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Logistics and maintenance research activities for DONES facility

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ABSTRACT

DONES is planned to operate on a continuous basis with only two beam stop periods per year for maintenance. The planned operational availability is 70 %, which calls for a carefully analyzed preventive maintenance. The purpose of the research is to propose a realistic and comprehensive logistics and maintenance plan. All the maintenance activities are included in a Maintenance Matrix based on the Plant Breakdown Structure of the project. This is the basis for the creation of a maintenance plan that will lead to a Work Schedule. Special mention within this matrix will be given to those Maintenance operations that must be included in order to comply with regulation. The need of replacement of components impose some requirements on the dimensions of architectural features of the main building such as doors, airlocks, corridors and shipping bays. To enable these replacements, the flow of materials has been developed and analyzed by an intralogistics simulation with AnyLogic. The results of this simulation lead to modifications on either the building or the components such that the replacements are feasible. The periodic replacement of an activated component has been analyzed using FMEA methodology resulting in proposals for the plant equipment designers as well as the remote handling equipment designers. Virtual reality simulations are used for a staged approach to the maintenance operation. The simulation of the HEBT scraper helped to define in detail each step or the maintenance operation. This tool has proven to be very useful to prompt changes in both the plant equipment design and the remote handling equipment. Also, the procedure of the operation itself can be refined and optimized. The conclusion of the research activities is the contribution to the definition of the building, plant equipment and achievement of the target availability.

1. Introduction

The Eurofusion Roadmap [1] includes IFMIF-DONES (International Fusion Materials-Irradiation Facility-DEMO Oriented Early Neutron source) as one of the fundamental facilities for the progress of fusion. This facility, also known simply as DONES, has the objective to irradiate materials with similar conditions expected in DEMO (Demonstration fusion power plant), that is around 14 MeV neutron flux with a density 10^{18} to 10^{19} n m^2 s^{-1}. In order to reach the desired level of damage (20 dpaNRT) in a reasonable time (2.5 years), the irradiation must operate continuously (24/7) except for two planned yearly beam stops, one short stop of 3 days and one long stop of 20 days for more difficult maintenance operations. The target operational availability is 70%, which requires a thorough and well organized preventive maintenance, able to reduce the downtime to a very small value.

The research activities carried out in the area of 'Logistics and Maintenance' are explained in the following sections. These activities are carried out simultaneously with the engineering design of systems and components. The main goal of this concurrent engineering of the activities in the project is to detect inconsistencies and prompt changes in the baseline design, before the design is considered definitive. Changes proposed by different areas are discussed in 'Interfaces and Design Change Meeting' (IDCM) periodic meetings leading to a new baseline. The current design with the last modifications is explained in [2].

IFMIF-DONES includes an accelerator, which is based on the LIPAC (Linear IFMIF Prototype Accelerator) that has been installed in Rokasho (Japan) as a result of the collaboration agreement between Europe and

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Japan "Broader Approach". At the LIPAC facility, Europe has provided the accelerator plant equipment. European researchers contributed during installation and they are now participating in the operation and maintenance activities. The experience gained in said accelerator will be a fundamental pillar for an adequate definition of the maintenance of IFMIF DONES. Start-up of LIPAC and operation information can be found in Refs. [3,4].

In the following sections we explain the 'Logistics and Maintenance' activities carried out so far in the context of the 'Work Package Early Neutron Source' of Eurofusion. A general description of each activity is included followed by a case study for such activity that would clarify how it is applied to a concrete equipment. For such case study, the 'High Energy Beam Transport scraper' (HEBT scraper) has been chosen, because it is considered representative of remote hanling operations, but it also involves some hands-on operations.

2. Maintenance matrix

The 'Maintenance Matrix' (MMx) is a core document for the gathering of maintenance operations and the principal information related to them. The format used is a spreadsheet, such that filters can be applied and analysis of the information is made easier.

The information for a maintenance operation is included on a single line of the data sheet. The identification of said operation begins with three digits that uniquely define the plant equipment in the PBS (Product Breakdown Structure) of the project. The detailed content of the MMx is explained in the report [5] which can be provided upon request.

The main objective of the MMx is the collection of a complete list of maintenance operations, even at this early stage of project definition, in order to distribute them throughout the year. Some tasks can be done at any time, even during irradiation, others however require that the particle beam is off. This must be taken into account when assigning them their execution period.

Some representative information included currently in the MMx is shown in Fig. 1.

The cranes and other maintenance equipment to be installed, will be defined based on the operations included in the MMx.

