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Parametric modelling of EU-DEMO Remote Maintenance strategies and concepts

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One of the major challenge in the commercialisation of fusion is maintaining the powerplant reactor in a sufficiently short period of time to achieve commercial levels of plant availability. To inform the development of an appropriate remote maintenance strategy for EU-DEMO, a simplified, parametric model, called the Maintenance Duration Estimator (MDE) has been created to model potential remote maintenance strategies for the in-vessel Components. This tool will inform the development of practical and efficient remote maintenance technologies and methodologies for EU-DEMO. Using the MDE model, it has been estimated that EU-DEMO will be able to achieve the required minimum 30% lifetime plant availability over a 20 year operational lifetime. Here we will present the structure and functionality of the MDE, as well as some case studies of analysis performed.

Keywords: Remote maintenance, strategy, simulation, plant availability

1. Introduction

As a technology demonstrator, economics will not be the major driving factor for EU-DEMO, but the design of any commercial fusion power plants will be driven by the need to maximize power plant availability, and therefore profitability. This creates a strong motivation to complete maintenance in an efficient and timely manner. For the purpose of designing and evaluating remote maintenance systems, a requirement has been placed on the remote maintenance systems to complete any maintenance operations within a number of predefined durations [1].

For a planned maintenance campaign, the current requirement is that an in-vessel maintenance campaign last no longer than 250 days [2]. Of these 250 days, 30 days are assumed to be allocated for a cooldown period, to enable short lived radionuclides to decay away and the structure of the vacuum vessel to cool to a safe temperature. The final 30 days of a maintenance campaign are assumed to be for vacuum pump down and conditioning operations. Therefore, this leaves a maximum of 190 days to complete all in-vessel maintenance operations, including the installation of new breeder blankets and divertors, as required. The MDE was used to estimate whether the current maintenance strategy and tooling concepts are able to meet this challenging requirement.

Unplanned maintenance, due to hardware or process failures during a planned outage, or due to the failure of power plant hardware during power generation will also impact the availability of EU-DEMO. This work includes an attempt to investigate the time taken to recovery from a failures of remote maintenance equipment on the critical path of EU-DEMO maintenance, and the time taken to recovery from a failure of a piece of in-vessel equipment. Due to the current design and reliability information available about the EU-DEMO power plant systems, it was not possible to estimate the number of EU-DEMO plant failures, and their impact on plant availability.

2. Structure of the MDE model

The MDE was created using Microsoft Excel®, as this is a well universally available program with a large userbase, and this has enabled to MDE to be shared and modified easily and without the need for specialized or expensive modelling software.

2.1. Model components

In order to create the maintenance model, the following aspects of a maintenance campaign were defined in the MDE:

- The critical path of in-vessel maintenance activities, based on the current RM concept for in-vessel hardware. Any maintenance activities not on the critical path will not have an impact on the duration of a maintenance campaign and were therefore not included in the model.
- The simplified logistical activities required to support the in-vessel maintenance activities (delivery to RM tooling, collection of removed items of in-vessel hardware, etc). A more detailed assessment of DEMO logistics was carried out separately [3].
- The time taken to perform specific in-vessel maintenance activities, informed by the current RM tooling concepts and operational experience gained maintaining the JET reactor.

In addition to these, the following other durations were simulated:

- The recovery activities to recovery from a simulated failure of a specific piece of RM tooling.
- The time taken to recovery from a non-compliant weld on the blanket pipework.

2.2. Assumptions

Due to the early stage of the EU-DEMO design process, it was necessary to make a number of assumptions about the location and maintenance requirements of various pieces of in-vessel hardware [4]. The duration of specific in-vessel and ex-vessel maintenance operations have also had to be estimated, using operational experience from JET reactor

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maintenance. These assumptions are reassessed on a regular schedule to ensure that they are still relevant and valid.

3. Maintenance scenarios investigated using the MDE

3.1. Duration of planned breeder blanket maintenance campaigns

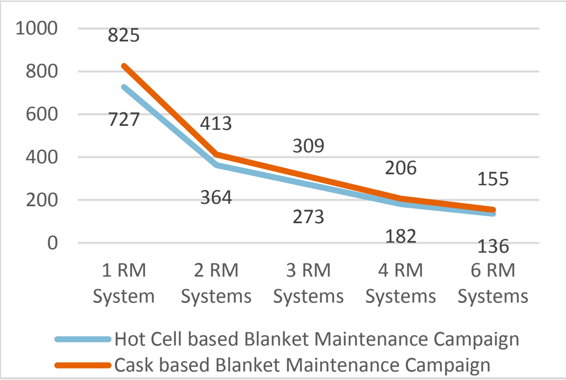

Fig. 1 - Estimated duration of breeder blanket maintenance, in days, based on the number of RM systems operating in parallel

Using the MDE, it was estimated that replacing all of the installed breeder blanket segments would take between 825 if a single set of RM equipment maintains all 16 ports in series and 155 days if 6 ports are maintained simultaneously. This shows that it is necessary to operate a minimum of four RM systems simultaneously, assuming a hot cell-based maintenance strategy, and 6 RM systems if using a cask-based RM system, to meet the required 190 day target duration.

