3 JET Operations

3.1 OVERVIEW

Since January 2000, UKAEA 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 between UKAEA and the European Commission (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 UKAEA Culham (see Chapter 4), under the responsibility of the EFDA Associate Leader for JET.

The JET Restart in early 2008 followed the planned 2007 major shutdown, and marked the end of the installation phase of the remaining elements of the first JET Enhanced Performance programme (referred to as JET EP1). These included new and improved plasma diagnostic systems and a new high-power ITER-like antenna (ILA) to launch radio frequency (RF) waves to heat the JET plasma. In addition, the new High Frequency Pellet Injector that was installed in the 2007 shutdown was the first project to be delivered in the second set of major enhancements (denoted EP2, see section 4.7).

The EFDA experimental campaigns resumed as planned on 7 April 2008 following the Restart phase; although not all of the performance targets for the JET systems had been fully met, the level of performance was sufficient to meet the initial requirements of the experimental programme. Eight campaigns in all were conducted over a period of 46 operational weeks between 7 April 2008 and 7 April 2009. Excluding public and privilege holidays, the remaining working days were taken up with either planned maintenance (12.5 days) or unplanned intervention (6.5 days).

The ILA is aimed at proving that the key technical objectives for the ITER Ion Cyclotron Resonance Heating (ICRH) heating systems are feasible. The objectives include achieving a large increase in the power launched per unit antenna area, and demonstrating resilience of the antenna and the RF generators against large sudden perturbations in the load conditions due to Edge Localised Mode (ELM) instabilities in high performance (H-mode) plasma operation scenarios. Compared with the existing RF antennae in JET, the ITER-like design is much more demanding due to the compact arrangement needed to achieve the high power density and the complexity associated with the technology needed to achieve the ELM resilience. A large proportion of the eight campaigns executed in 2008/09 was dedicated to the commissioning of the ILA, and substantial progress has been made towards meeting its objectives, especially in demonstrating tolerance to ELMs.

Many key JET sub-systems, such as the power supplies, all the plasma heating and current-drive systems and in total more than 80 diagnostic systems, have operated at a very high level of performance and availability throughout 2008. For example the neutral beam heating system delivered its highest ever power level (>23 MW) to the JET plasma in 2008. Such high levels of performance and availability have allowed JET to make further significant progress towards meeting its primary goal of providing results vital to ITER's implementation and operation.

3.2 OPERATIONS OVERVIEW

JET operation is conducted in a shift pattern, with two eight-hour experimental sessions per operational day. Altogether, the operations during experimental campaigns in 2008/09 have been very successful from the point of view of the system availability and performance. A total of 5,378 technically successful pulses were produced in 409 achieved programme sessions (Table 3.1). It is notable that the number of JET pulses with neutral beam power above 20 MW on JET in 2008 was much higher than in any previous year and remarkable that 11 pulses above 23 MW were obtained in one single day of operation.

Campaigns	Planned sessions	Planned contingency sessions	Achieved programme sessions	Restart + lost sessions	Technically successful pulses	Programme pulses (useful for physics)
C20a	40	6	21	19 + 6	280	172
C20b	35	1	36	0 + 0	463	257
C21	53	5	55	0 + 3	671	427
C22	45	9	43	2 + 9	543	328
C23	44	6	49	0 + 1	628	400
C24	35	11	35	2 + 1	455	276
C25	41	19	50	0 + 10	698	480
C26	120	26	120	0 + 0	1,640	1,149
TOTAL	413	83	409	23 + 30	5,378	3,489

Table 3.1: *A breakdown of the number of pulses achieved in the experimental campaigns in 2008/09 including the number of Restart and lost sessions during Campaigns. Column 6 shows the number of technically successful pulses achieved and Column 7 shows how many of these pulses proved useful to the physics programme*

The programme was subject to some rearrangements in order to cope with a number of temporary system failures or outages. Many of the programme rearrangements were necessitated by short outages of the refrigerator supplying supercritical helium to the divertor cryopump. This was caused by instability in the mechanically controlled servo-valve system, which regulates helium flow through the compressor, due to ageing of this component (it is planned to replace the servo-valve arrangement with an electronically controlled system in the next Shutdown). Another frequent cause of programme rearrangements was temporary unavailability of RF power to feed the ILA because of faults in the RF generator or its power supply. These systems were especially critical given the high proportion of the programme dedicated to ILA commissioning.

The incorporation in the programme of up to 20% of the available sessions as contingency, which was higher than in earlier campaigns under EFDA, provided significant flexibility. This helped to allow experiments that could be executed without the temporarily unavailable systems to be brought forward. In this way, the use of machine time was maximised and the number of sessions that could not be exploited for the benefit of the programme was very small.

As mentioned above, not all of the JET systems had been commissioned to full performance by the end of the Restart phase on 4 April 2008. A total of 23 Restart sessions had to be programmed instead of scientific sessions in order to complete Restart milestones. The majority of those sessions (19) were executed during the first campaign C20a, mostly instead of the originally planned ILA sessions that had to be delayed due to the problems experienced with the HV power supply serving the RF generator connected to the ILA at the end of the Restart. The improved approach to programme flexibility, already mentioned, allowed these changes to be accommodated without serious impact.

A total of 11 planned maintenance days were incorporated into the campaigns. In addition five days (two at the beginning of C20 and three at the end of C25) on which experiments were planned had to be used for interventions on the machine, mostly to cope with technical problems due to water leaks on the Octant 8 neutral beam injector box attributable to ageing of components that are now being progressively replaced.

