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Technical Specifications (In-Cash Procurement)

Tech Spec, Halo Rogowski Coil R&D Design, Prototype and Assessment

This document describes the technical specifications for the detailed design development of theHalo Rogowski Coil diagnostic sensor to be used on ITER. This specification outlines requirements for development of a viable engineering design, prototype manufacture, and testing procedure to test the design performance.

Halo Rogowski Coil
R&D Design, Prototype and Assessment

Technical Specification

1. Abstract

This document describes the technical specifications for the detailed design development of the *Halo Rogowski Coil* diagnostic sensor to be used on ITER. [1] This specification outlines requirements for development of a viable engineering design, prototype manufacture, and testing procedure to test the design performance.

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2. Background and basic design

2.1 Rogowski Sensors

Rogowski loops are simple and reliable inductive sensors that measure the net current through the cross-section of the loop. They can be highly accurate and insensitive to currents in nearby conductors provided they are sufficiently uniform. There are many successful applications in science and industry. (See ref. [7] for a basic overview of Rogowski coils.) The current through the Rogowski loop can be related to the induced magnetic field by applying Ampere's law along the Rogowski contour L_{Rog}:

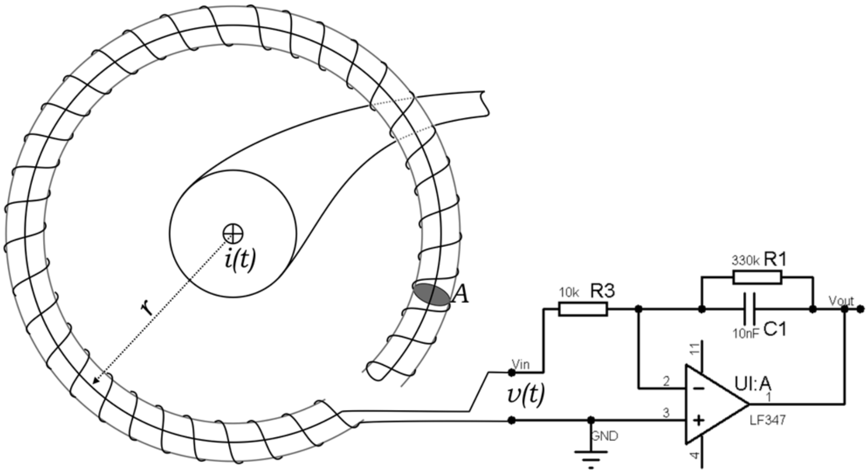


Figure 1: Schematic view of a continuous Rogowski loop with integration circuit.

$$\oint_{L_{Rog}} \vec{B}_i^{Rog} \cdot d\vec{l}_i = \mu_0 I_P \qquad (1)$$

A Rogowski typically approximates this function by integrating in time the induced voltage along a helical path that tracks this contour and correcting for the flux change within the guiding center contour by a suitable return scheme (Figure 1).

$$V_{in} = V_{\mathrm{Rog}} = -\frac{\partial \phi}{\partial t} = -\mu_0 An \frac{\partial I}{\partial t} = -M_{\mathrm{Rog}} \frac{\partial I}{\partial t} \qquad (2)$$

Eq. (2) relates the voltage measured on the Rogowski to the mutual inductance, M_{Rog}. Thus, making use of the integrator circuit of Figure 1, the output signal is proportional to the instantaneous current encircled by the Rogowski coil, i.e.

$$V_{out} \propto I_{\mathrm{Rog}} \qquad (3)$$

The scope of work of this document is the loop itself up to the first junction, including this and other interface work.

2.2 Overview of Rogowski sensors on ITER

On ITER two sets of Rogowski coils are to be used to measure the Halo Currents, i.e. currents flowing outside the plasma through plasma facing components, generally in response to plasma movement or wall interaction. These are the Blanket Rogowski system and the Divertor Rogowski system. The Blanket system consists of a set of ~400 (nearly) identical coils mounted around the electrical connections of the blanket shield blocks, known as the electrical strap and pedestal (see Figure 2). The Divertor system comprises a set of 11 distinct coils, with one set mounted on each of 6 divertor cassettes. Both systems use a coil design with non-circular cross section. In addition, the Divertor coils are non-planar. Representative sketches of the pertinent system elements are depicted in Figure 2 through Figure 4.

The coils are located within the ITER vacuum vessel, and hence are subject to large loads. These include nuclear heating loads, which may be severe in the divertor region, stray electromagnetic radiation in the microwave range from the ECH gyrotrons, which may be quite intense, and large impulsive electromagnetic loads during a plasma disruption.

In summary, the Rogowski coil sets on ITER are expected to:

1. Provide sufficient measurement sensitivity to detect currents over the entire expected range.
2. Be designed for passive cooling with minimal measurement drift
3. Be sufficiently robust to survive in the ITER environment

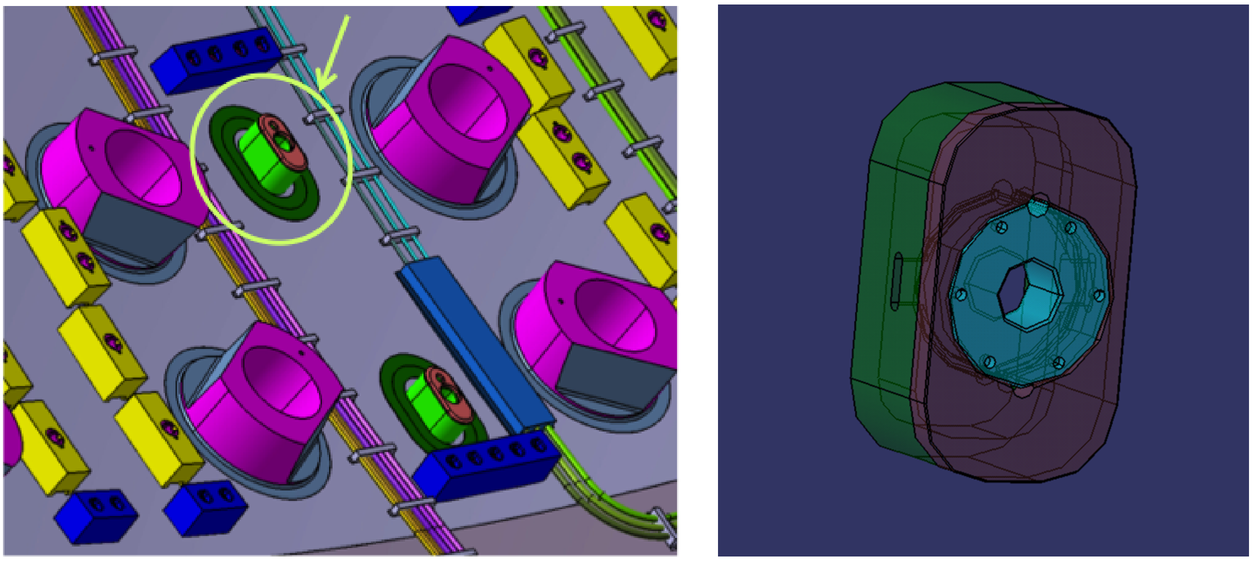


Figure 2. Blanket electrical pedestal on VV wall (left) and detail (right).

