ITER ORE Assessment: a New Approach and Analysis Tool

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Abstract: This paper discusses the results of a recent worker dose assessment performed for some of the ITER port interfacing systems (e.g., NBI, ECH&CD, ICH&CD, LHH&CD, Diagnostics, TBM). Although we have found that the level of design detail required by a proper worker dose assessment is significantly more than what is available at this stage of the ITER design, the methodology developed for this study should be well applicable for future, more comprehensive studies. Part of the methodology development is a system for keeping track of exposure times used in similar activities, to facilitate the process of estimating exposure times and to ensure consistency. This system is codified in a computer code, which, for lack of a better name, we have called the "ORE_Code". This may become a valuable tool, in the very near future, as ITER makes the transition from program to project and the pace of design evolution picks up. Accordingly, it will be far easier to determine the ORE impact of future design changes with the use of ORE-Code, and designers can have much faster feedback on proposed design options or alternatives.

1. Introduction

A licensing process for the ITER machine is currently on going in France and one of the main issues to be addressed in the Preliminary Safety Report is the occupational radiation exposure (ORE) assessment. The difficulties of the task come from the progressive evolution of the designing phases, and as a consequence the maintenance procedures have only been roughly delineated. Because the As Low As Reasonable Achievable (ALARA) approach in terms of ORE minimization is one of the main ITER guidelines, constant checks of adopted design solutions and monitoring of expected worker doses are done as soon as the design gets progresses.

In this paper a sample of the methodology followed in one of the last ITER ORE assessment is presented. The study interested the hands-on operations on Ion-Cyclotron Heating and Current Drive (ICH&CD), Electron-Cyclotron Heating and Current Drive (ECH&CD), Neutral Beam Injector (NBI), Lower Hybrid & Current Drive (LHH&CD), Diagnostics and Test Blanket Module (TBM) systems. The hands-on works mainly concern the maintenance in the Port Cells (PCs) where the components are installed, as testing and inspection activities, small in-loco repairs, pre and post activities to be done in assistance to remote handling (RH), relating to transfer of the activated components and port plugs to/from the Hot Cell (HC) .

2. Phases of the work

The work has been scheduled in four different phases:

- The first one deals with the identification of the operations entailing human intervention. On the purpose, the so called "elementary activities" or "standard activities" have been outlined. They are simple and routine operations like pipe inspection, setting and transport of tools, pipe cutting, welding, scaffolding, etc. For each "elementary activity" (maintenance and testing activities) a work-effort was set.

  The work effort is the product of the number of persons involved in a task and the exposure time necessary to perform the task. The exact definition of work effort would require a well-defined maintenance plan and procedures generally not yet defined. Therefore, at present, work efforts have been set up on the base of the currently available information taken from similar fields of application and/or on the base of engineering judgment. A list of the elementary activities and the related work effort estimation is given in table 1, as example.

- In the second phase the elementary works have been aggregated in more complex operations, the so-called main operations (e.g.: window replacement, flange sealing/unsealing), after an additional grouping in minor and major activities. In table 2 a subset of the tasks for one main activity (ECH&CD primary window replacement) is shown, as example.

Category	Elementary Activity	Notes	WE (person-h)
testing, monitoring & inspections			
	visual inspections		0.25
	radiation monitoring		0.25
	weld inspections (small pipes/tubes)	<5 cm	0.50
	weld inspections (medium pipes/tubes)	5-10 cm	0.75
	weld inspections (large pipes/tubes)	>10 cm	1.00
	weld inspections (port seal welds)		2.00
	leakage testing (small areas)		0.50
	leakage testing (medium areas)		1.00
	leakage testing (large areas)		2.00
making and breaking services connections			
	connect electrical cable		0.10
	disconnect electrical cable		0.10
	connect I&C cable		0.10
	disconnect I&C cable		0.10
	connect fibre optic cable		0.10
	disconnect fibre optic cable		0.10