The source documents for the definition of the maintenance operations are the: 'Design Description Document' (DDD) for each plant system, RAMI (Realiability Availability Maintenability and Inspectability) analysis, 'Safety Analysis Report' (SAR). The DDD describes the components, their functions and their interfaces. Some RAMI analysis are already available that provide expected failure rates for subsystems [6]. The SAR includes the safety classification of the subsystems. This information is taken into account for the frequency of maintenance. The most safety relevant components will have higher frequency for check-ups, maintenance or replacement.

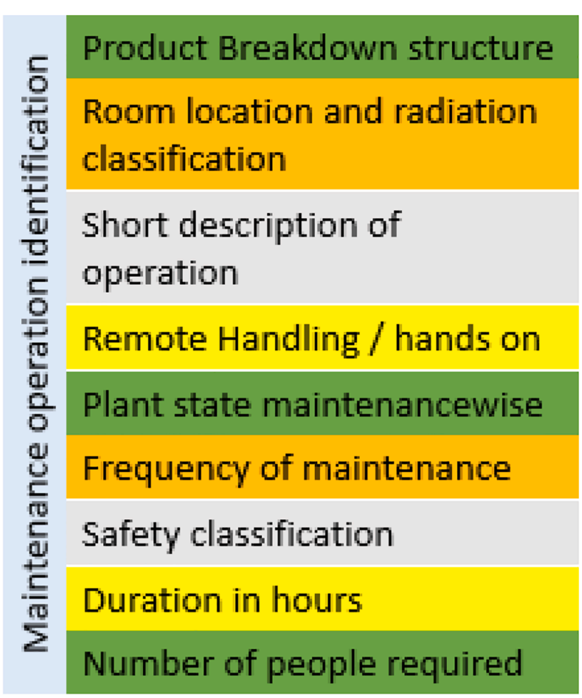

Fig. 1. Key information in the Maintenance Matrix.

Essential information within the MMx is the need to use remote handling (RH) equipment in order to carry out the operation. Some areas where RH is needed and the RH equipment defined in those areas can be found in [7].

Based on the MMx, the 'Maintenance Plan' will be updated in order to comply with two main functions:

- Ensure that safety functions continue to be fulfilled over time
- Keep the downtime to a minimum

As an applied example of the content of the MMx, the most important information of the 'HEBT scraper' is indicated below:

- Maintenance operation ID: 6.6.2_001, Exchange Scraper assembly with spare. (note: other operations for the same device will have succesive indexes like 6.6.2_002, 6.6.2_003).
- Location during operation: R113 (Accelerator Vault).
- Classification of room during operation: Forbidden (red).
- Classification of room during maintenance: Limited permanence (yellow).
- Type of maintenance: Preventive.
- Method: Remote Handling.
- Required plant state: beam off.
- Frequency: To be confirmed according to radiation hardness of elements and cumulated dose rate. In order to be on the safe side, one maintenance operation a year is considered.
- Safety classification: SIC-2.
- Duration in hours: 16.
- Number of people: 2 (RH operator and RH coordinator).
- Performer: staff (no outsourcing of this maintenance operation).

3. Flow of materials

The objective of the 'Flow of Materials' (FoM) analysis is to prompt any changes or modifications that are needed in order to ensure the transport of plant equipment through the facility and especially through the main building.

Changes may be needed in the dimensions of corridors, airlocks, doors or shipping bays or other features of the building.

For the transport of activated equipment in the context of its replacement, a modular system has been defined [8], that is used along with the software AnyLogic, to carryout simulations and detect clashes.

Some components are considered critical for FoM, due to their large size, weight, or its radioactivity. The data of these components are recorded in a spreadsheet that system responsibles are due to check and update whenever modifications in the equipment of their systems occur.

As input for the AnyLogic simulation, the information of these components and the path through the building for the transport of a 'Total Transport Unit' (see [8]) is used. The Total Transport Unit is made up of the component itself, one or more steel pallets and one or more Omnidirectional Mobile Platforms (OMPs).

