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TSZ9KQ

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MQP Level 3

Instructions for EM Analyses

This document provides instructions and guidelines for electromagnetic analyses and electromagnetic analysis reports. These instructions give:Requirements for performing electromagnetic analyses.Requirements for reports that document electromagnetic analyses.Guidance for how to comply with the requirements listed above.

Approval Process			
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Change Log			
Instructions for EM Analyses (TSZ9KQ)			
Version	***Latest Status***	***Issue Date***	***Description of Change***
v0.0	In Work	05 Sep 2016	
v1.0	Signed	07 Sep 2016	First release
v1.1	Signed	05 Oct 2016	minor changes following comments received on the draft
v2.0	Signed	14 Nov 2016	The version, updated in accordance to all comments, received from the reviewers - involved DA's representatives and EM analysis experts
v2.1	Signed	24 Nov 2016	Minor update, following the changes introduced in the ITER_D_22MAL7
v2.2	Signed	12 Jan 2017	The statement "Level 2 Procedure for Analyses and Calculations [2] and its Level 3 Working Instruction (this document) are in the scope of the Process Software Control and Model Development" is added in Section 2 (Scope) by request from QAA.
v2.3	Signed	17 Jan 2017	Word document template changed to "MQP_Procedure_Template_438T76_v2_4.dotx". The text to display in hyperlinks to ITER documents is shortened to UID.
v2.4	Revision Required	28 Feb 2017	1. The obsolete reference [14] MQP Documents Policy (4B9LWQ) is substituted with the superseding it [14] MQP Documentation Management Procedure (7M445D). 2. The requirement to use SI units from "Guideline/template for Analyses Reports" 6NVTVK is recurred here explicitly again (Section "5.10 Units", Req.29). For further details and specifics of the conversion of values and expressions between systems, commonly used for EM analyses (SI, CGSM, Gaussian CGS, etc.), and the units, used in DINA model and output, the 6NVTVK is referenced. 3. Added Req.33 in Section "6.11 Documents and Analysis Recording and Retention": The reviewers are asked to check compliance with "Instructions for the Storage of Analysis Models" U34WF3 (Req.33 and to save the checklist in the IDM (as an attachment to comments, etc.). Added references - newly issued [34] "Instructions for the Storage of Analysis Models" (U34WF3, 20.02.2017) and [35] "How To Store Analysis Models" (UDNLAG, 20.02.2017). 4. Added Req.27 in Section "6.8 Final Report and Acceptance Data Package (ADP)": The acceptance criteria for the numerical results of EM analysis shall be substantiated and checked against the potential safety limits and, when applicable - against the design margins (for example - brought by the codes). Margins and safety factors must be expressed with regards to known safety limits." 5. The Part "5 Specific Technical Requirements in EM Analysis and Calculations" is reworded to "5 Domain- and Subject-Specific QA Requirements in EM Analysis and Calculations Procedure".
v2.5	Revision Required	04 Apr 2017	Minor changes to address comments from reviewers. References updated following to latest changes. Misprints corrected.
v2.6	Revision Required	30 Oct 2017	The document is updated from v2.5 following the later decisons on the strategy as agreed with QAA. In particular: - Technical requirements are moved to Appendix. - Checklists are separated to the 3 independent IDM documents - for revew, for technical check and for independent peer-review. - The latest MQP Document Template 438T76 v2.5 is used. - The text is updated for consistency with the current set and status of applicable and reference documents. The changes addresses comments, which have been received on v2.5.
v2.7	Signed	05 Dec 2017	The introduced changes answer the last received comments (on v2.6) and

			reflect the latest changes in reference documents. 1. Former Applicable document [AD3] "Quality Assurance for ITER Safety Codes Procedure" 258LKL is removed following the recommendation from GSO (according to the new version v1.1 of the document "Guideline - Framework Instruction for Safety Demonstration Art 3.8 INB Order" PQT8AC). 2. The reference [RD22] "Deviations and Non-conformities (MQP)" 2LZJHB is split to [RD22] "Procedure for management of Nonconformities (MQP)" 22F53X and [RD23] "Procedure for the management of Deviation Request (MQP)" 2LZJHB. 3. The reference [RD6] "IO Management Implementation Plan (IMIP)" 2NCR3F is changed to [RD6] "ITER Project Management Plan (PMP)" 2NCR3F. The text is updated for consistency with the current set and status of applicable and reference documents.
v2.8	Revision Required	20 Dec 2017	In the new version 2.8 of Instructions: -> The Compliance Matrix for INB order [RD3] is adedd (Appendix C). -> Requirements from the Art.3.8 of the INB order, concerning the nuclear safety demonstration are addressed specifically in the separate Table A2. -> The new reference document [RD30] "Guideline-Framework Instruction for Safety Demonstration Art.3.8 INB Order" (PQT8AC) is adedd. -> The requirements to review analyses that are classified as Protection Important Activities (PIA) by a member of the IO EPNS Division is added (Section 5.7).
v2.9	Approved	15 Jan 2018	some issues with hyperlinks have been resolved to avoid errors in the conversion do pdf
v2.10	Signed	30 Mar 2020	As per approved MQP doc request https://user.iter.org/?uid=YRZYUN the changes are: §4.3: Removed reference to French Quality Order of 10 August 1984. §5.2: A reference to CIO/AS has been replaced with CIO/IEA. §5.2: A reference to «Science, Control & Operation Department / Science Division / Plasma Modelling & Analysis» has been replaced with «Science, Control & Operation Department / Science Division / Plasma Modelling & Analysis» §5.6: The text has been harmonized to the other MQP Instructions from IEA. §8: A reference to the instructions for storage of analysis models has been added. The overall document readability has been improved by simplifying several sentences and removing redundancies. All reference documents and cross-references are hyperlinked.
v2.11	Approved	08 Jun 2020	Under same MQP doc request minor update of the document with the following changes: - Chapters numbering - UID added for the ref. [RD10] - Some typos and formats corrected No technical changes.
v3.0	Signed	27 Jan 2021	As per approved MQP doc request https://user.iter.org/?uid=4F9Z4Z the changes are: - Complete re-write of the document - Review by DAs
v3.1	Signed	08 Mar 2021	Updated according to comments in v3.0: - fixed units definitions in table 6; - fixed reference to chapter 9 under paragraph 7.3.

v3.2	Signed	22 Mar 2021	Fixed broken cross references on R14 and at page 35. The same issue was propagated to ITER_D_PRAT8Q and VNYHRB. The two checklists have been fixed as well and the version numbers in this document are updated accordingly.
v3.3	Approved	22 Mar 2021	Fixed broken cross references on R14 and at page 35. The same issue was propagated to ITER_D_PRAT8Q and VNYHRB. The two checklists have been fixed as well and the version numbers in this document are updated accordingly.
v3.4	Approved	10 Oct 2025	Org changes (EPNS, CIO) and some minor changes

Contents

1 Purpose

This document provides instructions and guidelines for electromagnetic analyses and electromagnetic analysis reports. These instructions give:

- Requirements for performing electromagnetic analyses.
- Requirements for reports that document electromagnetic analyses.
- Guidance for how to comply with the requirements listed above.

Associated with this document are:

- A template for electromagnetic analysis reports [8].
- Checklists for:
- Reviewers [5].
- Independent Peer Reviewers [6].
- Technical Checkers [7].

The QA requirements given in [1] are implemented in this document.

2 Scope

This document applies to the ITER Organization (IO) involved in the performance of electromagnetic analyses and calculations. It also applies to Domestic Agencies (DA) or external contractors who are asked to perform analysis or calculation tasks for the ITER project, see [1]. The rules governing the propagation of the requirements specified in these Instructions to external contractors or interveners are specified in [11], and shall be followed.

These instructions cover the activities associated with planning, preparing, technical checking and reviewing, issuing, and revising electromagnetic analyses and calculations.

These instructions apply to the development of electromagnetic analyses and calculations of ITER Systems, Structures and Components (SSCs) of any Quality Class (QC). The instructions are mandatory when any of the following apply to an electromagnetic analysis or calculation:

- They are required or planned to be retained as a design verification and validation.
- They are required to document that an existing, modified, or proposed SSC will meet design or operational requirements.
- They constitute alternative calculations (see definition) for completing design verification of an SSC.
- They are required by other ITER procedures.

This process is not mandatory for preliminary or scoping calculations that are to be superseded by later analyses. For preliminary or scoping calculations, the Quality Assurance (QA) requirements shall be defined on a case-by case by the Analysis Coordinator, see [1] for the definition of the role of the Analysis Coordinator.

