

## Call for Nomination Documents

# Summary of the Technical Specification for IVC Conductor Irradiation testing

Summary of the technical specification. To be used for the Call for Nominations.

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## 1 Purpose

This technical specification specifies neutron and gamma irradiation tests and associated services to assess the performance and reliability of a prototype In-Vessel Coil (IVC) conductor. The Contractor shall be in charge of the definition of a time and cost effective irradiation test program to be reviewed by ITER, if approved, be responsible for all aspects of its implementation including quality assurance, design, manufacturing, and conduct and report the results from the irradiation tests.

A key component of the IVC conductor is the mineral insulation which consists of compressed MgO powder. The insulation provides three main functions, namely structural support of the copper conductor, thermal conduction between the stainless steel jacket and the copper conductor, and electrical insulation between the stainless steel jacket and copper conductor. The latter two functions depend on properties of the MgO which are known to be affected by radiation flux and fluence.

Although prior research has addressed these effects, the results are known to be highly dependent on the composition of the MgO (grain size, compaction, impurity content) as well as the spectrum of flux and fluence.

The purpose of the tests described here is to characterize the radiation effects on the insulator, nominally MgO, as formulated and integrated into the planned Mineral Insulated Conductor (MIC) configuration under irradiation test conditions which simulate conditions in the ITER fusion reactor. This specification provides a description of the test samples, test procedures, and measurements which are required to characterize the behaviour of the MIC in a radiation field so that the assumptions used in the design process can be confirmed and/or refined.

## 2 Acronyms and Definitions

ELM coils	Edge localized mode coils
VS coils	Vertical stabilisation coils
IVC	In-Vessel coils
IO	ITER Organization
PF	Poloidal Field
RO	Responsible Officer
IT	Irradiation Testing
SS	Stainless Steel
TBD	To be defined
RIED	Radiation Induced Electrical Degradation
RIC	Radiation Induced Conductivity
RITES	Radiation Induced Thermoelectric Sensitivity
RIEMF	Radiation Induced Electromotive force
TIEMF	Thermally induced Electromotive force
RITCL	Radiation Induced Thermal Conductivity Loss

CONDUCTOR: In this document, the term conductor is used for the part formed of a tube of copper, insulated by mineral, inserted into a metal jacket and compacted.

### 3 Background

#### 3.1 ITER In-Vessel Coils

ITER is project now underway in France to construct a device that will demonstrate nuclear fusion power at a power plant relevant scale. ITER relies on magnetic confinement of a deuterium – tritium plasma to achieve thermonuclear conditions. The main components of the magnetic field are supplied by superconducting coils located outside the ITER vacuum vessel.

However, a set of in-vessel coils (IVCs) is required to make local adjustments to the field on a fast time scale.

ITER is incorporating two types of In-Vessel Coils (IVCs): ELM Coils to mitigate Edge Localized Modes and VS Coils to provide Vertical Stabilization of the plasma. The ELM coils consist of three (upper, midplane, and lower) 6-turn rectangular “picture frame coils”, for a total of 27 coils. The VS coils consist of one upper and one lower 4-turn solenoidal “ring” coil connected in an anti-series “saddle” arrangement. Strong coupling with the plasma is required so that the ELM and VS Coils can meet their performance requirements. Accordingly, the IVCs are in close proximity to the plasma, mounted in between the blanket shield modules and the vacuum vessel. All IVCs are supported via bolts to the rails which are welded to the VV wall. This location leads to difficult integration with diagnostics and cooling water manifolds, and results in a radiation and temperature environment that is severe necessitating new solutions for material selection as well as challenging analysis and design solutions.

