JET–CP(98)41

Operational Experience from the JET Remote Handling Tile Exchange

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ABSTRACT

The first fully remote handling operations on a fusion Tokamak have been completed at JET. The JET MKIIA Divertor has been successfully removed and replaced with the MKII Gas Box Divertor configuration using only remote handling methods inside the JET torus [1].

The remote maintenance and modification of components at JET were undertaken using a man-in-the-loop approach, where the operator was provided with both visual and tactile feed-back from a two arm servo-manipulator positioned inside the torus by an articulated boom. Using this methodology the operator was provided with a sense of presence inside the torus and therefore able to perform a wide range of tasks in the same way as if he himself were inside the torus.

The operational experience gained from this first ever fully remote handling operation at JET has revealed the value of making detailed preparations and having a system flexible enough to accommodate a range of unplanned tasks. This paper describes the experiences from the setting up and subsequent managing of the remote handling operations.

1. INTRODUCTION

During 1997 JET completed a series of D-T experiments which resulted in levels of radioactivity which made personnel access to the torus limited to the most brief of tasks. The JET programme required that in early 1998 the MKIIA Divertor must be replaced with the MKII Gas Box Divertor and this task must be done using the suite of remote handling equipment already commissioned to meet this requirement.

2. OPERATIONAL DOCUMENTATION

An overall Remote Tile Exchange (RTE) Shutdown Logic plan was compiled, which listed each task with a brief description to demonstrate the feasibility of the task. For each of the planned tasks a task plan was produced, this detailed the complete sequence for the task together with procedures, data sheets, tools and boom teach files required, see Fig. 1.

Procedures were written and boom teach files constructed using a graphical simulation system called "KISMET" [2]. The final phase was to validate the procedures, teach files and data sheets etc. in the full size mock-up facility of the JET torus.

There were approximately 35 in-vessel pre-planned tasks; ranging from installing an in-vessel viewing system to dust collection from the divertor structure.

Within a task there were a number of procedures and each one containing very detailed instructions, see Fig. 2. This proved to be a very time consuming activity but it ensured that each task was successfully completed without errors. From the experience gained from the RTE a number of improvements are to be implemented:

- The task plan will contain more information thus reducing or eliminating the number of procedures.

- Within boom teach files where data sheets are required, these will automatically appear as part of the file. The operator will call up a file from the Man Machine Interface (MMI) and the relevent data sheets will appear. He will then select the appropriate data sheet and the remote handling equipment will automatically move to the required position. This has the added advantage of reducing the chance of operator error, as he does not have to type in a list of data which may incur mistakes.