The use of maintenance casks increases the duration of breeder blanket maintenance by an average of ~13%. This is due to the additional logistical operations and enabling activities required to support the deployment and operation of contamination control casks.

3.2. Duration of planned divertor cassette maintenance

For divertor cassette maintenance, the duration of in-vessel maintenance is approximately half the duration of a blanket maintenance campaign. This is due to the smaller number of pieces of in-vessel hardware, and the simplified layout of in-vessel pipework reducing the number and duration of in-vessel maintenance activities.

Use of casks adds ~20% to the total duration of the maintenance campaign, requiring that a minimum of three casks to be operated in parallel to achieve the required maintenance duration. A hot cell-based maintenance system also requires a smaller number of RM systems to complete a maintenance campaign within the target duration of 192 days.

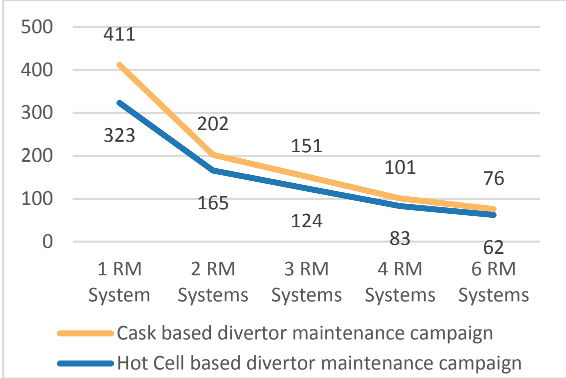

Fig. 2 - Estimated duration of divertor cassette maintenance, in days, based on the number of RM systems operating in parallel

3.3. Duration of un-planned recovery operations

In the event of an unrecoverable failure of a piece of in-plant hardware, the failed item of in-vessel hardware would need to be removed from the port and replaced before EU-DEMO could return to an operational state. In this scenario, only a single sector of EU-DEMO would need to undergo in-vessel maintenance. In this scenario, it has been assumed that there is not a defined allowable duration for this recovery maintenance.

For the purpose of this assessment, it was assumed that all pieces of in-port hardware would need to be removed and replaced as part of the recovery for a single failure.

Table 1. Duration of a single sector maintenance campaign, in days

EU-DEMO Port	Cask Maintenance	Hot Cell maintenance
Upper port	45	39
Lower Port	25	21

3.4. Impact of the double null on maintenance durations

As part of a wider assessment of the 2016 Double Null configuration of EU-DEMO [5], a double null maintenance campaign was modelled in the MDE to assess the impact of the design changes required to enable the installation and maintenance of the upper divertor, shown in Fig. 3~~Fig. 3~~.

As shown in Figure. 4, when compared to the single null baseline configuration of EU-DEMO, the double null adds approximately between 9%-13%. This is due to the different configurations of in-port components and their associated pipe work for each of the double null concepts, all of which require replacement during a blanket maintenance campaign.

These durations are based on very early design information, and will need to be updated as more detailed design information becomes available. In future work, the maintenance model will need to be updated as the Double Null concept matures, to enable comparative analysis of the single null and double null maintenance concepts.