TABLE 1. List of elementary activities and corresponding work effort

Major Activity	Description	Minor Activity	Description	Work Effort (person-h)
6.1	perform radiation survey inside port cell	6.1.1	perform radiation survey inside port cell	0.25
6.2	reinstall large shield blocks	6.2.1	reinstall large shield block1	9.35
		6.2.2	reinstall large shield block2	5.15
6.3	reinstall small shield blocks	6.3.1	reinstall small shield block1	9.15
		6.3.2	reinstall small shield block2	5.15
6.4	clear port cell of all debris	6.4.1	clear port cell of all debris	4.00

TABLE 2. Subset of the Work-Effort Estimates for ECH&CD Primary Window Replacement (Reinstall Bio-Shield Blocks)

- In the third phase the frequency of the main operations have been established. In the context of this study, maintenance frequency refers not only to the frequency of planned and unplanned maintenance, but also to the frequency of component/system testing and calibration.The maintenance frequency of most of the components is not well known at this stage of the design. Accordingly, where design did not yet give specification, assumptions were done on the base of the expertise. As the design develops and better information becomes available, it will be easy to pro-rate the current worker dose estimates on the basis of the new maintenance frequencies.

- In the fourth phase the radiation field levels have been selected, based on the ITER Nuclear Analysis Report [3]. The radiation dose rates vary from upper values (200 μSv/h at the maximum) just beyond the VV ports, relaxed values (50 μSv/h) in the huge zone penetrating the cryostat, named interspace zone, and lower values (5 μSv/h) in zones beyond the bio-shield blocks. For all the activities performed in the external zone of PCs when the bio-shield blocks have been removed the dose rates of the interspace zone has been considered. Clearly, these are notional values, as the fields can vary significantly inside the port-interspace and port-cell, due to geometry effects and shielding effectiveness. Moreover, we have not taken into account contributions from radiation fields produced by activated or contaminated equipment located inside these spaces. In the table 3 the assumptions for radiation fields in the zones involved in the maintenance operation is summarized. Furthermore, no account has been taken of possible contributions from airborne tritium.

SYSTEM	Dose rate inside port-interspace	Dose rate inside port-cell (bioshield removed)	Dose rate inside port-cell (bioshield in place)
Ion-Cyclotron Heating and Current Drive	50	50	5
Electron-Cyclotron Heating and Current Drive	30 equatorial port 100 upper port	30 equatorial port 100 upper port	5 equatorial port 5 upper port
Neutral Beam Injectors	Not Analyzed	Not Analyzed	10 (inside NB cell)
Lower Hybrid Heating and Current Drive	10	10	5
Diagnostics	Not Analyzed	Not Analyzed	Not Analyzed
Test Blanket Modules	50	50	5

TABLE 3. Radiation Field Levels used in the worker dose estimates (μSv/h)

3. Software tool

To handle the large quantity of data and to allow user friendly updating of data as the design evolves and the maintenance knowledge base improves, a software tool, named "ORE_Code" [2], has been developed in Excel spreadsheet format. Dedicated Excel workbooks have been formatted to record data useful to evaluate ORE for maintenance procedures and, dedicated Visual Basic routines have been developed to easily manage such data.
The workbook dedicated to ORE data recording is made up of several worksheets (fig. 1), set for data recording in structural way.