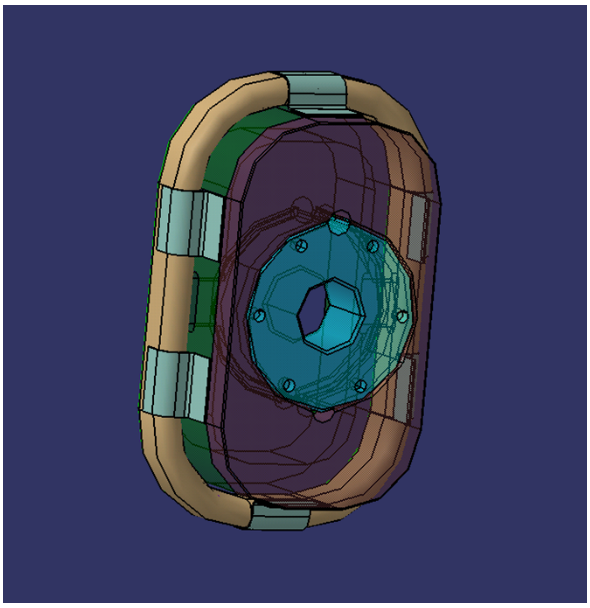
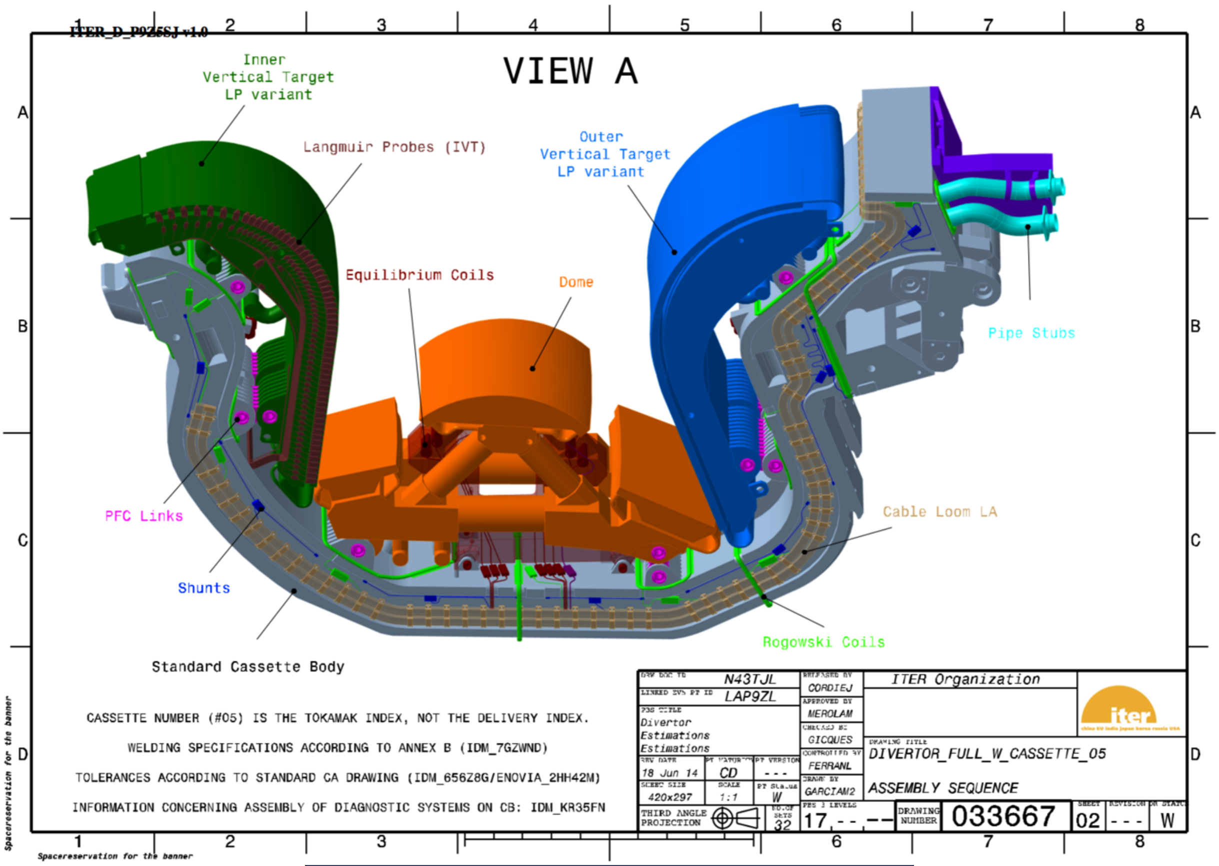


Figure 3. Blanket Rogowski coil mounted to pedestal.



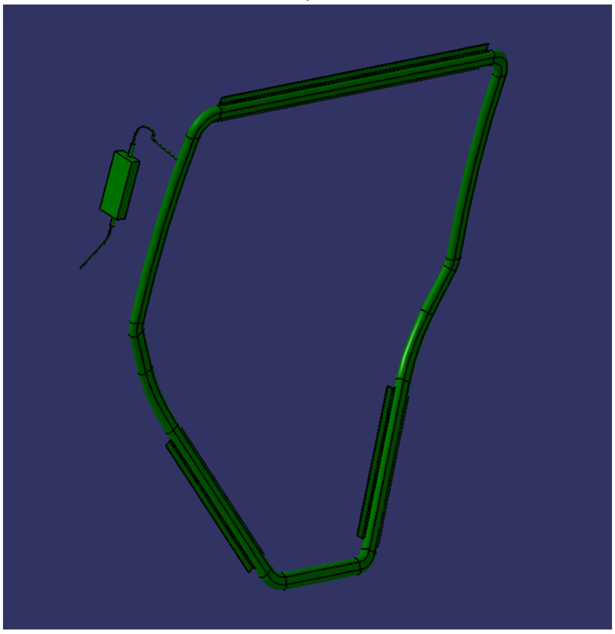


Figure 4. Divertor cassette with Rogowski coils and the specific coil (#4) to be supplied (bottom).

