3 JET Operations

3.1 INTRODUCTION

Since January 2000, CCFE has had the responsibility for the operation and safety of the JET facilities under the European Fusion Development Agreement (EFDA). The legal and financial provisions are defined by the JET Operation Contract (that confers the contractual management to the EFDA Associate Leader for JET). The JET research programme is carried out by Task Forces of visiting European scientists from fusion laboratories associated to EFDA, including CCFE, under the responsibility of the EFDA Associate Leader for JET.

Experiments ceased in October 2009 for a major shut-down for the installation phase of the second JET Enhancement Programme (EP2). By far the largest task has been removal of the old plasma-facing tiles and installation of the new plasma-facing “ITER-like Wall” (ILW). This EP2 shutdown was completed shortly after the end of this reporting year, in May 2011, and therefore spanned the entire period of this report.

EP2 comprises a series of 24 upgrade projects. These vary in scale, and include new or improved diagnostic systems as well as much larger projects such as the Enhanced Radial Field Amplifier (ERFA), Neutral Beam Enhancement (NBE) and the ILW. The major items required for the EP2 programme have been manufactured by industry, mostly via EFDA Article 7 contracts placed by the European Commission, with commercial management of the contract being carried out by the EFDA-JET Close Support Unit. Technical management of the contract was normally carried out within the project team for the particular EP2 enhancement. The project team and its leadership, from the initial design phase through procurement to commissioning, have in general been provided by one or more European Fusion Associations following a call for interest. The project team has worked closely with CCFE as JET Operator throughout the project, with the Operator having responsibility for installation of equipment and preparation of necessary infrastructures, and assuming responsibility for eventual routine operation after handover following commissioning by the project team. Installation was subject to acceptance of equipment by the Operator to ensure compliance with all the applicable quality and safety requirements, and compatibility with technical interfaces.

CCFE has led some EP2 projects as a Fusion Association – in particular Neutral Beam Enhancement (NBE) which is the second largest project after the ITER-like Wall Project (ILW) - see Chapter 4. The ILW project, as an exception to the normal EFDA-JET Enhancement management arrangements, has been led by CCFE as Operator through all its project lifetime stages. This reflects the fact that the design of the very large number of in-vessel components and preparation for their installation are intimately related to the machine

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structure and the need to take into account requirements dictated by remote handling considerations, which are the Operator's responsibility.

3.2 ITER-LIKE WALL PROJECT

The ILW project was approved by the EFDA Steering Committee in April 2005. The project has been led by CCFE with core engineering and installation related activities based at JET including secondees from other EURATOM Fusion Associations. Certain specialist technical tasks have been based outside JET but under the overall management of the ILW team.

The objective of the ILW Project was to install in JET, a beryllium (Be) wall and an all tungsten (W) divertor which is now the planned material configuration for the deuterium-tritium phase of ITER. In combination with other EP2 enhancements to JET, ILW will provide a test bed for integrated scenarios with ITER relevant edge conditions and compatibility with the wall, thus speeding up the early phases of ITER.

The ILW project has consisted of two main strands: Engineering Design and Manufacture, which designs and procures all the new components required inside JET; and Installation Preparation which is responsible all the preparatory work and procurements required to install the new wall. Because most of the installation was by remote handling the effort involved in tool design and manufacture, procedure preparation, training, etc., was a very substantial part of the overall job.

By April 2010 the assembly of tile components into final assemblies was in full swing. Removal of the old tiles was also,well under way, which meant the first of the new tile installations was scheduled for late August. The project met this deadline with the first tile, a Mushroom tile, being installed on 22 August. By the end of 2010 (see next section), tile installation was progressing rapidly. However, a large number of anomalies started appearing. The interior of the JET vessel was not exactly as the configuration models showed. This meant that tile systems did not fit and needed to be removed for further modification.

Remote photogrammetry surveys of the vessel wall once the old carbon tiles had been removed created great challenges for the assembly of the diagnostic conduits which feed an array of thermocouples in the new tiles. The conduits snake around the machine avoiding the existing structures and many modifications were required. Trial assembly was carried out on a full scale jig reproducing the measured mounting locations inside the machine (Figure 3.1). Along with the preceding remote handling "mock-up" trials this paid off with very few installation problems for a complex system of 15 conduit packages and 6 cable looms, each with its own remote handling tooling package.

Figure 3.1*: Trial assembly of diagnostic conduits on a full scale jig.*

By April 2011, all but one of 19 European Commission Article 7 procurement contracts were completed. The final contract is expected to complete by the end of June 2011 although all components from this contract have been delivered. These 19 contracts provided all of the new tile components. However, anomalies meant that further JOC contracts were required to modify the parts.

