5 MAST

5.1 MAST OPERATIONS

5.1.1 INTRODUCTION

The Mega Amp Spherical Tokamak (MAST) began operation in 2000. The most recent physics campaign ended in September 2013 and a major upgrade of the device is now underway (Section 5.2), the first stage of which will be completed by 2015. MAST is designed to study high temperature, low aspect ratio, highly elongated ($\kappa > 2$) plasmas (Figure 5.1).

![Figure 5.1: MAST](image)

The low aspect ratio (the ratio of major radius $R$, to minor radius $a$) of spherical tokamaks enables, simultaneously, high plasma stability and good energy confinement. The high natural plasma elongation and strong plasma shaping provide a large plasma current carrying capability, allowing high performance operation at relatively low toroidal magnetic fields. The mission of MAST is:

- to explore the long term potential of the spherical tokamak as a fusion component test facility (CTF) and/or ST power plant;
- to advance key tokamak physics for optimal exploitation of ITER and DEMO design optimization;
- to provide unique insight into underlying tokamak physics.

Since 2007, the MAST programme has been guided by an international Programme Advisory Committee (PAC).

Many U.K. universities and international collaborators are involved in the MAST programme and the most recent MAST experimental campaign was characterised by particularly strong collaborator
involvement, mostly notably in the development of a number of advanced measuring instruments (Section 5.1.4). Collaborators are also strongly involved in the development of other plant such as heating and fuelling systems, execution and analysis of experiments, theory and numerical modelling etc. Indeed, experiments are often led by international collaborators, university researchers and/or PhD students. The MAST control room is equipped with remote participation facilities. There is strong coupling between theoretical and experimental activities and a wide range of sophisticated codes are available for planning and interpretation of experiments.

5.1.2 MAST TECHNICAL PARAMETERS

MAST and NSTX (a comparable device at Princeton Plasma Physics Laboratory, U.S.A.) are the world’s leading spherical tokamaks. Their poloidal cross-section and current carrying capability (> 1MA) are similar to those of major conventional tokamaks such as ASDEX Upgrade in Germany and DIII-D in the U.S.A. The MAST load assembly comprises a large cylindrical vacuum vessel (height 4.4m, diameter 4m) with a removable centre column and internal poloidal field coils (Figure 5.2).

![Figure 5.2: MAST cross-section](image)

This is a very adaptable arrangement that allows considerable flexibility over plasma and divertor configurations, enables enhancements to be more easily implemented, offers outstanding diagnostic access and plasma imaging opportunities, and allows innovative plasma start-up techniques to be deployed. High purity plasma conditions are ensured by high temperature baking, periodic boronisation and inter-shot helium glow discharge cleaning.
MAST is equipped with two long pulse, high power, neutral beam injectors (NBI) and a high power 28GHz microwave system in the electron cyclotron frequency range (collaboration with Oak Ridge National Laboratory, U.S.A), for plasma start-up studies. MAST benefits from a digital plasma control system and a range of plasma fuelling techniques, including a cryogenic pellet injector and a controllable high-field-side gas fuelling system. In addition, a fast gas valve is available for disruption mitigation studies (collaboration with FZJ Germany). There are external coils for error field compensation and internal coil arrays for both control of edge localised modes (ELMs) and controlled excitation of Toroidal Alfvén Eigenmode (TAE) instabilities. A divertor science facility enables the capability to conduct controlled investigations of plasma-material interactions, measure divertor parameters and study impurity transport using a spark gap impurity injector (with Dublin City University).

