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Systems engineering procedure for requirements management of divertor system of tokamak reactors

Francesca Giovanna Lanzotti [a,d,g,*], Giuseppe Di Gironimo [a,d], Jessica Korzeniowska [b], Vito Imbriani [c], Giuseppe Mazzone [e], Jeong-Ha You [f], Domenico Marzullo [c,d]

[a] University of Naples Federico II, Dept of Industrial Engineering (DII), P.le Tecchio 80, 80125 Napoli, Italy
[b] UK Atomic Energy Authority, Culham Science Centre, Abingdon, Oxfordshire, OX14 3DB, UK
[c] University of Trieste, Dept of Engineering and Architecture, Via A. Valerio 6/1, 34127, Italy
[d] Consorzio CREATE, Via Claudio 21, 80125, Napoli, Italy
[e] ENEA, Fusion and Tech for Nuclear Safety and Security Dept, via E. Fermi 45, 00044 Frascati, Italy
[f] Max Planck Institute for Plasma Physics, Boltzmann Str. 2, D-85748 Garching, Germany
[g] University of Padua, 35122 Padova, Italy

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ABSTRACT

Systems Engineering allows to address the design of complex systems from the early stage until the end of its lifetime with the aim to realize successful systems. The intrinsic complexity of tokamak design requires to adopt Systems Engineering guidelines to write correctly and efficiently a large set of system requirements. Well-formed requirements would make efficient and consistent the downstream design, integration, and verification of a system. The process of requirements definition, conformed to Guide to System Requirements Definition recommended in fusion field, is far from simple and fast. The requirements definition phase encourages the early identification of issues that can be acted in the life cycle. This paper firstly highlights a new procedure to include requirements of a tokamak component in the requirement management tool of the whole system. This work identifies engineering requirements and constraints and describes their impact on the selection of the design principles of the EU-DEMO divertor system. The new identified procedure is developed using a participative approach involving experts belonging to different working groups.

1. Introduction

The EUROfusion Consortium Research Institutions is undertaking a DEMO Requirements Management approach to ensure robust requirements-based design and verification through the whole DEMO life cycle with the aim to support the efficient realisation of the DEMO Power Plant. The vacuum chamber with a torus-shaped surrounded by magnetic coils, so-called tokamak, is one of the most advanced devices designed to produce thermonuclear fusion power. The design of tokamak reactor is a real challenge for many reasons. In this context, a Systems Engineering approach allows to design a system that is intrinsically characterized by technological complexity [1]. This interdisciplinary approach is adopted to design complex systems since the conceptual design stage with the aim to realize successful systems [2]. The main purpose is to investigate the relationships amongst different parts of the whole system and their interactions with other systems and the external environment. Requirements Engineering, as a field of Systems Engineering, has been becoming increasingly relevant since the initial phase of the design of complex systems [3]. The synthesis activity of such large assemblies requires an appropriate procedure as a sequence of techniques and/or actions conducted in a precise order [4]. Requirements management is recognised as a crucial phase that is characterized by the ability to write requirements and also to make them readable and traceable with the aim to follow their evolution step by step over time [5]. The DEMO requirements approach under development provides a guide on how to define and write requirements at any level of the DEMO system, implementing consistently procedures and elevating the overall standard of requirements across the project within a framework developed by DEMO Requirements Management Team at UKAEA. Each work package indeed has been training in writing good requirements, whilst engaging in the definition and in the further use of requirements. The main aim of this phase is to formalize efficiently a

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* Corresponding author.
E-mail address: francescagiovanna.lanzotti@unina.it (F.G. Lanzotti).

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large set of requirements coming from different technical areas.

System Engineering methodology has indeed been followed to support the design and development of different DEMO work packages. Grossetti et al. [6] focused on requirement engineering activities of the DEMO Heat and Current Drive (HCD) system, concerning an initial definition of the HCD requirements and functions through the development of a system architecture model developing use cases diagrams. This referenced work, part of Framework Programme 8 (FP8) Horizon 2020, has been carried out before the new Requirements Management procedures currently adopted on DEMO project and created within the Framework Programme 9 (FP9) after the last Gate Review (G1). The approaches were very different in FP8, with no consistent management approach from DEMO central team.

In [7], Tenaglia et al. proposed a tool to ease this process avoiding errors as much as possible following Systems Engineering principles. They show how the divertor system can be included in a wider Requirement Management procedure defined for DTT following a Systems Engineering approach. They highlight the relevant interface parameters and develop a data analysis to allow an interactive visualization of requirements traceability able to show impact of changes in the divertor on the design and operations of the machine. Requirements management phase for the DEMO divertor is still considered an open issue.

The main objectives of this work are:

- Identify and formalize requirements for the divertor system and the divertor subsystems;
- Adopt a method and a tool to elicit and define requirements;
- Minimize the risk of forgetting important requirements.

