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** See annex of F. Romanelli et al, "Overview of JET Results",*
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ABSTRACT

Remote handling operation has been carried out on the Joint European Torus for over 16 years with in excess of over 21,500 hours of in-vessel remote handling activities. During this period the operations team has developed to provide the unique skills required to achieve the demanding remote operational campaigns undertaken today. This paper describes the challenges experienced in recruiting, training and retaining the remote handling system operators and examines the evolution of the team profiles currently used. The operations team have a number of key skills that vary depending on the role of the team member. A degree of overlap in skills is essential to ensure that operations can continue with the temporary loss of an operator. The remote handling system at JET utilises two Articulated Booms. A 12.5 metre boom is fitted with a force reflecting servo manipulator (MASCOT) and a 9.4 metre boom is used to transport tooling and components to and from the work area. MASCOT is a two armed master slave system; each arm has 7 degrees of freedom with the capability to carry a mass of up to 20kg. The content of this paper documents the development of the JET remote operations team over the past 16 years, and should provide a resource of value for future tokamak remote handling operations such as ITER and DEMO.

1. CONTROL ROOM LAYOUT

The remote handling control room at JET accommodates a full operations team consisting of five operations staff to operate the remote handling system and three staff used on a part time basis to assist in the manual interface with the RH system during the loading/unloading activities. The five work stations allocated to the operations team include the MASCOT master interface (Manipulator operator), Oct.5 Boom operator interface, Oct.1 Boom operator interface, MASCOT/view HMI interface and operations management interface.

In addition to the above work stations there is the facility to operate a second MASCOT master station at the same time. This can be used for recovery scenarios or training/development activities.

2. REMOTE OPERATIONS RESOURCE PROFILE.

To achieve successful remote In-Vessel operations at JET it is necessary to utilise five operators on each of the operational shifts. These operators comprise of:-

- 1 RH Operations Engineer.
- 1 RH Deputy Operations Engineer.
- 1 MACOT Operator
- 2 Boom Operators

During the 2012 intervention Remote Handling Operations were carried out using a two shift working pattern covering 16 hours of operations 6 days per week. To support this type of shift pattern it is necessary to train three teams plus additional personnel to cover sickness and leave. A total of 19 operations staff were trained to complete the 2012 shutdown. This is now the favoured mode of remote handling operation at JET.

During the EP2 Shutdown (2010) Remote Handling Operations was carried out using a two shift working pattern covering 16 hours of operations per day, 7 days per week. This proved to be a very challenging shift pattern to support and required 25 operations staff to support.

The disparity between the staffing levels in the EP2 shutdown and the 2012 intervention were by natural wastage and utilisation elsewhere within the unit.

3. STAFF PROFILE FOR REMOTE OPERATIONS

For successful remote handling operations at JET a team of five staff are required to operate the remote handling system within the Torus as shown in Fig.3 below.

3.1 MECHANICAL TECHNICIANS

The mechanical technicians have two main roles to fulfil. They have there operational requirement (Boom/MASCOT operators) and also play a mechanical maintenance role on the R/H equipment. As part of the mechanical maintenance role the technician will be required to work in our machine shop on modification and manufacture of tooling and mechanical parts.

The appointee will also be required to occasionally work in Beryllium and Radiation controlled areas, wear RPE up to and including a airline feed pressurised suit.

The minimum requirements for the role are: - Recognised time served engineering apprenticeship (or equivalent) with relevant qualification in engineering or workshop technology. This is essential as the technicians will be required to carry out all of the mechanical maintenance of the RH system along with tooling modification in the machine shop. They should also have the capability to work from drawings and schematics and have a good working knowledge of Microsoft office. JET In-Vessel shutdown operations are staffed in shifts and the appointee must be prepared to provide support for shifts or be on call as required, have the ability to co-operate and work as part of a team and have an excellent working knowledge of English.

The mechanical technicians are utilised to facilitate all the routine mechanical maintenance tasks on the remote handling systems and tooling. They are also used for the fault diagnostic and recovery/repair of the equipment. This philosophy of using the technicians to maintain and operate the equipment leads to sense of ownership.

3.2. OPERATIONS MODIFICATIONS ENGINEER

The operations modifications engineers also have two main roles to fulfil. They have an operational requirement (Management of an R/H In-Vessel operations team) and generation/development of the remote handling procedures and techniques used within the Torus.

The minimum requirements for the role are: - Professional Engineering Qualification or Equivalent Experience with excellent man management skills and project management skills. Report writing and presentation skills are a major activity within this role so an excellent working knowledge of Microsoft office and Access is essential. A good knowledge of remote handling operations, remote handling machine tool design and fastening technologies is also desirable.