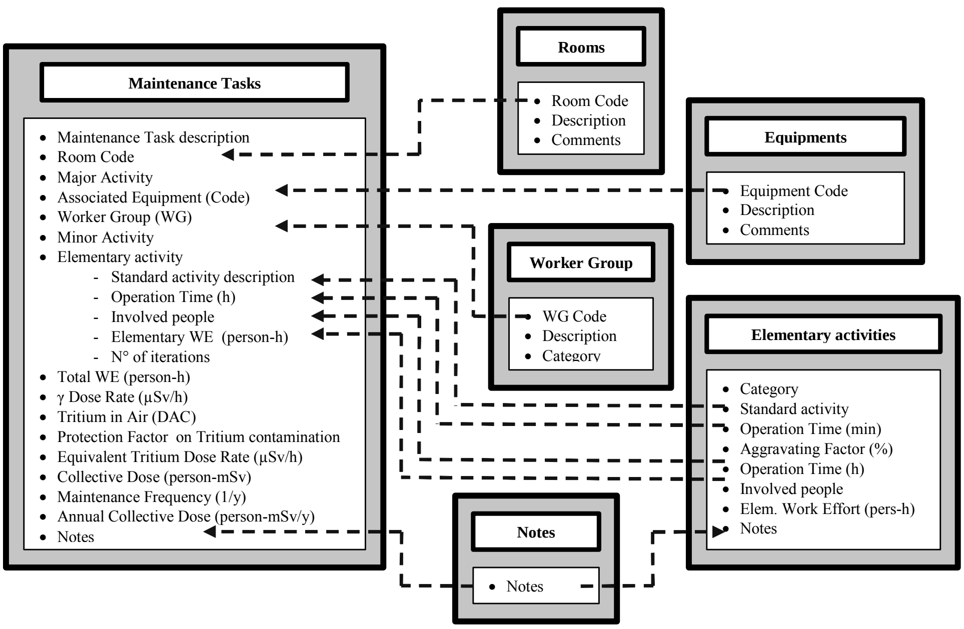

FIG. 1. Relations between the worksheets in ORE_Code

A main sheet is dedicated to list the overall data useful to do an ORE assessment and auxiliary sheets are dedicated to standardize data.
The meaning of the different worksheet is listed below.

- *Maintenance Tasks:* used to list all operations related to the maintenance tasks to be evaluated.
- *Rooms*: auxiliary sheet used to list information on the Rooms where maintenance is performed.
- *Equipment*: used to list information on equipments subjected to maintenance.
- *Worker Groups*: used to define Worker Groups who are implicated in the maintenance to be performed.
- *Elementary activities*: used to list elementary operations and related numerical data, such as: time required for the single operations, involved people and work effort in terms of person-hour.
- *Notes:* auxiliary sheet used to list all the notes used in the other sheets.

4. ORE assessment for port interfacing systems

Work effort estimates are likely to be less reliable than any of the other parameters necessary to evaluate ORE, like dose rate, for example. This is not by design, but as a consequence of where we are in the design process. The values assigned can be improved from experiential data. As a sample in all the systems analyzed for I&C components of each system we have chosen arbitrarily a notional annual work effort of 100 person-h. Using a radiation field of 5 μSv/h we obtain a notional annual dose of 0.5 person-mSv/a. Instead for each system the worker dose associated with maintenance of components inside the hot-cell was not estimated due to lack of sufficient information.
Because the absolute values of the worker dose calculated with the methodological approach is only indicative and shall be validated with the collection of tried data, in the following figures (fig. 2, 3, 4, 5, 6 and 7) only the relative influence of the main tasks on the total dose for each system's maintenance is outlined. The scope is to highlight the importance of the single task and to focalize the attention of the designers on the project's improvements and on maintenance procedures optimization.

4.1 Neutral Beam Injectors

In the present ITER design there are three heating and current drive neutral beams. Once the NBI is activated by plasma neutrons, maintenance on components inside the box will be performed by remote handling operations.

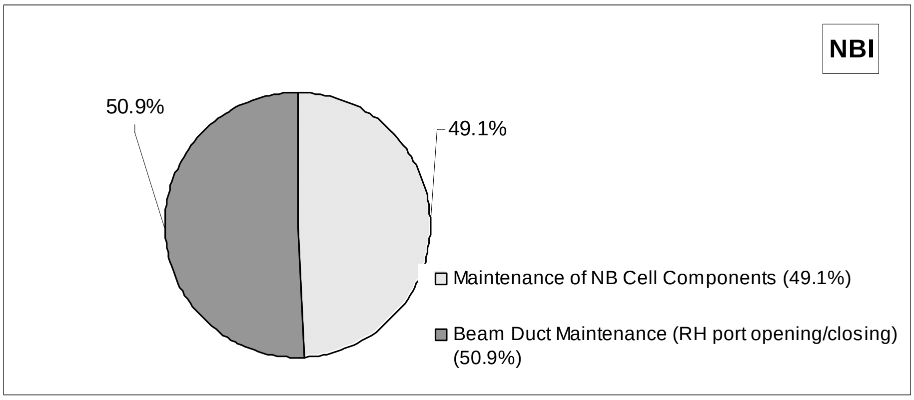

FIG. 2. Contribution of the main maintenance tasks to the annual worker dose for NBI system