One of the last major items to be delivered was the bulk tungsten tile assemblies. There are fifty modules in all, each weighing in at 60kg. Integration of diagnostics, such as the Langmuir probes, was carried out at JET along with final fit check on a jig (Figure 3.2).

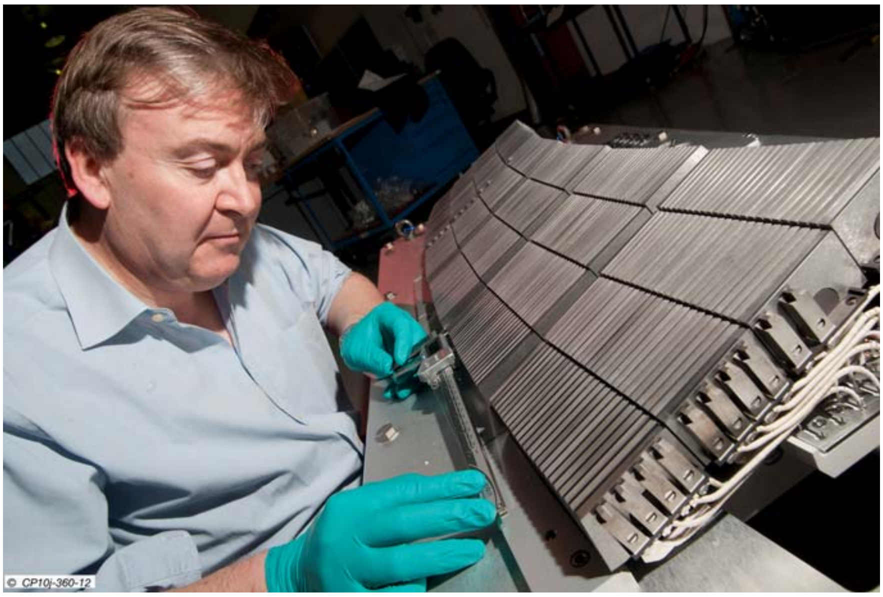


Figure 3.2*: Final fit check of bulk tungsten tiles on a jig.*

The parts database showed that by early February 2011 the project had received, inspected and accepted all 85,273 parts required for the new wall. As most components were available well before this date, the focus in early 2010 was on assembly of components into tile assemblies ready for installation. Later in 2010, the focus switched to supporting the installation of tile systems and correcting any issues arising as a result of tiles not fitting as expected. By April 2011 a total of 3,180 tiles have been successfully installed out of a total of 3,360 and the project is in its final few days of installation. Once this is complete the remaining work is to close out the project properly by ensuring all the documentation is correctly referenced and archived, final reports are produced and any remaining responsibilities are handed over.

The Installation Preparation strand, which provided all the remote handling (and manual) tools, installation procedures, mock-up components and trials, made considerable advances. By April 2010, all Remote Handling tooling, jigs, mock-ups and installation procedures were completed. It is a credit to the Remote Handling Group that very few modifications to tooling were necessary, and, apart from some minor modifications, the tooling operated as designed. In addition, the Logistics Teams proved highly capable of handling some quite challenging scenarios when items need to be removed from in-vessel for modification and then returned afterwards.

3.3 EP2 SHUT-DOWN AND INSTALLATION OF THE ITER-LIKE WALL

The EP2 Shutdown has been the most significant since the installation in JET of the Divertor Assembly in 1992-4, and has consisted of four Remote Handling (RH) and three manual in-vessel phases. Although activities for the in-vessel installation of the ILW form a major part of the shutdown, there is also a significant range of ex-vessel tasks including the installation of the remaining EP2 diagnostic enhancements and the work associated with the Neutral Beam Enhancement (NBE).

3.3.1 STRATEGY

It was important to complete the EP2 Shutdown as soon as possible in order to obtain the important results from JET operation with the ILW. A strategy was agreed between EFDA and CCFE to achieve this:

- The starting date of the in-vessel operations should be as early as RH preparations allow;
- The full planned scope of shutdown and enhancement work should be maintained and necessary diagnostic calibration tasks included;

- The intensity of the RH activities should be as high as practicable with a target of achieving pump-down of the vacuum vessel by the end of 2010.