The appointee may be required to occasionally work in Beryllium and Radiation controlled areas, wear RPE up to and including an airline feed pressurised suit. The operations engineer is involved during the component design to ensure that the design is remote handling compliant. Once a design is understood then a handling assessment is carried out to determine how the component will be handled and how it will be deployed into the Vessel. The results of the assessment are fed into the tooling design and in some instances back into the component design. The operations procedures are then generated in preparation for the remote handling mock-up trials. The outputs from these trials are fed back to the component design, tooling design and procedure generation.

The next paragraph details the typical software packages that an operations engineer would require training.

VR4Robots, Operation documentation system (ODS) builder, ODS Active Process map, (APM) creator, (ODS APM Executor, MASCOT/Boom and view HMI and a number of auxiliary interfaces.

4. OPERATOR TRAINING

4.1 MASCOT OPERATOR TRAINING

One of the major challenges of training an operator for this role is identifying a suitable candidate during the initial selection process. Most people can be trained to safely operate the system however only a small percentage have the required skills and aptitude to become a primary MASCOT operator used for advanced In-Vessel tasks.

All of the MASCOT training is carried out by a qualified agreed trainer.

The training activities cover: -

- General MASCOT Introduction
- MASCOT Mechanical Hardware Introduction
- Control System: Software & Hardware
- MMI Introduction
- Hands-on Training

The initial four training activities have a relatively short duration. These could be completed in 1 week however due to the complexity of the system software and hardware these activities are normally split over a two week period. The duration for hands on training is 22 hours however this is carried out over a three week period to minimise fatigue to the operator. Once this level of training is achieved the trainee can safely operate the MASCOT under constant supervision and most individuals can reach this level of competency. Progression from this level is achieved by continued hands on training under constant supervision.

After the initial training activity has been achieved continued hands on mentoring is performed using full scale mock-up environments and supervised shutdown activities. A fully experienced operator used for advanced shutdown activities and training of new operators can take up to 2 years to achieve. Not all operators will reach this level, experience has shown after the selection process approximately 1 in 3 trainees have the appropriate skills and aptitude to succeed as a primary operator.

5. BOOM OPERATION TRAINING

Training for the articulated Boom covers both Octant 5 and Octant 1 articulated Booms.

The training activities cover: -

General Boom Introduction.

- VR4Robots
- Boom Mechanical Hardware Introduction.
- Control System: Software & Hardware.
- MMI Introduction.
- Hands-on Training.

The initial five training activities have a relatively short duration. These could be completed in 2 weeks however due to the complexity of the system software and hardware these activities are normally spread over a four week period. The duration for hands on training is 25 hours, this is carried out over a four week period to minimise operator fatigue. Once this level of training is achieved the trainee can safely operate the articulated Boom under constant supervision. Unlike MASCOT the majority of the hands on training is carried out offline using the virtual reality environment. This allows for a number of operators to be trained together.

After the initial training has been successfully completed the operators are introduced to some of the more advanced mode operations.

- Teach and repeat file generation.
- Boom operation using 6 axis force moment
- Boom operation with linked end effectors

Boom operator competency is recorded and tracked via a skills matrix. Competency level is grouped into four separate levels as shown in fig.8 below.

6. MODIFICATION ENGINEER TRAINING

Training the remote handling operations engineer covers a large range of training activities. They are trained on Boom and MASCOT operation up to the second competency level. This contributes to robust operational procedures being generated due to the detailed system experience obtained from the training process. The other benefit is the ability to substitute operators during routine operational tasks.

Additional areas of training required are:-

6.1. VR ENVIRONMENT

Advanced level of VR4Robots operation is required to enable the engineer to manipulate the In-Vessel model using the Boom and MASCOT human machine interfaces to allow task evaluation to be carried out. Modification of the models maybe required to determine the ideal handling techniques that are required. Once the optimal handling positions and techniques have been determined the information is passed back to the design office for final designs to be completed.

6.2 ODS (OPERATIONAL DOCUMENTATION SYSTEM)

There are a number of modules that the operations engineers need to be fully trained on. These include the ODS Builder, active process map creator (APM), APM executor (this is a web based front end that outputs the method details from the ODS builder that are linked to an interactive process map that was generated in the APM creator), Task module manager (component/tooling tracking system used to track and manage many components/tooling across a number of task modules).