2.3 Measurement requirements

The ITER Measurement Requirements specify the accuracy required of the complete system of Rogowski current sensors for the needs of the ITER program. Numerical modeling of the ITER plasma we used to ascertain an optimized distribution of sensors, assuming reasonable values for individual coil sensitivity. [2] These requirements are translated into specifications on individual coils, resulting in the baseline design described in Section 2.5. This expected sensitivity range and accuracy can be found in Table 1. *The tender shall deliver a coil design meeting or exceeding these sensitivity and accuracy requirements.*

The accuracy requirements are further expanded in Table 2. Here, the probable error sources have been itemized and an allowance allocated to each of these. The "Relative error" is comprised solely of the calibration error, while the "Absolute error" is comprised of three components: stray field, integrator and pickup error. A detailed discussion of the error sources can be found in References [1] and [3].

Table 1: Summary of the Rogowski coil measurement specifications from [2].

Specification	Parameter	Range	dt	Accuracy (2σ)
Current within the blanket Rogowskis (typ.)	I_{bkt_rog}	6 - 120 kA	1 ms	Absolute: 1.5kA; Relative: 0.3%
Current within the divertor Rogowskis (typ.)	I_{div_rog}	6 - 120 kA	1 ms	Absolute: 1.5kA; Relative: 0.3%

Table 2: Error source allocation for both sets of Rogowskis (1σ).

Error	Allowance	Integrated	Comments
Calibration error	0.3%	no	
Integration error	0.1%	yes	Integration can be time limited to a few seconds as required
RF/noise pickup	0.1%	yes	Integration can be time limited to a few seconds as required
Stray field sensitivity	0.1%	no	See text for explanation
Relative error	*0.3%*		Composed of calibration error
Absolute error	*0.3%*		Composed of integration, RF and stray field errors
Total error	***0.6%***		

2.4 Engineering Requirements

The engineering requirements for the coil design are summarized as:

1. Physical size: the coil must fit within the allotted space envelope (configuration management model - CMM) volume
2. Assembly: the coil is to be welded to the attachment structure, and coil design must insure a viable assembly process. This includes requesting assembly space that may exceed the CMM.
3. Thermal: the coil is passively cooled and must be thermally stable such that measurement errors are within tolerance
4. Vacuum compatibility: the coil must adhere to ITER vacuum standards [4]
5. Structural stability: the coil shall be able to withstand all loads detailed in the Load Specifications [14]
6. Manufacturability and robustness: The coils design should use well-characterized materials and elements.
7. The design should be shown to be cost-effective taking account the manufacturing volume.

2.5 Baseline Design Description

The Baseline Design of reference [3] was developed in response to the measurement requirements in above Section 2.3. This design was vetted at a Conceptual Design Review in July of 2011. Since that time the interfaces have evolved, and the details of the design have been updated accordingly. The essential design is nonetheless valid.

This design is meant as a guideline for the Rogowski sensor design, and it is recommended that the tender review this in detail. However, the design may be modified as required to optimize margins to the measurement and engineering requirements

Thus, the tender may propose modifications of the baseline proposal, *and is encouraged to do so as necessary*. The formal approval of IO shall be obtained once the updated design is defined through a recorded deviation process.

Table 3 gives target values for the output signal of the Rogowski coil design used in the baseline coil design of [3]. These signal levels are derived based on requirements for sufficient signal given the long cable distances and what is reasonably measureable with current ADC technology. These target output levels are relative to the maximum expected value for the halo currents, rather than "typical" values. Estimates of typical halo currents are found in [13], and reproduced in Table 4.

Table 3. Target specifications for the Rogowski sensor output signal levels.

Parameter	Input	Blanket Rogowski	Divertor Rogowski
Maximum instantaneous signal	dI/dt = 600kA/s	>200 mV	>200 mV
Total integrated signal (max)	120 kA	>50 mVs	>50 mVs
Frequency response		>10 kHz	>10 kHz
Effective stray area, cross field sensitivity		0.02% of total effective area	0.02% of total effective area

Table 4. Typical halo current values for estimating the expected Rogowski sensor performance.

Parameter	Blanket Rogowski	Divertor Rogowski Entire Cassette	Divertor Rogowski Target Leg
Instantaneous signal, dI/dt	210 kA/s	500 kA/s	185 kA/s
Total current, I	70 kA	125 kA	45 kA

3. Scope of Work for Design Development, Prototyping and Testing

The work to be executed by the selected company has been divided into four global activities to be roughly executed sequentially:

- Activity #1: Engineering design development based on baseline proposal
- Activity #2: Testing of engineering design, including assembly
- Activity #3: Testing of measurement performance
- Activity #4: Conclusions and recommendations

Each of these activities is further split into a set of tasks which are detailed respectively in Sections 3.1 (activity #1), 3.2 (Activity #2), 0 (Activity #3) and 3.4 (Activity #4). The selected company is expected to carry out these activities mostly sequentially. However, preparation of the testing activities (#2 and #3) will probably start before the development of the engineering design is finished. In particular, it is highly recommended to start in the early phase of the project to define the test procedures and to procure and/or develop any specific test tools that might be required.

3.1 Activity #1: Engineering R&D Tasks

In view of the performance requirements (see Section 2), detailed design requirements (see Section 3.1.6 below) and environmental constraints (see Appendix A – Summary of the environmental constraints and Load Specifications), the following tasks shall be executed by the supplier:

Activity 1 **Engineering R&D Tasks**

Task 1.1. Definition of the optimum former material and geometry

Task 1.2. Definition of an optimum strategy for winding process

Task 1.3. Definition of coil bending and shaping process

Task 1.4. Definition of methodology to insure structural integrity and thermal transport*

Task 1.5. Optimization of coil fixation method attachment process*

Task 1.6. Definition/confirmation of the mechanical integrity.*

Task 1.7. Definition of cabling integration in termination*

Task 1.8. Definition of the assembly procedure*

Task 1.9. Definition of the Factory Acceptance Tests

** Interface documentation changes likely*

Practically, the global outcome of this activity shall be:

- o DOC1: a report justifying each aspect of the design adopted (in particular assumptions, trade-offs, mechanical and thermal analysis, ….)
- o DOC2: a list of elements to be manufactured and/or procured to build a prototype.
- o DWG1: 3D CAD model of the coil together with fabrication drawings.
- o DOC3: a detailed description of the fabrication and assembly processes.
- o FAT: a description of the Factory Acceptance Test regimen and detailed procedures for implementation.