Limited access into the NB cell is possible during a machine shutdown period. Accordingly, hands-on maintenance is possible only on components that are located inside the NB cell, but outside the shielded NB box.
Serviceable equipment (pneumatic/hydraulic servo-mechanisms, control valves, pressure transducers, temperature sensors, voltage and current meters, etc.) for the system components are located inside the NB Cell, which are believed to require regular maintenance.
In addition, there is a small hands-on contribution from opening and closing RH ports to perform maintenance on the beam ducts, using the in-vessel remote-handling system, which needs to be deployed for in vessel interventions. The impact of the main tasks in the total of the annual worker dose for the NBI maintenance is shown in Figure 2.

4.2 Ion Electron Cyclotron and Current Drive

The ITER Ion-Cyclotron Heating & Current Drive System is composed of Radio-Frequency (RF) power generation, transmission and wave launching equipment, whose operation is coordinated and monitored by a computerized control system, under the supervision of the ITER central control system.

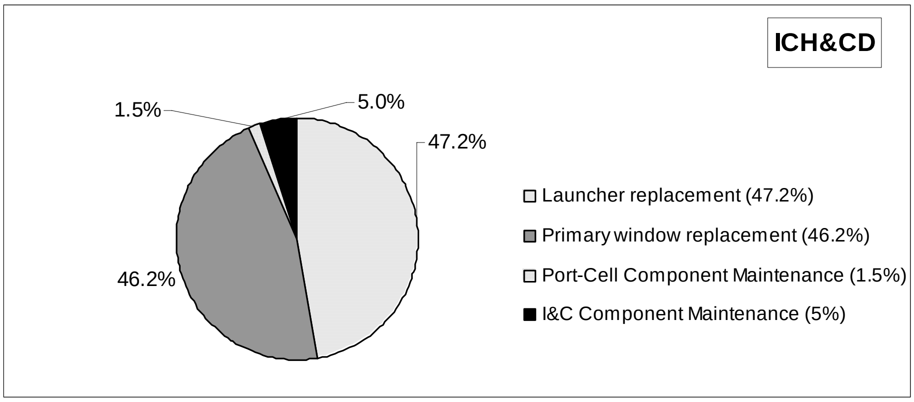

FIG. 3.
Contribution of the main maintenance tasks to the annual worker dose for ICH&CD system

From this study it was put on evidence that removing even a single primary window, *in-situ*, effectively has the same worker dose burden as replacing the entire launcher. Therefore, it can be concluded that, from a worker dose perspective, when a primary window has failed, the entire launcher should be removed and the window replaced inside the hot cell. Spreading of contributions is shown in Figure 3.

4.3 Electron Cyclotron Heating and Current Drive

As for the ICH&CD the worker dose associated with replacing even a single window is greater than that for replacing the entire launcher. Accordingly, if a single window were to fail during an operating campaign, from a worker dose perspective, it would be preferable to remove the entire launcher (including windows) and perform the component replacements inside the hot cell.
The high relevance of the upper launcher replacement to the annual worker dose was in relation to the radiation field in the zone that was about 3 times higher than at equatorial level. Spreading of contributions is shown in Figure 4.

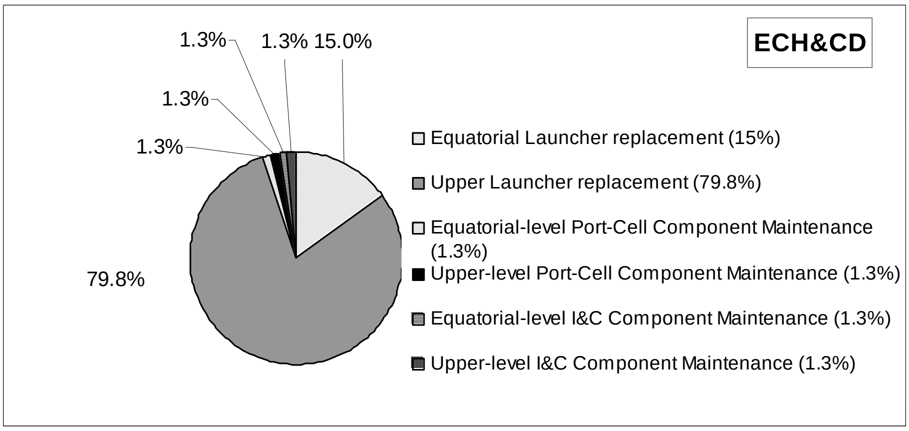

FIG. 4.
Contribution of the main maintenance tasks to the annual worker dose for ECH&CD system