MAST is particularly renowned for its comprehensive array of advanced, and in some cases world leading, diagnostics including: very high temporal and spatial resolution (~ ion Larmor radius ~1cm) kinetic diagnostics (Thomson scattering, charge exchange recombination spectroscopy, Motional Stark Effect (MSE) etc.); 2D beam emission spectroscopy (collaboration with RMKI Hungary); a fast ion deuterium-alpha (FIDA) system; a collimated neutron detector array (collaboration with Uppsala University, Sweden); a synthetic aperture microwave imaging system (collaboration with the universities of York and Durham); a fast edge Doppler spectroscopy system; visible and infra-red imaging diagnostics; magnetic measurements up to 5MHz; retarding field energy analyzers (collaboration with Liverpool University) and a wide range of electrical probes. New diagnostics in 2013 included a Coherence Imaging (CI) system for measuring plasma flows (developed with Durham University and the Australian National University), a charged fusion products detector (developed by Florida International University in collaboration with PPPL), a Doppler back-scattering system for turbulence measurements (developed by UCLA), a ‘ball-pen’ probe (developed in collaboration with the University of York) and a pellet imaging system provided by NIFS, Japan. All of these systems worked beautifully and results from a number of them will feature prominently at the High Temperature Plasma Diagnostics conference in 2014 where there will be three invited talks on the CI system, the DBS system and the charged fusion products detector respectively.

5.1.3 Engineering Activities & Operating Schedule

Late availability of the 400kV supply to site and earth faults on the transformer core of the MFPS power supply (used for radial plasma position control), and in the toroidal field (TF) circuit, delayed the start of the 2013 campaign. A major survey of the MAST power supplies revealed a number of areas of the plant requiring immediate attention and longer term remedial work to be carried out in parallel with the upgrade project. Although most immediate power supply problems
were addressed, two residual problems remained throughout the campaign:

- an automatic tap changer on the regulating transformer of the TF power supply failed so manual adjustment was necessary when changing the TF value;

- the P3 charging circuit (used during plasma start-up) was limited to about 3.5kV (limiting the scope of planned magnetic reconnection experiments).

In view of the late start to the campaign a higher operational duty cycle was implemented and the campaign was extended by one month to recover some of the lost time. We also optimised run-time by interleaving experimental programmes and running multiple programmes on each day. As a result the 2013 campaign was highly successful with good progress made in all physics programme areas. Good progress was also made on tests in support of MAST Upgrade – e.g. vertical plasma position controller using Field Programmable Gate Arrays (FPGAs), neutral beam notching & development of a real time NBI power control system.

5.1.4 NEW TECHNICAL DEVELOPMENTS

The 2013 experimental campaign benefited from a number of new technical developments.

A Neutral Beam Injection (NBI) Systems

MAST is equipped with two neutral beam injectors. For the 2013 experimental campaign, the SW PINI source was reconfigured from a supercusp magnet configuration to a so-called ‘chequerboard’ configuration. The chequerboard source has a very different species mix from the supercusp having a significantly lower full energy species fraction (D\(^+\)) and significantly higher half (D\(_2\)\(^+\)) and third (D\(_3\)\(^+\)) fractions. At the same time the S PINI ion source remained unchanged in supercusp configuration in order to allow direct comparisons between different ion sources during the MAST physics campaign. Experimental measurements confirmed calculations of the species mix in the chequerboard configuration. The physics programme in 2013 benefited from a new beam power ‘notching’ system which was deployed, for example, in experiments to study momentum transport and in studies of the plasma current profile evolution. Results from tests of the beam notching system are being used to optimise the design of a more sophisticated real-time neutral beam power control system for MAST Upgrade. Tests were also carried out on the neutral beam source gettering systems in 2013 in order to identify developments necessary to ensure efficient, reliable and reproducible long pulse operation of the sources in MAST Upgrade.

B Coherence Imaging
A coherence imaging flow diagnostic has recently been developed for MAST by the University of Durham and the Australian National University and operated throughout the last experimental campaign (Figure 5.3). Coherence imaging (CI) is a recently developed technique which can be used to perform time resolved 2D imaging of impurity flows using visible emission line Doppler shifts. It is based on using an imaging interferometer to measure the spectral coherence of an emission line at a single fixed interferometer delay. This technique can provide orders of magnitude more spatial information than is typically possible with traditional dispersive Doppler spectroscopy, while using simple and robust optical designs; this makes it particularly well suited to studying spatially complex scrape-off layer (SOL) and divertor flow patterns. During the last campaign the new diagnostic has performed flow imaging of intrinsic C⁺, C²⁺ and He⁺ impurities in both the main chamber SOL and divertor. The resulting images have revealed a wealth of detailed impurity flow patterns, with typical spatial scale lengths of approximately 2 – 5cm radially and >15cm poloidally. Frame rates up to 1 kHz and spatial resolution of a few mm have been achieved. Accurate impurity flow measurements in the SOL and divertor regions of magnetic confinement fusion devices are essential for benchmarking sophisticated transport models and developing our understanding of SOL and divertor physics. This is very important for predicting the performance and lifetime of plasma facing components in ITER and in the development of novel divertor geometries in tokamaks and stellarators.