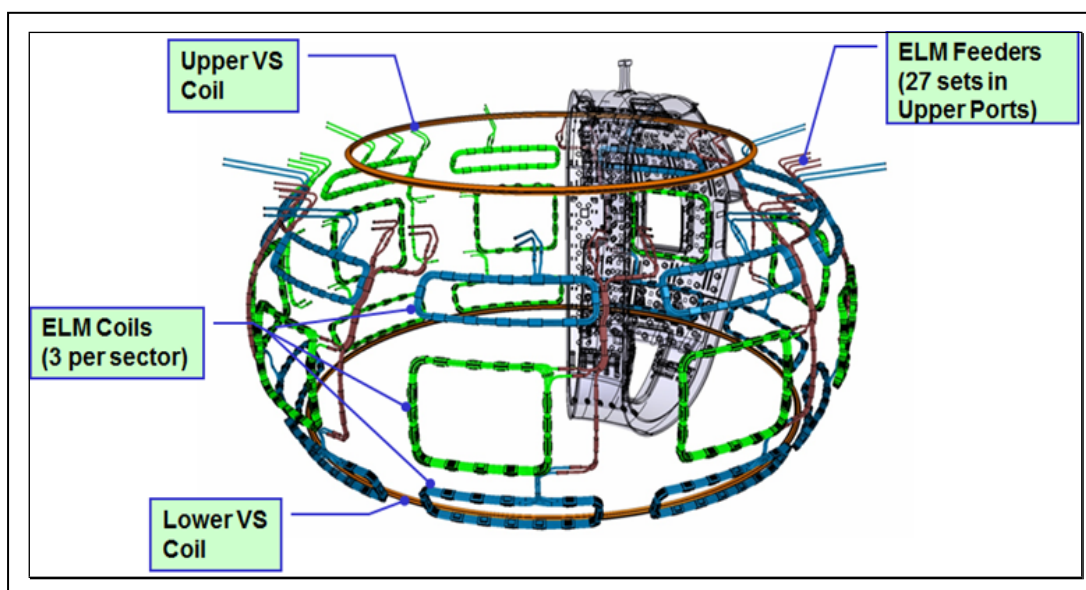


Figure 1: Overview of the IVCs inside the machine

### 3.2 IVC Conductor

The in-vessel environment is severe, characterized by large transient electromagnetic fields, high radiation flux, and high temperature. To withstand this environment and provide the required functionality a “mineral insulated conductor” (MIC) technology has been selected for the IVC conductor [i]. A key component of the MIC is the mineral insulation which will consist of compressed MgO powder. The insulation provides three main functions, namely structural support of the copper conductor, thermal conduction between the stainless steel jacket and the copper conductor, and electrical insulation between the stainless steel jacket and copper conductor. The latter two functions depend on properties of the MgO which are known to be affected by radiation flux and fluence [ii]. Although prior research has addressed these effects, the results are known to be highly dependent on the composition of the MgO (grain size, compaction, impurity content) as well as the neutron flux spectrum and fluence. Figure 2 shows the MIC configuration, consisting of an axially water-cooled (through the hollow centre) copper conductor surrounded by mineral insulation and a stainless steel jacket.

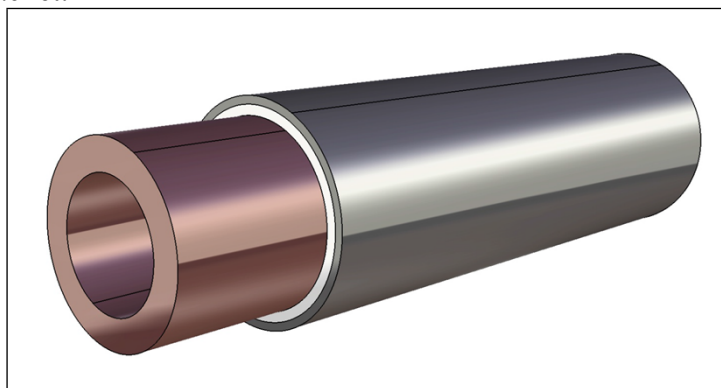


Figure 2: Mineral Insulated Conductor

Cross-section of the Mineral-Insulated Conductor for ITER ELM and VS in-vessel coils is as shown in Figure 3. Geometry and materials are listed in Table 1.

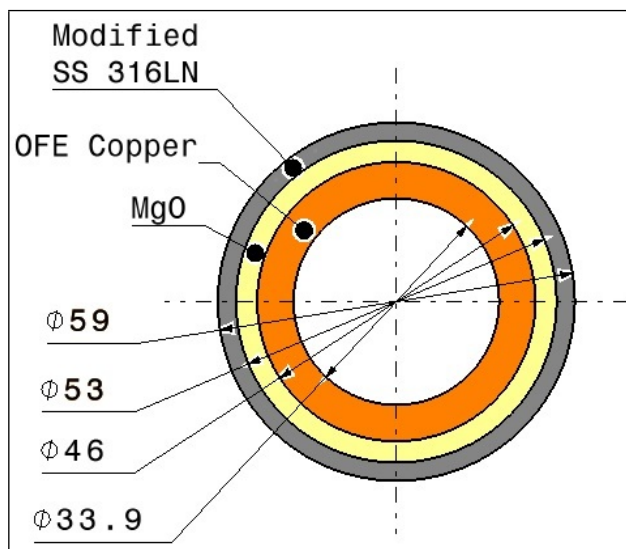


Figure 3. Cross-section of the Mineral-Insulated Conductor for ITER ELM and VS in-vessel coils

Conductor Parameter	ITER IVC MIC
Jacket material	Modified SS 316LN
Jacket outer diameter, mm	59
Jacket inner diameter, mm	53
Jacket thickness, mm	3
Conductor material	Cu-OFE CW009A
Copper conductor outer diameter, mm	46
Copper conductor inner diameter, mm	33.9
Copper conductor thickness, mm	6.05
Insulation material	Magnesium Oxide
Insulation thickness, mm	3.5