3.3 MAINTENANCE AND INTERVENTION ACTIVITIES

The eleven planned maintenance days were used to carry out a large number of essential routine and preventative maintenance activities in areas that are not accessible during plasma operation to reduce the risks of failure of systems essential to the programme. Maintenance periods usually consisted of a Friday plus weekend. However, some periods were extended in order to allow remedial work requiring more time or to accelerate progress in projects such as the Disruption Mitigation Valve and the High-Frequency Pellet Injector.

The maintenance day planned in August was extended to three days for the following reasons:

- about one month before this period, several Neutraliser Gas Valves on two neutral beam sources developed faulty status indicators, which had necessitated a reduction in the neutral beam power and therefore needed attention;
- the cooling water flow on several of the neutral beam accelerator grids was reversed. This was triggered by an endoscopic inspection of the internal cooling channels which showed that the erosion mechanism on the inlet side of the grid, which had been responsible for a water leak in one of the neutral beam boxes in March 2008, had caused significant erosion on these grids. The flow reversal was beneficial because, whilst the internal cooling circuits are symmetric with respect to the flow and return directions, some grids had been predominantly operated in one orientation over their >20 year life time and significantly more erosion had occurred at the inlet where turbulence is highest;

Figure 3.1: *A close up view of the cooling channel of a neutral injection accelerator grid using an endoscope down the inlet water connection. Note the erosion pit in the copper material near the centre of the image caused by in the turbulent cooling water close to the inlet*

- in order to increase the liquefaction efficiency of the helium refrigerator serving the neutral beam cryopump systems the refrigerator had to be warmed up during this maintenance period to release impurities.

The maintenance day planned for 13 October was extended to a maintenance period from 13 to 20 October, which covered the week of the 22nd IAEA Fusion Energy Conference. The main motivations for this extended maintenance period were:

- since the end of July it had not been possible to transfer any liquid helium from the central liquefaction and storage system to the Dewar vessel feeding the High Frequency Pellet Injector (HFPI); this led to significant delays in progressing the commissioning of the HFPI project. Investigations suggested that a blockage formed of water or air ice might have built up in one of the cryogenic valve boxes, affecting the valve regulating the liquid helium flow to the HFPI Dewar vessel. It was therefore decided to warm up and inspect the valve box during this maintenance period. This action successfully restored the supply of liquid helium to the HFPI Dewar and commissioning was subsequently resumed;
- Torus Hall access was necessary for installation and commissioning of components of the Disruption Mitigation Valve (DMV) system. This maintenance period provided an opportunity to significantly accelerate the DMV project;
- the upper guide bearing pads were inspected as part of a continuing investigation into occasional binding of the rotor of the poloidal field flywheel generator on initial start-up from rest at the start of day.

Figure 3.2: *A view of the rotor of one of the flywheel generators during original construction (left), in which the surface of the top guide bearing is visible. The photograph on the right, which was taken during the recent inspection and adjustment, clearly shows the top guide bearing pads*

Campaign C25 ended three days earlier than planned in December due to a further failure of an aged neutral injection accelerator grid which had not benefited from the reversal of the flow direction performed in August (see above) as it had been operated in both orientations during its lifetime and hence there was significant erosion on both the inlet and outlet sides of the grid. A second beam source with an aged accelerator grid was also exchanged as a precaution. This remedial work on the Octant 8 neutral beam injector box and the subsequent re-commissioning were completed in time to start campaign C26 as planned on 12 January. The replacement beam sources have new accelerator grids, with their accelerators rebuilt in a modified configuration in preparation for operation following completion of the EP2 Neutral Beam Enhancement (NBE, see Section 4.7.1B). All the beam sources are being progressively converted to NBE configuration, and at the end of campaign C26 a total of six NBE accelerators had been installed. In addition, the tetrode modulator-regulator tube of one of the

HV power supply modules of the Octant 4 neutral beam injector box was replaced at this time.

Figure 3.3: *A close up view of a failed neutral injection accelerator grid where the erosion (resulting in the brown region in the centre of the image) has generated in a small hole (visible as a white dot), causing a water leak into the vacuum of the Neutral Injection Box*

On 30 December failure of a small power supply serving the control system of the draining and refilling system that monitors the torus in-vessel component cooling circuit resulted in the system reverting to its fail-safe (drained) state. This in turn inhibited the supply of liquid nitrogen to the divertor cryopump, which consequently warmed up to ambient temperature releasing a small quantity of water vapour. This event followed the longest ever period (14 months) in JET's operating history with the cryopump continuously cold but during this period the leak rate of air into the vacuum vessel had been consistently low and there had been no significant ingress of water e.g. from the neutral injector boxes (the Octant 8 neutral beam rotary high vacuum valve seal is in good condition and hence the water contamination to the torus from the water leak on a PINI described above and the subsequent exchange of two PINIs was insignificant). Although unfortunate, the amount of water released was very small and consequently the effect on torus vacuum conditions was slight. There was no impact on the start of campaign C26 and useful information was obtained, such as quantifying the amount of water vapour and hydrocarbons regenerated from the cryopump after such a long period of operation with uninterrupted good vacuum conditions.