Figure 5.3: Left: Photograph of the MAST CI diagnostic in the lab showing its construction, with a 30cm ruler for scale. Right: Example data image, in the vicinity of the centre column, showing C²⁺ emission and flows towards (blue) and away from (yellow) the camera.

C  Doppler Back-scattering

During the 2013 campaign, Doppler Backscattering (DBS) was successfully implemented at MAST through a collaboration between CCFE and the University of California, Los Angeles (UCLA). DBS is a well-established and versatile diagnostic technique for the measurement of intermediate-scale ($k_\theta \rho_\theta \sim 1$) density fluctuations and flows in magnetically confined fusion experiments. This was the
first time DBS has been implemented for core measurements in a spherical tokamak and the first installation using two independent axes for beam steering. Figure 5.4 shows the quasi-optical Gaussian beam system used to combine two 8-channel DBS systems via a polarizer, and mirrors used to steer the beam. The 2D beam steering allowed optimization of the scattering alignment for particular plasma conditions, enabling high-k measurements, including $k_{\theta}$ over 20 cm$^{-1}$ ($k_{\theta} \rho_s \sim 10$), and enabled local measurements over a large radial range, $0.3 < r/a < 1.0$. Results included the first observations of intrinsic rotation reversals in a spherical tokamak, measurements of magnetic field fluctuations through a novel reconfiguration of the quasi-optical system for cross-polarization scattering, and measurements of intermediate and high-k density fluctuations over a broad range of plasma conditions, to complement low-k measurements with Beam Emission Spectroscopy.

Figure 5.4: Computer rendering of quasi-optical Gaussian beam system used for Doppler Backscattering at MAST.

D  Charged Fusion Products detector

A compact, four-channel system of collimated and individually oriented surface barrier detectors was designed and constructed to detect charged fusion products emitted from deuterium-deuterium (DD) fusion reactions in MAST (Figure 5.5). The prototype instrument was developed at Florida International University in collaboration with the Princeton Plasma Physics Laboratory. Each detector probes a different region of the plasma, detecting charged fusion products emitted along curved trajectories. This diagnostic takes advantage of the unconfined nature of charged products, 3 MeV protons and 1
MeV tritons, from DD fusion reactions during the neutral beam injection (NBI). The large gyro radii of these charged products, particularly the 3 MeV protons, allow the ions to leave the plasma without completing a full gyro orbit. The diagnostic was installed and operated at MAST in 2013. It was used, together with the neutron camera and the fast ion deuterium alpha (FIDA) spectrometer, in dedicated fast particle physics experiments involving both the classical behaviour of beams in the plasma and the effect of plasma instabilities on fast ions. Analysis of the recorded detector signals made it possible to determine particle production rates, from DD fusion reactions, at different locations inside of the plasma and their evolution in time. A time resolution of down to one millisecond enables the observation of effects of different plasma instabilities. Charged fusion product diagnostics provide an opportunity to determine evolving fusion reaction rate profiles in spherical tokamaks with relatively compact detectors.