These instructions do not cover spot-checking or surveillance activities on Protection Important Activities (PIAs). Requirements for these activities are specified in [1].

This document is generated from [1].

3 Definitions and acronyms

3.1 Definitions

Term	Definition
Computational model	The numerical implementation of the mathematical model, usually in the form of numerical discretization of the geometry (e.g. into Finite Elements), solution algorithm, and convergence criteria.
Conceptual model	The collection of assumptions and descriptions of physical processes representing the solid mechanics behaviour of the reality of interest from which the mathematical model and validation experiments can be constructed.
Discretization	The mapping of a continuous space into discrete counterparts as it is done with a FE mesh.
Error	A recognisable deficiency in any phase or activity of modelling or experimentation that is not due to lack of knowledge, e.g. choosing an incorrect material property for use in the computational model, programming errors.
Mathematical model	The mathematical equations, boundary values, initial conditions and modelling data needed to describe the conceptual model.
Electromagnetic analysis	The computation of electromagnetic and electric potentials to determine magnetic fluxes and induced currents distributions in space under consideration of physical laws and through the application of mathematical equations.
Uncertainty	A potential deficiency in any phase or activity of the modelling, computation or experimentation process that is due to inherent variability or lack of knowledge. Uncertainty can be as quantified as follows: $uncert.[\%] = \frac{R_{correct} - R_{calculation}}{R_{correct}} \cdot 100\%$ However, since a "correct" result in the ideal sense is not usually available, a result with an insignificant error can be considered correct.
Validation	The process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the mathematical model. Validation is based on comparisons between numerical simulations and relevant experimental data.
Verification	In these instructions, verification is the process of determining that computational model accurately represents the conceptual model. Note that this definition is slightly broader than the ASME V&V definition, where verification is the process of determining that a computational model accurately represents the underlying mathematical model and its solutions [13].

Table 1 - Definitions.

The list of definitions used in this document is given in Table 1. These definitions supplement those in [1] where definitions are given for alternative calculations, analyses, calculations, calculation software, deliverables, independent calculations, Independent Peer Reviewer, Reviewer, Technical Checker, and technical checking.

3.2 Abbreviations

The list of abbreviations used in this document is given in Table 2. For a complete list of ITER abbreviations see ITER_D_2MU6W5 - ITER Abbreviations.

2D	Two-dimensional
3D	Three-dimensional
BC	Boundary Condition
CAD	Computer Aided Design
DET	Data Exchange Task
DoF	Degree of Freedom
EM	Electromagnetic
IDM	ITER Document Management system
INB	Installation Nucléaire de Base
IO	ITER Organization
FE	Finite Element
PD	Plant Description, ITER_D_2X6K67
PEC	Plasma Equilibrium Code
PIA	Protection Important Activity
PR	Project Requirements, ITER_D_27ZRW8
QA	Quality Assurance
QC	Quality Class
RO	Responsible Officer of the system
SRD	System Requirement Document
SRO	Safety Responsible Officer
SSC	System, Structure and Component
V&V	Verification and Validation

Table 2 - Abbreviations.

4 References

4.1 Applicable Documents

[1] Procedure for Analyses and Calculations (ITER_D_22MAL7)
[2] Instructions for the Storage of Analysis Models (ITER_D_U34WF3)
[3] Software Qualification Policy (ITER_D_KTU8HH)
[4] Order dated 7 February 2012 relating to the general technical regulations applicable to INB - EN (ITER_D_7M2YKF)
[5] Checklist for EM Analyses: Reviewing (ITER_D_PRAT8Q v3.6)
[6] Checklist for EM analysis: Independent Peer Review (ITER_D_VNYHRB v2.6)
[7] Checklist for EM Analyses: Technical Checker (ITER_D_SYCCLR v3.2)
[8] Template for EM Analysis Reports (ITER_D_6NVTVK v2.1)
[9] Manual for ITER Electro-Magnetic Analyses (ITER_D_SYC9KF)
[10] GUIDELINE- FRAMEWORK INSTRUCTION FOR SAFETY DEMONSTRATION ART 3.8 INB ORDER (ITER_D_PQT8AC)
[11] Provisions for Implementation of the Generic Safety Requirements by the External Actors/Interveners (ITER_D_SBSTBM)
[12] IO Generic Template (ITER_D_34BAZX)

[13] ASME V&V 10-2006 – Guide for Verification and Validation in Computational Solid Mechanics.
[14] Guideline for Identification of the Protection Important Activities (PIA) (ITER_D_SBYJXD)
[15] Quality Classification Determination (ITER_D_24VQES)
[16] Procedure for ITER CAD Data Exchanges (ITER_D_2NCULZ)

5 General Principles

The management requirements for electromagnetic analyses are those defined in [1]. Technical requirements for electromagnetic analyses are defined in Appendix A, and shall be followed.

6 Workflow

The workflow for electromagnetic analyses is defined in [1].

7 Responsibilities

General roles and responsibilities for analysis and calculations are defined in [1]. In this document, the roles and responsibilities are defined for analyses conducted under different arrangements, for example:

- ITER Task Agreements (TAs) or Procurement Arrangements (PAs).
- Direct IO or DA contracts.
- Performed by IO or DA staff.

The requirements and responsibilities listed in [1] shall be applied to electromagnetic analyses and the associated reports. Additional clarifications on the roles and responsibilities for electromagnetic analyses are given in this chapter.

Document [1] defines the roles and responsibilities of the IO Responsible Officer, IO Analysis Coordinator or Requester, Contract Manager, Performer's Manager or Supervisor, Performer, Reviewer or Technical Checker, and of the Independent (Peer) Reviewer for all different types of Analyses and Calculations in general. The following chapter re-call some of them or further clarifies the specific roles within the context of the Electromagnetic Analysis process.

7.1 Performer

The Performer executes and documents the analysis or calculation in accordance with these Instructions.

7.2 Approver of Analysis Report

The approver of the electromagnetic analysis report in IO IDM shall:

- Ensure that the Performer, Reviewers and Technical Checker are Suitably Qualified and Experienced Persons (SQEP).
- Ensure that any software tools are properly qualified.
- Ensure that the purpose and scope of the document are fully met.
- Ensure that the Reviewers and Technical Checker fulfil the scope of their review.
- Ensure that the review has been exhaustive and certified. The review has included all necessary actors and interfaces, and covered all relevant aspects in relation to the purpose

and scope of the analysis task. As a minimum, this includes the reviews specified in Section 7.3.

7.3 Reviewers of Analysis Report

This section lists the minimum points that must be reviewed for electromagnetic analysis reports. The points are assigned to Reviewers, an Independent Peer Reviewer and a Technical Checker, see [1] for definitions. The outcomes of the reviews shall be stored in IO IDM as specified in Chapter **Error! Reference source not found.Error! Reference source not found.**.

To reduce the workload of the reviewers of the electromagnetic analysis report it is required to specify the scope of review of each reviewer. This scope can be defined either in the report itself, or else be done directly in IO IDM.

For the reviews defined in Subsections 7.3.2, 7.3.3 and 7.3.4, the use of different checklists may be used if these checklists are agreed in writing with the entity in the IO responsible for these Instructions. Based on the present IO organisation, the responsible entity is the Integrated Engineering Analysis Section of the Central IntegrationDivision. A prerequisite for the use of alternative checklists is a demonstration that the alternate checklists are at least as comprehensive as the ones given in these Instructions.

7.3.1 Safety Responsible Officer (SRO) Review

SRO for the SSC shall be assigned as an Observer in IDM. If the SRO requests to be a Reviewer in IDM, the SRO shall be assigned as a Reviewer.

7.3.2 Reviewers

The checks listed in Table 3 shall be performed. The review may be performed by a single reviewer or be split between two or more reviewers.

The requirements listed in Table 13 shall be followed when performing a review. The outcome of the review shall be recorded using the template in [5].

Check ID	Check
R1	Report title, format and metadata
R2	Abstract, purpose and scope
R3	Scope of reviewers
R4	Definitions and abbreviations
R5	Units
R6	Geometry (excluding applicability)
R7	Applicability of geometry [1]
R8	Material properties (excluding applicability)
R9	Applicability of material properties [1]
R10	Design criteria for Static EM Field Compatibility (only applicable to EMC analyses)
R11	Loads (excluding applicability) [2]
R12	Applicability of loads [1]
R13	Conceptual model and analysis methodology
R14	Description of the Computational Model (only applicable to Computational Model)
R15	Hand calculations (only applicable to hand calculations)
R16	Results
R17	Verification of Computational Model: Software Installation
R18	Verification of Computational Model: Components volume and equivalent electric properties
R19	Verification of Computational Model: Accurate time step sampling for transient analysis
R20	Verification of Computational Model: Input for plasma disruption analysis
R21	Verification of Computational Model: Requirement on skin effect checks
R22	Verification of Computational Model: Requirement of mesh accuracy
R23	Comparison with Alternative Results
R24	Conclusions
R25	References

Table 3 – Minimum checks to be performed by Reviewers.