The report of the analysis includes not only the clashes detected with the features of the building to be modified, but also the number of modules (OMPs and pallets) that are needed for the transport of each component. Fig. 2 shows part of the trajectory for the container with a new 'HEBT scraper' to be installed, used as an example consistent with the rest of the article. The green arrows in the plant view of the building

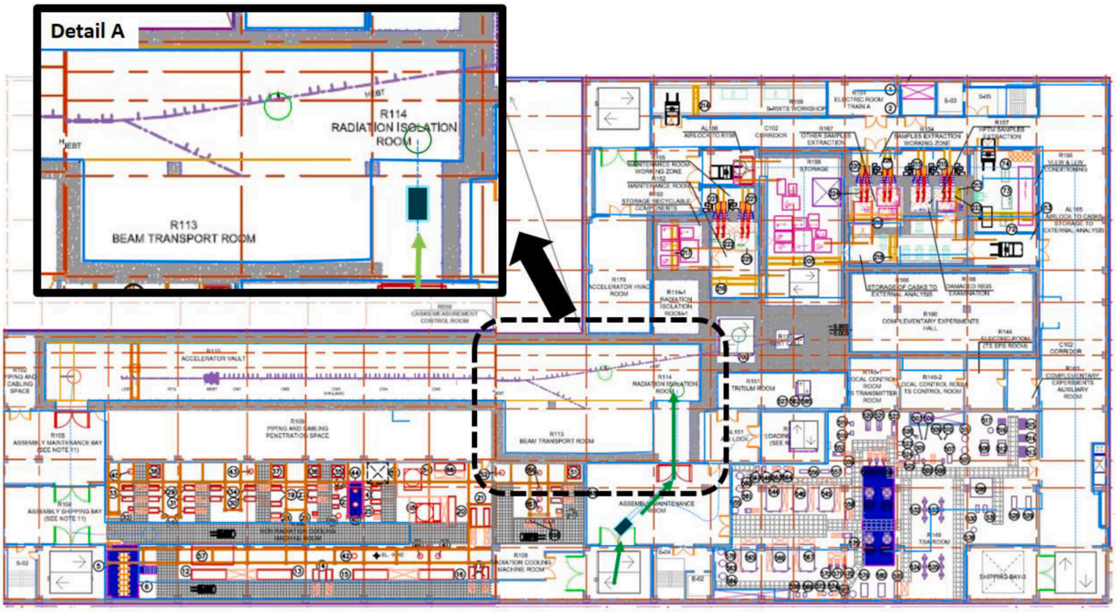

Fig. 2. Example of AnyLogic software use for 'HEBT scraper' transport. Green arrows describe planned trajectory in this floor of the building. Detail A shows the stop point for the trasportation (dark green circle), and operation location (light green circle).

indicate the planned way. The equipment represented as a green rectangle gets out of the shipping bay, moves across a room and enters the Accelerator Vault. Detail A shows with a dark green cirlce the postion where the transport mean stops. The bridge crane in the room would pick up the equipment and place it in the operation location, signaled as a light green circle. In case any clash with doors, shipping bay or any other architectural feature had happened, a red text-box would appear for notification.

4. FMEA analysis

Failure Mode and Effect Analysis (FMEA) for a maintenance operation, can provide some insight on the corresponding risks. This kind of analysis will be extended eventually, to all the maintenance operations that are considered critical in terms of health of workers and radiological contamination spread.

The analysis is carried out studying in detail the single steps contributing to the maintenance operation. For these steps, the plant equipment, the maintenance equipment involved and the manual operations are considered. For maintenance operations using remote handling equipment, there is a simulation of the maintenance process that is used in order to help with the identification of the risks (see Section 5).

This FMEA analysis is integrated with the rest of the works in the project, exchanging the required information with Safety area and the designers of the equipment.

Taking into account the severity (S) of the effects if the accident actually happens, the probability of occurrence (O) and the likelihood of potential failure being detected (D), a 'Risk Priority Number' (RPN) was computed for each maintenance operation.

$$RPN = SxOxD$$

Each of the three factors: severity, probability of occurrence, detection, was assigned a value between one and five, using a qualitative method, based on literature and engineering judgement. Risks with values in the highest range were all analysed in more detail.

After the analysis, several mitigation measures are proposed that would lead to a decrease on severity, probability of occurrence or an improvement in detection capability. Considering the product of the required budget for each mitigation measure and the concerned effect on the RPN, an implementation plan is defined.

We provide hereafter the example applied to a periodic maintenance operation of replacement of an activated plant equipment, the removal of the 'HEBT scraper' in the accelerator vault of the facility, see Fig. 3.

A summary of the main risks identified and the mitigation measures proposed are:

- Risk: Radiation gauge provides wrong reading. Mitigation: Redundancy and periodic calibration.
- Risk: Human operator gets injured in the operations before the shielding is open. Mitigation: Improve protective gear, remove sharp edeges from design and schedule training sessions.
- Risk: Door opening and closing system fails. Mitigation: Add redundancy in the system to open or close the door.
- Risk: Load drops from crane. Mitigation: Increase reliability of gripping system in the crane.
- Risk: Activated part or water from the cooling circuit of the part falls down when manipulating the equipment with the crane. Mitigation: Change design of plant equipment to reduce probability of activated parts getting loose and falling down.