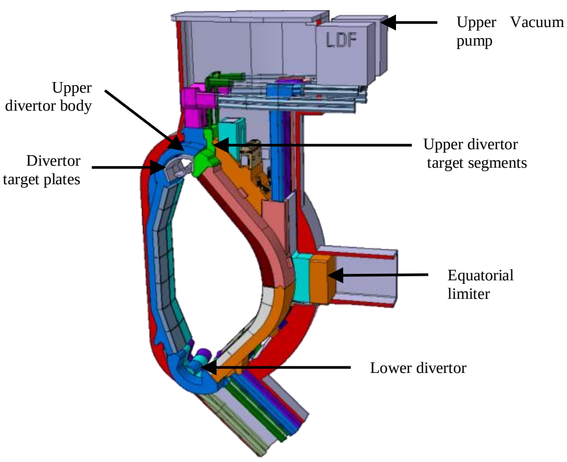

Fig. 3 – One of the 2016 Double Null configuration

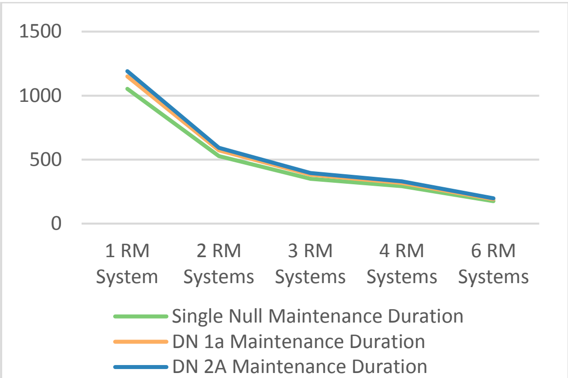

Fig. 4 - Estimated duration of maintenance operations for the double null concepts, in days, based on the number of RM systems operating in parallel

3.4.1. Assessment of the impact of pipe cutting and welding activities and technologies

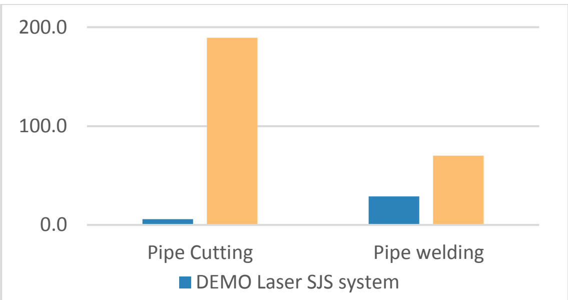

Fig. 5 – Duration of EU-DEMO pipe cutting and welding operations for a single sector, in hours, comparing laser and mechanical technologies

Currently it has been assumed that it will be necessary to use welded pipe connections for any pipe joint located close to the plasma volume, due to the levels material degradation estimated to occur in those areas. As part of the development of a suitable pipe cutting and welding tool, laser cutting and welding technologies were compared to current mechanical pipe cutting and TIG welding systems, and their impact on the estimated maintenance durations were assessed.

Using the MDE, it has been estimated that using a laser-based pipe cutting system saves approximately 180 hours per DEMO sector, as a laser based system is able to cut through the pipework in a single pass, while a mechanical system requires multiples cutting passes. For welding operations, the laser-based system is able to reduce the total duration of welding operations from 70 hours down to 29 hours per sector. Again, this saving is due to the laser-based system's ability to weld the pipe join in a single pass.

As the concepts for both mechanical pipe cutting and welding systems become more mature, this assessment will be updated to help inform the concept development and technology down-selection process.

3.4.2. Impact of planned ex-vessel maintenance campaigns on the lifetime availability of EU-DEMO

In power stations, there is a strong economic motivation to reduce the duration of power plant outages, as this reduces the power plant availability and impacts the potential profitability of a commercial power plant. The MDE was used to model DEMO's operational lifetime for 20 calendar years, to investigate the impact of the various maintenance campaigns on the lifetime power plant availability.

The Operational Concept Document for DEMO [6] describes the proposed maintenance schedule for the EU-DEMO, and describes three different types of scheduled maintenance campaign:

Table 23 - Proposed EU-DEMO maintenance campaigns

Type of maintenance outage	Scheduled Frequency of maintenance		Target Duration (days)
	Full Power Years (FPY)	Calendar years	
Short Term	0.02	0.04 (12 days)	4
Minor	0.49	1.05	64
Major	1.58	3.7	192

The short-term maintenance campaign is scheduled to occur after 12 days of DEMO power plant operations, and would be to perform very rapid maintenance of power plant hardware outside of the DEMO bioshield. Minor maintenance campaigns will occur annually and enable more comprehensive maintenance and inspection of plant hardware and equipment, but it is currently assumed that no maintenance activities will occur within the bioshield. The definition of the frequency and timing of maintenance and inspection operations which will occur during these maintenance outages us still at an early stage, and therefore it is not possible to complete a detailed assessment.

The current maintenance program for EU-DEMO states that in-vessel maintenance activities, including the replacement of breeder blankets and divertor cassettes, will occur during the Major maintenance outages, which are scheduled for after ~3.7 calendar years, or 1.58 years of continuous plasma pulsing (1.58 Full Power Years). It is these maintenance campaigns which have been modelled in the MDE.