2. Materials and methods

The first step for the design and development of an innovative system is the Requirements Management phase [8]. The requirement identification is considered a technical and logical process because instructions and rules should be carefully followed. Specific methods and tools are used from the initial phase of the product following step by step the system development. However, this phase is far from simple and quick, writing well-structured requirements is a very challenging phase. This activity can be classified as “iterative”, it is reviewed and refined periodically along with other processes, and “recursive”, it can be applied at any system level to converge into a valid and mature requirement set. Requirements engineering is a multidisciplinary process that requires social interactions. The four key activities to be carried out are: collecting, analysing, deciding, and acting [12].

2.1. Background overview

Systems Engineering approach allows to support system requirements, analysis, design, verification, and validation activities coming from a traditional document-based approach with information collected by many sources [9]. Stakeholders needs, as the first step of the decomposition, are expressed in Natural Language that is characterized by three main problems: the lack of consistency, imprecision, and ambiguity [10]. The definition of the so-called SMART requirements is essential to avoid design failure and a great level of expertise is required for this phase [11]. Focusing on requirements specification and system architecture, as the second and third step of the left side of the V-model (Fig. 1), requirements decomposition moves from system to subsystem until the component requirements.

At each level a corresponding logical architecture can be defined (Fig. 2). During the first step of the product development, it is necessary to move not only from the left to the right side (horizontal dashed arrows in Fig. 2), but also in the opposite direction (tilted dashed arrows in Fig. 2) before moving to the subsequent level. The continuous arrows highlight the feedback from the bottom to the higher level to show the iterative and recursive nature of the process. A design architecture is expressed as a set of interacting components that collectively exhibit the desired properties. These properties should exactly match the desired characteristics of the system as expressed in the system requirements.

2.2. Requirements management method

The Requirements Management, proposed in this work, aims at outlining the systematization of a procedure for propagating requirements from system to subsystems level enabling the concurrent work. The System Requirement Document (SRD) must be well-structured and clearly organized following precise guidelines to create a set of efficient requirements. Each requirement shall be characterized by different properties such as the clearness, the consistency, the editability and the traceability to realize a good quality product. The communication and the verification activities with Requirements Manager of the project are necessary to successfully develop the project. Feedbacks are important factors to be considered step by step for the successful evolution of all system levels. In this work the roles and responsibilities of two main actors are explained to enable the management of the project:

- System Design Lead (SDL): accountable role of system requirements definition and document. He manages the system requirements;

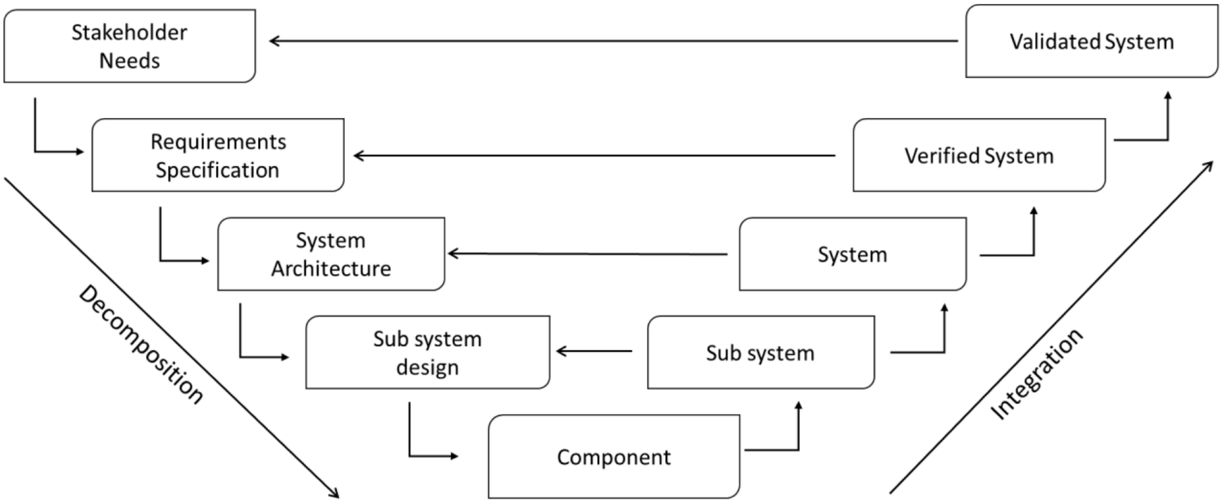


Fig. 1. V-Model.

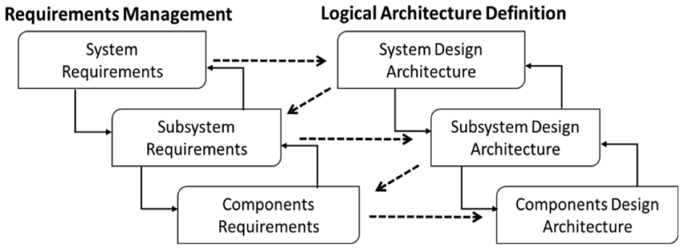


Fig. 2. Correlation between requirements management and logical architecture definition.