The supplier shall provide 3D CAD models for all components in a suitable form for integration into the ITER CAD database (ITER uses ENOVIA from Dassault Systemes). [8][9]

3.1.1 Definition of the optimum former material and geometry (Task 1.1)

The baseline design defines a basic geometry for the coil itself. However, the material of the former and which the Rogowski coil is wound needs to be defined. The precise former 3D geometry can still be varied as long as the global space envelope proposed in the baseline design is not exceeded. The possible materials shall therefore be identified and the geometry adjusted to produce optimum performance while keeping manufacturing cost low. Moreover, a former material and/or method of winding must be identified to keep nuclear heating low and maintain overall required thermal performance (Section 7.2.2). An attractive option, removal of the former after coil winding, should be explored and results reported.

Expected output of the task:

- o Presentation of a trade-off analysis (including cost) for the former material and choice of a preferred solution (to be included in DOC1)
- o Geometry of the former defined through a CAD design and the associated fabrication drawings (DWG1)

3.1.2 Definition of an optimum strategy for winding process (Task 1.2)

A winding process shall be proposed and justified taking into account the following elements:

- Process shall insure sufficiently high precision to meet the function specifications.
- Processes shall be repeatable to ensure uniform quality of the units produced
- The production cost shall be minimized considering that 340 identical Blanket coils, and 6 sets of Divertor coils (11 per set) will eventually be procured.

Expected output of the task:

- o Procedure for winding (to be included in DOC3)
- o Description of tools required to execute these actions (to be included in DOC3)
- o Estimation of cost of production (to be included in DOC1)

3.1.3 Definition of the bending and shaping process (Task 1.3)

The coil will need to be bent and formed into shape. This shape is planar and identical for all blanket Rogowskis. In the divertor case, there are 11 different shapes with some being three dimensional, i.e. non-planar. It therefore requires a specific bending and shaping process to reach the desired shape with the specified tolerances. An appropriate bending and shaping process shall therefore be proposed that ensures that the measurement and error requirements of the coil are not compromised.

Expected output of the task:

- o Procedure for bending and shaping (to be included in DOC3)
- o Description of tools required to execute these actions (to be included in DOC3)
- o Estimation of cost (to be included in DOC1)

3.1.4 Definition of methodology to ensure structural integrity (Task 1.4)

The wound, shaped Rogowski coil will require elements to ensure its structural integrity during installation and operation. These elements should also commensurately ensure a high level of thermal transport to maintain the coil at a reasonable temperature once attached in its final configuration. Possible options include inserting the coil in a thin metal casing or brazing portions of the winding together. The supplier will be in charge of investigating the various suitable options and making a trade-off analysis. The preferred option shall then be described in detail and a corresponding design proposed.

Expected output of the task:

- o Trade-off analysis, including cost (to be included in DOC1)
- o Design description and associated production procedure for the preferred option (to be included in DOC3)
- o Estimation of cost (to be included in DOC1)

3.1.5 Optimization of the tabs geometry, attachment process and assembly (Task 1.5)

The Rogowski coils need to be attached to the structure (blanket pedestal or divertor depending on its location). Apart from its basic mechanical function, this attachment must also provide an efficient thermal bridge between the Rogowski coil and the structure. In the baseline design, the use of tabs welded to the interfacing structure is suggested. However, there are a number of alternative solutions. The supplier shall explore these various solutions (like brazing/ casing options for example, but note that potting solutions with ceramic are not suitable from past R&D and are excluded) and present a trade-off allowing to clearly identify the most suitable option. Moreover, the supplier shall define a strategy to insure minimal thermal excursions of the coil. The supplier should keep the assembly requirements in mind to ensure installation is feasible. This trade off shall consider at least the following criteria:

- Heat transfer efficiency
- Reliability of the attachment given the load specification
- Simplicity of installation on the structure, which will be done in situ in the vacuum vessel (self-jigging, minimum assembly time, minimum space requirement for assembly, …)
- Cost of production.
- Minimal distortion of the coil

Expected output of the task:

- Presentation of a trade-off analysis (including cost) for the attachment and choice of a preferred solution (to be included in DOC1)
- Analysis justifying that the attachment will support with margin the maximum expected load (to be included in DOC1)
- Detailed design of a thermal compensation/calibration strategy (to be included in DOC1)
- Detailed assembly procedure (duration included) for both the blanket and divertor cases (to be included in DOC3)

3.1.6 Definition of the mechanical integrity (Task 1.6)

The mechanical requirements are essentially defined by the following 3 types of information:

- Useable space envelope and 3D geometry of the support (blanket or divertor), "CMM"
  This information will be provided to the supplier as a form of a CAD model (STEP file or Catia model). See Appendix B – Drawings, etc.
- Maximum force and moment affecting the coil
  IO will provide the Load Specifications [14], which apply to the coil. It will be up to the supplier to derive the maximum forces and moments given its design.
- Temperature range for both operation and survival modes
  This information is summarized in Appendix A, with details in the Load Specifications [14]. It includes the nuclear heating parameters (gamma ray flux, neutron flux) but also the ECH flux and the temperature of the attachment surface (either blanket pedestal or divertor cassette body). Based on its coil design, the supplier will be able to derive the maximum temperature and maximum temperature gradient (both under normal and survival conditions) affecting the coil.

Expected output of the task:

- A set of maximum forces, moments and temperatures that affect the coil under normal and survival conditions. These values shall be justified based on calculations and simulation, to be detailed in DOC1. These calculations will be critical for assessing compliance with the engineering requirements.

3.1.7 Definition of cabling integration (Task 1.6)

The Rogowski coil will need to be connected to the electrical services loom inside the vacuum vessel. A proposed junction box geometry is sketched in reference [3]. There are inherent problems with this strategy, in that the twisted pair lead may have uncompensated area leading to measurement error. The strategy should be reviewed and optimized.

Expected output of the task:

- Presentation of strategy for loom connection of the Rogowski coils, including errors introduced (to be included in DOC1)

3.1.8 Definition of assembly procedure (Task 1.8)

The coils in the divertor have the additional complication that several will need to be segmented, i.e. installed in two parts due to access restrictions. Thus, a coils design and assembly procedure for these coils must be devised. Paramount in this design is that the assembly procedure can be reasonably executed, and that errors post assembly are maintained within the specifications of Table 2.