4.4 Lower Hybrid and Current Drive System

For the maintenance of the LHH&CD the main tasks foreseen are the primary window replacement, the secondary window replacement, the VTL dummy load replacement and I&C component maintenance. It should be noted that these worker doses are not necessarily additive because the replacement of primary and secondary windows and dummy load can be performed in coincidence with the launcher replacement and inside the hot cell. The only exception is I&C maintenance that would be performed during each annual shutdown period and is independent of the others. Spreading of contributions is shown in Figure 5.

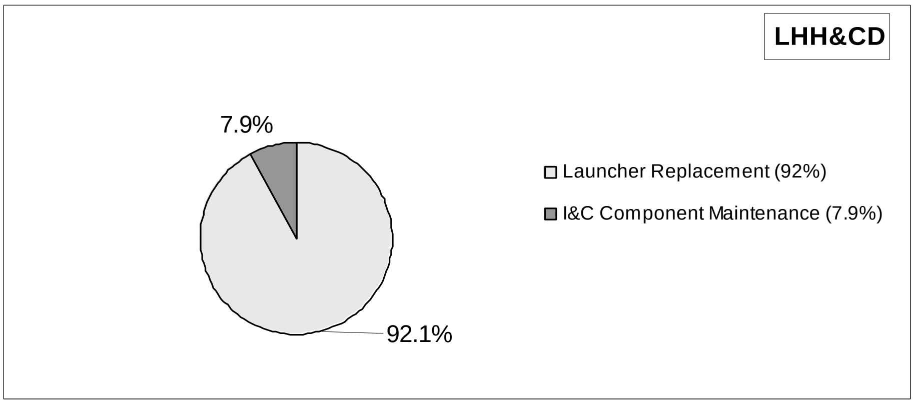

FIG. 5.
Contribution of the main maintenance tasks to the annual worker dose for LHH&CD system

4.5 Diagnostics

The diagnostic systems are the most complex to assess, from a worker dose perspective. One of the reasons is that, for equatorial ports, there are several systems sharing a single port, with each system potentially having different calibration and maintenance requirements. In all, there are 105 diagnostics in ITER.
Equatorial port 1 has been used as basis for the ORE assessment [2] to develop a procedure that might be applied to all other ports. Spreading of contribution is shown in Figure 6.

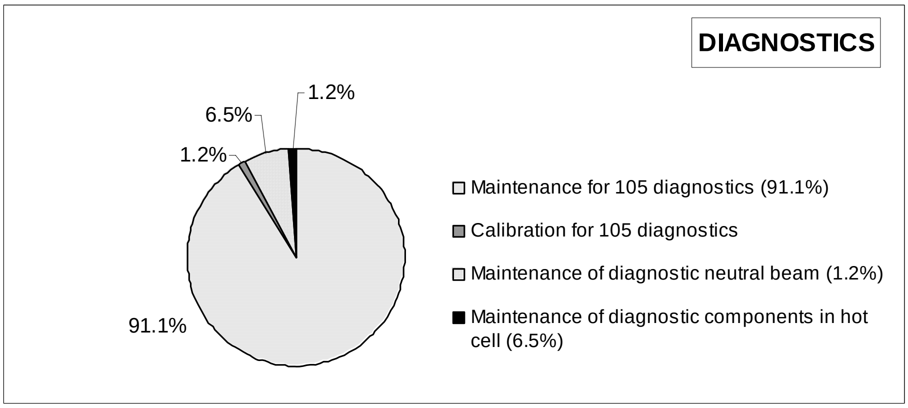

FIG. 6.
Contribution of the main maintenance tasks to the annual worker dose for Diagnostics

4.6 Test Blanket Modules

The replacement of blanket modules, for the maintenance, is an activity performed remotely, by the use of a RH cask. For the cask to reach the vacuum vessel port requires a significant amount of hands-on work, however.
We have assumed that the test blanket modules would be replaced once every three years. However, as there are three test blanket module ports, on average, the test blanket module replacement frequency will be one port per year. It has been assumed that there is no hands-on work associated with this activity; hence there is no worker dose. Spreading of contributions is shown in Figure 7.