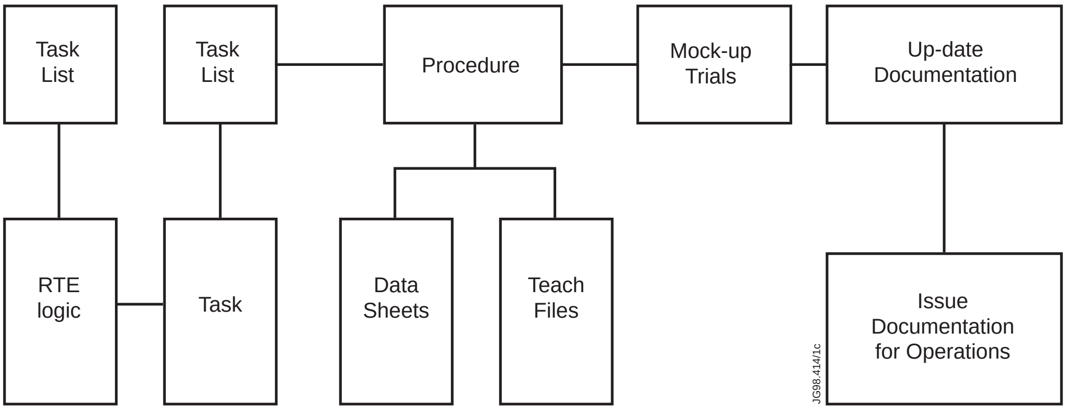

Fig. 1 Overview of operational documentation

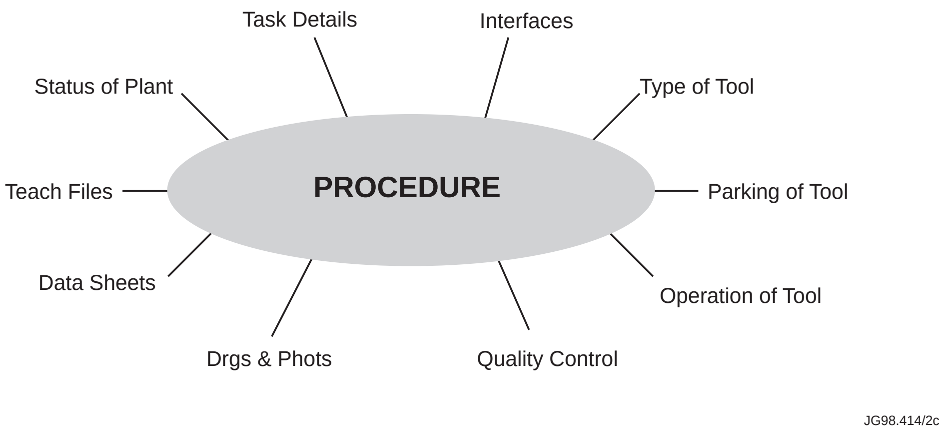

Fig 2 Schematic contents of a Procedure

3. OPERATOR TRAINING

A Remote Handling Equipment Operator Training manual was written, which detailed a training programme for the operators of the various remote handling equipment. The aim of the training was to produce fully trained and qualified personnel to operate a range of equipment by means of the relevent MMI. Each person was briefed on the general principal of the design and operation of each piece of equipment. This was followed by the MMI training and guidance on what to do when faults occur. The training was supervised by the appropriate Equipment Responsible Officer (ERO). On satisfactorily completing the training, personnel were given a certificate of qualification to operate the specific equipment. The final outcome of the programme was to establish a list of approved operators, and only these personnel were allowed to operate Remote Handling Equipment.

During the training programme it soon became clear which personnel were suited to Manipulator (Mascot) or Articulated Boom operations. Mascot operators had to have a good hand-to-eye coordination, be very patient and understand the mechanics of the task being undertaken. Boom operators had to have a knowledge of kinematics in order to understand the combination of Boom movements. They need to be computer literate as the movement of the Boom is controlled through the MMI via a key board. They must also be aware of the environment of the in-vessel because of the need to monitor at all times the clearances between Boom and the in-vessel components. It was found that the best operators of both Mascot and Boom were the workshop technicians who were involved in their general maintenance; this gave them an insight into the mechanism and as such they appreciated the operating capability of the equipment.

Once the operators had completed the training programme they were then trained on the actual tasks that they would be involved in during the RTE. This phase of training utilised the full size In-Vessel Training Facility (IVTF) [3]. It is equipped with in-vessel components which realistically represent the actual ones and where possible spare components were used. The components which needed to be remotely handled were modelled to be a true representation in terms of; size, shape, weight and surface finish. All the remote handling features required for the attachment of the special remote handling tools [4] were all incorporated. The realistic mock-up facility proved invaluable in the checking of tasks, the validation of procedures and the training of operation teams.

The Facility was also used during the RTE to both refresh operators with the environment of the planned task and also to prepare for any unplanned tasks.

An essential element of the training programme was to demonstrate the feasibility of recovery from equipment failure. A number of failure scenarios were proposed and trained for; boom joint, Mascot arm, cyclops arm and camera arm. During the RTE there was no major failure of any of the equipment, thus demonstrating the reliability of the equipment.

4. OPERATIONS MANAGEMENT AND PLANNING

The RTE shutdown was planned for two shift operation and a six day working week. The duration of each shift was 10.5 hours and within the shift there were two four hour working periods. The times for the various tasks were established from the comprehensive mock-up trials programme. It became apparent from the mock-up phase that when the Mascot operator was manipulating complex components there was a limit to the time he could maintain the high level of concentration required. Taking this into consideration as well as possible equipment failures, a 20% contingency was incorporated into the final RTE shutdown plan. This contingency proved to be necessary for the Mascot operator, as he did need to rest from time to time mainly due to eye strain or his hands starting to ache. During a typical continuous operating period of four hours, the operator needed a fifteen minute rest from operations. Mascot operator fatigue during long operating periods is a factor to be considered in planning of task timescales, particularly on repetitive tasks. The overriding theme throughout the RTE was safety of the in-vessel components; and at no time was safety compromised for speed.

Three operation teams were trained for the RTE, this provided a rest period for each team as well as cover for sickness. Each team consisted of:- Operations Engineer, Deputy Operations Engineer, Boom operator and Mascot operator. The function of the Operations Engineer was to ensure that the correct procedures were followed and for the safe completion of the task. The Deputy Operations Engineer would; adjust camera views for both Mascot and Boom operators, record all activities and times in the daily log, report any equipment faults to the Equipment Engineer and finally be a back-up to the Operation Engineer to ensure safe operations.

5. RESPONSE TO UNPLANNED EVENTS

The general philosophy for the remote handling at JET has been to develop a flexible system based on a man-in-the-loop control strategy. This approach has proved to be correct. It gave us the ability to deal with a number of unexpected and unplanned tasks which were undertaken within a realistic time frame and without any significant cost implications.

Two new tasks were added to the shutdown just four weeks before the start; dust collection from the tile surfaces at octant 1, and the second was to position a mirror within the torus to measure the light transmission through a number of diagnostic windows.

A number of unplanned tasks were also performed during the shutdown:-

- Cleaning of the MKIIA base carriers to remove tritium contaminated flakes.
- Cleaning of diagnostic windows positioned in the lower main vertical port of the torus.
- Deployment of a tritium bubbler to survey the tritium levels within the torus.
- Recovery of a damaged diagnostic waveguide.

6. CONCLUSIONS

The successful completion of the RTE shutdown demonstrates the viability of remote handling as a means of repair, maintenance and the re-configuration of fusion devices.

The adaptability of the JET Remote Handling system has been demonstrated by the ability to deal with unplanned and unexpected tasks. A realistic mock-up facility where task procedures can be validated, operators trained, and where unplanned tasks could be studied has proved to be essential. The substantial amount of time spent on producing detailed procedures, task plans and a realistic planning schedule, based on mock-up times, proved to be time well spent. This effort was rewarded in the completion of the RTE within the planned schedule, and ensuring that this was achieved in an efficient and safe way.

7. REFERENCES

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