7.3.3 Independent Peer Reviewers

The checks listed in Table 4 shall be performed by the Independent Peer Reviewer. Note that the list of checks is identical to that for Reviewers, except that there are no checks on the applicability of the geometry, material properties and loads.

Also note that the requirement that check R12 be performed by the RO of the SLS of the SSC is only applicable to Reviewers, not to Independent Peer Reviewers.

The requirements listed in Table 13 shall be followed when performing an Independent Peer Review. The outcome of the review shall be recorded using the template in [6].

1 Checks concerning applicability shall be performed by the RO of the SSC.
2 This check shall be performed by the RO of the SLS of the SSC. It is also recommended that the RO of the SLS checks how the loads are applied to the FE model (part of R14).

Check ID	Check
R1	Report title, format and metadata
R2	Abstract, purpose and scope
R3	Scope of reviewers
R4	Definitions and abbreviations
R5	Units
R6	Geometry (excluding applicability)
R8	Material properties (excluding applicability)
R10	Design criteria for Static EM Field Compatibility (only applicable to EMC analyses)
R11	Loads (excluding applicability)
R13	Conceptual model and analysis methodology
R14	Description of the Computational Model (only applicable to Computational Model)
R15	Hand calculations (only applicable to hand calculations)
R16	Results
R17	Verification of Computational Model: Software Installation
R18	Verification of Computational Model: Components volume and equivalent electric properties
R19	Verification of Computational Model: Accurate time step sampling for transient analysis
R20	Verification of Computational Model: Input for plasma disruption analysis
R21	Verification of Computational Model: Requirement on skin effect checks
R22	Verification of Computational Model: Requirement of mesh accuracy
R23	Comparison with Alternative Results
R24	Conclusions
R25	References

Table 4 – Minimum checks to be performed by Independent Peer Reviewers.

7.3.4 Technical Checkers

The checks listed in Table 5 shall be performed by the Technical Checker:

Check ID	Check
TC1	Conceptual model and analysis methodology.
TC2	Mathematical model.
TC3	The analysis model is properly stored in the analysis database.
TC4	The model in the database matches the report.
TC5	The results of the model in the database match the description in the report.
TC6	Analysis results are reasonable, and hand calculations are correct.

Table 5 – Minimum checks to be performed by Technical Checkers.

The requirements listed in Table 14 shall be followed when performing a technical check. The outcome of the review shall be recorded using the template in [7].

8 Interactions with Other Processes

The interactions with other processes are defined in [1].

9 Records

Electromagnetic analysis reports shall be titled such that the scope of the analysis (Component, PBS, loads) is described as well as possible within the confines of a reasonable number of characters.

Electromagnetic analysis reports that follow these Instructions shall be uploaded in IO IDM as document type "Calculations" (Analysis and Calculation report following MQP procedure 22MAL7). Records of electromagnetic analyses that are outside the scope of these instructions shall not be uploaded as document type "Calculations". This is important, as it allows the project to determine which analysis reports can be used for design verification and validation purposes, see Chapter 2.

General requirements for the storage of analysis reports are given in [1].

All analysis models that support the analysis report shall be uploaded to the IO Analysis Model Database in accordance with [2]. If calculations are performed using software such as Excel or Mathcad, the relevant spreadsheets or worksheets shall also be uploaded to the analysis model database.

The following templates shall be used for documenting reviews and technical checks, unless otherwise agreed, see Section 7.3:

- Checklist for Reviewers of electromagnetic analysis reports [5].
- Checklist for Independent Peer Reviewers of electromagnetic analysis reports [6].
- Checklist for Technical Checkers of electromagnetic analysis reports [7].

Completed checklists shall be uploaded to IO IDM in a manner that makes it impossible to modify them at a later stage in an untraceable manner. Possibilities include:

- Uploadingthe checklists as attachments to 'comments'. This is the recommended approach.
- Attaching the checklists to the reports
- Uploading checklists as stand-alone documents. In this case they shall be uploaded as document type "Engineering Analysis". In addition, links shall be made from the analysis report to these checklists, thereby making it possible to identify that the review has been performed.

Appendix A Technical Requirements

The general requirements for analyses are given in [1]. The following chapter provides more specific requirements for the electromagnetic analysis domain. Additional recommendations and guidelines on how to meet some of the requirements given in the following chapters can be found in [9].

Appendix A.1 Requirements for all Types of Electromagnetic Analyses

Appendix A.1.1 Conceptual Model and Analysis Method

The chosen conceptual model shall represent the physical reality sufficiently accurately to cover the intended purpose of the analysis. In order to do so it is necessary to have a clear definition of the intended use of the model.

Appropriate analysis method(s) shall be used. Note that hand calculations and finite element analyses are valid analysis methods, so long as they are used in an appropriate manner and domain.

Appendix A.1.2 Geometry

Analyses shall be based on geometry that is referenced through a frozen version of the CAD models consistent with the current design of the SSC. The uncertainty in the geometry, e.g. due to tolerances, shall be considered.

Analyses performed during or after the construction phase shall consider any relevant non-conformances.

Deviations from the current design geometry shall be justified. The quantitative effect of the deviations on the results shall be estimated, and considered in the conclusions of the analysis

Appendix A.1.3 Material properties

The analysis shall be based on referenced material properties that are consistent with the procured materials. The analysis shall also consider the uncertainties in material properties. A practical way of ensuring this in EM analyses is: 1) to use resistivity at lowest foreseen operating temperature for the component on which induced mechanical loads need to be assessed; 2) use resistivity at the highest foreseen operation temperature for the components expected to have a shielding effect on the SSC under investigation. In case of analyses involving non-linear (ferromagnetic) material, the B-H curve selected among the ones available shall be: 1) the one with the lowest available saturation in case of static magnetic shielding calculations; 2) the one with the highest available saturation in case of assessment of magnetization forces on SSC.

Appendix A.1.4 Loads

All input loads used for analyses shall come from the relevant approved Load Specification.

Where there are uncertainties in the input data, the input data shall be considered in a conservative manner. This may require performing more than one calculation.

Appendix A.1.5 Units

All analyses shall be performed using S.I. base and derived units. The only exception to this rule is that degrees Celsius may be used instead of Kelvin. The table below lists the most common units used for electromagnetic analyses.

Quantity	Unit name	Unit symbol	In SI base units
Length	Meter	m[3]	
Mass	Kilogram	kg	
Time	Second	s	
Temperature	Kelvin	K	
	Celsius	°C	
Density			kg/m^3
Energy, Work	Joule	J	$kg{\cdot}m^2/s^2$
Force	Newton	N	$kg{\cdot}m/s^2$
Frequency	Hertz	Hz	1/s
Moment		N·m	$kg{\cdot}m^2/s^2$
Power	Watt	W	$kg{\cdot}m^2/s^3$
Pressure	Pascal	Pa	$kg/s^2/m$
Electric Current	Ampere	A	
Electric Current Density		A/m^2	A/m^2
Electric Potential	Volt	V	$kg{\cdot}m^2/A/s^3$
Electrical Resistance	Ohm	Ω	$kg{\cdot}m^2/s^3/A^2$
Resistivity		Ω ·m	$kg{\cdot}m^3/s^3/A^2$
Magnetic Flux	Weber	Wb	$kg{\cdot}m^2/s^2/A$
Magnetic Flux Density	Tesla	T	$kg/s^2/A$
Magnetic Field Intensity		A/m	A/m
Magnetic Permeability		H/m	$kg{\cdot}m/s^2/A^2$

Table 6 – List of S.I. Units

Appendix A.2 Additional Requirements for Finite Element Analyses

Appendix A.2.1 Software Package

Any software package used to perform FE analyses shall be validated. The software package shall be used in its validated domain.

If a validated Finite Element software package has non-negligible uncertainties when used properly, the uncertainties shall be covered either by performing sensitivity studies or by applying a suitable safety factor to the results.