3.3.2 PLANNING AND ORGANISATION

The above strategy led to the overall plan consisting of an initial phase of ex-vessel activities allowing the early removal of the Neutral Injection Box (NIB) central support columns before the installation of the in-vessel access facilities. A revised shutdown organisation and communication structure was introduced in order to clarify the responsibilities for activities undertaken and to ensure visibility of this within the planning. The detailed plans continued to be developed and refined with over 8000 tasks programmed during the shutdown period.

3.3.3 PREPARATION WORK

Preparation work started in 2009 and continued through into the early part of the shutdown itself as infrastructure and systems were finalised and commissioned. In particular the following were completed:

- Finalisation and commissioning of the enhanced controlled ventilation system in the Torus Assembly building (J1A) including connection to the new Beryllium inspection facility;
- Final setup and commissioning of the Beryllium inspection facility including slit boxes for work on new Be ILW components;
- Final build of 3 new ISO transport containers (with ‘Chesim’ doors for connection to the facilities) for the storage of the removed carbon wall components;
- Upgrade of both manual and remote access ISO storage containers for compatibility with the new extended Tile Carrier Transfer Facility boom and task module component and RH tool storage system;
- Construction of storage and handling facilities within the Beryllium handling facilities for the refurbishment of divertor tile carriers including ventilated tents, slit boxes, and test jigs;
- Establishment of a laser scanning facility for the dimensional measurement of carbon tiles removed from JET;
- Completion of the Beryllium machining workshop;
- Construction of a second containment facility for a neutral beam central support column;
- Installation of a new storage stillage for NIB shielding panels.

3.3.4 SHUTDOWN ACTIVITIES

Remote Handling phase 1 and the first manual phase were successfully completed during 2009/10.

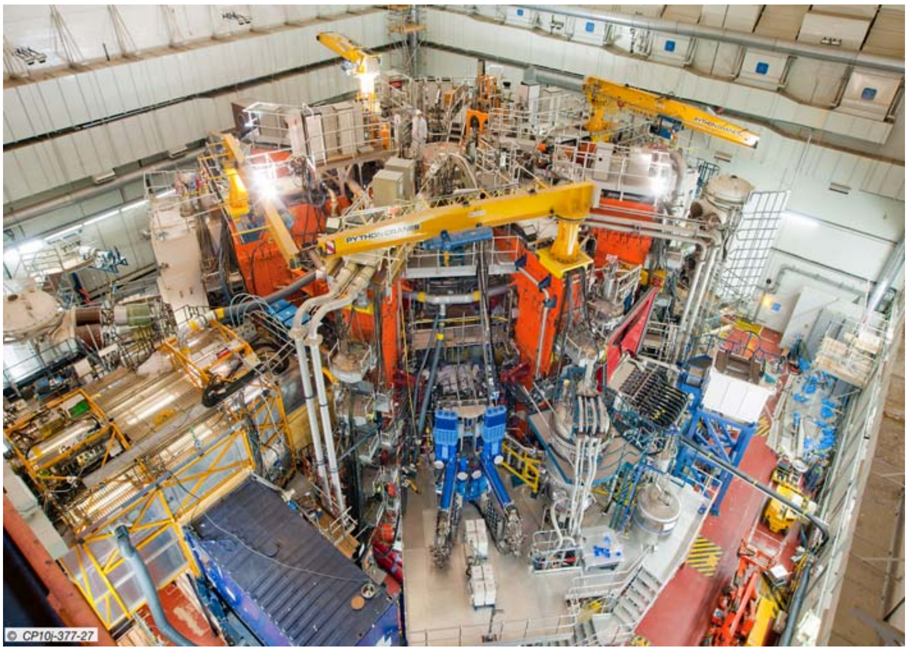


***Figure 3.3**: JET Torus Hall during shutdown.*

A Remote Handling phase 2

The second remote phase commenced on 29 March 2010 and continued the removal of the CFC first wall tiles in various areas and redundant diagnostic conduits. Remote welding of mounting blocks in 21 locations was undertaken and a detailed photogrammetry and stereo camera survey was undertaken of the new route to allow preparation for the installation of the new ILW diagnostic conduit system.

Electrical testing of the cabling within the divertor structure was undertaken and alignment checks of the KE11 High Resolution Thomson Scattering diagnostic made. Diagnostic window transmission tests were completed using a new remote handling compatible calibrated white light source.

A dimensional survey using over 450 targets of the vessel was undertaken using photogrammetry, followed by a full recording of the vessel walls using a stereo camera system providing valuable as-built information for both the ILW installation and future upgrades.