- Requirements Manager: control role of the quality of requirements instructing re-work when necessary and trainer of people involved in the project. Indeed, he supports the SDLs for requirements definition and management of system and subsystems and provides methods and tools to work on the requirements.

The developed SRD Template allows to easily collaborate with the different people involved in the project. It is an Excel spreadsheet characterized by a colour-coded section and six tabs, shown in Fig. 3:

- Cover page, the cover page contains information regarding the document itself, for example authors, version etc.
- Glossary, the glossary page provides an area to define each term necessary for understanding the requirements. Each abbreviation and word that could not be known or easily misinterpreted for their ambiguity should be written here;
- Assumption, this page, optional to complete, records the assumptions needed for system requirements and provides supporting information to the requirements. This should be completed whilst working on the system requirements. There is currently no formal process for assumptions management;
- Parent SRD, this page is a reference for users and contains the Parent Requirements from the SRD above the system of interest. This will be provided to users pre-populated and is to be used when working on Propagation Step 1 tab, defined below in same section. It contains only those coloured sections which are relevant to the child system. This tab is locked for editing, so users will not be able to change information. If there are any issues found with the parent requirements, users are requested to contact the Requirements Manager or the contact for the SRD indicated on the top row of the tab;
- Propagation (Step 1), this tab includes those parent requirements that are relevant to a specific system of interest. This section begins the propagation process, while a more detailed process is carried out in the System Requirements tab, described below in the same section;
- System Requirement, this tab contains the bulk of information of each requirement for the system of interest and all associated attributes. The System Design Leads or delegated persons shall complete this section.

In Fig. 4 the scheme of the requirement management procedure is provided to allow to identify, from left to right, the requirement flow down with the relative expected sequence of Excel tabs and the coloured sections per each tab that shall be completed in order. Moreover, the workflow of the SRD between SharePoint and the chosen Document Management System (DMS) is shown, and which actors involved in the project shall populate, control, revise the SRD. Working copies of the SRDs, named as SRD(n-1), shall be uploaded in the SharePoint to be accessible to the Requirements Manager to facilitate the collaboration. Once the Requirements Manager states that the quality is suitable, the SRDs, renamed as SRD(n), shall be uploaded to the DMS for official approval. The Parents SRD tab is characterized by two sections:

- Blu section: the general section;
- Yellow section: the applicability section.

The System Requirement tab is characterized by five sections:

- Blu section: the general section;
- Orange section: the action section;
- Yellow section: the applicability section;
- Pink section: the propagation section;
- Green section: the verification section.

The colour-coded sections should be used for all requirements capture at different levels of system and subsystem. Most of the information shall be entered in the System Requirements (SR) tab. The other tabs provide supporting information and enable the completion of the SR tab. One SRD should be completed for each subsystem, top levels requirements for major systems will have the plant requirements as their parent SRD (Fig. 5).

2.3. Colour-coded sections

The *blue section* shown in Fig. 6 is the General Section collecting requirement statement and all the general requirements information related to a specific requirement. This should be completed before other-coloured sections of this tab with headings to give structure to the list and information to give context. In the comments section, information about how to manage that requirement through the concept phase, or what work still needs to be done can be added for individual requirements. Each heading corresponds to each column; sentence or small paragraph shall be included in each cell:

1. HEL, assign a Human Engineering Label;
2. Requirements, enter the main text of the requirement statement;
3. Object Type, choose Heading, Information or Requirement from the drop-down list to indicate what type of requirements has been entered in the 'Requirement' cell;
4. Requirement Type, choose which type of requirements has been written from the drop-down list amongst Functional, Operational, Non-functional System or Non-functional Implementation and Interface;
5. Requirements Comments, add additional information, justification, notes;
6. Status, select the status of a requirement from a drop-down list in the status cell.

The *orange section* (Fig. 7) corresponds to the action section in the

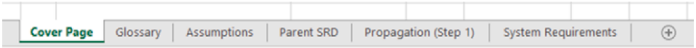


Fig. 3. Six tabs of the Excel spreadsheet.