[3] In ITER the reference unit of length is [m]. All FE models shall be made with lengths being defined in meters rather than for example mm. This simplifies the integration of different models, as well as the exchange of models between different IO divisions and IO DAs. A standard unit of length also reduces the risk of mistakes which may occur when material properties are transferred between FE models with different units.

Appendix A.2.2 Coordinate systems

The global coordinate system for FE models shall have its positive z-axis pointing vertically upward. For equipment located in the Tokamak Complex it is recommended to use the ITER Tokamak Global Coordinate System, since it simplifies the possible integration of the FE model in a higher level model. In case this requirement causes particular disadvantages in the performance of the analysis, a different origin may be chosen. One or more local coordinate systems may also be used.

Appendix A.2.3 Element Types and Shapes

The choice of element types and shapes shall be justified.

The choice of element type is partly a question of the physical problem being solved, e.g. elements with vector formulation or edge potential formulation. Such choices are justified as part of the justification of the conceptual model. However, the choice of element types is also a question of the assumptions that underpin each element type and its options.

Many FE elements have limits to the shape they can have whilst giving reliable results. The documentation for FE codes usually comes with definitions of acceptable shape criteria, such as Jacobian ratios. The software itself also usually comes with shape checking tools that check if the FE mesh respects these criteria. Shape checking shall be performed. If poor quality elements have been identified by the check, their use shall be justified.

Chapter 5 of [9] gives some guidance on the choice of element types and shapes.

Appendix A.2.4 Solution Settings

The solution settings chosen for the analysis shall be documented and justified.

Appendix A.2.5 Verification

The accuracy of the results obtained with the FE model shall be verified by the Performer of the analysis.

The results of these verifications of the FE model shall be reported in the analysis report. Chapter 6.1 of [9] provides a procedure to perform the verification and gives some background information on the necessity of the requirements.

Appendix A.2.5.1 Numerical Code Verification

The purpose of code verification is to check whether in the FE software the solution algorithms are correctly implemented. This is typically done by the software vendor for commercial software. Analysis software and its installation of the computer used for the analysis shall be qualified according to [3].

Appendix A.2.5.2 Volumes Check

Volumes check shall performed. The purpose of a volumes check is to verify that volumes of the components modelled in the FE analysis are consistent with the volumes extracted from the 3D CAD models of the same components, which is especially important when the analysis calculates total forces/moments on volumes. The report shall include tables showing the comparison (for each relevant SSC) of the volumes measured in the FE model and in the original CAD model. Significant differences shall be justified, since such differences may indicate modelling errors.

Appendix A.2.5.3 Time step sampling

When the inputs to a transient EM analysis are provided at a large number of time points and it is required to sample a subset of such analysis points to reduce the calculation time, it shall be verified that the sampling did not reduce the accuracy of the calculation. This is accomplished by performing additional analyses, where the number of time steps immediately preceding and following the EM loads maxima is increased considerably. Further information can be found in §8 of [9].

Appendix A.2.5.4 Input Loads Check

For analyses based on inputs generated by a Plasma Equilibrium Code (PEC), e.g. DINA, it shall be verified that the analysis model is able to reproduce the poloidal field and its time derivative in an accurate way. This is accomplished by performing FEM static field calculations and comparing the results with the field produced using the currents calculated by the PEC. This check shall be performed at every time step and for all locations that are relevant to the scope of the analysis. An example of a specific procedure for ANSYS is provided in §6.1 of [9].

Appendix A.2.5.5 Skin effect verification

It shall be checked that the model is sufficiently accurate to reproduce skin effect phenomena that are relevant to the analysis performed. Further recommendations can be found in §8.3 of [9].

Appendix A.2.5.6 FE Mesh Discretization

A common cause of poor accuracy in FE models is insufficient mesh density. The FE code does not warn the user of inaccuracies due to too coarse a mesh. The mesh density shall therefore be justified, and the sensitivity of the results to the mesh density shall be considered in the interpretation of the results. Several methods exist for this, but §8.1 of [9] gives some guidance in this regard.

Appendix A.2.5.7 Comparison with Alternative Results

A verification of calculated results with alternative calculations shall be performed for every FE analysis. Alternative results can be obtained with any of the following methods:

- A hand calculation (usually the analytical result of a simplified conceptual model).
- The same analysis performed with a different, already verified FE model that is validated to be suitable for the analysis task.
- By performing a comparable FE analysis independently (or referring to a previous independently performed analysis). Being performed independently includes that it is performed by a different analyst based on comparable input data such as geometry, material properties, and loads. The FE mesh, the boundary conditions, and load application must be created anew, and the element types, real constants, and solution settings must be chosen anew, i.e. not copied from the original analysis. Also, the conclusions must be drawn independently from the independent analysis results.

All methods have in common that the results are obtained in an alternative way that bypasses possible sources of error and uncertainty in the FE analysis.

In case more than one type of result is intended to be obtained by the electromagnetic analysis, alternative calculations may be required for each type of result.

Appendix A.3 Additional Requirements for Hand Calculations

An essential part of a hand calculation is the justification of the conceptual model that the hand calculation is based on, see subsection Appendix A.1.1.

The estimated accuracy of the hand calculation must be stated, along with the consequently chosen uncertainty factor.

All equations used in the calculation shall be shown. A reference shall be given for any non-trivial analytical formulas used. To improve the clarity it is recommended to use an equation editor. Equations shall be referenced, for example using the format below:

The toroidal field B at the plasma centre calculated as in (Eq. 1) and (Eq. 2).

$$B = \frac{\mu_0 I}{2\pi r} = \qquad \text{(Eq. 1)}$$

$$= 5.3\ \mathrm{T} \qquad \text{(Eq. 2)}$$

where: μ_0 = $4\pi\ 10^{-7}$ kg·m/s^2/A^2, the magnetic permeability in vacuum.

I = 164 MA, the total poloidal current.

r = 6.2 m, the radius at the plasma centre.

- In the first part the equation is given using symbols.
- The result shall be given including the unit.
- All symbols used in the equation shall be defined somewhere in the document.

Appendix A.4 Requirements for Electromagnetic Analysis Reports

This section covers the requirements for electromagnetic analysis reports. Analyses performed inside IO shall follow the template for electromagnetic analysis reports, [8]. This is based on the IO Generic Template for documents, [12]. DAs and subcontractors may use their own templates, but the reports shall contain all of the contents described in this section.

Electromagnetic analysis reports should be provided in Microsoft Word format (.docx) in order to facilitate revisions and updates. If final reports are provided in PDF format, the Word version shall be stored in IO IDM as an attached file.

It is recognised that electromagnetic analysis reports can serve a wide range of purposes, and that a fixed list of section headings is not always appropriate. The list of headings covered here is appropriate in most cases. If any of the sections listed here are not applicable for a particular report, the sections shall be included, along with the text “Not applicable” underneath it. The author should add additional sections if these are required.

The headings in this section are capitalised to indicate that they correspond directly to headings in the template for electromagnetic analysis reports.

Appendix A.4.1 ABSTRACT

The abstract of the electromagnetic analysis report shall contain the following information:

- The ITER SSC to which the electromagnetic analysis is related.
- The assessed components or parts of the system. PBS codes should be used where practical.
- The type of analysis performed, e.g. eddy current analysis for calculation of EM loads or static magnetic field calculations for EM Compatibility.
- The loads that were considered in the electromagnetic analysis.
- Any recent significant changes of design, design criteria or load specification.
- A statement that the report was written following these Instructions, and that the loads applied in the assessments are consistent with the system load specification.

Appendix A.4.2 CHANGE LOG

This section is mandatory, unless changes are logged using the in-built feature in IO IDM. This section contains a log of the changes made to the document between different versions. If changes are not logged directly in IO IDM, they can be logged using the format below.

Version	Location	Change
1.1	2.2	The following sentence was inserted: DINA inputs were updated using the latest scenario.
	Appendix A	The presentation of the B-H curves and temperature-dependent resistivity was improved.
1.0		First version.

Appendix A.4.3 SCOPE OF REVIEWERS

The scope of the review shall be specified for each reviewer, allowing each reviewer to focus on his/her part. Chapter 7 defines the required reviewers and their scope. Additional reviewers can be added.

The scope of reviewers can be specified either in the analysis report itself or directly in IO IDM. The former is often necessary due to the character limits of the relevant fields in IO IDM. This section is mandatory, unless the scope of Reviewers is specified directly in IO IDM. If the scope of reviewers is not specified directly in IO IDM, it can be specified using the format below.

