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Appendix 10 Vacuum Cables

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ITER Vacuum Handbook
Appendix 10

Guide to the Supply of in-Vacuum Cables for the ITER Project

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10 Requirements for the Supply of In-Vacuum Cables for the ITER project

10.1 Scope of this Appendix

The ITER project will include up to 80 km of in-vacuum cabling. This Appendix provides information on the various *accepted* forms of cabling for use on the ITER project for each Vacuum Quality Class, as well as general guidelines for their use.

It is intended that the *suppliers* of in-vacuum cables should follow the guidance in this Appendix to achieve the requirements of the ITER Vacuum Handbook.

The *supplier* is at liberty to utilise other techniques not described in this Appendix provided that the components manufactured comply with the requirements of the ITER Vacuum Handbook.

10.2 General

In-vacuum cabling should comply with all the general vacuum requirements for its Vacuum Quality Class (VQC). *Accepted* cable types for each VQC are listed in Table 10-1.

Use of cable insulation containing halogens is strictly forbidden for all VQC. Fluoropolymer (Teflon, Tefzel, PTFE, PFA, FEP, ETFE,etc…), PVC and Fluorosilicone sheathed cables are therefore completely forbidden.

Table 10-1 - *Accepted* vacuum cabling

Cable type	Vacuum Quality Class			
	VQC1	VQC2	VQC3	VQC4
Single Core Coaxial Solid Sleeved Mineral Insulated Cable (MI cable)	✓	✓	✓	✓
Multi-core Coaxial Solid Sleeved Mineral Insulated Cable (MI cable)	†	✓	✓	✓
Tri-axial Mineral Insulated cable	†	✓	✓	✓
Metal braided Fibre insulated cable	†	✓	†	✓
Ceramic coated wire	✓	✓	✓	✓
Bare wire / Non insulated cable with ceramic breads or spacers	†	†	†	†
Optical fibre Ceramic / metal coating	✓	✓	✓	✓
Polyamide, Kapton® coated cable*	×	✓	×	✓
Epoxy / resin insulated cable*	×	†	×	†
Nylon sheathed/braided*	×	†	×	✓
Silicon rubber insulated wire (Fluor free)*	×	×	×	×

Polyurethane, Polyethylene, Polypropylene, Polyester, Plastic *	×	×	×	×

✓ Cable *accepted* for use
× Cable prohibited from use
† Restricted use conditions apply

* restriction on baking temperature to be considered

Any other cabling type and changes to Table Table 10-1 is subject to *acceptance* procedures as detailed in the ITER Vacuum Handbook

Silver plated conductors should be avoided in VQC 1.

10.3 Mineral Insulated cable (MI)

The procurement specifications and manufacturing control plan needs to be tightly controlled and should be submitted for *acceptance* before tender in order to mitigate the potential of cabling adversely affecting the ITER vacuum.

The procedures should include:

- A high standard of cleaning for vacuum and of the handling of the constituent parts of the cable.
- Method of packing the insulant (A high and defined packing density of insulate so as to limit the void fraction ideally to <5 % this may be achieved by using preformed solid insulate rather than powder and specifying a hammering operation after each drawing operation during manufacture).

In addition:

- Cables need to be sealed and vacuum leak tested by helium “bombing”, prior to installation. A He leak rate of $<10^{-10}$ Pa.m^3/s shall be achieved.
- Cables should be proven to achieve outgassing rates of lower than 10^{-9} Pa.m^3/s/m for hydrogen and 10^{-11} Pam^3/s/m for other species at 100ºC (after a 48 hour 200ºC bakeout cycle for cables of <5mm diameter).
- The use of tri-axial MI cable will be limited and subject to specific *acceptance*.
- The use of multi-core cable will be limited and subject to specific *acceptance*.

10.4 Metal braided fibre insulated cable

The use of metal braided ceramic fibre insulated cable is to be limited in VQC 1 and 3 systems and MI cable will be preferred for use whenever possible. Any proposed use requires specific *acceptance* by the ITER Vacuum Responsible Officer at the design stage.