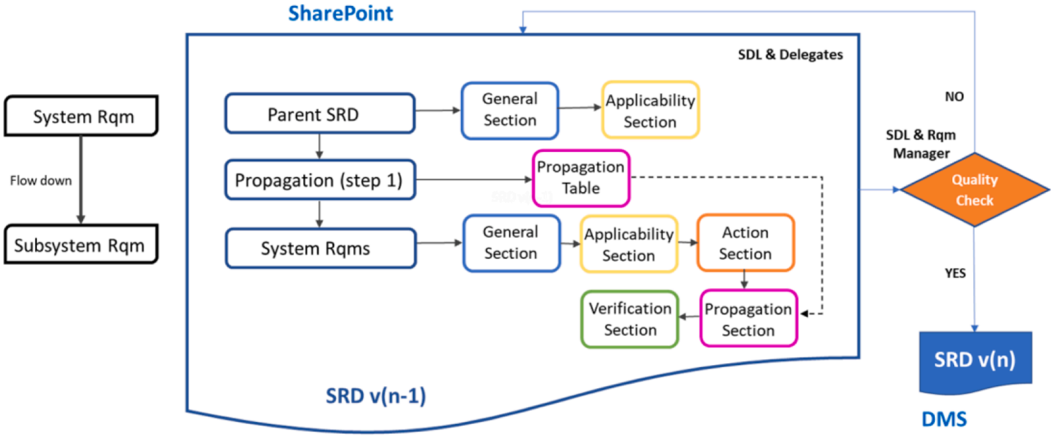
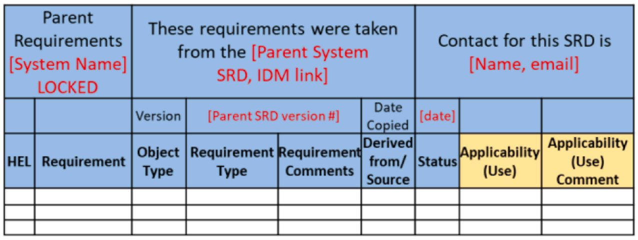
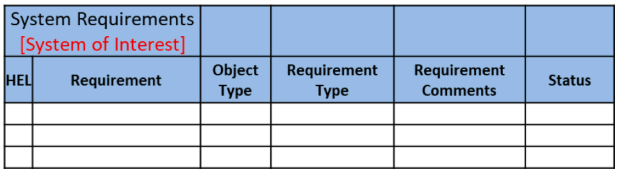


Fig. 4. Scheme of the Requirement Management procedure.



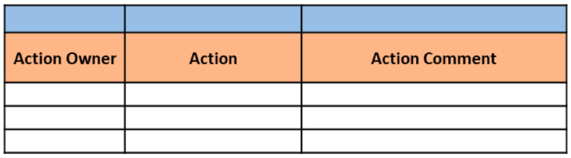
Parent Requirements [System Name] LOCKED		These requirements were taken from the [Parent System SRD, IDM link]				Contact for this SRD is [Name, email]		
		Version	[Parent SRD version #]		Date Copied	[date]		
HEL	Requirement	Object Type	Requirement Type	Requirement Comments	Derived from/ Source	Status	Applicability (Use)	Applicability (Use) Comment

Fig. 5. Parents SRD tab.



System Requirements [System of Interest]					
HEL	Requirement	Object Type	Requirement Type	Requirement Comments	Status

Fig. 6. General Section of the System Requirements tab.



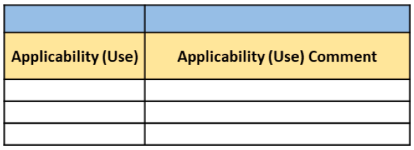
Action Owner	Action	Action Comment

Fig. 7. Action Section of the SR tab.

SRD template. It contains information on actions to be taken regarding the requirement, such as if further information needs to be found to update the requirement, wording needs to be changed, or other tasks.

- Action Owner, enter the initials of author who is responsible for completing the action written in the Action cell, explained below in the same section. If the action owner is not listed as an author, full name and email are provided in the Action Comment;
- Action, explain the action briefly and add the expected date for completing it;
- Action Comment, add additional information, or updates on the action.

The *yellow section* (Fig. 8) is the Applicability Section that indicates which phase of the project this requirement is applicable. In this column the Requirements Manager can add associated comments, explanations,



Applicability (Use)	Applicability (Use) Comment

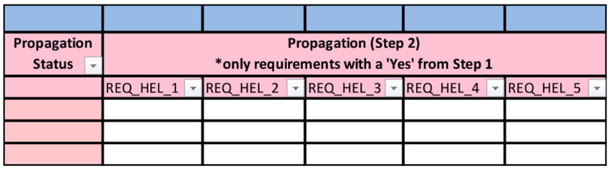
Fig. 8. Applicability Section of the SR tab.

queries to be discussed or changed.

The *pink section* (Fig. 9) allows to determine if each parent requirement is relevant to the design of a specific system of interest. The propagation process enables the traceability amongst different system levels. The concept of propagation has been introduced to enable traceability between different requirements levels. By assuming that parent requirements are traceable to requirements at lower level, it can ensure that all top-level requirements are considered by specific systems and eventually met. This is a useful tool to check if each requirement is necessary. The full table can be collapsed into the *Propagation Status* column that provides a quick visual check red or green coloured whether the system requirement has been propagated from an appropriate parent requirement or further work is required. In case of an unpropagated requirement to subsystems, more investigation is needed. The System Design Lead can state that it is unnecessary and must be deleted. Otherwise, it must be maintained and how it can be propagated at a lower level shall be understood.