Reviewer	Scope of review
J. C. Maxwell	Reviewer o R1. Report format. o R2. Abstract, purpose and scope. o …
L. Galvani	Reviewer (Load Specification) o R12. Loads (excluding applicability). o Part of R15. The described application of loads to the FE model is consistent with the System Load Specification.
T. Edison	Technical Checker o …

Appendix A.4.4 PURPOSE

This section of the report outlines the aim of the report.

Appendix A.4.5 SCOPE

This section should contain a description of the parts of the ITER Project to which the document applies. It may also be necessary to define areas where this document is NOT applicable. Applicability can typically be defined in terms of:

- Geometry – e.g. pressure vessel with its nozzle but not the connected pipe and its weld. PBS codes should be used where practical.
- Loads – e.g. only the category-I-to-IV loads specified in the SLS [x], without any Beyond Design Basis ones.
- Results – e.g. volumetric forces and moments, stray field calculation for EM compatibility.
- Context – e.g. Preliminary Design Review.

Appendix A.4.6 DEFINITIONS AND ABBREVIATIONS

This section shall contain lists of all definitions and abbreviations used in the document.

Appendix A.4.6.1 DEFINITIONS

This section is only required if certain terms have specific meaning in the context of this document, that is outside the normally accepted dictionary definitions. As an example, see Table 7.

Term	Definition
Computational model	The numerical implementation of the mathematical model, usually in the form of numerical discretization of the geometry, solution algorithm, and convergence criteria.
Validation	The process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the mathematical model. Validation is based on comparisons between numerical simulations and relevant experimental data.

Table 7 – Definitions.

Appendix A.4.6.2 ABBREVIATIONS

All abbreviations and acronyms used in the report shall be listed in alphabetical order, e.g. as below:

BC	Boundary Condition
EM	ElectroMagnetic
FE	Finite Element

Table 8 – Abbreviations.

For a complete list of standard ITER abbreviations see: ITER_D_2MU6W5 - ITER Abbreviations.

Appendix A.4.7 UNITS AND INPUT DATA

Appendix A.4.7.1 UNITS

All units used in the analyses and the analysis report shall be listed. These units shall be S.I. base and derived units. Whilst FE models shall be always created using S.I. units, analysis reports may use standard S.I. prefixes to aid presentation. For example, whilst currents in an FE model shall always be defined in A, the analysis report could list this parameter in MA.

Appendix A.4.7.2 GEOMETRY

A figure of the geometry used in the electromagnetic analysis shall be shown, and the main dimensions relevant to the analysis indicated. Special attributes of the geometry that cannot be easily recognized in a figure and that are relevant to the analysis shall be described, e.g. small gaps between components.

The geometry used to build the FE model must be unambiguously traceable. This can be achieved by:

- Providing references to the relevant approved CAD files, drawings or Data Exchange Task (DET) [16].
- Including a full set of dimensions and/or drawings in the analysis report.
- Attaching CAD files or drawings to the FE model in the ITER Analysis Model Database.

Appendix A.4.7.3 MATERIAL PROPERTIES

The physical material properties of the analysed SSC shall be listed here. These material properties shall be traceable, and consistent with the procured materials.

Material properties can be reported in tables like the ones below. It shall be clearly documented which parts are made from which materials. This can for example be done by adding a column to the table below. The link between materials and geometry can also be made in the preceding "Geometry” section.

Material designation	Property	Notation	Value	Unit	Source
Air/Vacuum	Relative Magnetic Permeability	μ_r	1	–	–
CuCrZr at 350°C	Relative Magnetic Permeability	μ_r	1	–	–
	Electrical Resistivity	ρ	$4.4 \cdot 10^{-8}$	Ω·m	[Y] ITER_D_2232UB

Table 9 – Example table of material properties at 20°C. In this example, [Y] is the ITER Material Properties Handbook (MPH).

Appendix A.4.7.4 DESIGN CRITERIA FOR STATIC FIELD EM COMPATIBILITY

The design criteria for calculations of compatibility to static fields, i.e. maximum allowed static magnetic field for dimensioning of shielding components, shall be stated here. The data shall be extracted and referenced only from approved sources.

The service limits of the system are usually provided as results of testing activities or as input in the technical specification of the analysis.

Appendix A.4.7.5 LOADS

All input loads used for analyses shall be listed here, with reference to the applicable System Load Specification. All loads shall be described clearly and unambiguously. Where there is uncertainty in the loads, these uncertainties shall be reported.

For transient loads the time functions of all loads shall be given either in form of a table or on a diagram that allows the identification of characteristic magnitudes of the load time functions. Loads that are shown graphically should also be defined numerically. Lengthy input may be put in appendices or in attached text files or spreadsheets.

Appendix A.4.8 METHODOLOGY

The principle of the analysis approach shall be described. This is especially important if the analysis involves multiple steps or different analysis types. An example of this would be using the results of a magneto-static analysis to determine the static toroidal field that is used in combination with a disruption analysis that covers only the poloidal field variations.

The conceptual model shall be justified, in particular the inherent simplifications compared to the physical reality. General recommendations about methodology are provided by [9].

The applicability of specific methods depends on the scope of the analysis. For example, methods based on definitions of local magnetic field and its time derivative shall not be applied to components that are located inside the bioshield. Specific recommendations are given in [9].

It shall be justified that the analysis methods are used in their validated domains. If the analysis method conforms to the methodologies used by IO and described in [9], it can simply be stated that the method is in accordance with the above-mentioned reference.

Sensitivity studies may be required if the conceptual model or analysis method cannot be justified by referring to the recommended procedures.

Appendix A.4.9 DESCRIPTION OF FE ANALYSIS

This section is mandatory if the report concerns an FE analysis. All subsections are mandatory, unless stated otherwise.

Appendix A.4.9.1 SOFTWARE PACKAGE

The name and version number of the software package used for the analysis shall be stated, e.g. "The FE analysis was performed using ANSYS 2019 R2 EMAG".

In case analyses are classified as PIA, the Performer has to check that the software package is accepted as validated by the responsible entity in the IO. It shall be justified that the software package is used in its validated domain.

It shall be stated what uncertainties, if any, are associated with the use of the validated Finite Element software package for the reported analysis.

Appendix A.4.9.2 TYPE OF ANALYSIS

The type of analysis shall be stated, e.g. 3D transient analysis with nodal vector potential formulation.

Appendix A.4.9.3 COORDINATE SYSTEM(S)

All coordinate systems used in the FE analysis shall be defined. This includes but is not limited to the following:

- Local coordinate systems that are used for boundary conditions and load application.
- Coordinate systems used for results.
- The global coordinate system in which the FE model geometry is created.

Appendix A.4.9.4 FE MATERIAL PROPERTIES

All material properties used in the FE model shall be listed. These may be different from the physical material properties, for example when 'smeared' material properties are used, or when resistivity are modified to correct differences between the modelled volumes and the volumes defined in the input geometry. In case the physical material properties are used in the FE model it is acceptable to combine the requirements of this section with those of Appendix A.4.7.3, and report all of the required information in a single paragraph.

In case tuned values of resistivity are used, they should be compared to the theoretical values. Significant discrepancies should be explained, as they often indicate problems with the FE model.

Since material properties are usually temperature dependent, the assumed temperature(s) of the structure could be stated in this section.

Material properties can be reported in tables like the ones below.

Part	**Material number**	**Orignal Resistivity (Ω·m)**	**Volume Ratio ( )**	**Equivalent Resistivity (Ω·m)**
First wall (Cu)	1	$4.4 \cdot 10^{-8}$	0.8	$5.5 \cdot 10^{-8}$
First Wall (SS)	2	$8.15 \cdot 10^{-7}$	0.9	$9.06 \cdot 10^{-7}$
Blanket Shielding Block	3	$8.15 \cdot 10^{-7}$	0.75	$1.1 \cdot 10^{-6}$

Table 10 – Example table of material properties 1. Electrical Resistivity from [Y] have been adjusted to compensate for the voids in the volumes [Y].

<table>
<tr><th colspan="2">Material</th><th rowspan="2">Part</th><th colspan="5">Material properties</th></tr>
<tr><th>#</th><th>Name</th><th>Name</th><th>Notation</th><th>Value</th><th>Unit</th><th>Ref.</th></tr>
<tr><td rowspan="3">1</td><td rowspan="3">CuCrZr</td><td rowspan="3">Blanket First Wall</td><td>Magnetic permeability</td><td>MURX</td><td>1</td><td></td><td></td></tr>
<tr><td rowspan="2">Electrical Resistivity</td><td>RSVX</td><td>$4.4 \cdot 10^{-8}$</td><td rowspan="2">Ω·m</td><td rowspan="2">[Y]</td></tr>
<tr><td>RSVY</td><td>$1 \cdot 10^{-5}$</td></tr>
</table>

Material		Part	Material properties				
#	Name		Name	Notation	Value	Unit	Ref.
2	Stainless steel 316(L)N-IG	Vacuum Vessel	Magnetic permeability	MURX	1		…
			Electrical Resistivity	RSVX	$8.15 \cdot 10^{-7}$	Ω·m	…

Table 11 – Example table of material properties 2.