Table 1. Geometry and materials for ITER in-vessel coils Mineral-Insulated Conductor

## 4 Technical requirements

### 4.1 Contractor's capabilities

To perform the irradiation tests, the Contractor shall have access and the capacity to conduct irradiation tests in neutron and gamma irradiation facilities, including post-irradiation examination activities which require a hot-cell facility. Experience in designing complex in-situ irradiation tests including on-line measurement capabilities with control of temperature and vacuum during the irradiation test is essential. The Contractor shall have the capacity to conduct radiation damage analysis (transmutation, gas production, displacement per atom, dose rate), mainly for neutron irradiated materials and shall have an access to specific expertise in assessing radiation-induced degradation of material properties ( electrical, mechanical, thermal, outgassing) in various types of irradiated materials, such as ceramics, insulators, etc.

This Contract aims to assess, through dedicated Irradiation Tests and specific radiation effect expert studies, radiation-induced degradations of physical properties in a Mineral Insulated Conductor.

As a minimum requirement the Contractor shall have practical knowledge and understanding of gamma and neutron radiation effects on insulator materials with a particular emphasis for

magnesium oxide materials and the following effects: Effect of irradiation on electrical break-down; RIED, RIC, RITES, RIEMF, TIEMF, RITCL, neutron induced structural changes.

The Contractor shall have an access (including license) to the software package needed to conduct the radiation testing activities, i.e. software packages where applicable for:

- Ionising dose calculation
- Design including CAD work
- Data acquisition
- Data processing.

The Contractor shall have an access to nuclear radiation software/codes and nuclear cross-section libraries for both fission and fusion applications. The Contractor shall write, where required, the codes/scripts to run the software.

### 4.2 Irradiation conditions

Peak irradiation conditions that IVC would receive during ITER operation at full fusion power of 500 MW are given in Table 2. It is expected the irradiation tests will be able to replicate the effect of radiation from the ITER fusion plasma. The characteristics of the source shall be evaluated by the Contractor to determine the appropriate choice of sample locations, flux level, and test duration to offer the best compromise between irradiation time and requirements of this specification. The Contractor shall characterize the irradiation conditions of the irradiation channel by providing the neutron energy spectrum (n/cm<sup>2</sup>/s) and nuclear heating (in Gy/s) preferentially based on dosimetry measurements, or alternatively through radiation transport analysis. The neutron and gamma flux and spectrum will be determined by the characteristics of the test source as well as the ability to place the samples at a particular distance from the source behind objects (either part of the facility or added to the test chamber) which would influence the energy of the particles incident on the samples.

<b>Fast Neutron Flux (E&gt; 0.1MeV)</b>	$\geq 4.18 \times 10^{13}$ n/cm <sup>2</sup> -sec
<b>Fast Neutron Fluence</b>	2-3 (10 <sup>20</sup> n/cm <sup>2</sup> )
<b>Absorbed dose</b>	300 Gy/sec
<b>Total dose</b>	4210 MGy

**Table 2: ITER Radiation Field (Peak) Seen by IVC MIC [iii]**

### 4.3 Properties to be measured

<b>Property</b>	<b>Before start of irradiation</b>	<b>After completion of irradiation</b>	<b>During irradiation (tbd)</b>	<b>Comments</b>
Electrical breakdown	YES  Similar specimen	YES	no	Measure of break down after: 10%, 50% and 100% of max dose

Radiation Induced Conductivity	YES Initial conductivity resistivity	YES	Leakage current shall be monitored (leakage current to be measured for calculation of conductivity)	Measure after: 10%, 50% and 100% of max dose
Thermal conductivity of MgO	YES The same specimen that will be irradiated, if possible	YES	no	After 100% of max dose
Online check of insulation resistance (optional)			YES	To be measured once a day.

**Table 3: Measurements for the IVC conductor samples.**

## 5 Tentative Schedule

The tentative schedule for the tender process is as follows:

Activities	Schedule
Call for Nomination	February 2017
Pre-Qualification of Companies	April-May 2017
Invitation for Call for Tender	June 2017
Tender Submission	July-Aug 2017
Contract Award	Sept-Oct 2017

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<sup>i</sup> F.Long et al., Manufacture of Mineral Insulated Conductor for ITER Prototype ELM and VS coils, Fusion Engineering and Design, Volume 95, June 2015, Pages 67-71.

<sup>ii</sup> ITER\_D\_T3BQ3V, Radiation damage properties of Magnesium Oxide (MgO) for electrical insulation applications of In-Vessel Coils.

<sup>iii</sup> Three-dimensional Neutronic Analysis of the ITER In-Vessel Coils, ITER\_D\_3XHDCS