B Manual phase 2

A second phase with manned entries into the vessel began early August 2010 for 9 days. The work included the removal of final tiles which were inaccessible to remote handling, the replacement of two glow discharge antennas and the installation of the first ILW components in the form of tungsten coated CFC magnetic pick up coil covers. Brackets were welded in position for the installation of the new LHCD antenna corner tiles.

In addition a significant manual inspection of the vessel condition was undertaken which revealed that a number of limiter earth straps, bellows protection plates, RF antenna tile fixings and diagnostic conduits required repair or modification. It was concluded that a third phase of manned entries would be required in order to prepare for and implement the required work.

Figure 3.4: *Manual work inside the JET Torus.*

C Remote Handling phase 3

Following the manual work remote handling recommenced with the start of significant ILW installation work. This included the mushroom, upper outer saddle coil and dump plate tiles in the roof of the vessel. Further LHCD antenna corner tile jig and survey work was also undertaken. In addition the Inner Wall Guard Limiter extension blocks were installed in readiness for welding during the next manual phase.

D Manual phase 3

With the short third RH phase completed the additional manual phase commenced on 27 September 2010. This phase of work contained some tasks displaced from the earlier but curtailed manual phase 2 but was largely associated with the additional tasks identified during the manual inspections. All the entries required welding support for the different installation or repair activities. This included the Mushroom shunt tile bosses, Inner Wall Guard Limiter (IWGL) extension blocks, KL12 mirror box mounting bracket and glow discharge electrode installations. Repairs were undertaken to a number of bellows protection plates to improve their security, replacement of RF antenna tile mounting inserts and the securing of IWGL mounting pins.

E Remote Handling phase 4

With all the repairs completed, RH phase 4 started on 8 October 2010 to install the bulk of the ILW and its new diagnostic system. The overall sequencing of the work had been modified to best match the anticipated availabilities of the ILW components. In particular the surveys undertaken in remote phase 2 showed that significant reworking of the ILW conduit system was required in order to accommodate unexpected variations in the vessel geometry and it was moved as late in the plan as possible for installation. Overall installation efficiency was reduced due to the fragmentation of packages of work either due to availability or installation issues requiring modification of components. Significant systems such as the divertor carriers were shipped to the machine in the ISO container transfer facility, however about 50% of the tile assemblies were 'posted' up into the Tile Carrier Transfer Facility for installation because the use of ISO containers would have been inefficient for transporting the small batches of tiles requiring remedial work.

The phase commenced with further diagnostic calibrations using the light source. This was followed by the installation of the Divertor tile carriers. These were protected under a floor system while other work continued above. Tiles in all areas were installed keeping clear the routes for the new conduits and any operation space need for the RH tooling. The bulk tungsten Load Bearing Septum Replacement Plate was successfully installed in the Divertor with each carrier assembly weighing around 60kg. The ILW conduits were installed in position during a number of sessions allowing the remote installation of the cable loom from the vacuum feed through location to a number of socket locations. Both TAE antennas were installed including the Octant 4 system which required modification to accommodate the new wall. At the end of the reporting period installation was continuing with occasional challenges being met to modify the new tiles to fit unexpected features in-vessel. The EP2 in-vessel installation was declared complete on 10 May when the Octant 5 RH boom was removed. The old wall had been removed and over 3500 new tile assemblies had been fitted along with a new diagnostic conduit system, cables and vacuum feed-throughs to monitor the tiles.

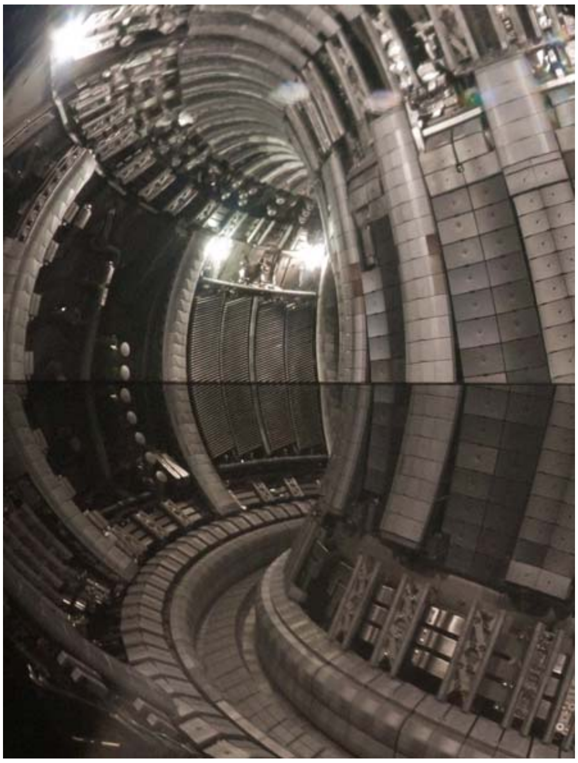
Figure 3.5: *ILW tiles on the inner wall during Remote Handling phase 4.*