Appendix A.4.9.5 FE MESH

This section is mandatory, but the subheadings may change depending on the analysis software. It has to include a comprehensive description of the mesh used i.e. element shapes, order, formulation and settings.

The template [8] gives some guidance on how to report the FE mesh.

Appendix A.4.9.6 BOUNDARY CONDITIONS

Each set of boundary conditions (BCs) shall be described, including degrees of freedom and the coordinate system. The BCs shall also be shown on a figure.

In case the BCs are not constant throughout the analysis, the changes shall be described.

Internal constraints (e.g. coupled equations) shall be described in this section Boundary Conditions or in a separate section. They shall also be shown in one or more figures.

Usually the boundary conditions of the structure under consideration represent either the surrounding structures or a part of the structure not represented in the FE model (e.g. in case of cyclic boundary conditions).

Often flux-parallel conditions are applied to the boundary of the model as opposed to modelling the far-field decay with specific elements (e.g. INFIN111 in ANSYS EMAG), in which case appropriate justifications shall be provided.

The basic principles of the constraints are part of the justification of the conceptual model, and should therefore be justified in section Appendix A.1.1. Such justification does not need to be duplicated here. This paragraph should focus on their implementation in the FE model, for example: *«The direction of the electric currents is restrained by setting the VOLT Degree of Freedom (DoF) of all nodes of the surface to zero.»*

Appendix A.4.9.7 LOAD APPLICATION

This section covers how the defined loads are applied to the FE model.

Note that the loads applied to an FE model may be different from those defined in the Loads section (Appendix A.4.7.5). An example of this could be the source current applied to a coil modelled with a different cross section. In this case, it is appropriate to adjust the current density based on the ratio of the cross section to the original one, such that the total current is preserved.

Appendix A.4.9.8 SOLUTION SETTINGS

The solution settings shall be listed and justified.

Appendix A.4.10 RESULTS

- All results values shall be given with their units (including graphs and contour plots). Clear titles shall be given when presenting graphs.
- All relevant results to meet the scope of the electromagnetic analysis shall be given. In case a large number of similar results are calculated, it may be more practical to present some results either in appendices or in attached spreadsheets.
- In case an uncertainty factor is applied to the results to account for the uncertainties of the electromagnetic analysis, it is recommended to give in the Results chapter the result value found in the analysis excluding the uncertainty factor. The uncertainty factor should however be mentioned. It is recommended to apply the uncertainty factor to the results in a separate section or in the conclusions.
- The coordinate system used for the results shall be specified.
- The point of summation of moments shall also be explicitly stated.

Appendix A.4.11 VERIFICATION OF THE FE ANALYSIS

This section is mandatory if the report concerns an FE analysis. The results of all of the checks listed in Sub-section Appendix A.2.5 and applicable to the electromagnetic analysis shall be reported here.

A comparison shall be made between the results of the FE analysis and those of the alternative calculation(s), see paragraph Appendix A.2.5.7. An example of how this could be presented is shown below:

Type of Result	**Result of this analysis**	**Result of independent assessment**	**Difference**	**Reference**
Maximum radial moment on Blanket Module #1	1050 kN·m	960 kN·m	−9 %	
Maximum current induced on WG #8	7.8 kA	8.66 kA	11 %	

Table 12 – Example of how the results of an FE analysis could be compared to results from alternative calculations.

The reference can be another document, or a different section in the analysis report, e.g. in case of a hand calculation.

Appendix A.4.12 CONCLUSIONS

- The conclusions shall summarize the most significant findings, and be comprehensible for persons familiar with the design and loads of the system, with an engineering background but not necessarily with expertise in electromagnetic analyses.
- The scope of the electromagnetic analysis should be recalled before writing the conclusions.
- The result values given in the conclusions shall consider the uncertainty of the electromagnetic analysis.
- Results for which the FE model cannot meet accuracy requirements shall either not be reported or be marked as "preliminary" or "best estimates".
- Result values shall not be given without a judgement. Rather than an absolute judgement (e.g. "the design criteria are met") it is recommended to make quantitative judgements,

e.g. the shielded housing reduces the stray magnetic field to 90% of the maximum allowed by the supplier.

- If appropriate, recommendations for design improvements (e.g. of a magnetic shield) can be given in the conclusion chapter or in a separate chapter.

Appendix A.4.13 REFERENCES

- All documents that are referenced by the analysis report shall be listed here.
- References shall be stored in IO IDM or be publically available (e.g. design codes or engineering handbooks).
- References shall be approved.
- References to IO IDM documents shall include the version numbers.
- An approver and at least one Reviewer must be assigned to a reference.
- It is recommended that use is made of the cross-reference or bibliography capability in MS Word.

Appendix A.4.14 APPENDIX A

Appendices can be included if appropriate.

Appendix B Not Used

Appendix C Completion of Checklists

The completion of Reviewer and Independent Peer Review checklists shall be performed following the requirements and guidance listed in Table 13.

Check	Requirements and Guidance
R1	**Report title, format and metadata.** The requirements of Appendix A.4 (not including sub-paragraphs) are met, including that: • IO analyses reports follow the template for electromagnetic analysis reports. • Reports stored in IDM are in the Microsoft Word format (.docx). If not, a Word version is stored in IDM as an attached file. • The report is titled such that the scope of the analysis (component and loading conditions) is described as well as briefly as possible. EM analysis reports that follow the Instructions for Electromagnetic Analyses are uploaded in IO IDM as document type “Calculations”.

R2	**Abstract, purpose and scope.**
	The requirements of the following paragraphs are met:
	• Appendix A.4.1. The abstract of the electromagnetic analysis report contains the following information:
	  o The ITER SSC to which the electromagnetic analysis is related.
	  o The assessed components or parts of the system. PBS codes should be used where practical.
	  o The loads or load combinations that were considered in the electromagnetic analysis (type of analysed plasma disruptions, static magnetic field…).
	  o Any recent significant changes of design, design criteria or load specification.
	  o A statement that the report was written following these Instructions and that the loads applied in the assessments are consistent with the system load specification.
	• Appendix A.4.4. The “purpose” section outlines the aim of the report.
	• Appendix A.4.5. The scope defines the applicability of the report, typically in terms of geometry, loads, results and context.

R3	**Scope of reviewers.** The requirements of Section 7.3 and Appendix A.4.3 are met, including that: • For PIA analyses, the SROhas been assigned to perform at least all of the checks listed in Paragraph **Error! Reference source not found.**. • One or more Reviewers have been assigned that between them cover at least all of the points listed in Paragraph 7.3.2. • Where required by ITER_D_22MAL7, an Independent Peer Reviewer has been assigned that covers at least all of the points listed in Paragraph 7.3.3. • A Technical Checker has been assigned to cover at least all of the points listed in Paragraph 7.3.4. The scope of the review is specified for each reviewer, either in IDM or in the report itself.
R4	**Definitions and abbreviations.** The requirements of Appendix A.4.6 are met, i.e. all definitions and abbreviations used in the report are listed, in alphabetic order.

Check	Requirements and Guidance
R5	**Units.** The requirements of Appendix A.1.5 and Appendix A.4.7.1 are met, i.e. analyses are performed using S.I. base and derived units.

R6	**Geometry (excluding applicability).**
	The requirements of the following paragraphs are met:
	• Appendix A.1.2, including that:
	  o Analyses are based on geometry that is unambiguously traceable. Where relevant, the references are approved.
	  o The uncertainty in the geometry, e.g. due to tolerances, has been considered.
	  o Analyses performed during or after the construction phase has considered any relevant non-conformances.
	  o Deviations from the current approved design geometry have been justified.
	  o The quantitative effect of the deviations on the results has been estimated, and considered in the conclusions of the analysis
	• Appendix A.4.7.2, including that:
	  o A figure of the geometry used in the analysis has been shown, and the main dimensions relevant to the analysis indicated.
	  o Special attributes of the geometry that cannot be easily recognized in a figure and that are relevant to the analysis have been described.
	The magnitudes of geometrical imperfections considered in the analysis through any modification of the initial mesh have been stated.