3.4 JET TECHNICAL DEVELOPMENTS AND PERFORMANCE HIGHLIGHTS

Several new JET records have been set by the additional heating systems during this period: The total combined power delivered to the plasma from neutral beams, RF and Lower Hybrid waves reached 33 MW in March. High plasma current operation at 4.3 MA was achieved together with total heating power of 27 MW in an ITER-relevant plasma configuration. Such high current, high power operation is essential to obtain values of key plasma parameters closer to those in ITER, and is a unique capability of JET in support of ITER. This is the highest plasma current achieved in JET operation under the EFDA arrangements.

3.4.1 ION CYCLOTRON RADIO FREQUENCY HEATING

Over 4 MW has been coupled from the full ITER-like array (ILA) in L-mode plasmas – this is a much higher value of coupled power per unit area of antenna than from the previous design installed on JET, which are known as the A2 antennae. New techniques for RF arc detection had to be implemented for the ILA, since in an ELM-resilient system it is necessary to be able to discriminate between faults due to arcing and perturbations arising from the changes of antenna coupling during ELMs. For a system with wide load tolerance as with the ILA, the conventional 'voltage standing wave ratio' measurement becomes insensitive to arcing and cannot be relied upon for protection purposes. Therefore, a new Scattering Matrix Arc Detection (SMAD) method has been developed and has been successfully commissioned on the ILA. This is based upon multiple RF probe measurements which undergo fast real-time processing using advanced algorithms to generate a trip signal when real arcs occur. With the SMAD operational, it became possible to progress towards the optimum settings of the ILA tuning elements for ELM tolerance.

The ILA described above is only one of three different ELM-tolerant ICRH systems that have all been brought into operation on JET over the past year. These systems are all designed to prevent RF power reflected back from the antenna during transients caused by ELMs from reaching the RF generators and causing trips. The second system uses two of the four antennae of the A2 design installed on JET in a new configuration called External Conjugate-T (ECT). More than 4 MW has been coupled to H-modes throughout ELMs using the ECT system. The third ELM-tolerant system relies on interconnection of the remaining pair of A2 antennae and RF generator via '3dB coupler' devices that direct any RF power reflected from the antennae to RF dumps rather than allowing it to return to the RF generators where it would cause trips. A total of >8 MW of RF heating power has been delivered to H-mode plasmas with ELMs using a combination of these three systems (ILA, ECT and 3dB couplers), which exceeds by about a factor of two the maximum power previously delivered to similar plasmas.

3.4.2 NEUTRAL BEAM HEATING

In February a new JET record of 192 MJ was achieved for the total energy injected by neutral beams in a single pulse. This is a measure of the ability of the neutral beam systems to deliver very high power for long pulse lengths approaching ten seconds, and the ample power and energy handling capability of the JET divertor.

Comparative performance statistics for the JET neutral beam systems over past years is shown in Figures 3.4-3.7. A particular feature of these statistics is that the average neutral beam power and pulse length in 2009 have reached new highs - the average injected beam energy per pulse in 2009 is 81.8 MJ compared with the best previous figure of 65.9 MJ in 2007. The magenta bars for the year 1997 in these figures is to highlight that the neutral beam system was not been operated normally at this time because of the constraints set by operating with D-T plasmas.