3.4 PROJECT FOR PROTECTION OF THE ITER-LIKE WALL (PIW)

The PIW project was launched in 2009, with the scope agreed between EFDA and CCFE as the JET Operator in February 2010. One goal of the project is to provide additional real-time diagnostic data to the JET protection systems relating to surface and bulk temperature of Plasma Facing Components (PFCs) using simple cameras with image processing algorithms, as well as pyrometers. The aim is to cover 50% or more of the outer limiters (viewing both co- and counter clockwise), upper dump plates, and divertor tile 5, and maximise the coverage of other areas. This is achieved by integrating additional cameras on existing diagnostic imaging systems (wide angle and divertor views) as well as installing new imaging systems (two wide angle views using a novel in-vessel mirror box concept and one neutral beam shine through area view).

__Figure 3.6:__ One of the two mirror boxes was successfully installed as one of the last in-vessel activities. An image taken with a digital camera and telephoto lens is seen on the right.

Note that this image consists of two halves, top and bottom, with some objects observed twice. It is of the "left" of the torus in contrast to the traditional views taken by other diagnostics.



The project also provides software to detect and/or predict when surface temperature and/or energy limits have been exceeded and initiate the appropriate response (Vessel Thermal Map VTM and an upgrade to the Wall Load Limitation System WALLS). Another important aspect of the project is a change in the way the plasma is stopped. The old soft and fast stops will be changed to be less damaging to the PFCs. In response to wall overheating and some other events, a newly designed control system (Real Time Protection Sequencer RTPS) will take over the control of local managers (plasma shape, gas injection, and heating) to stop the discharges.

The new diagnostics and control systems are on track for commissioning with first plasma in 2011. The system is expected to be fully operational by the end of Restart.

3.5 UPRGRADING JET DATA-HANDLING

The JET raw data sizes have followed Moore's Law, roughly doubling in volume every two years, since the first pulse in 1983. The peak in October 2009 was 18GB per pulse. After the EP2 shutdown it is estimated that 60GB per pulse will be collected. At the normal pulse repetition rate of 25 pulses per day this means that 1.5TB per day is expected during the physics campaigns in 2011. One of the challenges throughout the lifetime of JET has been to maintain the pulse repetition rate and the data access times whilst the amount of data has continued to increase exponentially.

Figure 3.7: *Inside of the Old ST9310 Powderhorn.*

In late 2009 work began to plan an upgrade to replace the tape storage and data-handling systems of JET's mass-data warehouse. The tapes on the existing tape-storage system were only capable of storing 200GB raw data (400GB compressed), and it was cost effective with the increase in data to move to 1TB tapes (2TB compressed). The StorageTek 9310 (otherwise known as Powderhorn) tape library unit had been pronounced end-of-life from December 2010. Hence the decision was taken to upgrade the tape-library to a new unit and use the EP2 shutdown period to transfer the 3 copies of all the JET data tapes to the new format – this operation alone took nearly 10 months. The photos below show the old and new tape libraries.

Figure 3.8: *The New SL3000 Tape Library.*

The new SL3000 library currently holds 320 1TB tape cartridges, but can be expanded with bolt-on cabinets and 5TB tape drives.

The mass-data store computer, a Sun E4900, was purchased in October 2004 with 8 x 1.2GHz CPUs and 64GB memory. In the 12 months of operation prior to the EP2 shutdown, the E4900 had begun to suffer from being overloaded, and as the unit had been declared end-of-life in April 2009 it was decided to upgrade the system to provide more processing power, and particularly IO performance, to serve JET for at least the next 5 years. A key requirement of the upgrade was a replacement system that would run all the existing software out of the box. Hence a Sparc based system running Solaris was required. A Sun (now Oracle) M8000 with 3 processor boards each having 4 quad-core 2.88GHz CPUs and 128GB memory was purchased. The system has 4 x 10Gb and several 1Gb network interfaces spread over 2 I/O boards (plus a spare one) to allow for redundancy and resiliency. The system can be upgraded with a fourth processor board if required. Disk space attached to the M8000 for online storage of JET data has also been increased to 150TB.

The M8000 was installed in June 2010 and it went into production 4 months later in October. The old E4900 is not being scrapped, but will be used as a server for performing data backups from other JET computer systems.