If such cable is *accepted* for use, the procurement specification and manufacturing control plan should be submitted for *acceptance* by the ITER Vacuum Responsible Officer. This plan should ensure that manufacturing processes are tightly controlled to ensure low vacuum outgassing and should include:

- Cleaning and air bakeout of the constituent parts of the cable prior to assembly.
- Vacuum outgassing testing of the constituent parts of the cable prior to assembly.

- Control of cleanliness in assembly, in particular the use of dedicated dry machines.
- A high vacuum standard of handling component parts of the cable.

In addition:

- Cables should be proven to achieve outgassing rates of lower than 10^{-9} Pa.m^3/s/m for hydrogen and 10^{-11} Pam^3/s/m for other species at 100^o C (tested after a 48 hour 200ºC bake out cycle for cables of <5mm diameter).
- Possible nuclear heating of this type cable should be considered and special care shall be taken to avoid any detrimental effects on vacuum.

10.5 Other cables

Any cable used on VQC 1, 2 and 3 will be subjected to an *acceptance* criteria and to a detailed control plan. A high standard of cleaning for vacuum and of handling needs to be applied. An outgassing test should be performed prior to *acceptance*. In addition to initial vacuum compatibility of the cable, fire hazard and radiation resistance need to be considered.

- There is no limitation for Bare Wire with ceramic insulator spacers from a vacuum point of view if the cable is manufactured from *accepted* materials and if the appropriate cleanliness for its VQC has been achieved. From a practical point of view, it is advisable to limit their use to short distance cabling (less than 1m) and to detector internals.
- Polyimide and Kapton® coated cables are *accepted* for use on VQC 2 and 4, and are possible alternatives to MI or Fibre insulated cable for these VQC. PEEK outer weaving is *accepted* for cable bundles if required, but metallic woven sheaths are preferred.
- Any non-listed cable should undergo qualification tests prior to *acceptance*. Tests should, at the minimum, include a vacuum outgassing test over the whole operational temperature range, residual gas analysis and radiation aging tests.
- Silver plated conductors are strictly limited in VQC 1, 2 and 3.

10.6 Connectors and Terminations

All Mineral Insulated cables should be of the vacuum-tight termination type (both ends), and should not be perforated. Leak tightness will be proven by helium "bombing" of the cable, followed by leak detection. A leak rate of $<10^{-10}$ Pa.m^3/s is to be obtained. If the cables are part of a feedthrough assembly, the full feedthrough assembly should be leak tight to $<10^{-10}$ Pa.m^3/s.

Cable terminations made after crossing a boundary for VQC 1 and VQC 2 systems should be within a suitable termination vacuum enclosure connected to the SVS. This space can be within a feedthrough interspace and is to be connected to the SVS by 2 connections (½ inch VCR™ couplings are envisaged).

In-vacuum connectors should be designed for vacuum compatibility and are to comply with the general vacuum requirements for the relevant VQC. This includes, among other factors: design, materials, manufacturing process, cleaning and outgassing.

10.7 Cable Routing

It is not permitted for cables to pass across a pressure boundary to atmosphere.

The following considerations should also be taken into account when routing the cables.

- The routing scheme should offer good protection against damage to cables. Loops should be properly designed to permit adequate gas pumping, whilst protecting the cables from external contamination.
- The routing should offer appropriate thermal contact of the cable with cooled components to avoid any overheating of the cables that might affect vacuum performance or cable integrity.
- Thermal expansion and contraction of cabling shall be considered in the design.
- High voltage cables and signal cables shall be separated where possible.

10.8 References

[1] ITER D 22H4HUv1.0, FDR01-DDD18 31 Vacuum Pumping and Fuelling.

[2] R.J.H. Pearce and Al. Fusion Engineering and Design 82 (2007) 1294–1300 – "ITER relevant outgassing and leakage from different types of in-vessel cabling"

[3] G.Vayakis and Al., ITER IT, JAERI NAKA, N 55 RI 37 04-02-19 W 0.1

[4] R. Pearce and Al., UKAEA, TW3-TPDS-DIADEV, ITER D222N5N

[5] G 55 MD 32 98-06-02 F 1, "Table 2.4.1-2 - cable specifications"

[6] G 55 MD 37 98-06-03 W 0.1, "Table 2.4.4-1 - cable for use in-vessel"

[7] G 55 MD 5 96-12-11 W 0.1,DIAGNOSTIC ENGINEERING NOTE 19