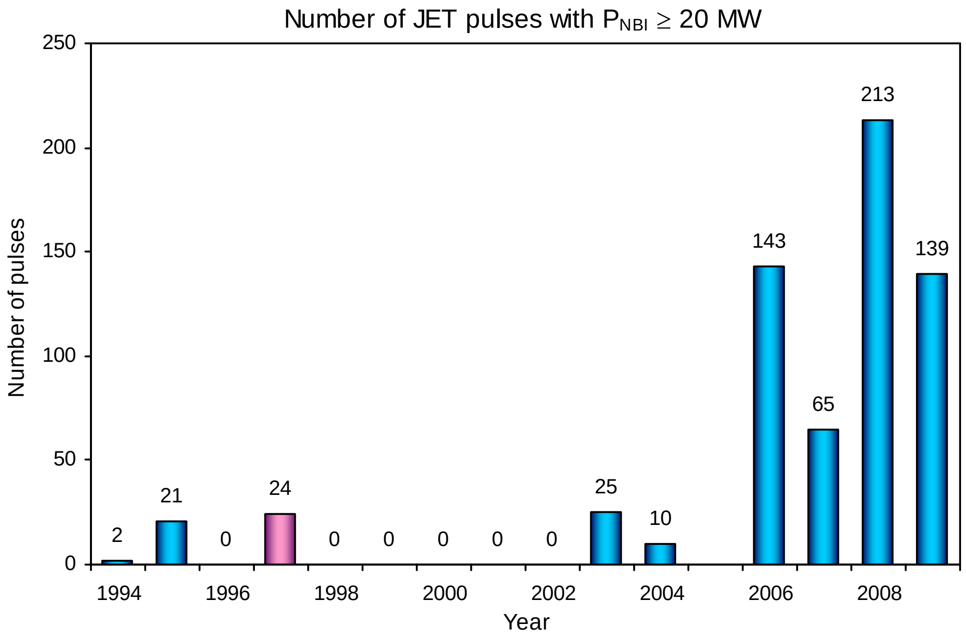

***Figure 3.4:** Comparison of number of JET pulses with neutral beam power greater than 20 MW by year from 1994-2009*

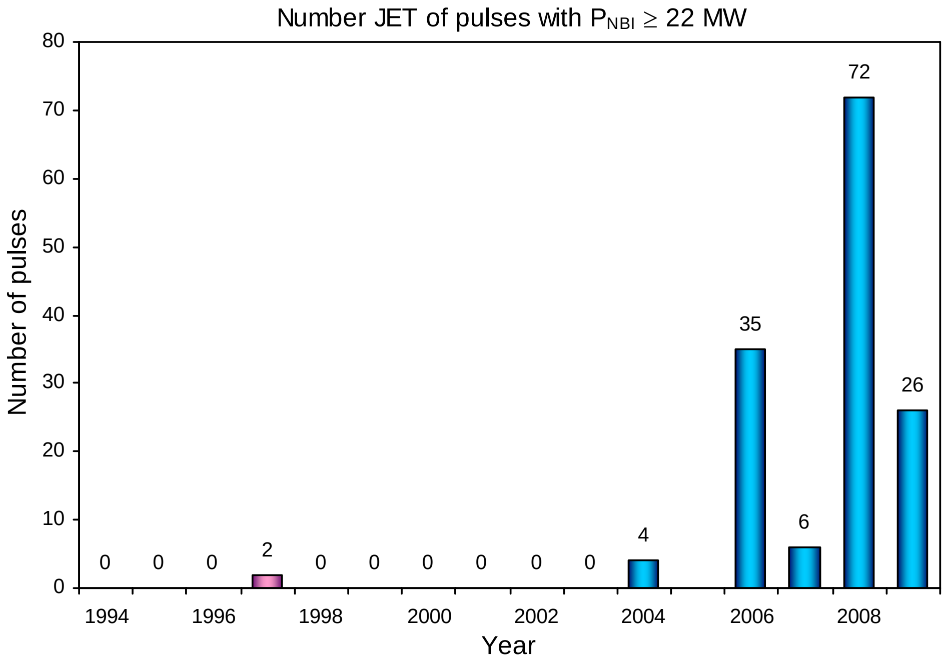

***Figure 3.5:** Comparison of number of JET pulses with neutral beam power > 22 MW by year from 1994-2009*

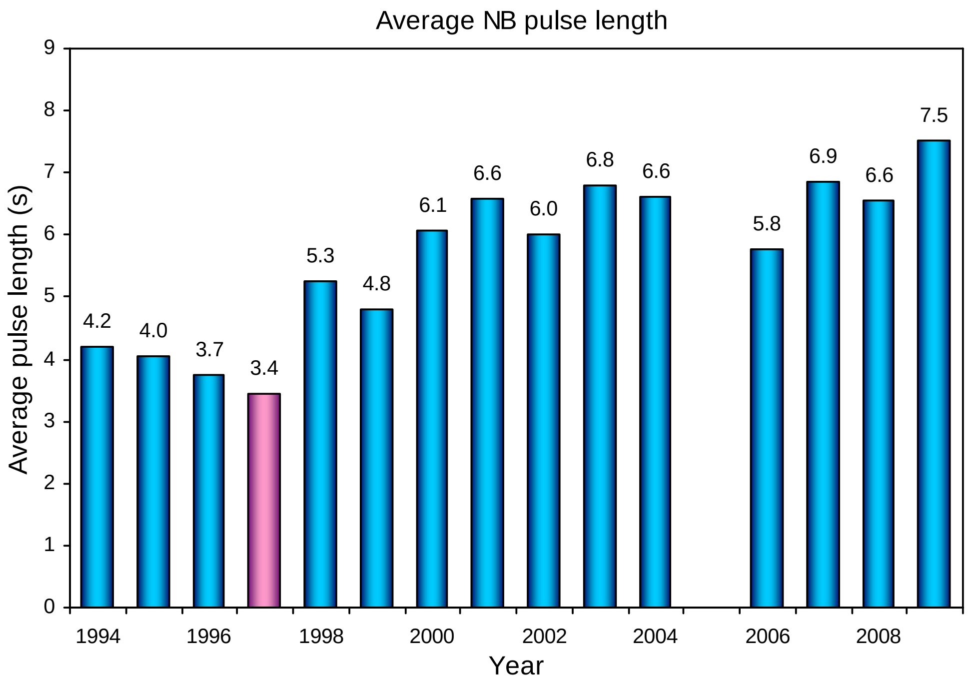

Figure 3.6: *Increasing trend of neutral beam average pulse length from 1994-2009*