Expected output of the task:

- Definition of the design and assembly procedure for segmented coils (to be included in DOC1)

3.1.9 Definition of the Factory Acceptance Tests (FAT) (Task 1.9)

The supplier shall define a suite of tests that assess the compliance of the design and prototype with the engineering and measurement requirements of the system (Activities #2 and #3). At a minimum these tests shall include Task 2.2, Task 2.3, Task 2.4, Task 3.1, Task 3.2, and Task 3.3. However, additional tests may be advisable.

Expected output of the task:

- A set of Factory Acceptance Test procedures to verify the engineering aspects of the design and prototype (to be included in FAT)

3.2 *Activity #2: Engineering Testing Tasks*

The successful outcome of activity #1 is a prerequisite to proceeding with the engineering tests as listed below:

Activity 2 **Engineering Testing Tasks**

Task 2.1. Assembly of a prototype

Task 2.2. Verification of engineering design requirements

Task 2.3. Test of vacuum compatibility

Task 2.4. Evaluation of thermal properties

Details for each task are given in the following sub-sections. Practically, the global outcome of this activity shall be:

- HW1: fully assembled and functional prototypes (including cables and pre-processing electronics)
- DOC4: a manufacturing dossier (See section 4 for details)
- DOC5: a compliance report on mechanical requirements
- DOC6: an outgassing report (corresponding to Task 2.3)
- DOC7: test report of the thermal conductivity (corresponding to Task 2.4)

3.2.1 Assembly of a prototype (Task 2.1)

The prototype assembled shall correspond strictly to the detailed design developed as part of Activity 1. The prototype shall include:

1. a blanket Rogowski coil
2. a divertor Rogowski coil #4 comprising two segments
3. a pedestal mockup (see Section 13. Appendix B)
4. a mockup of the relevant divertor region
5. cabling and junction interface between the Rogowski coil and the junction box, defined in Section 3.1.6

Expected output of the task:

- Functional prototypes – HW1

3.2.2 Verification of engineering design requirements (Task 2.2)

The prototype Rogowski coil shall be inspected and compliance with the manufacturing drawings verified. In particular, a number of dimensional measurements shall be performed including at least the following parameters:

Expected output of the task:

- A test procedure , part of Task 1.9
- External dimensions of the coil
- Winding specifications and uniformity (using X-ray technique or equivalent as required).
- Mass of the coil
- Thickness of casing (if applicable)

The verification procedures to be applied shall be detailed in a specific document. These procedures shall be provided to ITER upon request. The ITER Dimensional Metrology Handbook (DMH) [12] outlines the mandatory requirements for dimensional control of the components, assemblies and systems for the ITER machine. In addition the handbook provides significant guidance and helpful information on best practice for large volume metrology applications.

Expected output of the task:

- o A compliance report on mechanical requirements including procedures used to carry out the measurements (DOC5)

3.2.3 Test of vacuum compatibility (Task 2.3)

The outgassing test shall be performed on the parts of the prototype that will be under vacuum (i.e. the Rogowski coil + its tail). It shall be done following the rules described in the ITER Vacuum Handbook [1] and its appendix 17 [5].

Expected output of the task:

- o A test procedure, part of Task 1.9
- o A test report including all relevant parameters (to be included in DOC6)

3.2.4 Thermal assessment (Task 2.4)

The thermal assessment shall be conducted under representative vacuum condition with the unit mounted on its pedestal/divertor mockup. The coil shall be heating in such a manner as to simulate the expected heating conditions when installed in the tokamak. Practically, one might use the following procedure: the system is placed in vacuum; the mockup (bolted to a large conductive support plate) will act as a heat sink; the Rogowski is heated internally (for example by circulating a known current through the coil). Appropriate temperature and mechanical measurements are taken of the coil/pedestal system to assess the thermal properties, i.e. heating, final temperature, thermal conduction, coil distortion, etc.

Expected output of the task:

- o A test procedure, part of Task 1.9
- o A test report (to be included in DOC7)

3.3 Activity #3: Measurement Performance Testing Tasks

The final product must be validated against the Measurement Requirements of Section 2.3 under the environmental conditions of all operational scenarios:

Activity 3 Measurement Performance Testing Tasks and conclusions:

Task 3.1. Measurement of coil electronic properties

Task 3.2. Assessment of coil measurement capabilities

Task 3.3. Assessment of error sources, especially sensitivity to stray field

Task 3.1 through Task 3.3 shall be carried out on the individual Rogowski coils, as well as with the coil and its associated electrical train (cabling, pre-processing electronics, etc.). Both the instantaneous and integrate response shall be measured and reported. The tests need not be performed in vacuum, *unless* such conditions are expected to modify the system performance. However, the range of expected thermal conditions shall be explored. Details for each task are given in the following sub-sections. Practically, the individual outcome of these testing tasks shall be grouped in the following document:

- DOC8: a report on the Rogowski prototype measurement capabilities, comparing them to the design predictions and assessing compliance with the specifications.

3.3.1 Measurement of coil electronic properties (Task 3.1)

This task verifies that the prototype indeed conforms to the design specifications. All appropriate electronic properties shall be measured, including capacitance, resistance, frequency response, mutual inductance, etc.

Expected output of the task:

- A test procedure for measurement of the electrical properties, part of Task 1.9
- A test report including all relevant parameters (to be included in DOC8)

3.3.2 Assessment of coil measurement capabilities (Task 3.2)

The measurement capabilities of the Rogowski coils shall be assessed, including sensitivity over the entire expected measurement range and characterization of the measurement error. This shall be compared to both the design predictions and the measurement specifications.

Expected output of the task:

- A test procedure, part of Task 1.9
- A test report including all relevant parameters (to be included in DOC8)

3.3.3 Assessment of error sources, especially sensitivity to stray field (Task 3.3)

The sensitivity to external magnetic fields shall be assessed. These shall be translated into an equivalent signal error specification. Other sources of measurement error shall be determined and quantified.

Expected output of the task:

- A test procedure, part of Task 1.9
- A test report including all relevant parameters (to be included in DOC8)

3.4 Activity #4: Conclusions derived from the study

Once all previous activities are completed, a final report (DOC9) shall be written. It shall include in particular the global conclusions of the study, recommendations regarding possible improvement of the design, manufacturing processes and measurement procedures. Also, it shall mention any other test which would help to further characterize the prototype delivered.