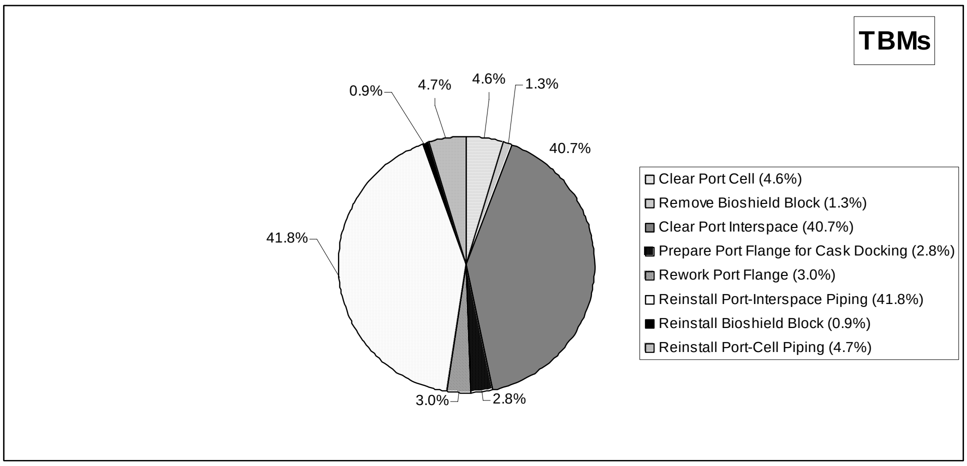

FIG. 7.
Contribution of the main maintenance tasks to the annual worker dose for TBMs

4.7 Results

The table 4 summarizes the estimated dose for each system.
The key result from this assessment is that the analyzed systems are expected to contribute a total of 178 p-mSv/a, or about 37% of the ITER facility target (500 pmSv/y) [3]. This estimate is indicative only and the ORE value could change significantly in the future, as a result of further design evolution and better input data.
Comparing the above results with the results obtained in previous analyses [4] the differences can be grouped into three classes: 1) design changes, 2) assumptions and 3) methodology.

The total worker dose for the analyzed systems has increased while a reduction was expected. A part of this increase comes from two systems that were earlier assumed to have zero doses – i.e., difference in assumptions. The remaining part is not as easy to rationalize, even though there were some important design changes. The standardization of the methodology can help in the acquisition of comparable results. The optimization of the work effort evaluation is a fundament step in this path.

SYSTEM	Estimated Dose (p-mSv/a)
Ion-Cyclotron Heating and Current Drive	10.0
Electron-Cyclotron Heating and Current Drive	38.7
Neutral Beam Heating and Current Drive	16.5
Lower Hybrid Heating and Current Drive	6.3
Diagnostics	84.5
Test Blanket Modules	22.4
TOTAL	**177.8**

TABLE 4. ORE summary for the systems assessed

5. Conclusions

We have taken as detailed look at the port-interfacing systems as it is permissible at this point in time. Given the current state of the design, and design uncertainties associated with prototype systems and components, our estimate of worker radiation exposure is by necessity indicative only. The key result from this assessment is that the analyzed systems are expected to contribute a total of 178 p-mSv/a, or about 37% of the ITER facility target.

Despite the high level of remote control of maintenance activities, we anticipate a significant amount of manual (hands-on) activities and associated worker radiation exposure. The methodology developed for and applied to this assessment gives significantly higher estimates of work effort, relative to the earlier studies. The next step of the process will be to challenge all of the underlying assumptions and to refine them, as appropriate, and to validate them so that they can be easily defended in the licensing arena.

Significant effort remains to not only improve the estimate, but to demonstrate that the ALARA requirement has been satisfied. The present assessment is only a small part of the overall, iterative process of design and analysis. Accordingly, it may be useful in assisting, or guiding, that process to a successful end.

Acknowledgment

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