Fig. 3. Removal of HEBT scraper with remote handling bridge crane. Simulation used for FMEA analysis.

5. Virtual reality simulations

Virtual reality simulations applied to the analysis of logistics and maintenance operations in radioactive environments have an enormous potential and are already in use in facilities such as ITER and WEST [9].

The tool developed for DONES is based on 'Unity 3D' [10] which is a software developped for the videogames industry. Application of this software in the nuclear fusion field is also referenced in [9]. During 2022 tasks of the Eurofusion Work Package, the use of VR googles has been implemented, providing an inmersive experience. It is possible to move around the virtual accelerator while the remote handling equipment is performing the maintenance operations.

The process for the production of a simulation starts by gathering all the required information in the 'Virtualization Task Document' (VTD), which is an Excel book with a sheet containing the operations, RH equipment used for each operation and the comments and related information.

This VTD is a tool for exchange of information between the team in charge of the maintenance operation definition and the virtualization group.

Operations are displayed hierarchically, so it is easy to apply filters and obtain a list of only the highest-level tasks to get the overall idea.

The simulation tool has been provided with several features that enhance the analysis of the maintenance operation, the main ones are:

- Different cameras can be chosen, providing a range of points of view.
- A free camera is also included, such that the user can move around and have a close view of a detail.
- There is a tool that allows ortographic measurement in different views (top, front, back, left and right), which is very convenient when we need to leave some safety distance between moving and stationary components.
- It is possible to modify the speed of the simulation and the intensity of illumination.
- There is a time stamp that can be reset, providing an estimate of the time required for each part of the operation.

As an example, some of these features can be seen in Fig. 4, where a manual operation is represented. The manikin approaches a closed radiation shielding (the green cylinder nearby), and loosens some bolts, disconnecting in this way the 'HEBT scraper' of the accelerator. Once the operator leaves the room, the shielding opens automatically and a RH bridge crane picks up the activated component and places it into a cask for transport.

All the maintenance operations involving remote handling equipment will eventually be simulated. The replacement of three plant equipment in the Accelerator Vault and the replacement of plant equipment from a room named Access Cell have been simulated so far.

The virtual reality simulations proved to be useful for users to identify required changes in the plant equipment and RH equipment, as a result for this simulation the following issues were pin down:

- Position of bolts fixing the plant equipment to the structure, were not reachable to the robotic arm.
- Plate with connectors was not compatible with RH operation.
- Distance to reach the bolts to be operated by worker manually was too big.

The iterative process involving: Simulation team, RH equipment designers and plant equipment designers, will prevent inconsistent design of equipment and planning of processes. Nevertheless, the current simulations must be updated when more details of equipment and services are available (cable trays, cooling piping, gas supply and other services)

Fig. 4. Screenshot of the HEBT scraper simulation. Manikin simulating worker performing a manual operation.

6. Conclusions and future work

The target operational availability for DONES call for a carefully analysed preventive maintenance. First all the maintenance operations should be collected in a way that allows applying filters and obtaining valuable information, this has been done in the MMx. The analysis of the Flow of Materials, FMEA of maintenance operations and virtual reality simulations, led to changes in building features, plant equipment design and maintenance procedures. The global objective being, prompt any required modifications before the designs are frozen and the construction process started. The target for having a definitive design is 2025, when the Project Team of the 'IFMIF DONES España Consortium' will take over the implementation of the engineering design. Some buildings that will initially host laboratories are already under construction in the plot of land chosen for the facility in Granada (Spain). More details on current status of the facility can be found in Section 4 of [2].

Future activities in the 'Logistics and Maintenance' area, include the update of the ones included in this article, with the data of building and plant equipment, but also new activities such as the analysis of the installation process and the alignment strategy, that may also trigger some changes in the building and plant equipment to optimize performance.

A working group for the exploitation of the lessons learned during installation, comissioning and operation of LIPAC has recently started its activity. Given that many of the plant equipment is pretty similar in the accelerator of IFMIF DONES, the outcome of this working group will be of great help for an optimal and realistic approach to 'Logistics and Maintenance' activities.

Machine learning and other artificial intelligence techniques are being investigated in similar facilities [11,12], also in DONES a research line is starting within the maintenance group, that aims to identify hidden patterns and look for precursors of dangerous failures. At this stage of the project, the focus is on the type of instrumentation that will provide the source data and the procedure to handle such data.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors are unable or have chosen not to specify which data has been used.

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