Figure 5.5: Prototype charged fusion products detector: cross-section of the detector/collimator design (left); raw data showing ~100ns pulses produced by individual 3MeV protons & 1MeV tritons (right)

### E Ball-pen Probe

The plasma potential plays an important role in the confinement at the edge of a tokamak. The steady state electric field, determined from the gradient of the plasma potential, drives rotation shear near the separatrix whilst fluctuations in the E-field drive local ejections of plasma as filaments. Conventional Langmuir probes measure the floating potential (Vf), which is strongly affected by the electron temperature. To attempt to make a direct measure of the plasma potential a ball pen probe (BPP) has been designed, built and operated during the experimental campaign on MAST in 2013 (Figure 5.6)
Figure 5.6: Photo of the BPP prior to operation in 2013, accompanied by a schematic of the probe face. Dimensions are in mm. BPP1-BPP3 are ball pen probe pins in floating mode, Vf1 and Vf2 are Langmuir probes in floating mode and P1 in Isat mode. G1-G4 lie flat to the body during operation and measure Isat. The probe is a modification of the Gundestropp probe previously operated on MAST.

The BPP was found to reduce the effect of electron temperature on the potential measurement by a factor ~5, confirmed by a comparison with the TS system (Figure 5.7).

Figure 5.7: Comparison of the electron temperature measurement from the Thomson scattering system with the BPP. Te can be derived from BPP data by taking the difference between the BPP potential and the floating potential.

It was used to make successful measurements of the potential, electron temperature and radial E-field profile in the edge of MAST. Fluctuations in the potential can be measured in the edge and near scrape-off layer (SOL) region and have been used to identify potential Geodesic Acoustic Mode (GAM) oscillations. In the far SOL the probe impedance increases rapidly and a filtering of higher frequency fluctuations is observed. This can be rectified in the future through addition of a high load impedance in the amplifier circuitry.
F Embedded control and data acquisition using FPGAs

During the MAST 2013 campaign Field Programmable Gate Arrays (FPGAs) were successfully deployed in the plasma vertical position control system and for real time streaming of toroidal field system voltage data. A Durham University student successfully completed a PhD on data acquisition and control, focusing on the use of FPGAs for the high performance data acquisition of the Synthetic Aperture Microwave Imaging (SAMI) diagnostic (developed in collaboration with the University of York) and a Toroidal Alfvén Eigenmode (TAE) excitation and detection system. A new PhD student from Durham University has started in 2013 to continue the development of the SAMI diagnostic and to develop an upgraded CO₂ interferometer phase measurement system to provide a more capable line integrated electron density diagnostic for MAST Upgrade. High speed analogue to digital converters provide a data stream that is processed in real-time to give electron density measurements with a latency of about 1 microsecond (using techniques similar to those used in modern 'software defined radios'). A further Durham PhD student will be arriving in 2014 to develop FPGA based bolometer electronics which will provide the excitation waveform for the bolometer head bridge and perform the phase sensitive detection on the imbalance signal giving the plasma radiated power. These signals will also be available in real time allowing for the real time tracking of the plasma distribution in the MAST Upgrade super-X divertor in the future. With many systems now able to output real time values (either via UDP over Ethernet or via multi-gigabit Aurora links) a light weight data unit has been proposed which will allow passing of data between measuring devices and clients (such as feedback controllers) with latencies of order 1µs using Aurora over optical fibre links. This data network will also be important for applications such as the MAST Upgrade real time protection (RTP) system which will intervene for example in the case of coil current combinations causing excessive stress levels on supporting structures, flash overs or other fault conditions. An FPGA based fault logging system will also monitor the precise time of plant status changes (e.g. interlock status) in order to diagnose the event sequence of plant failures. The many new FPGA devices will require a robust and standardised control interface either using Modbus and/or HTTP (to allow monitoring/control via a remote web browser). This is made possible using processors running Linux allowing servers to be implemented directly on the FPGAs. The recent development of the Zynq architecture from Xilinx (ARM embedded with a high performance FPGA) allows very powerful systems to be developed with relative ease. A graduate engineer will be starting full time in 2014 to assist in the realisation of all these new systems.
5.2 MAST UPGRADE PROJECT

5.2.1 Overall

2013 was a critical year for the MAST Upgrade project as many of the outstanding designs were closed out, most of the key hardware contracts awarded and the construction of the new facility began. On all these fronts, good progress can be reported, with total value of contracts committed now exceeding 70% of the estimated £17M total and the strip-out and early rebuild activities broadly on schedule.