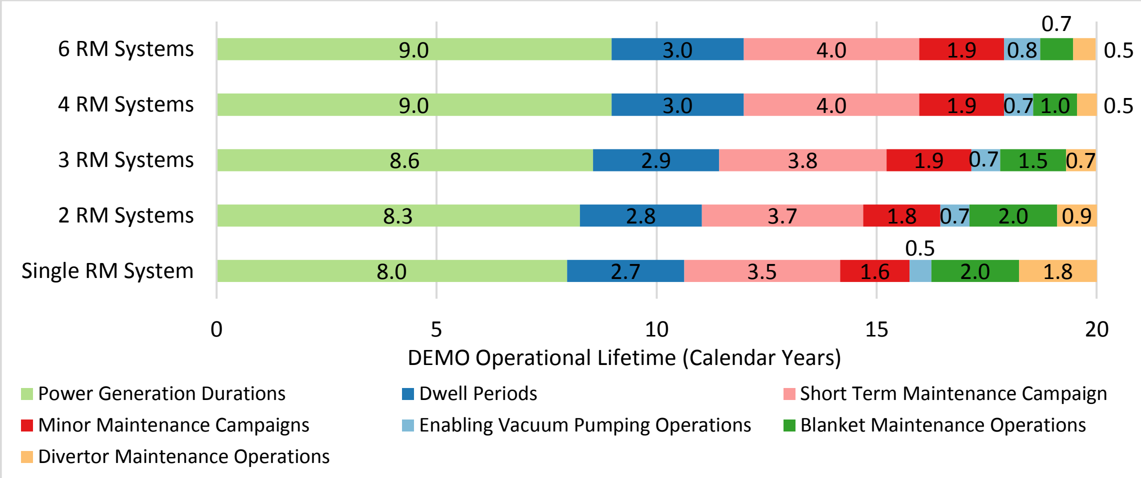

Fig. 6 - Summary of the simulated 20 year operational lifetime of an EU DEMO reactor, in calendar years, using a hot cell based RM system

As shown in Fig. 6, it is estimated that in-vessel maintenance operations, currently assumed to be the most challenging from a technology point of view, only account for between 6% and 20%. Increasing the number of RM systems operating in parallel reduces the total maintenance duration and therefore allows the total power plant's availability in increase.

Based on the currently assumed performance of the vacuum pumping system, it is assumed that this will account for between 2% and 4% of DEMO's operational lifetime. Any in-vessel maintenance tasks that requires breaching the vacuum boundary of DEMO vessel requires that the first vessel be brought up to ambient pressures, and then the vessel needs to be pumped down to a very pure vacuum prior to resuming power plant operations. The number of maintenance operations requiring access into the vacuum vessel should be minimized as much as possible to minimize this unavailable plant downtime.

Short-term maintenance campaigns account for 18-20% of the assumed 20-year lifetime, while minor maintenance campaigns account for 8-10% of EU-DEMO's assumed 20 year lifetime. To reduce the impact that these planned maintenance activities have on DEMO's lifetime availability, all reasonable effort should be made to reduce the frequency and number of these maintenance outages. The design of any ex-vessel systems should also be optimized for remote inspection and maintenance activities, with the goal of minimizing the time required to complete these maintenance tasks

4. Conclusion

As a proof of concept for commercial fusion power, EU-DEMO needs to minimize the reactor downtime. The MDE was created to enable a simplified comparative analysis of various DEMO maintenance strategies and configurations, and has provided insight into the impact of parallelization of in-vessel maintenance, has assisted with assessment of various pipe cutting and welding operations.

The MDE model has also identified the need to reduce the frequency, range and duration of any preventative maintenance campaigns, due to their disproportionate impact on EU-DEMO's power plant availability. This reinforces the need to engage with EU-DEMO system designers to understand the maintenance requirements of their systems, and to allow all necessary remote maintenance procedures and tooling to be developed and optimized to minimize plant downtime.as much as possible.

Acknowledgments

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References

[1] O. C. e. al, "Overview of progress on the European DEMO remote maintenance strategy," *Fusion Engineering and Design,* Vols. 109-111, pp. 1392-1398, 2016.

[2] T. Galliara, "DEMO Remote Maintenance System Requirements Document (2N7U3U)," Unpublished internal document, 2016.

[3] G. Fischer, "Final report on Deliverable AWP2017-RM-4.5-T004 - D001 - Perform silulation tests and scenarios (2MXLQG)," Unpublished internal document, 2017.

[4] I. Farquhar, "Assessment of Maintenance Durations for Alternative Architectures (2NG9CD)," Unpublished internal document, 2017.

[5] I. Farquhar and A. Morgan, "Double-Null tokamak configuration: Remote Maintenance feasibility and impact assessment (2NC9R3E)," Unpublished internal document, 2017.

[6] J. Anthony, "Operational Concept Document for DEMO (2M6ALV)," Unpublished internal document, 2016.