic species from the leak detector input gas stream. This can be done by the correct choice of getter installed in series with the leak detector inlet. The applicable conditions for this test must be agreed with the ITER Vacuum Responsible Officer.
4. The helium enclosure used for these tests must be capable of tolerating temperatures above ambient since the increased thermal conductivity of helium will raise the temperature of this item above the level it would reach with only atmospheric air in the enclosure.

12.4.6.2 Global Leak Check with the Component under test Hot

Essentially, this is a repeat of the cold global leak test described in Section 12.4.5.1 except that, if a leak indication is observed, the item may need to be cooled down before probe tests can be performed. The temperature at which the hot leak test is performed shall be recorded and shall be within the limits as specified in the leak testing procedure.

If, with the component at the specified hot temperature, no leak rate of size greater than that specified for the component has been observed, then provided that the conditions of Section 12.4.5.3 have been met, the component will be deemed to have satisfied the hot leak test requirement.

If, however, with the component at the specified hot temperature, a leak rate of size greater than that specified for the component has been observed, then a probe test to localise any leaks present must be undertaken.

The supplier should be aware that under some conditions, a leak may be observed at temperature but may disappear when the component is cooled to ambient temperature. If this is the case, then it may be necessary to implement an agreed procedure for leak location at elevated temperature.

12.4.6.3 Probe Test

1. This method of probe leak testing baked components is the essentially the same procedure as detailed in 12.4.5.2., but with additional steps as noted below:
2. If the probe test cannot be carried out at the hot temperature, the component shall be cooled to ambient temperature
3. Steps 1 – 7 of section 12.4.5.2 shall be carried out.

4. If, after probe testing at ambient temperature, no leak has been identified, then, as agreed with the ITER Vacuum Responsible Officer, a further temperature cycle shall be completed as specified up to the point on the cycle where it is specified that the hot leak test shall take place.
5. Then either
   a. an agreed procedure for leak location at this elevated temperature shall be carried out

   or

   b. the component shall be cooled and step 2 of this Section shall be carried out in the hope that the hot leak may have opened up further and now may be detectable at or close to ambient temperature.
6. Step 5 shall be repeated until no leaks which have not been localised are evident at the hot temperature.
7. When all detectable leaks have been located and the component is close to ambient temperature, then the leak detector is isolated by closing valve V3. Valve V1 is closed and the item under test shall be vented to dry nitrogen or clean dry air admitted through the vent valve. The ITER Vacuum Responsible Officer shall be contacted to agree a procedure to rectify the leak or leaks.
8. When any agreed repair has been successfully accomplished, the global hot leak test procedure of this Section is repeated.

12.4.6.4 Final Cold Acceptance Check

This test shall be carried out following a satisfactory global hot leak test procedure when the item under test has cooled down to a temperature in the range 60°C to 80°C, since experience has shown that small leaks can be blocked by water vapour below this temperature.

It shall follow the procedures of Section 12.4.5.1.

12.4.6.5 Acceptance Criteria

These shall be the same as those specified in Section 12.4.5.3

12.5 Responsibilities

It shall be the responsibility of the supplier to ensure that all vacuum leak tests carried out off-site and of the ITER Vacuum Responsible Officer when such tests are carried out on-site that they be performed in accordance with the contract or other specification. All deviations from such specification or agreed variation thereof shall require a non-conformance to be raised covering each specific case. In the case of any particular component, a nominated ITER Vacuum Specialist may witness the tests.

All records as detailed in the following section shall be completed and shall become part of the final document package for the component concerned.

12.6 Reporting

Full records of the tests carried out on any component shall be completed in order to maintain traceability of the leak test history of a particular item. The records shall consist of the following.

1. Data records of the output of the leak detector for all the global tests specified including the standard leak calibration and response time determination. These data records shall include the date and time of all tests as well as anything else of relevance, such as the start and finish time of helium gas application to the item under test.
2. A record of the helium concentration during the leak test where that is required. In the case of a simple cold leak test this will be on request of the ITER Vacuum Responsible Officer, but in the case of a full cycle of leak testing involving temperature variation it will be required.
3. A record of the system total pressure throughout a temperature cycle since it may pinpoint the time when a leak opened up and be instrumental in the subsequent diagnosis of the leak.
4. The make, model and date of manufacture of the helium mass spectrometer leak detector used in the tests.
5. The nominal value of all standard leaks used, their date of calibration, ageing and temperature characteristics, and the ambient temperature(s) experienced during the tests.
6. The results of all tests showing whether it was a pass or fail, and, if a failure, the measured leak rate and the location of the leak, together with the steps taken for any repair or elimination.

   The magnitude and location (if applicable) of ***all*** leaks identified during testing shall be recorded. This includes leaks of magnitude lower than the acceptance criteria for which no remedial action may have been taken.