The anticipated completion date of April 2015 is still achievable although this has (and will continue to) require a significant increase in the total amount of manpower allocated to the project to deliver this. To offset this cost increase, most of the outstanding non-essential, non-upgraded-related hardware that was previously included in scope has been removed.

Sections 5.2.2 to 5.2.6 summarise the progress made in the key project work streams. To assist with the understanding of the progress reported, a cross-section of the core of the MAST-U machine is provided in Fig 5.8 with labels identifying some of critical sub-systems that make up the Load Assembly.
5.2.2 Physics

During this period, the MAST-U Physics work stream has continued to assist in the specifications of critical MAST-U components, particularly in the areas of Load Assembly, Diagnostics and Power supplies.

The plasma vertical position system has evolved considerably since it was presented at the 2010 PAC. The coils themselves are now of a more conventional design, albeit with a thin jacket, the ‘passive ring’ has been removed and the coil moved towards its location. These changes have been partly to accommodate nearby structural metalwork, partly to minimise the risk of failure due to electrical breakdown, and partly to make the manufacturing process less risky. The result is a design which is less agile than originally conceived but this is largely compensated for by a reduction in the instability growth rate and the higher power available from the new RFA. The new design is also less demanding in terms of power supply current than some intermediate designs were, with the result that the power supply has been de-rated somewhat but retains a considerable safety margin.
The sensitivity of magnetic sensor locations on the ability to control the plasma has been studied as well as a detailed assessment and specification of heat treatment of components in respect of their magnetic response properties. A significant success has been in the specification of testing and subsequent analysis of data from a measuring rig that the coil supplier has developed, in cooperation with the load assembly team, to determine the detailed magnetic field distribution around the coils. Figure 5.10 shows a representation of the physics model from which the magnetic field is calculated, together with the 432 locations at which comparison is made between calculation and measurement. The data quality is excellent, with field measured down to around a thousandth of the earth’s magnetic field.

In addition, the project physicists have begun to work with the newly appointed Restart Manager to agree the initial experimental programme and the resultant commissioning priority for the new systems. This is vital to allow the project to correctly phase the installation of the numerous MAST-U subsystems.
5.2.3 Load Assembly

The Load Assembly is effectively the core of the MAST-U machine and encompasses the airside coil set, primary vacuum boundary and all load bearing structures within it (such as coils, armour and support structures).

**Divertor**

Divertor coils

5 out of the 14 new divertor coils have been completed, with many of the remaining 9 in their final phases of manufacture. The supplier remains confident that all remaining divertor coils will be completed in time for the build sequence.

**Figure 5.11:** Completed D2 Divertor Coil

Divertor Support Structures

A large number of steel support structures are required to support the
coils, armour and diagnostics that make up the MAST-U Divertors. Many of the end plate support structures have been delivered to site with testing, acceptance and pre-assembly work well underway. One of the primary challenges that has been addressed during this process has been selecting raw material and subsequent heat treatment cycles to get the magnetic permeability of the austenitic stainless steel structures down below a limit of 1.05.

**Divertor Armour**

Each divertor contains over 500 graphite tiles to accommodate the divertor strike points (where power densities of up to 10MW/m² are expected) and protect the more sensitive structures. Manufacture of the divertor end plate armour is over 40% complete (see Fig 5.12) and contracts for the remaining armour in the divertor nose region are imminent. As the tiles are being delivered, these will be fitted with electrical heaters (to assist baking and vacuum conditioning) as well as support structures and specialist diagnostics that make up a completed tile module (including thermocouples and Langmuir probes).