4. Reporting

Regarding the hardware to be delivered, it shall come with a manufacturing dossier that includes at least the following elements:

- As-Built Drawings, Documents, and Data (with signatures)
- Contractor Release Note
- Quality Plan
- Material Control Reports, incl. Certificates, Inspections, Concessions etc..,
- Manufacturing Documentation, incl. Manufacturing procedures, Non-Destructive Testing (NDT) Procedures, Process specifications etc..,
- Records of approved Non-Conformances (NCR) and Deviation Requests (DR)
- Certificates of conformance
- Control Reports (Visual Examination, Non-Destructive Tests, Leak Tests, Certificates of Cleanliness, Pressure Test, Geometric measurements, etc.)
- Codes and Standards conformity certificates
- Completed Manufacturing & Inspection Plans
- Manuals and Instructions for the handling, assembly and maintenance of equipment within the supply

Regarding each Test Procedure delivered as part of Task 1.9 (FAT), a Test Plan including the acceptance criteria shall be developed by the supplier for each test. The IO will have 2 weeks to review the test plan and send recommendations back to the supplier. These recommendations shall be incorporated into the test plan within two weeks, if mutually agreed between the IO and the supplier.

Each Test Procedure shall include:

- The goal of each test,
- The tests conditions,
- The testing method and testing facilities,
- The measurements to be performed during and/or after the tests to check the integrity of the sample,
- Test pass/fail criteria, based on ITER requirements

Each Test Report shall include:

- The description of the prototypes, (reference, manufacturer, …),
- The identification of the prototypes (traceability with respects to the controls performed on the sample during and/or after the manufacture),
- The reference of the test procedure used,
- The records of the measurements carried out during and after the test,
- The conclusion of the test with respect to the pass/fail criteria.

5. Deliverables

The supplier is required to deliver the following items by the successive deadlines (one per milestone) specified in section 9.

Milestone	**Deliverables**		
	Item name	**Item description**	**Number of items**
Kick-off meeting	-	-	-
End of Activity #1	DOC1	Design Report	1 (electronic file)
	DOC2	List of parts	1 (electronic file)
	DOC3	Fabrication and assembly procedure	1 (electronic file)
	FAT	Factory Acceptance Test Description	1 (electronic file)
	DWG1	Fabrication drawings	One set of CAD drawings
End of Activity #2	HW1*	Rogowski prototypes	1
	DOC4	Manufacturing Dossier	1 (electronic file)
	DOC5	Verification report	1 (electronic file)
	DOC6	Outgassing test report	1 (electronic file)
	DOC7	Thermal conductivity test report	1 (electronic file)
End of Activity #3	DOC8	Measurement capability assessment	1 (electronic file)
End of Activity #4	DOC9	Final report	1 (electronic file)

* Exception: HW1 (Rogowski prototypes) will only be delivered physically to IO after activity #3 is successfully completed although it shall be fabricated in the scope of activity #2. Indeed it is required at the supplier premises for the final test tasks, which are part of activity #3.

The delivery address (physical and Email) for the various items is the following:

ITER Organization
c/o Christopher Watts, 81/214
Route de Vinon sur Verdon
13115 Saint Paul Lez Durance
FRANCE

Email: Christopher.Watts@iter.org

6. Requirements for Labeling, Packaging, Handling, Shipment

6.1 *Scope of application*

The following generic requirements apply both for the shipment of equipment, etc. from the manufacture/assembly site to the ITER Site or to any intermediate site.

Suitable precautions shall be taken to avoid damage to the equipment. The components shall be fitted with the required accelerometers or other sensors and shall be packed as defined below.

The equipment shall be subject to control and inspection, as defined below.

6.2 *Labeling and Traceability*

All hardware components and the main subcomponents shall be clearly marked in a permanent way and in a visible place.

6.3 *Packaging and Handling*

Any special IO or regulatory transportation requirements shall be documented and provided to the Supplier prior to shipment.

Subsequent to the Factory Acceptance Test, the components shall be partially disassembled to the maximum size that can be shipped. All components requiring re-assembly at the ITER Site shall be clearly labeled and tagged.

The supplier shall design and supply appropriate packaging, adequate to prevent damage during shipping, lifting and handling operations. Where appropriate, accelerometers or other sensors shall be fitted to ensure that limits have not been exceeded. When accelerometers are used, they shall be fixed onto each box and shall be capable of recording the acceleration along three perpendicular directions.

Shock absorbing material shall be used.

Each shipment shall be accompanied by a Delivery Report prepared by the Supplier, stating as a minimum:

- The packing date;
- The full address of the place of delivery and the name of the person responsible to receive the package, as well as of the Supplier's name and full address;
- Packing List;
- Any additional relevant information on the status of the components.

The Delivery Report shall be signed by a representative of the IO and its Supplier.

6.4 Shipment, Transportation and Delivery to the ITER Site

The components shall exclusively be delivered to the ITER Site using a reputable transport company under the responsibility of the Supplier.

Before the shipment, a Release Note shall be prepared in accordance with the "Contractor Release Note" [15] and approved by the IO.

Upon receipt of the package, the IO shall open the package and make a visual inspection of its content to check:

- The integrity of the package, including identifying visible damage;
- The number and type of components contained in the shipment;
- The enclosed documentation;
- The integrity of the components.

In the case of anomalies the IO shall make any additional relevant remark on the inspection.

If the components are in an acceptable condition, the IO will sign the Delivery Report. The original of the Delivery Report shall be kept by the IO and a copy of it shall be kept by the Supplier.

6.5 Responsibilities (including customs and other logistics)

Once the Delivery Report is signed by IO, the ownership of the components is transferred from the Supplier to the IO. The transfer of ownership to the IO shall not relieve the Supplier of its obligations under this Contract in case of non-conformities of the components for the duration of the warranty period (1 year after the signature of the Delivery Report of the component).

The supplier shall provide shipping and delivery to the ITER Organization address cited in Section 5. All customs and other logistical matters will be conducted by the supplier unless specified otherwise.

7. Specific requirements and conditions

The minimum requirements are that the components are fabricated per the scope of work outlined above. In addition, the design proposed shall obey requirements related to vacuum compatibility, heat transfer, load specifications, etc.