6.3 HMI INTERFACES

There is a vast array of HMI aplications that are used to interface with the remote handling equipment. These include such systems like: - Boom, Mascot, Winch, Third arm, Cameras, 6 axis force moment sensors, TIG & MIG welding controls, Photogrammetry/Stereo camera controls and gap gun interface.

6.4 RH DESIGN SPECIFICATION/METHODOLOGY

Training in this area is paramount to provide the operator with a detailed understanding in the fundamentals of remote handling compliant designs. The modifications engineer is often interacting during the initial design phase of new components and tooling ensuring the remote handling standards developed over the many years of operation on JET are fully incorporated into the design where practically possible.

6.5 RH OPERATIONS TRAINING

To maximise the productivity of In-Vessel operations, it is essential training is given on the operations within the remote handling control room during one of the planned In-Vessel operational periods. This includes management of the operational team, how to resolve issues encountered during component installation/removal along with process errors of remote In-Vessel tasks.

7. RECRUITMENT

There are three main roles that need to be filled during the recruitment process. These are:- Mechanical Technicians, Deputy In-Vessel Modifications Engineers and In-Vessel Modifications Engineers. Filling these roles has proved to be a very challenging process as the vast majority of the candidates have little or no remote handling experience, due to the unique nature of our software and systems it is unlikely that they retain the knowledge to operate these systems without being trained.

The recruitment process for the mechanical technician involves a number of tests. The purpose of these tests is to ascertain if the candidates posses the required skills to be trained for this role. These tests include:-

Mechanical fitting test piece:- The candidate is requested to complete a mechanical fitting test piece. This involves the production of a component that is fabricated to a drawing using standard engineering hand tools.

A challenging time limit is applied to the production of the test piece to determine how the candidate prioritises the manufacturing process. We look for candidates that fabricate the test piece to the tolerances stated on the drawing and that have not sacrificed quality in preference to finishing the test piece.

Mascot Test: - The candidate is also tested on the MASCOT system. It is difficult to assess candidates in the limited time frame but the practical test is designed to determine if they posses the required attributes to be trained as a primary MASCOT operator. As mentioned earlier in the paper only 1 in 3 individuals attain this level of ability. The goal is to determine the skill level in hand/eye coordination, spatial awareness, finesse and the ability to understand detailed mechanical assemblies.

Boom Test: - During the Boom test the candidates are shown how to operate the Boom system in simulation using simple joystick mode. The test involves movement of the Boom to a predetermined position whilst maintaining a minimum operating clearance of 200mm between the Boom and the Vessel wall by moving one joint at a time under joystick control. The VR model is manipulated for the candidate to provide the required views to achieve the task.

It is generally found that candidates with CNC machine tool experience performance very well due to their X Y Z programming skills.

The final process is: - the interview with the candidate to determine the relevance of past employment and education/training achievements, ability to read detailed assembly drawings, assessment of machine shop competence and conformation they are prepared to work on shift during the remote handling operations campaigns, this may involve working in Beryllium and Radiation controlled areas, wear RPE up to and including a airline feed pressurised suit.

The recruitment for the Deputy and In-Vessel modifications engineer is similar to the process above but without the mechanical fitting test. Additional areas of experience required are experience in management of technical teams, ability to carry out detailed handling assessments on mechanical assemblies and experience in the generation of detailed assembly procedures.

8. RETENTION

Due to the investment in training and mentoring of the operational staff it is imperative to concentrate on retention due to the number of years of training necessary to replace primary operators. A number of areas that contribute to staff retention are:-

Maintain a competitive employment package that can compete with local industry.

Job satisfaction is prominent within the remote handling operations group. One of the major contributions for job satisfaction is the involvement in the cutting edge upgrades of a leading Fusion device.

Career progression is one of the major retention tools that are available. Investment/mentoring and continued training allow for an excellent career path and many strong operational staff have been developed using this methodology.

CONCLUSION.

The current remote handling operations team has evolved over 16 years and experienced many thousand hours of successful In-Vessel remote handling operations. The current philosophy of equipment/software and layout/design plus the development of the staff contributes to the high performance in productivity and quality achieved today at JET.

The training of an operations team can take many years of development to achieve a successful team that performs at a suitable standard. This should be completed before any remote operations are commenced.

Staff retention is paramount in retaining the capability of a high performing remote handling operations team. At Culham good results have been achieved with the involvement in the CCFE apprenticeship scheme. The Remote Handling Unit offers training placements to the apprentice scheme and has successfully retained three graduated apprentices who are currently at various stages of their career progression. The graduated apprentice offers a good platform for continued development and provides the opportunity to develop the candidate to align with the needs of the operations team.