![Completed T5 divertor tiles (front and rear surface shown)](image)

**Figure 5.12: Completed T5 divertor tiles (front and rear surface shown)**

**Divertor Cryopumps**

As reported in the previous annual report, the cryoplant was previously removed from the MAST Upgrade core scope as this was not affordable within the current budget. However, this shutdown is effectively the only opportunity to install the cryopumps onto the end plates (that will ultimately be fed with the cryogens that the cryoplant would provide). The pumps have therefore been fully designed and manufacturing of the concentric ring structures that make up the pump are well underway (see Fig 5.13). Thus far, this is progressing according to the schedule and it is expected these will be assembled and tested in time for when they are required in the end plate build sequence.
P6 coil – Vertical Stabilisation

As well as the divertor coils, one of the most time critical in-vessel coils is the P6 coil which controls the plasma’s vertical position. This coil had to undergo a last minute redesign to ensure it could sustain the increased currents and induced loads required to control the more unstable MAST-U plasmas. At the time of writing, copper conductor has been procured and the Supplier has begun the winding of the first coil. The delivery schedule for the P6 coil will be very challenging so as well as working with the supplier to accelerate this as much as possible, alternative build sequences are being considered by the project team.

TF coils

To generate the increased toroidal field for this new machine (of 0.8T at R=0.8m), a new central conductor is required to provide the current return path for the existing 24 TF coils. Having successfully manufactured the 24 wedges that make up this so called “Centre Rod” (see Fig 5.14), the supplier is in the process of completing the bonding trials and has begun priming and wrapping the wedges ready for final potting. This operation is critical and the project effectively only has 1 shot at getting this right. As a result, the Contract Project Manager has worked extremely closely with the supplier to ensure all quality control procedures are in place and assure a good result.

It is expected that the potting and final preparation will be completed in April 2014 at which point it will be delivered to site ready for assembly into the airside coil set, providing the critical ‘Centre Column’ module which sits at the heart of the MAST-U machine.
The other key upgrade of the TF coil assemblies are the sliding joints; these provide a high-current joint between the outer limbs and the centre rod whilst accommodating relative movement between these assemblies (e.g. during thermal, vacuum and EM excursions). All 48 sliding joints have now been delivered. Preparations are underway to solder felt metal strips to the sliding faces prior to installation in early 2015.

**Airside coils**

The airside coil set comprises the P1 coil (the central solenoid), a Pc coil and 2 Px coils (for plasma shaping and x-point control). To meet the high level requirements for the MAST-U machine (e.g. current, pulse length etc), these coils are pushed to their engineering limits. An R&D programme was therefore undertaken during the period and, having achieved the required performance, the supplier has been instructed to proceed with the winding and potting of these coils.
Centre Tube

Diagnostics

Assembly of the centre tube diagnostics is well underway, prior to the installation of the graphite armour that will protect both the diagnostics and the centre tube itself, see below. The diagnostics infrastructures will be made up of external procurements, many of which are nearing completion, as well as on-site manufacture. Figure illustrates one of the many magnetic coils being wound in a CCFE laboratory.

![Figure 5.16: On-site winding of a Magnetics Pick-Up coil](image)

Graphite Armour

The design has been completed for all centre tube armour and manufacturing of these C-series tiles has begun. These will protect the sensitive diagnostics that line the centre tube (see above), the gas and pellet fuelling lines as well as the centre tube vacuum boundary itself.
Vacuum Vessel modifications

One of the few existing Load Assembly components that will be reused as part of the upgrade is the vacuum vessel. This cylindrical steel vessel (approximately 4m diameter, 4m tall), along with centre tube and the upper and lower end plates, forms the primary vacuum boundary for the MAST-U machine. As part of the upgrade project, this needs to be modified to accommodate the large number of new systems that make up the MAST-U Load Assembly; in particular, a total of 59 new ports are required in this vessel. A contractor has been brought in to do the precision machining (see Fig 5.18) and, at the time of writing, this was on schedule and 80% complete with 15 of the 59 new tubulations also successfully welded into place (see Figure).
5.2.4 Heating and Fuelling

A key part of the project is improving the reliability and pulse length capability of the Neutral Beam Heating systems. To achieve this, two of the critical beamline components are being replaced; namely the Bend Magnets and Residual Ion Dumps (see Figure 5.20). During the period, designs have been reviewed for both, with a contract underway for the supply of the magnets. The Residual Ion Dumps will
be assembled on site from externally manufactured High Heat Flux panels with associated support structures, cooling infrastructure and instrumentation. All components are expected to be available for installation in late 2014.