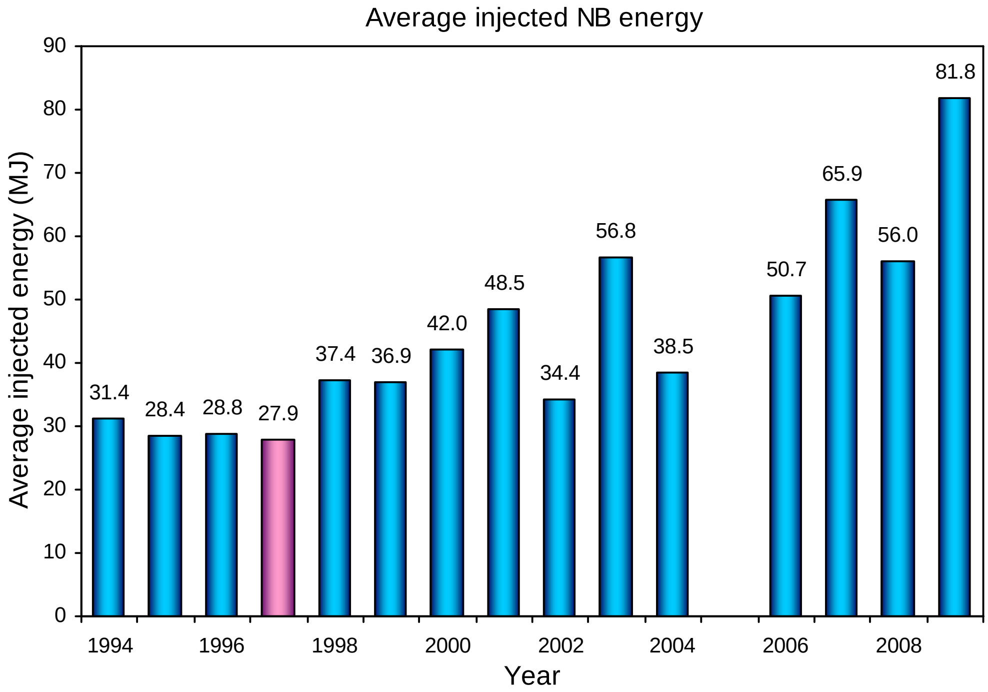

Figure 3.7: *Increasing trend of neutral beam injected energy per pulse*

3.4.3 LOWER HYBRID CURRENT DRIVE

Over the course of the 2008 campaigns the performance of the Lower Hybrid (LH) Current Drive system was progressively optimised, and a number of targets were achieved or exceeded for power coupled at different relative phasings of the launcher array. Significant time was devoted to launcher vacuum conditioning by controlled energisation of the launcher without plasma, e.g. in between JET pulses. For example, with 0^o phase shift between adjacent multi-junction units in the LH launcher a maximum power of 5.7 MW was achieved in 1 s pulses using 23 out of the 24 klystrons (one klystron was non-operational throughout the campaigns and will be replaced in the EP2 shutdown). With the same phasing 3 MW pulses of 6s duration were obtained with just 12 klystrons. Pulses of 5 s duration were achieved at a power level of 4 MW with 45^{o} phasing and 3.5 MW at 90^{o} phasing. For scenarios with good coupling, the maximum achievable power was in general set by the conditioning limit at which the onset of arcing occurs, rather than limitations of the klystron system, and these results represent the best LH performance obtained in campaigns under the EFDA arrangements.

3.4.4 DISRUPTION MITIGATION VALVE

The Disruption Mitigation Valve (DMV) provides JET with another ITER-relevant capability. Its function is to inject large quantities of gas into the plasma on a very rapid timescale in order to mitigate the effects of plasma 'disruptions'. Such disruptions can cause large mechanical and heat loads on the vacuum vessel and its internal components. The DMV will allow studies of how these adverse effects can be reduced – another key requirement for ITER. The technical commissioning of the DMV was successfully completed and work has begun as part of the JET experimental programme to explore its effectiveness in mitigating the effects of disruptions.

3.4.5 HIGH FREQUENCY PELLET INJECTOR

The new High Frequency Pellet Injector (HFPI) system is capable of injecting large hydrogen and deuterium ice pellets (35-70 mm^3) at frequencies up to 15Hz to fuel JET plasma. It can also produce small pellets (1-2 mm^3) at high frequencies up to 60 Hz. The purpose of injecting small pellets at such high repetition frequencies is to trigger ELMs at higher than their natural frequency. This reduces the magnitude of the heat pulse per ELM on plasma facing components. The availability of a reliable technique to achieve this is crucial for ITER. After successful off-line commissioning, deuterium pellets from the new system were injected for the first time into JET plasma during late shift on 18 June 2008. Unfortunately, due to the problems of liquid helium delivery to the HFPI mentioned earlier, further commissioning was held up until the autumn. Since then, limitations in pellet transmission through the flight tubes of the delivery system have been identified and modifications to some of the mechanical components and further optimisation of the new HFPI pellet extruder are in hand. The HFPI project included provision of new pellet diagnostic systems including photography stations and microwave cavities to measure pellet dimensions, mass and confirm integrity. Images of some 4mm and 1.2mm pellets delivered by the HFPI are shown in Figure 3.8.

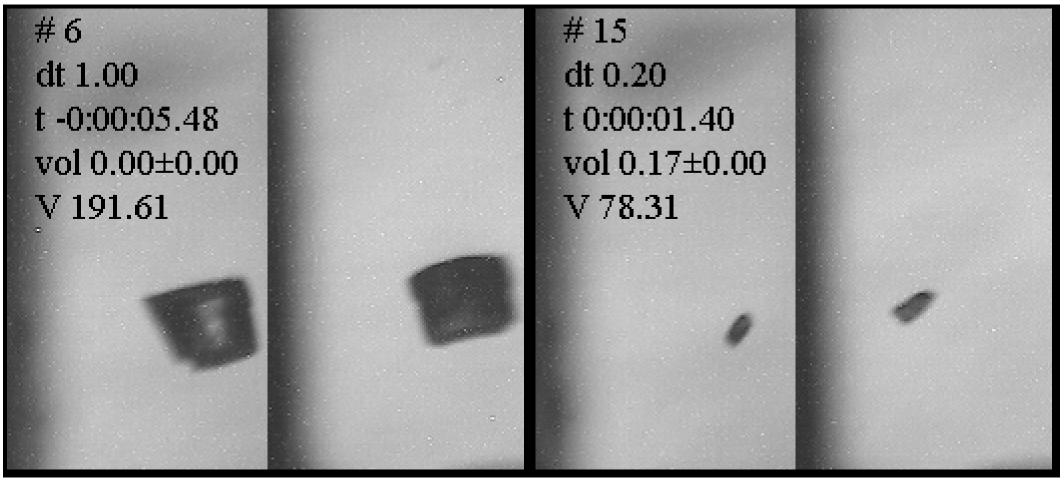

Figure 3.8: *Images of deuterium ice pellets from High Frequency Pellet Injector taken with the new in-flight photography system. The left hand pair of images shows of a 4mm size pellet, and the right hand pair of images a 1.2 mm pellet*