R7	**Applicability of geometry (*).** Analyses are based on applicable geometry, i.e. the current approved design.
R8	**Material properties (excluding applicability).** The requirements of the following paragraphs are met: • Appendix A.1.3, including that the analyses consider the uncertainties in material properties. • Appendix A.4.7.3, including that: o The physical material properties of the analysed SSC are listed, and traceable to approved references. It is clearly documented which parts are made from which materials.
R9	**Applicability of material properties (*).** Analyses are based on physical material properties that are consistent with the procured materials of the analysed SSC.
R10	**Design criteria for Static EM Field Compatibility (only applicable to EMC analyses).** The requirements of Appendix A.4.7.4 are met, including that: • The criteria are clearly stated. • The data are extracted from approved references.

Check	Requirements and Guidance
R11	**Loads (excluding applicability) (**).** The requirements of Appendix A.1.4 and Appendix A.4.7.5 are met, including that: • All input loads used for analyses are listed and described clearly and unambiguously. • All listed input loads come from the relevant approved System Load Specification. • Any uncertainties in the loads are reported, and considered in a conservative manner. For transient loads, the time functions of all loads are given in the form of either a table or a diagram that allows the identification of characteristic magnitudes of the time functions.
R12	**Applicability of loads (*).** The approved System Load Specification on which the analysis is based is still consistent with the current design of the SSC.

R13	**Conceptual model and analysis methodology.**
	The requirements of the following paragraphs are met:
	• Appendix A.1.1, including that:
	  o The chosen conceptual model represents the physical reality sufficiently accurately to cover the intended purpose of the analysis.
	  o Appropriate analysis method(s) are used.
	• Appendix A.4.8, including that:
	  o The principle of the analysis approach is described.
	  o The conceptual model is justified, in particular the inherent simplifications compared to the physical reality.
	Justification is provided that the analysis methods are used in their validated domains.

<table>
<tr><th>Check</th><th>Requirements and Guidance</th></tr>
<tr><td>R14</td><td>Description of the Computational Model (only applicable to Computational Models).
The Computational Models are well documented, and are an appropriate implementation of the conceptual model and analysis methodology. The requirements of the following paragraphs are met:

Appendix A.2.1 and Appendix A.4.9.1, including that:

The name and version number of any software package used to perform analyses is stated.
Any software package used is validated.
It has been justified that software packages have been used in their validated domain.
It is stated what uncertainties, if any, are associated with the use of the validated analysis software package for the reported analysis.
If a validated analysis software package has non-negligible uncertainties when used properly, the uncertainties are covered either by performing sensitivity studies or by applying a suitable safety factor to the results.

Appendix A.2.2 and Appendix A.4.9.3, including that:

All coordinate systems used in any Computational Model are defined
The global coordinate system in the Computational Models has its positive z-axis pointing vertically upward.

Appendix A.2.3, including that:

The choice of element types and shapes is justified.
Shape checking has been performed and reported. If poor quality elements have been identified by the check, their use is justified.

Appendix A.2.4, including that:

The solution settings chosen for the analysis are documented and justified.

Appendix A.4.9 (excluding paragraphs covered above), including that:

The type of analysis is stated.
All material properties used in the Computational Models are listed
A description of the Computational Models is given, including pictures of the mesh, and details of element properties (e.g. element types and options, real constants and section properties.
Each set of boundary conditions (BCs) is described, including degrees of freedom and the coordinate system. The BCs are also shown on a figure.
In case the BCs are not constant throughout the analysis, the changes are described.
Internal constraints (e.g. coupled equations) are described, and shown on one or more figures.
The report describes how the defined loads are applied to the Computational Models. The described application of loads to the Computational Models is consistent with the System Load Specification.

The solution settings are listed and justified.</td></tr>
</table>

Check	Requirements and Guidance
R15	**Hand calculations (only applicable to hand calculations).** The hand calculations are well documented, and are an appropriate implementation of the conceptual model and analysis methodology. The requirements of Appendix A.3 are met, including that: • All equations used in the calculation are shown. • A reference is given for any non-trivial analytical formulas used. • Equations are referenced. • The result of calculations shall be given including the unit. All symbols used in the equation shall be defined in the report.
R16	**Results.** • Results are reasonable for the given inputs and assumptions. • The requirements of Appendix A.4.10 are met, including that: o All results are given with their units (including graphs and contour plots). o Clear titles and axis labels are given when presenting graphs. o All relevant results to meet the scope of the analysis are given. o Results shall be given corresponding to the design criteria. o The point of summation of moments shall be explicitly stated. The coordinate system used for the results shall be specified.
R17	**Verification of Computational Model: Software Installation.** The requirements of Appendix A.2.5.1 are met, including that analysis software and its installation of the computer used for the analysis shall be qualified according to [3].
R18	**Verification of Computational Model: Components volume and equivalent electric properties.** The requirements of Appendix A.2.5.2 are met, including that: • A volume check is performed and reported when the analysis calculates total forces/moments on volumes. • The report includes tables showing the comparison (for each relevant SSC) of the volumes measured in the Computational Models and in the original CAD models. Significant differences have to be justified, since such differences may indicate modelling errors.
R19	**Verification of Computational Model: Accurate time step sampling for transient analysis.** The requirements of the paragraphs Appendix A.2.5.3 and Appendix A.4.11, including that when it is required to sample a subset of the analysis time points to reduce the calculation time, it is verified that the sampling did not reduce the accuracy of the calculation.
R20	**Verification of Computational Model: Input for plasma disruption analysis.** The requirements of Appendix A.2.5.4 are met, including that: • A static input load check has been performed and reported, checking that the magnetic field distribution corresponds to the field produced using the currents calculated by the PEC. A static input load check has been performed and reported, checking that the time derivative of the magnetic field is consistent with the input produced by the PEC.
R21	**Verification of Computational Model: Requirement on skin effect checks.** The requirements of Appendix A.4.11 are met, including that the mesh density is adequate to catch the effects of eddy currents in proximity of the surface of the components under analysis (skin effect) if high gradients are expected.

Check	Requirements and Guidance
R22	**Verification of Computational Model: Requirement of mesh accuracy.** The requirements of Appendix A.2.5.6 are met, including that: • The mesh density is justified, e.g. by means of a mesh sensitivity study. • The sensitivity of the results to the mesh density is considered in the interpretation of the results.
R23	**Comparison with Alternative Results.** The requirements of Appendix A.2.5.7 and Appendix A.4.11 are met, including that the results of analyses have been verified by comparing them to those of alternative calculations.
R24	**Conclusions.** • The conclusions are reasonable and representative of the outputs. • The conclusions properly meet (or cover) the scope and purpose. • The requirements of Appendix A.4.12 are met, including that: o The conclusions summarize the most significant findings, and are comprehensible for persons familiar with the design and loads of the system, with an engineering background but not necessarily with expertise in electromagnetic analyses. o The result values given in the conclusions consider the uncertainty of the electromagnetic analysis. Results for which the Computational Models cannot meet accuracy requirements are either not reported, or marked as "preliminary" or "best estimates".
R25	**References.** The requirements of Appendix A.4.13 are met, including that: • All documents that are referenced by the analysis report are listed. • References are stored in IO IDM or are publically available. • References in IO IDM are approved. • References to IO IDM documents include the version numbers. An approver and at least one Reviewer must be assigned to IDM references.

Table 13 – Requirements for completion of Reviewer and Independent Peer Reviewer checklists.

(*) This check shall be performed by the RO of the SSC.

(**) On the Reviewer Checklist, this check shall be performed by the RO of the SLS. On the Independent Peer Reviewer checklist this requirement does not apply.

The completion of Technical Checker checklists shall be performed following the requirements listed in Table 14.

Check	Requirements and Guidance
TC1	**Conceptual model and analysis methodology.** The requirements of the following paragraphs are met: • Appendix A.1.1, including that: o The chosen conceptual model represents the physical reality sufficiently accurately to cover the intended purpose of the analysis. o Appropriate analysis method(s) are used. • Appendix A.4.8, including that: o The principle of the analysis approach is described.