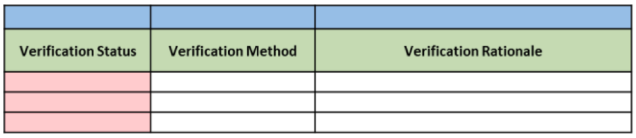
The *green section* (Fig. 10) is the Verification Section. The verification phase allows the users to consider the requirements verification and to carry out the systems validation. This phase enables to prove how the system of interest meets the requirements:

- Verification Status, this cell will automatically become green or red depending on the information in the Verification method cell, defined below in the same section. The default colour is red which indicates that verification has not been considered for this requirement. If attempts have been made to determine a potential verification method, this cell will automatically be green coloured;



Propagation Status	Propagation (Step 2) *only requirements with a 'Yes' from Step 1				
	REQ_HEL_1	REQ_HEL_2	REQ_HEL_3	REQ_HEL_4	REQ_HEL_5

Fig. 9. Propagation (Step 2) Section of the SR tab.



Verification Status	Verification Method	Verification Rationale

Fig. 10. Verification Section of the SR tab.

- Verification Method, users should decide an approach for verifying if a requirement has been satisfied or not in the final product realisation, choosing from one of four methods:

  Analysis, technique based on analytical evidence obtained without any intervention on the submitted element. Mainly used where testing to realistic conditions cannot be achieved or is not cost-effective;

  Demonstration, technique to demonstrate correct operation of the submitted element against observable characteristics without using physical measurements. Observations are compared with expected responses;

  Inspection, technique based on visual or dimensional examination of an element; the verification relies on the human senses or uses simple methods of measurement;

  Test, technique performed onto the element by which functional, measurable characteristics, or performance capability is quantitatively verified when subjected to controlled conditions that are real or simulated;
- Verification Rationale, an explanation for choosing the method proposed.

2.4. *Systems engineering procedure for the DEMO divertor*

The case study deals with the application of the Systems Engineering procedure to the DEMO divertor subsystem. The DEMO project needs a systematic approach from the concept phase with the aims to:

1. Understand the uses of requirements in a wider context;
2. Know how to write basic requirements;
3. Know how to use the System Requirements Document (SRD) template;
4. Establish design inputs.

The SRD of DEMO lists the technical requirements and constraints. The repository of the SRD is the DEMO SharePoint to avoid sending copies backwards and forward to DEMO Requirements Management Team. The DEMO SRD 2021 starts to follow the guidelines of the "DEMO Handbook for System Requirements Definition" [13] which provides the underlying principles of the DEMO requirements approach described in "DEMO Guide to System Requirements Definition" [14]. The DEMO Requirements Handbook describes the strategy for managing requirements throughout the concept design of DEMO (2021–2024). Requirements are characterized by "shall statements" and are defined as "living things" that grow and move with the project. amongst the main features that a good requirement may have, they should be singular, design agnostic, clear (unambiguous), verifiable (testable), well-structured and consistent with others in the set [15]. Indeed, there is a list of words that should be avoided in writing requirements. Tables and figures can also be included as part of requirements. The structure of each requirement statement should be characterized by a subject *plus* the modal verb 'shall' *plus* the main verb starting from the proposed approach in [16]. This approach has been edited for DEMO training. An example is given by the following sentence: *[The system or sub-system of interest]* + *shall* + *[what the system is required to do]*. This logical process allows to classify each word of requirements statement. The identified procedure has been adopted for the identification of the main requirements of the divertor system, in Fig. 11(b), placed in the lower part of the vacuum chamber of the European (EU) DEMO fusion power plant [17] whose baseline CAD model is shown in Fig. 11(a). The position of the system in the Plant Breakdown Structure (PBS) of DEMO follows the different levels of system and subsystem on DEMO, the so-called *ranks*. Requirements propagate from one rank to another, moving from higher rank systems to lower rank subsystems.

2.5. *Parents requirements definition*

Parent Requirements of the Divertor system (DIV) have been identified (Fig. 12). During concept phase key requirements and the related functions are looking for driving the design. This process is in continuous improvement when the system is under development during the concept design phase.

2.6. *Propagation of parent requirements from divertor system to cassette body subsystem*

This tab begins the process of propagating parent requirements to the requirements for the system of interest. This phase allows to trace where requirements come from and to identify which general divertor requirements are relevant to a specific subsystem, in Fig. 13 the Cassette Body (CB) propagation is shown. Parent requirements that are applicable to a specific system of interest should be implemented in the design of a specific subsystem. All requirements at the rank above should be considered and some of them should be selected.