**Figure 5.20**: Sectional view through one of the two NBI systems, showing the Bend Magnet and Residual Ion Dump components.

### 5.2.5 Diagnostics

All diagnostic systems have now been removed from the MAST vessel and the 40 control cubicles have been relocated to the assembly area where the internal hardware is being stripped, cleaned, upgraded and rebuilt.

A large fraction of the internal pick-up coils have been wound using the onsite facilities and contracts have been placed for the Langmuir Probe tips, a crucial set of diagnostics for measuring the performance of the new divertor.

As well as the significant number of diagnostics embedded in the load assembly (such as magnetics, Langmuir probes and bolometer arrays), MAST-U will also provide a number of brand new external diagnostics. This includes a new CO2 interferometer (see Fig 5.21), reciprocating probes, a divertor Thomson Scattering system as well as imaging spectroscopy and infrared imaging. Design, procurement and assembly work for all these systems is currently on schedule.
5.2.6 Pulsed Power Supplies
Both the new TF Power Supply and Divertor Field Power Conversion system were delivered to site in late 2013, within a month or two of the target date (see Fig 5.22 and Fig 5.23). Other than a slightly damaged transformer, this equipment passed inspection and now awaits a suitable window for commissioning.

Strip out of the primary power supplies area for the divertor and radial field power supplies has been completed. Some minor civil works are required before the new supplies can be installed, along with the DC Link infrastructure, at which point a new set of busbars will be installed to enable initial commissioning to begin in late 2014.
5.2.5 Buildings and Infrastructure

This workstream continues to coordinate the area layouts within the MAST building, both during the shutdown phase and for operations. Re-commissioning of the new 50T crane along with the removal of a large section of the blockhouse east wall were both critical in removing the vessel into its assembly area (see Figure).

To accommodate the increased neutron loads that will be produced by the new machine, a large number of enhancements are required to the MAST bio shield (otherwise known as the blockhouse). These include the thickening of the east and south walls (see Fig 5.24) as well as the modification of the entrance labyrinth and the construction of a new shielding wall along the north face of the MAST building (see Fig 5.24).

Finally, large parts of the Control and Instrumentation infrastructure are well into their design phase, including network requirements, cubicle layouts and control room design.
5.2.6 Machine Control, Protection and Data Acquisition

With MAST operations now complete, a number of key personnel have been released to begin the design of the machine control, protection and data acquisition systems. The Machine protection and Personnel Access and Safety Systems (PASS) are now well into their design phase and early functionality should be provided to allow early commissioning of some of the critical systems, including the new power supplies. Algorithm development has also begun for the plasma control system and these are expected to be tested and validated in the first half of the next financial year.
5.2.7 Key steps to complete the upgrade

To complete the project, the design and procurement team needs to place contracts for all outstanding components and ensure these are available before they are required for installation. This will then enable the shutdown team to complete the numerous sub-assemblies that make up the core of the MAST-U machine. In particular, the 5 modules that make up the Load Assembly should be fully assembled and tested during 2014, prior to installation and assembly back in the machine area to enable pump down early / mid 2015.

In parallel, the neutral beam heating systems will be refurbished and modified to achieve the performance required for the upgrade. Over 40 diagnostic cubicles are also being consolidated and rebuilt along with many of the existing diagnostics these serve. The new diagnostics specifically for the upgrade including CO2 interferometer, Langmuir probes, magnetics, cameras and Thomson Scattering system will be procured, tested and installed as part of the overall build process.

A new Personnel Access and Safety System (PASS) will also be designed and implemented in a phased manner to allow commissioning of individual power supplies as early as practicable and the machine control, protection and data acquisition systems will also be upgraded to enable safe and efficient operation of the more complex machine.

The project management team continues to plan and monitor all these outstanding tasks and is also working with the MAST-U restart team to ensure a smooth transition from construction through to integrated commissioning and finally to first plasma and scientific campaign running into 2016 and beyond.