7.1 Experience and qualification of contender

The tender offers will be evaluated on the following criteria:

- Evidence of competence to satisfactorily address all Activities with either in-house capabilities and/or through a demonstrated consortium or assembly of suppliers.
- Evidence of management capability for a project of similar nature and scope
- Demonstrated plan to fulfill all requirements of this call for tender
- Demonstrated competency in comprehensive reporting in the English language

7.2 Engineering requirements

7.2.1 Vacuum compatibility

While not forming part of a vacuum boundary, the Rogowski coils will be subjected to vacuum during operation of the machine. As such, they must conform to the requirements of the ITER Vacuum Handbook in terms of the methods of fabrication, finishing and baking. In particular, finished assemblies should be free from oil and grease, and any sharp edges or burrs should be removed. A copy of the ITER Vacuum Handbook [4] will be issued with this document for the supplier's information and adherence.

With regard to the vacuum categories assigned in the Vacuum Handbook, note that the Rogowski coils are VQC1B and non-SIC.

7.2.2 Heat transfer design constraint

The heat transfer from the Rogowski coil to the attaching interface is of utmost importance to make sure coil temperature will stay within a range where there will be no noticeable impact on its measurement performance and integrity over its designed lifetime. The supplier should take into account this important aspect when performing the optimization tasks related to the formers and the tabs. In particular, the supplier shall conduct appropriate thermal analysis considering the worst case scenarios detailed in the Load Specifications (EM, thermal, stray microwave radiation, etc. …).

7.2.3 Protection against Electron Cyclotron Heating (ECH)

Special care shall be put into the design regarding the ECH radiation (170 Ghz, wavelength of 1.7 mm). Indeed a proper design of the coil (in particular the casing) will allow minimizing the heating due to this source of radiation (as well as risk of arcing).

7.2.4 Stray magnetic field sensitivity

One of the largest error sources of the individual coils is their sensitivity to external magnetic fields. Thus, the stray area of the coils must be minimized to reduce this sensitivity to an absolute minimum. During the bending and forming process, such errors especially may be introduced, and the systematic and reproducible procedure for the bending process is a key deliverable. In addition, careful measurements of the stray field sensitivity must be performed.

7.2.5 Transfer of CAD information

The supplier shall provide 3D CAD models for all components in a suitable form for integration into the ITER CAD database (ITER uses ENOVIA from Dassault Systemes)

8. Work Monitoring / Meeting Schedule

It is worth noting that:

- A *kick-off meeting* will be held by teleconference.
- *Progress meetings* will then be scheduled every two weeks unless agreed otherwise during the kick-off meeting by both parties (IO and the supplier). The period between meetings might be revised during the course of the project if agreed by IO. For these regular progress meetings, the supplier shall prepared a summary of work carried out during the past period as well as a work plan for the next period.
- *Dedicated meetings* will be organized at the end of each of the three activities defined in Section 0. For each of these dedicated meetings, the supplier will have to send the corresponding deliverable documents and drawings (defined in Section 0) to IO a week before the meeting.
- *Irregular interactions* will occur to agree on test procedures as specified in Section 0.

9. Delivery time breakdown

The delivery times are detailed below for each milestone.

Milestone	**Deadline**
Kick-off meeting	K.O.
End of Activity #1	K.O. + 5 months
End of Activity #2	K.O. + 9 months
End of Activity #3	K.O. + 12 months
End of Activity #4	K.O. + 13 months

The anticipated duration for the work is up to 13 months. Any modification of any of these deadlines shall be previously approved by IO.

10. Quality Assurance (QA) requirement

The organization conducting these activities should have an ITER approved QA Program or an ISO 9001 accredited quality system.

The general requirements are detailed in ITER document ITER Procurement Quality Requirements (22MFG4)

Prior to commencement of the task, a Quality Plan Quality Plan (22MFMW) must be submitted for IO approval giving evidence of the above and describing the organisation for this task; the skill of workers involved in the study; any anticipated sub-contractors; and giving details of who will be the independent checker of the activities.

Prior to commencement of any manufacturing, a Manufacturing & Inspection Plan Manufacturing and Inspection Plan (22MDZD) must be approved by ITER who will mark up any planned interventions.

Deviations and Non-conformities will follow the procedure detailed in IO document MQP Deviations and Non Conformities (22F53X)

Prior to delivery of any manufactured items to the IO Site, a Release Note must be signed MQP Contractors Release Note (22F52F).

Documentation developed as the result of this task shall be retained by the responding company for a minimum of 5 years and then may be discarded at the direction of the IO.

11. Terminology and Acronyms

- CAD Computed Assisted Design
- EMD Electrical Discharge Machining
- FAT Factory Acceptance Test
- IO ITER Organization
- KO Kick Off
- MIC, MI Mineral Insulated Cable
- SIC Safety Important Component
- VV Vacuum Vessel

12. References

[1] System Design Description (DDD) 55.AM Shunts Div and 55.AN Rogowskis Div and 55.AP Rogowskis Blanket (4AFETS)

[2] R3.2-H: Evaluation of the estimation errors on poloidal halo current in each vessel sector; R3.5-H: Optimization of number and position of the basic set sensors within available flexibility (R9TWT7)

[3] Halo Current Rogowski Coil Reference Design (QE7X4N)

[4] ITER_D_2EZ9UM Vacuum Handbook, Issue 2.3

[5] ITER_D_2EXDST Guide to outgassing rates and their measurement, Issue 2.2

[6] ITER_D_2DSPT6 Electrical Design Handbook

[7] Rogowski Coil, Wikipedia (http://en.wikipedia.org/wiki/Rogowski_coil)

[8] ITER_D_2F6FTX Procedure for the usage of ITER CAD manual

[9] ITER_D_2DWU2M Procedure for the management of CAD work & CAD data (models and drawings)

[10] ITER_D_22F52F ITER requirements regarding Contractors Release Note

[11] ITER_D_28QDBS ITER Numbering System for Components and Parts

[12] ITER_D_46FN9B ITER Dimensional Metrology Handbook

[13] Measurement 21 (Halo Currents) Parameter 050 (QE6ZKT)

[14] System Load Specifications for the Halo Current Rogowski coils (folder Q9QFRL)

[15] Release Note Template (QVEKNQ)

13. Appendix A – Summary of the environmental constraints

Summary of the environment conditions for the pedestal + coil. See the Load Specifications for details. [14]

Configuration	Scenario	VV temperature	Temperature gradient	Pressure	ECH Heat Load	ICRH Heat Load	Nuclear Heat Load
Normal operations (with blanket modules)	Maintenance	20°C ± 5°C	-	1 atm	No	No	No
	Baking	200°C +20/-10°C	Up to 5 K/h	< 10^{-5} Pa	No	No	No
	Startup (first 5.5s)	100°C ±10°C	-	< 10^{-5} Pa	0.48 (*) MW/m^2	Very low level	No
	Pulse	100°C ±10°C	-	< 10^{-5} Pa	0.20 MW/m^2	Very low level	Yes