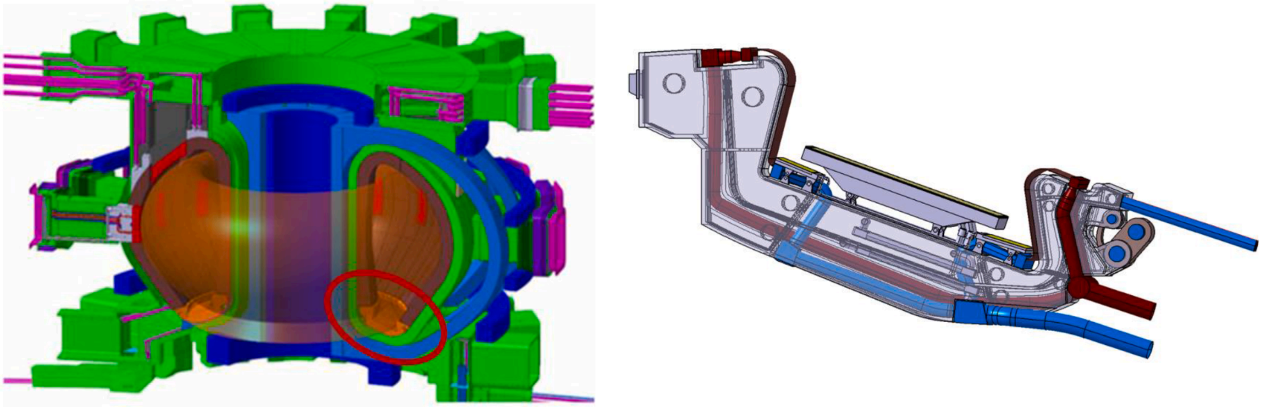
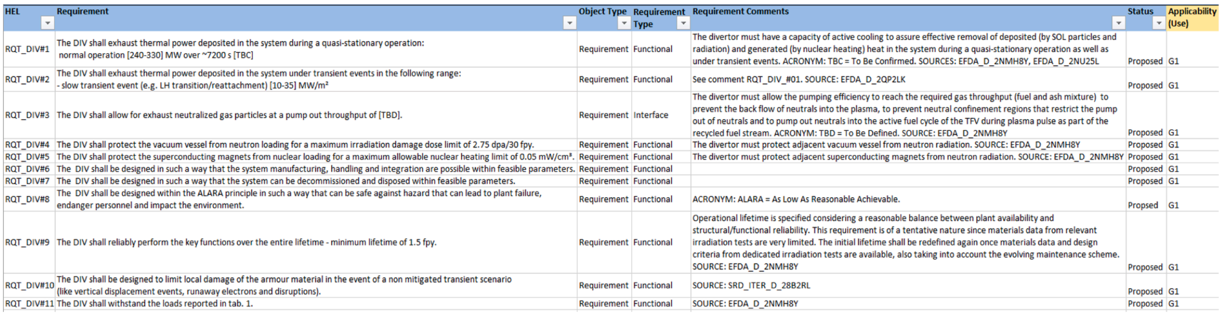
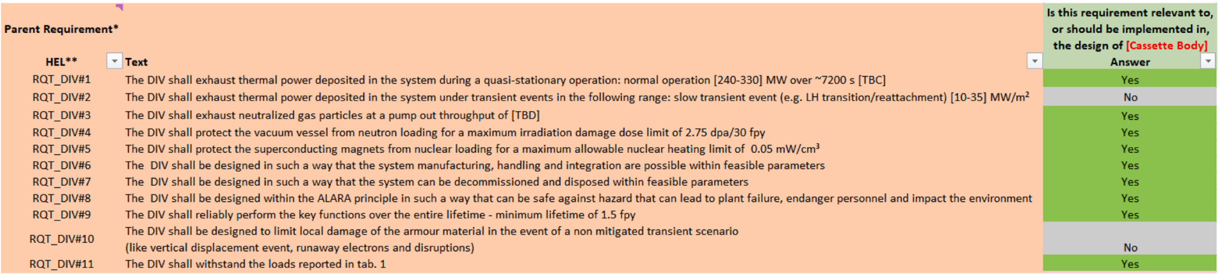


Fig. 11. (a): Baseline CAD model of the EU-DEMO with a red-coloured circle on the divertor position. (b): DEMO Divertor cassette Reference Design Option 2021-double cooling option [18]. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)