Check	Requirements and Guidance
	○ The conceptual model is justified, in particular the inherent simplifications compared to the physical reality. Justification is provided that the analysis methods are used in their validated domains.
TC2	**Mathematical model.** The mathematical model is described properly, and is appropriate given the analysis methodology. This includes the: • Coordinate system(s) used. • FE material properties. • FE mesh. • BCs. • Load application. • Solution settings.
TC3	**The analysis model is properly stored in the analysis database.** The models are stored in the ITER analysis database, and respect the requirements of the MQP Instructions for the Storage of Analysis Models (ITER_D_U34WF3), including that they: • Include all files necessary to get the reported results (e.g. including macros & spreadsheets). • Are linked to the analysis report, and their metadata is filled properly. • Are stored in a sensible and organized folder of IO's Analysis Model Database. • Are in a ready-to-run state. The technical checker shall rerun the analyses to verify this. • Are commented/organised to be clearly and unambiguously understandable by a third party. Proper storage formats are used, i.e. that privileges robustness and exhaustiveness.
TC4	**The model in the database matches the report.** The geometry, mesh, element types, material and element properties, BCs and loads of the model in the database match the description in the report.
TC5	**The results of the model in the database match the description in the report.** Important results match those described in the report. Given that results are often not stored in the database this check may require rerunning the analyses, see TC3.
TC6	**Analysis results are reasonable, and hand calculations are correct.** • Results are reasonable for the given inputs and assumptions, i.e. no observations are made that indicate that there are errors in the analysis. • The analysis uncertainties are judicious. • The numerical evaluations of hand calculations are correct.

Table 14 – Requirements for completion of Technical Checker checklists.

Appendix D Compliance Matrix for Checking Requirements from [1]

The compliance matrix below demonstrates that all the requirements for checking of analysis reports required by [1] are covered by requirements given in these Instructions. In this table 'R#' means 'Reviewer check number #'; 'TC#' means 'Technical Checker check number #'. They correspond to the checks listed in Subsections 7.3.2, 7.3.3 and 7.3.4, which are propagated to [5], [6] and [7].

	Requirement from [1]	**Covered by**
Review / Technical Check	Check that the requirements defined in the specifications are met including the scope and purpose as defined in the technical specification.	A contractual issue, not in the scope of these Instructions.
	Check that the calculation model data appropriately reflect the geometrical data and interfaces of the object under investigation.	R6, R7, R15, TC1
	Check the basic approach, assumptions, subject-specific data (such as loads), and any equations or formulas applied are appropriate.	R8, R9, R13, R14, TC1
	Check that input data are consistent with requirements or validated by referenced sources.	R6, R7, R8, R9, R10, R11, R12, R13, R14
	Check the calculations are mathematically correct.	TC6
	Check the requirements and acceptance criteria are appropriate and used correctly.	R10, R11, R12
	Check the conclusions reached are reasonable and consistent with the analysis or calculation approach, assumptions, input, and acceptance criteria.	R18, R24, TC6
	Check that the software is validated for the scope and purpose of the analysis.	R16
Independent Peer Review	Design or analysis philosophy is sound	R15, TC1
	Structural system, materials, acceptance criteria, and other pertinent factors are considered.	R6, R7, R8, R9, R10, R11, R12
	Analysis or calculation approach is reasonable and appropriate.	R15, R16, R17, TC1
	Inputs are reasonable and correct.	R6, R7, R8, R9, R10, R11, R12, R13, R14
	Assumptions are reasonably substantiated and justified.	R15, TC1
	Mathematical formulations and/or computer models (see def.) are appropriate and contain sufficient detail.	R16, R17, TC2
	Outputs are reasonable for the given inputs and assumptions	R18, TC6
	Acceptance criteria used are appropriate.	R10
	Conclusions are reasonable and representative of the outputs	R24

Table 15 - Compliance matrix for checking requirements from [1].

Appendix E Compliance Matrix for INB Order [4]

The compliance matrix between these instructions and the INB order dated 7 February 2012 [4] is shown Table 16 and Table 17 below. By following these Instructions and the references in the table below, all requirements from [4] relevant to electromagnetic analyses are met.

For Article 3.8 of the INB order, the requirements have been taken from the summary table of [10], rather than directly from the INB order.

Article in [4]	Requirement	Covered by
2.2.1	Surveillance of external interveners. The operator informs all external interveners of the provisions required for implementing the Ministerial Order hereof.	Chapter 2, which states that the rules governing the propagation of the requirements specified in these Instructions are specified in [11].
2.2.2	The operator surveys external interveners.	Outside the scope of these instructions. The requirements for surveillance plans are defined in [1].
2.5.2.II	The protection-important activities are carried out in accordance with procedures and using means for meeting *a priori* the requirements defined for these activities and for the protection-important components concerned, and to ensure them *a posteriori*.	These Instructions represent the procedures that shall be followed to meet *a priori* the requirements for PIA analyses. The reviews required by Section 7.3 ensure *a posteriori* that analyses under direct control of ITER IO meet the defined requirements. The surveillance plans required by [1] ensure *a posteriori* that analyses performed by external interveners meet the defined requirements.
2.5.3	Each protection-important activity undergoes technical monitoring, to ensure that: the activity is carried out in compliance with the requirements defined for the activity and, if necessary, for the protection-important components concerned; appropriate corrective and preventive actions have been defined and implemented.	Subsection Appendix A.2.5, Section 7.3, the surveillance requirements defined in [1].
2.5.5	Protection-important activities, their technical monitoring and the checking and assessment actions are carried out by individuals with the appropriate skills and qualifications.	Section 7.2, the surveillance requirements defined in [1].

Article in [4]	Requirement	Covered by
2.5.6	Protection-important activities, their technical monitoring and the checking and assessment actions are documented and are traced to demonstrate *a priori* and to …	The *a priori* definition of PIAs is outside the scope of these Instructions. The surveillance requirements are defined in [1].
	… check a *posteriori* that they comply with defined requirements.	The reviews required by Section 7.3 ensure *a posteriori* that analyses under direct control of ITER IO meet the defined requirements. The surveillance plans required by [1] ensure *a posteriori* that analyses performed by external interveners meet the defined requirements.
	The documents and corresponding recordings are kept updated, are easily accessible and legible, protected, kept under appropriate conditions and archived for an appropriate and justified period of time.	Chapter 8.

Table 16 - Compliance Matrix for the INB Order [4], excluding Article 3.8.

Group	Requirement	Covered by
Input data	Use of referenced, updated and validated input data.	Appendix A.1.2 (geometry), Appendix A.1.3 (materials), Appendix A.1.4 (loads).
	Use of controlled assumptions.	Appendix A.1.1 (justification of conceptual model and analysis method).
	Assessment of the uncertainties in input data.	Appendix A.1.4 (loads).
Methods	Establishment of a range of assumptions and sensitivity studies when assumptions include uncertainties.	Appendix A.1.1 (justification of conceptual model and analysis method).
	Verification of the consistency with safety demonstration.	Subsection **Error! Reference source not found.** (SRO review).
	Establishment of a list of validated and appropriate methods.	Appendix A.1.1 (justification of conceptual model and analysis method).
	Use of methods in their validation domain.	Appendix A.1.1 (justification of conceptual model and analysis method).

	Verification of the methods consistency with safety demonstration.	Subsection **Error! Reference source not found.** (SROreview).
	Sensitivity studies to be performed for covering methods uncertainties or additional safety factor in the results.	Appendix A.1.1 (justification of conceptual model and analysis method). Appendix A.4.12
Codes and calculation tools	Establishment of a list of validated and appropriate codes.	Outside the scope of these Instructions.
	Use of methods in their qualification domain.	Appendix A.2.1 (software package).
	Verification of the methods' consistency with safety demonstration.	Subsection **Error! Reference source not found.** (SRO review).
	Sensitivity studies to be performed for covering code uncertainties or additional safety factor in the results.	Appendix A.2.1 (software package), Appendix A.4.9.2 (type of analysis).
Reports and results	All input data, methods, codes and their validity domain and uncertainties to be included.	Reporting of input data : Appendix A.4.7.2 (geometry), Appendix A.4.7.3 (physical material properties), Appendix A.4.7.5 (loads). Reporting of analysis method, including its validity and associated uncertainties: Appendix A.4.8 (methodology). Reporting of FE software packages, including their validity and associated uncertainties: Appendix A.4.9.1 (software package).
	Intermediate and final results to be expressed in international units.	Appendix A.4.7.1 (units).
	Sensitivity studies to be performed for covering uncertainties or additional safety factor in the results.	Appendix A.4.8 (methodology). Appendix A.4.12 (conclusions).
Acceptance criteria	The acceptance criteria to be substantiated and checked against potential safety limits and when applicable design margins brought by codes.	Appendix A.4.10 (results).
	Margins and safety factor to be expressed with regards to safety limits.	Appendix A.4.12 (conclusions).

Table 17 - Compliance Matrix for Article 3.8 of the INB Order, [10].