Not Applicable	(red)	Rogowski coils not installed
Survival scenarios	(yellow)	No measurement requirements applicable
Operation scenarios	(green)	All measurement requirements applicable

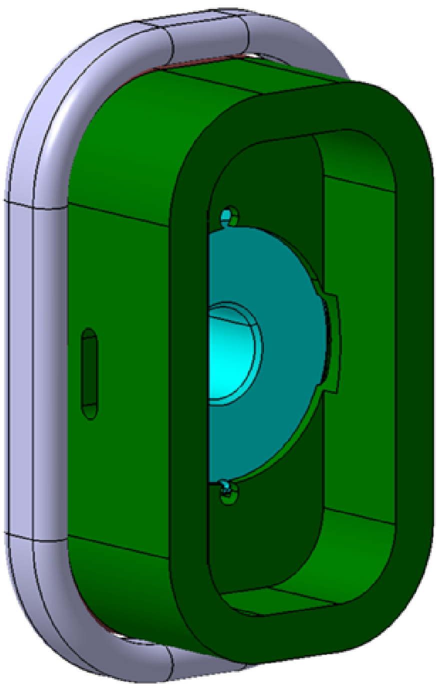
+ survival during transitions between scenarios with temperature gradient up to 5 K/hr

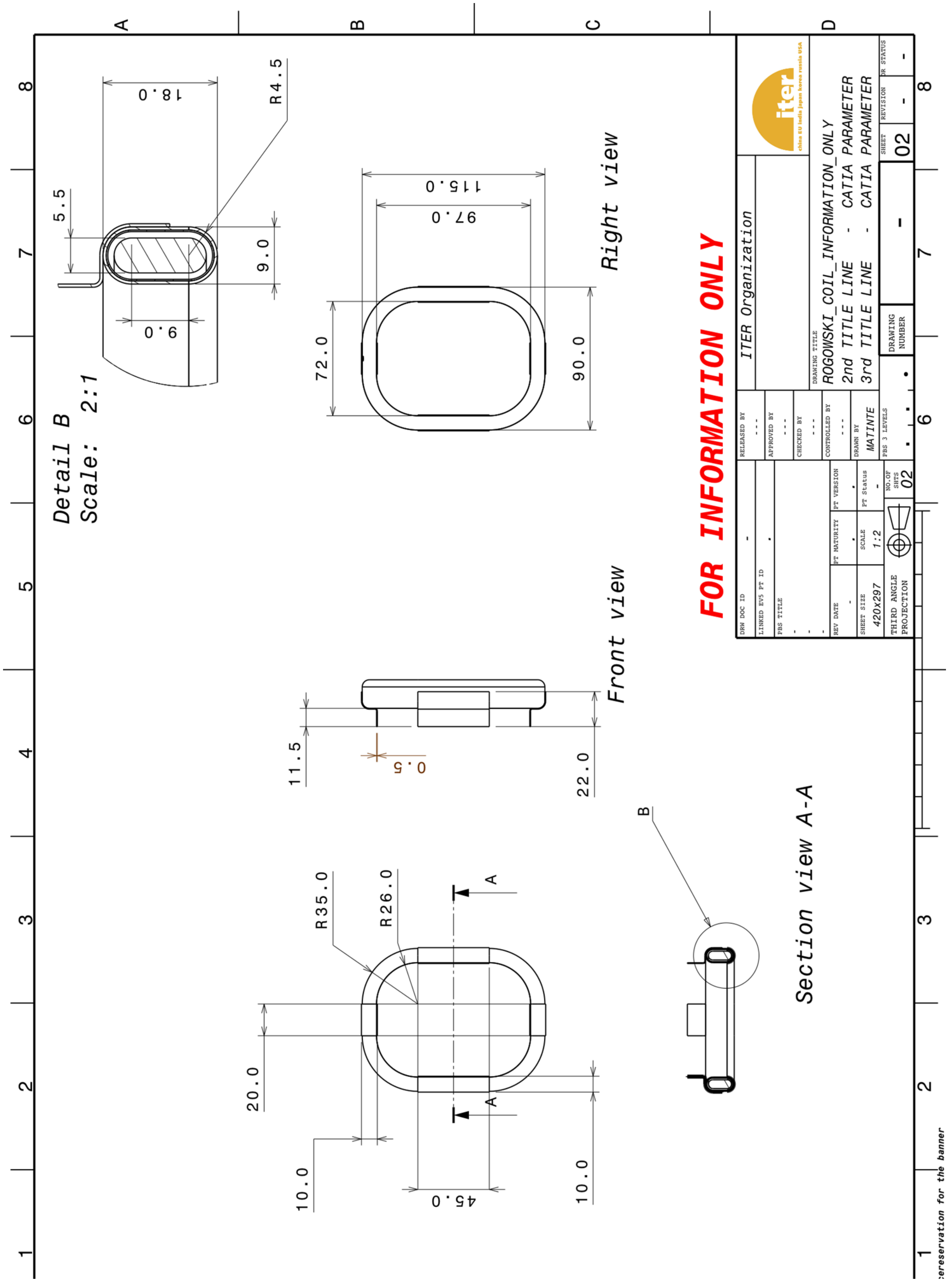
(*): this value of ECH heat load is valid for sensors located close to EP11. The other sensors are exposed to stray ECH which is much lower (evaluated to 20 kW/m^2)

14. Appendix B – Drawings, etc.

The following figures and drawings are cursory information provided to aid in assessment of the work scope. They shall not be assumed complete in any way. Rigorous drawings will be provided as part of the formal hand over of the design work. Additional drawings may be requested if required.

14.1 Geometry of the pedestal and Blanket Rogowski

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R4.5
5.5
9.0
9.0
Right view
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97.0
72.0
90.0
Front view
11.5
0.5
22.0
Section view A-A
R35.0
R26.0
20.0
10.0
45.0
10.0
A
B
FOR INFORMATION ONLY
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ROGOWSKI_COIL_INFORMATION_ONLY
2nd TITLE LINE - CATIA PARAMETER
3rd TITLE LINE - CATIA PARAMETER
DRAWN BY
MATINTE
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THIRD ANGLE PROJECTION
NO.OF SHTS
02
SHEET
02
DRAWING NUMBER

14.2 Geometry of the Divertor Rogowski