HEL	Requirement	Object Type	Requirement Type	Requirement Comments	Status	Applicability (Use)
RQT_DIV#1	The DIV shall exhaust thermal power deposited in the system during a quasi-stationary operation: normal operation [240-330] MW over ~7200 s [TBC]	Requirement	Functional	The divertor must have a capacity of active cooling to assure effective removal of deposited (by SOL particles and radiation) and generated (by nuclear heating) heat in the system during a quasi-stationary operation as well as under transient events. ACRONYM: TBC = To Be Confirmed. SOURCES: EFDA_D_2NMH8Y, EFDA_D_2NU25L	Proposed	G1
RQT_DIV#2	The DIV shall exhaust thermal power deposited in the system under transient events in the following range: - slow transient event (e.g. LH transition/reattachment) [10-35] MW/m^2	Requirement	Functional	See comment RQT_DIV_#01. SOURCE: EFDA_D_2QP2LK	Proposed	G1
RQT_DIV#3	The DIV shall allow for exhaust neutralized gas particles at a pump out throughput of [TBD].	Requirement	Interface	The divertor must allow the pumping efficiency to reach the required gas throughput (fuel and ash mixture) to prevent the back flow of neutrals into the plasma, to prevent neutral confinement regions that restrict the pump out of neutrals and to pump out neutrals into the active fuel cycle of the TFV during plasma pulse as part of the recycled fuel stream. ACRONYM: TBD = To Be Defined. SOURCE: EFDA_D_2NMH8Y	Proposed	G1
RQT_DIV#4	The DIV shall protect the vacuum vessel from neutron loading for a maximum irradiation damage dose limit of 2.75 dpa/30 fpy.	Requirement	Functional	The divertor must protect adjacent vacuum vessel from neutron radiation. SOURCE: EFDA_D_2NMH8Y	Proposed	G1
RQT_DIV#5	The DIV shall protect the superconducting magnets from nuclear loading for a maximum allowable nuclear heating limit of 0.05 mW/cm^3.	Requirement	Functional	The divertor must protect adjacent superconducting magnets from neutron radiation. SOURCE: EFDA_D_2NMH8Y	Proposed	G1
RQT_DIV#6	The DIV shall be designed in such a way that the system manufacturing, handling and integration are possible within feasible parameters.	Requirement	Functional		Proposed	G1
RQT_DIV#7	The DIV shall be designed in such a way that the system can be decommissioned and disposed within feasible parameters.	Requirement	Functional		Proposed	G1
RQT_DIV#8	The DIV shall be designed within the ALARA principle in such a way that can be safe against hazard that can lead to plant failure, endanger personnel and impact the environment.	Requirement	Functional	ACRONYM: ALARA = As Low As Reasonable Achievable.	Propsed	G1
RQT_DIV#9	The DIV shall reliably perform the key functions over the entire lifetime - minimum lifetime of 1.5 fpy.	Requirement	Functional	Operational lifetime is specified considering a reasonable balance between plant availability and structural/functional reliability. This requirement is of a tentative nature since materials data from relevant irradiation tests are very limited. The initial lifetime shall be redefined again once materials data and design criteria from dedicated irradiation tests are available, also taking into account the evolving maintenance scheme. SOURCE: EFDA_D_2NMH8Y	Proposed	G1
RQT_DIV#10	The DIV shall be designed to limit local damage of the armour material in the event of a non mitigated transient scenario (like vertical displacement events, runaway electrons and disruptions).	Requirement	Functional	SOURCE: SRD_ITER_D_28B2RL	Proposed	G1
RQT_DIV#11	The DIV shall withstand the loads reported in tab. 1.	Requirement	Functional	SOURCE: EFDA_D_2NMH8Y	Proposed	G1

Fig. 12. Parents requirements of the divertor.



Parent Requirement*		Is this requirement relevant to, or should be implemented in, the design of [Cassette Body]
HEL**	Text	Answer
RQT_DIV#1	The DIV shall exhaust thermal power deposited in the system during a quasi-stationary operation: normal operation [240-330] MW over ~7200 s [TBC]	Yes
RQT_DIV#2	The DIV shall exhaust thermal power deposited in the system under transient events in the following range: slow transient event (e.g. LH transition/reattachment) [10-35] MW/m^2	No
RQT_DIV#3	The DIV shall exhaust neutralized gas particles at a pump out throughput of [TBD]	Yes
RQT_DIV#4	The DIV shall protect the vacuum vessel from neutron loading for a maximum irradiation damage dose limit of 2.75 dpa/30 fpy	Yes
RQT_DIV#5	The DIV shall protect the superconducting magnets from nuclear loading for a maximum allowable nuclear heating limit of 0.05 mW/cm^3	Yes
RQT_DIV#6	The DIV shall be designed in such a way that the system manufacturing, handling and integration are possible within feasible parameters	Yes
RQT_DIV#7	The DIV shall be designed in such a way that the system can be decommissioned and disposed within feasible parameters	Yes
RQT_DIV#8	The DIV shall be designed within the ALARA principle in such a way that can be safe against hazard that can lead to plant failure, endanger personnel and impact the environment	Yes
RQT_DIV#9	The DIV shall reliably perform the key functions over the entire lifetime - minimum lifetime of 1.5 fpy	Yes
RQT_DIV#10	The DIV shall be designed to limit local damage of the armour material in the event of a non mitigated transient scenario (like vertical displacement event, runaway electrons and disruptions)	No
RQT_DIV#11	The DIV shall withstand the loads reported in tab. 1	Yes

Fig. 13. Propagation of parents requirements to the cassette body.

2.7. System requirements identification of cassette body subsystem

The third step concerns the definition of the system requirements of a specific system of interest (Fig. 14), only Parent Requirements with 'Yes' from the previous step have been copied in the column in the System Requirements tab in the pink section (see dot arrow in Fig. 4). The Propagation section will appear as a table of 'Yes' and 'No' responses, the matrix-like layout allows to quick visualize the relationship between the parents requirements in the pink column and the subsystems requirements in rows. One parent requirement can propagate to multiple system requirements and each subsystem requirement can have more than one parent requirement. The number of system requirements that can be propagated from a single parent requirement is unlimited. One template is to be completed per single system or variant.