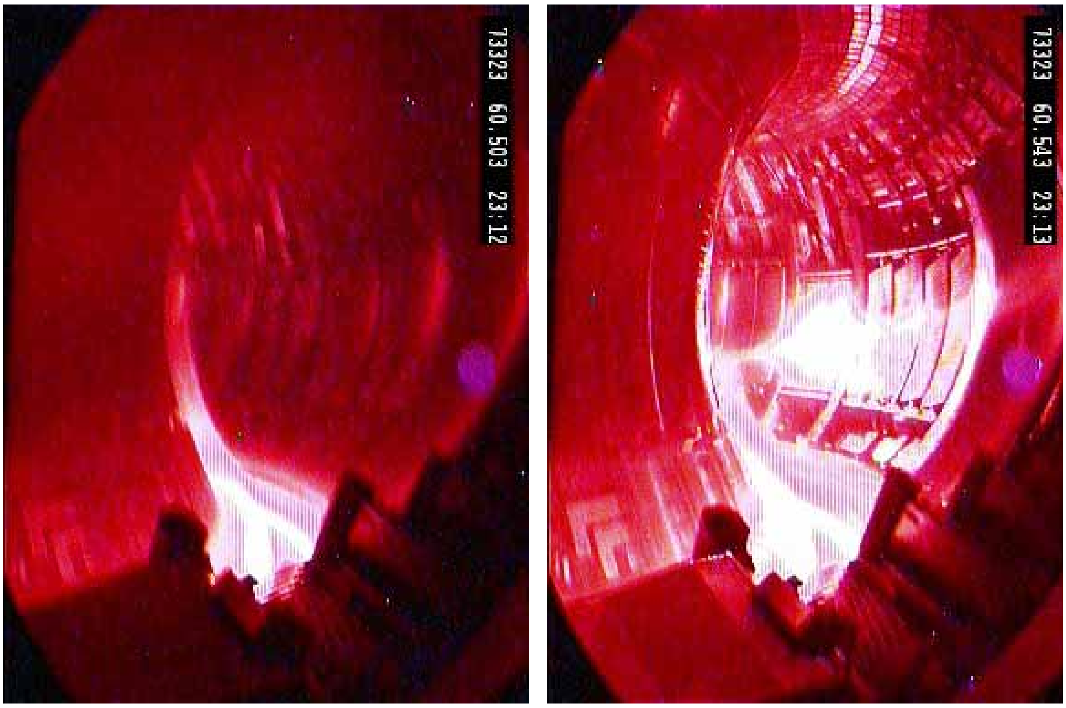

Figure 3.9: *View of the JET plasma just before (left) and during (right) injection of the first pellets from HFPI system on 18 June 2008 (JPN 73323)*

3.5 THE SECOND JET ENHANCEMENT PROGRAMME

The second JET enhancement programme (‘EP2’) comprises a total of 24 projects ranging from new and upgraded diagnostics, upgrades to the neutral beam heating system and the replacement of the plasma-facing tiles within the vacuum vessel. The major items needed for this programme are being procured via contracts placed by the European Commission with the management of the contracts being undertaken by the EFDA-JET Close Support Unit at Culham with technical management advice from the relevant project team. Normally the project activities, including project management, associated with the design, procurement and commissioning stages are the responsibility of one or more of the European Fusion Associations selected following a call for interest. UKAEA as Operator of JET is responsible for the installation of the equipment at JET and its subsequent operation following commissioning. The installation activities associated with all of these projects, plus other maintenance and modification activities that will be done at the same time, are being managed as part of the EP2 Shutdown project, which was set up during the year.

An exception to these arrangements is the ITER-like Wall project to replace the carbon fibre composite tiles that presently form the plasma-facing wall of JET with metal or metal coated tiles; in this case UKAEA as JET Operator also has overall responsibility for the project and performs the vast majority of the project tasks, though some of the project activities are the undertaken by other Fusion Associations.

3.5.1 ITER-LIKE WALL PROJECT

The leadership of and the core engineering and installation activities for the ITER-like Wall (ILW) project are performed by UKAEA as a part of the JET Operation Contract (JOC). The team includes secondees from other EURATOM Fusion Associations. Certain specialist technical tasks have been delegated to other European Fusion Associations (see below) but under the overall management of the JOC ILW team.

The objective of the ILW Project is 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, the ILW will provide a test bed for developing integrated scenarios with ITER relevant edge conditions and compatibility with the wall, thus speeding up the early phases of ITER.

The ILW project originally consisted of two main strands: (a) Engineering Design and Manufacture in which the design and procurement of all the new components required inside JET is performed; and (b) Installation Preparation in which all the preparatory work and procurements required to install the new wall are undertaken. Because most of the installation will be by remote handling the effort involved in tool design and manufacture, procedure preparation and training is a very substantial part of the overall job and also a major element of the Shutdown activities. Consequently the Installation Preparation activities are now managed as part of the EP2 Shutdown project.