ACKNOWLEDGMENT

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Figure 1: JET Remote Handling Control Room.

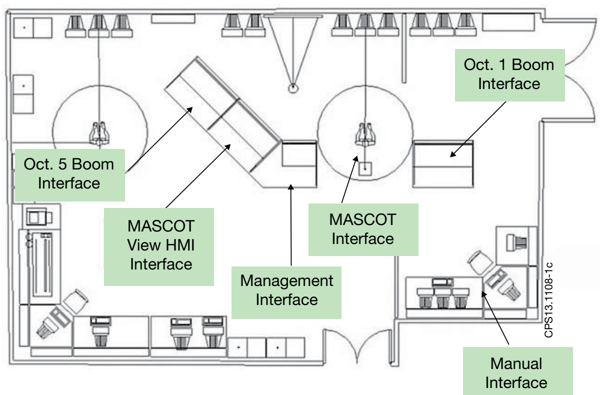

Figure 2: Control Room layout.

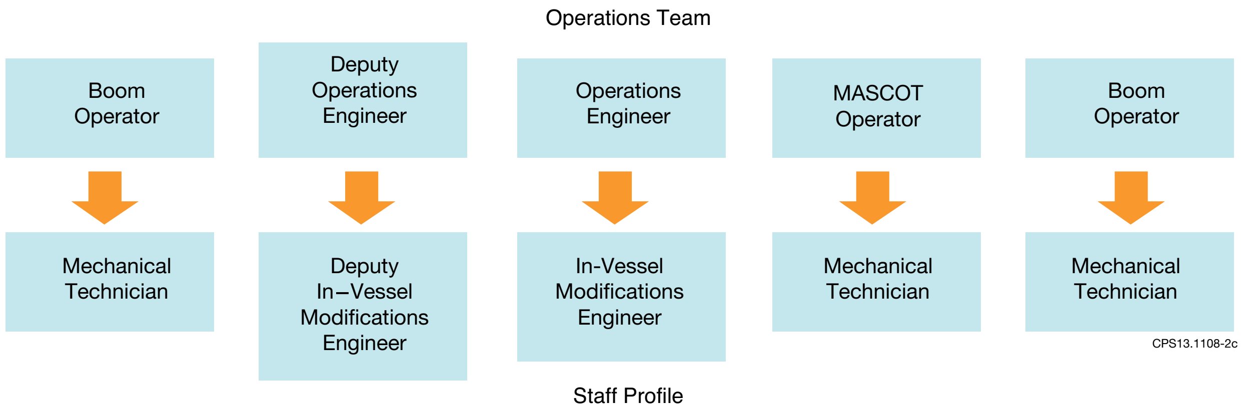

Figure 3: Remote Handling Resource profile.

Figure 4: Remote Handling maintenance.

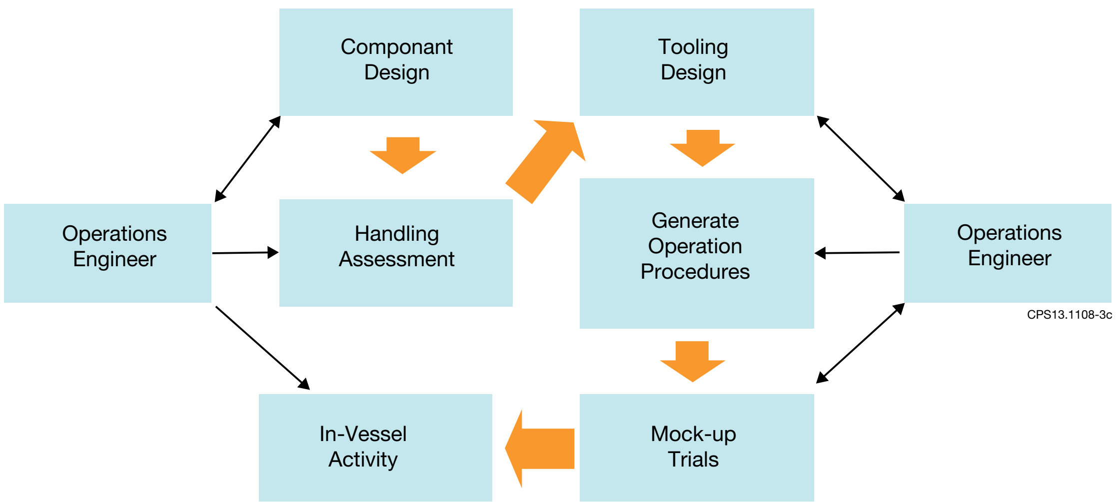

Figure 5: Component design process.