3. Discussion

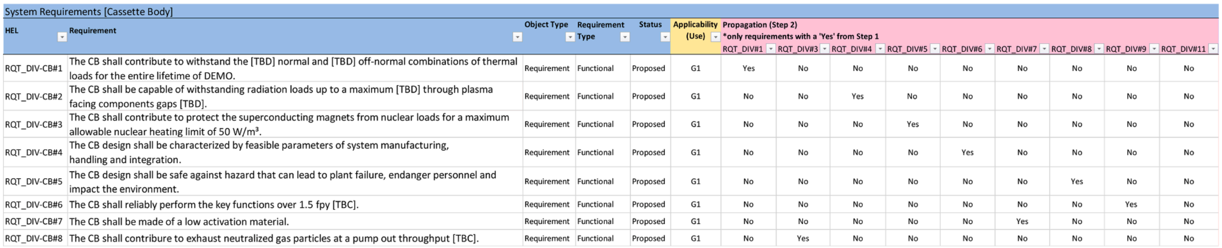
The Systems Engineering procedure is intended to formalize the system requirements, offering a procedure for establishing completely and consistently requirements' statement. During the concept design the requirements management has a key role for the identification and the elicitation process at system level and for the flow down through subsystems until components. Compared to other specific tools for requirements management, the Excel spreadsheet is more accessible, easier to use and to be shared following the described procedure in a concept phase of the project. DOORS or similar dedicated requirements management tool shall be indeed considered in later phases. Uploading manually the Excel spreadsheet requires an effort by designers when some modifications on the architecture need to be done, as shown in the strict correlation (Fig. 2) between the requirements management phase and the logical architecture definition at each level of vertical decomposition. However, the benefit of this process is to follow a clearly defined procedure to identify the requirements of each system in order to integrate them in the requirements set of the whole project.

4. Conclusion

This work outlines an approach for the successful requirements definition and elicitation. The case study deals with the identification of DEMO divertor requirements and its propagation to the cassette body subsystem enabling the traceability between different ranks of requirements. The propagation section plays an important role for the traceability because creates a connection between the higher requirement (parent requirement) and its relative lower requirement. The identified procedure will be applied to other divertor systems as plasma facing components, shielding liner, reflector plates even if it requires a significant effort e.g. for the collection and the integration of knowledge from different technical areas.

Declaration of Competing Interest

The authors declare that they have no known competing financial



System Requirements [Cassette Body]

HEL	Requirement	Object Type	Requirement Type	Status	Applicability (Use)	Propagation (Step 2) *only requirements with a 'Yes' from Step 1								
						RQT_DIV#1	RQT_DIV#3	RQT_DIV#4	RQT_DIV#5	RQT_DIV#6	RQT_DIV#7	RQT_DIV#8	RQT_DIV#9	RQT_DIV#11
RQT_DIV-CB#1	The CB shall contribute to withstand the [TBD] normal and [TBD] off-normal combinations of thermal loads for the entire lifetime of DEMO.	Requirement	Functional	Proposed	G1	Yes	No	No	No	No	No	No	No	No
RQT_DIV-CB#2	The CB shall be capable of withstanding radiation loads up to a maximum [TBD] through plasma facing components gaps [TBD].	Requirement	Functional	Proposed	G1	No	No	Yes	No	No	No	No	No	No
RQT_DIV-CB#3	The CB shall contribute to protect the superconducting magnets from nuclear loads for a maximum allowable nuclear heating limit of 50 W/m^3.	Requirement	Functional	Proposed	G1	No	No	No	Yes	No	No	No	No	No
RQT_DIV-CB#4	The CB design shall be characterized by feasible parameters of system manufacturing, handling and integration.	Requirement	Functional	Proposed	G1	No	No	No	No	Yes	No	No	No	No
RQT_DIV-CB#5	The CB design shall be safe against hazard that can lead to plant failure, endanger personnel and impact the environment.	Requirement	Functional	Proposed	G1	No	No	No	No	No	No	Yes	No	No
RQT_DIV-CB#6	The CB shall reliably perform the key functions over 1.5 fpy [TBC].	Requirement	Functional	Proposed	G1	No	No	No	No	No	No	No	Yes	No
RQT_DIV-CB#7	The CB shall be made of a low activation material.	Requirement	Functional	Proposed	G1	No	No	No	No	No	Yes	No	No	No
RQT_DIV-CB#8	The CB shall contribure to exhaust neutralized gas particles at a pump out throughput [TBC].	Requirement	Functional	Proposed	G1	No	Yes	No	No	No	No	No	No	No

Fig. 14. Requirements definition of the cassette body.

interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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