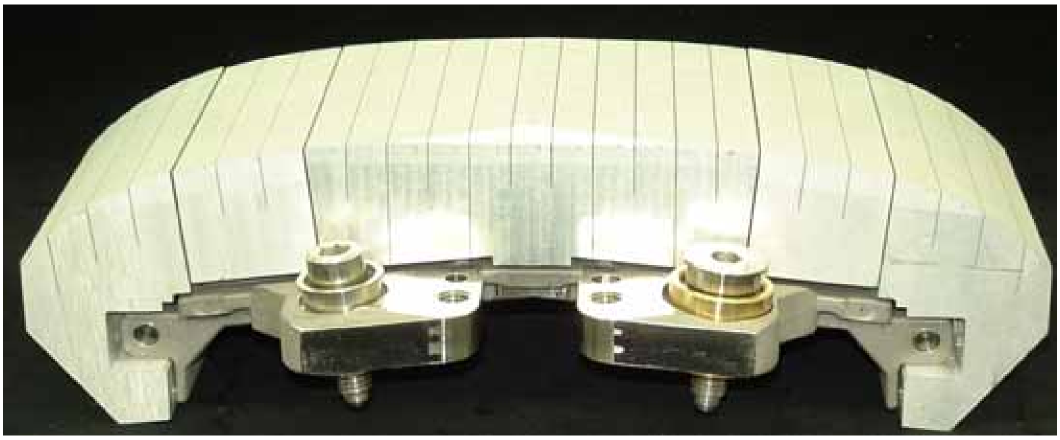

Figure 3.10: *Example of a manufacturing prototype of a poloidal limiter tile after assembly at JET*

Different technical solutions have been adopted for various areas of the wall:

- tiles formed of castellated slices of solid Be in inconel carriers for the main poloidal limiters;

- Be coated inconel tiles to cover the recessed areas of the vacuum vessel wall except in areas subject to the power loading from neutral heating beams ‘shining through’ the plasma where W coated carbon fibre composite (CFC) tiles are used;
- W coated CFC tiles in the divertor with the option of tiles made from solid W slices on carriers to replace the central ring of tiles on the floor of the divertor (‘the septum replacement plate’). The procurement of the items required and assembly of the tiles using solid tungsten for the septum replacement plate is being performed by one of the German Fusion Associations, FZ Jülich.

By April 2009, 7 out of the 19 European Commission procurement contracts were completed and the remainder were in the manufacturing phase. All of the significant aspects of the technical development programme for these contracts were completed before the start of the year except for the prototyping of the W coating of the CFC tiles, particularly to ensure that the coatings could cope with the required high power densities.

Apart from those associated with the W coating of the CFC, there have not been any significant technical issues with these procurement contracts, and deliveries of components has commenced. A database with a bar code based interface (BATS) has been developed and is being used to manage storage and assembly of the 86,000 parts required for the new wall. Over 26,000 parts have been delivered inspected and accepted into BATS so far. The next critical phase of the manufacturing will be loose assembly of tile carrier components at JET followed by final assembly and inspection on jigs at the three beryllium tile manufacturing companies.

Previous R&D activities for the ILW showed that the thick (200 μm) W coating applied by Vacuum Plasma Spraying (VPS) that was planned to be used for the outer areas of the divertor subject to net erosion could not be used because of problems due to internal delamination within the coating following testing at high power density. A re-evaluation of the lifetime of W coating based on results obtained from samples removed from JET in the previous Shutdown concluded that a coating thickness of the order of 20-30 μm would be sufficient even in the regions of the divertor subject to erosion.

The most straightforward way of producing such coatings was thought to be to use a double thickness of the ~ 15 μm coating applied by Physical Vapour Deposition that was used as a base layer for the VPS coating. Although the initial results of high power testing of such coating were successful, it was subsequently found that there were two different problems. Firstly, the surface of the coatings discoloured following exposure to air due to transport to the tile surface, and subsequent oxidisation, of the rhenium that was used as a ‘primer’ layer on the CFC before the tungsten layer was applied. Secondly, there was poor adhesion of the coating to some of the tiles that appeared to depend on differences in the orientation of the fibres at the surface of the CFC which is a function of the overall fibre orientation and the surface profile.

Following a further assessment of the options available it was decided that the W coating of the CFC divertor tiles should be done using the magnetron sputtering process that had been developed by the Romanian Fusion Association to coat the CFC tiles forming the neutral beam ‘shine through’ protection, which has proved to provide coatings of good adherence regardless of the orientation of the fibres at the surface of the CFC tiles.

Figure 3.11: *View into the vacuum chamber of the tungsten coating facility at MEdC (the Romanian Fusion Association)*

Figure 3.12: *Tungsten coated JET divertor tiles during series production at MEdC*

3.6 EP2 SHUTDOWN

The installation of the ILW will be the most significant shutdown and enhancement of the JET machine since the installation of the Divertor assembly in 1992-94. The shutdown will comprise four Remote Handling (RH) and three manual in-vessel phases. Although the in-vessel ILW activities form the major part of the work, there are also a significant range of ex-vessel tasks including the installation of the remaining EP2 diagnostic systems and diagnostic enhancements, and the work associated with the neutral beam enhancement project.