Figure 6: MASCOT Operator.

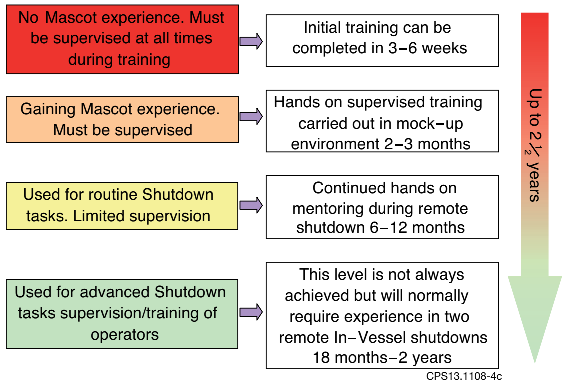

Figure 7: MASCOT Training schedule

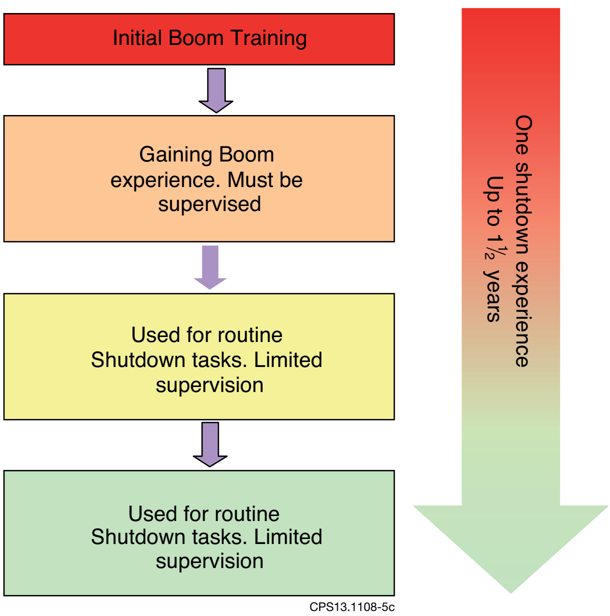

Figure 8: Boom compentency schedule.

Figure 9: Remote Handling control room operations.

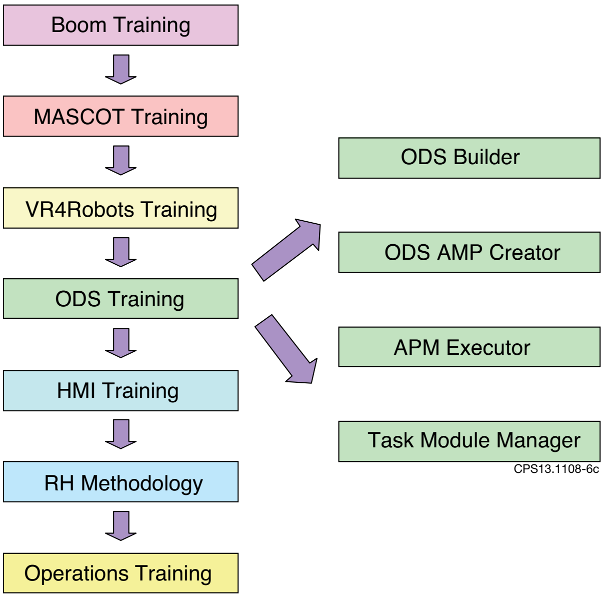

Figure 10: Modifications engineer training schedule.

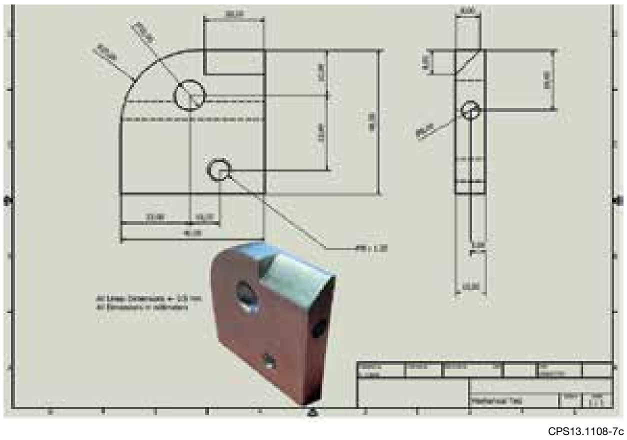

Figure 11: Mechanical fitting test piece.