3.6.1 STRATEGY

The importance of the results from JET operations with the ILW means that there is pressure to complete the Shutdown as soon as possible. There are several factors that influence the optimum strategy, primarily when the various components required will be delivered, how soon the preparations for the Remote Handling installation will be completed and how intensive the Shutdown activities can realistically be. The following strategy has been agreed between EFDA and UKAEA for the planning of the Shutdown:

- the starting date of the in-vessel operations should be as early as RH preparation activities allow;
- the full planned scope of enhancement and Shutdown work should be maintained, including the necessary in-vessel diagnostic calibration tasks;
- the intensity of the RH activities should be as high as practicable and with a firm target of achieving pump-down of the vacuum vessel by end of 2010.

3.6.2 PLANNING

In addition to the above strategy, the following assumptions have been adopted as the basis for the planning:

- the ex-vessel preparation work will commence one month before the RH access facilities are ready to be installed after the RH mock-up activities and the necessary maintenance of the RH equipment has been completed. This allows early removal of some diagnostics and the Central Support Columns from the Octant 4 and 8 Neutral Injection Boxes, which are being moved to the Assembly Hall so that they can be modified as part of the Neutral Beam Enhancement project. Completing this work before the installation of the RH access facilities reduces the risk that critical path activities will be delayed due to conflicting demands for critical resources, particularly the main 150T crane that serves the Torus and Assembly Halls;
- a compressed in-vessel work plan which relies on seven day/week working on a two-shift pattern that will allow 17 hours of RH activities to be performed within an overall working day of 19.5 hours duration. During all of the Remote Handling phases the only non-working days will be statutory holidays and any Sundays associated with them;
- increased effort will be deployed on ex-vessel tasks where required to ensure that they do not end up being on the critical path as a result of the duration of the in-vessel tasks being shortened by the intensity of the RH operations.

Optimising the Shutdown plan on the above basis has resulted in a start date of early October 2009 for the ex-vessel tasks, installation of the RH equipment in early November 2009 and pump-down of the vacuum vessel following the end of the in-vessel activities at the end of December 2010.

The proposed compressed Shutdown programme will place severe demands on individuals in order to maintain the consistent, intense work pattern needed to meet the planned schedule over the full period of the Shutdown. This will require a bigger RH operations team than in previous Shutdowns. Adequate deputy and back up personnel are being sought for all key posts to allow proper leave and rest periods to be taken and to provide flexibility in the case of sickness or other unexpected absences.

3.6.3 PREPARATIONS FOR THE SHUTDOWN

A Remote Handling tools and procedures

The Installation Preparation strand which provides all the RH (and manual) tools, installation procedures, mock-up components and trials has advanced considerably during the year. Over 70% of the design work and 50% of the installation procedures were completed. In addition, 27 contracts were placed (~30% of total required). Over 277 new tools are required some of which are simple but others quite complex such as the remotely installed and operated saw whose design is shown in Figure 3.13.

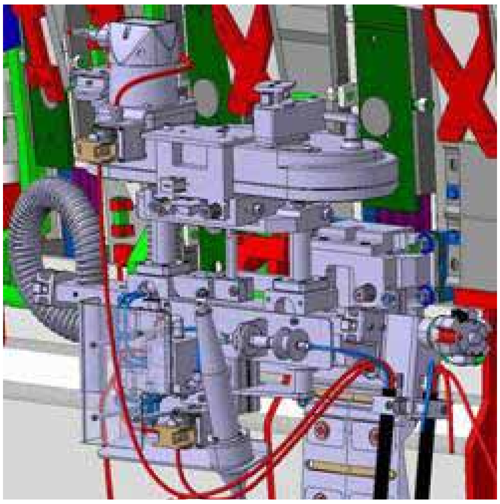

Figure 3.13: *CAD model of the remotely mounted and operated saw to be used to clear the path for a new diagnostic cable conduit*

In support of the shutdown UKAEA as the JET Operator is implementing a range of significant infrastructure upgrades these include:

B Lengthening of the second articulated Remote Handling boom

In previous shutdowns, all in-vessel installation and removal operations by RH were carried out with a long boom on which a Mascot manipulator is mounted. A second, shorter boom was used to transfer the components needed into the torus. Due to the time required to move the long boom to collect individual components from the short boom, this system would be too slow to meet the schedule of the EP2 Shutdown. For this reason the second RH boom has been extended by procuring extra links to allow a complete set of tiles and tools to be delivered in ‘task modules’ to the vicinity of work anywhere in the vessel. The new boom was assembled and commissioned during the year and ‘mock-up’ trials which simulate the real working environment are started. Figure 3.14 shows the lengthened second boom during its commissioning trials; the new task module which will be used to transport tiles and tooling into the vessel is mounted on the end of the boom in the foreground.

Figure 3.14: *The new lengthened Remote Handling boom during commissioning*

C Beryllium inspection facility

A dedicated area has been constructed within the Assembly Hall to allow the assembly of ILW tiles in controlled conditions including the ability to work on Beryllium components if required.

Figure 3.15: *Inspection of the carriers for the Upper Dump Plate tiles in the Beryllium Inspection Facility*

D Beryllium machining facility

Some of the inner wall of the JET vacuum vessel has been hidden behind tiles for many years and consequently there are some uncertainties regarding the accuracy of some of the CAD models that have been used to design the ILW tiles. Hence the need for some minor modifications of the rear faces of the new tiles cannot be excluded. A new controlled facility has been established to allow any necessary machining and subsequent inspection of beryllium tiles to be performed rapidly on site. This includes appropriate controlled ventilation to deal with any beryllium dust that the machining will generate.