FT2/2

DEVELOPMENT OF KEY FUSION TECHNOLOGIES AT JET

The JET Team (presented by M A Pick)
JET Joint Undertaking, Abingdon, Oxfordshire, OX14 3EA, UK

The recent operational phase in JET in which deuterium-tritium (D-T) fuel was used (DTE1) resulted in record breaking fusion performance and a set of definitive experiments enabling the threshold for H-mode transitions and the confinement in ELMy H-mode discharges to be scaled to ITER using direct evidence from D-T plasmas. In addition to these important contributions in plasma physics, JET has also made major advances in demonstrating the viability of some of the key technologies required for the realisation of future fusion power. Two of the most important technological areas which have been successfully demonstrated in JET are the ITER scale tritium processing plant and the exchange of the divertor and maintenance of the interior of JET by totally remote means.

The JET Active Gas Handling System (AGHS) demonstrated the first routine, safe and reliable operation of a closed loop tritium/deuterium fusion fuel supply and re-processing plant. The site inventory of 20g of tritium was circulated and reprocessed several times by the AGHS to provide over 64g of tritium for neutral beam injection and 35g of tritium for gas introduction into the JET machine. The AGHS has been used continuously during torus operation since May 1997 to pump the exhaust stream from the torus and to handle batches of mixed gases from regeneration of the torus and neutral injector cryopumps, separating these gases into hydrogen isotopes, helium, and impurities. Over 13 m^3 of mixed gas has been processed. The typical tritium purity achieved of 99.88% was well above that required for neutral injection and was better than the purity of the original tritium supplied to the JET site. Deuterium and impurities were detritiated in order to recover the tritium for re-use and to permit excess deuterium to be discharged to atmosphere. The main components of the system consist of a cryogenic fore vacuum system, an impurity processing system, two isotope separation systems and an Exhaust Detritiation System (EDS). The two isotope separation systems, a gas chromatography and a cryo-distillation system, were used in combination.

The EDS was designed to detritiate gas contaminated with low levels of tritium prior to discharge into the atmosphere and to provide ventilation to the torus and other major components in the event of a breach of the vacuum containment, either unplanned or for maintenance and repair purposes. Valuable experience was gained during the experiment in the practical aspects of safely operating, maintaining and repairing a tritium contaminated machine. In particular, an intervention to repair a small water leak in the tritium neutral beam injector, featured manned access inside the injector in full pressurised suits. The EDS was used throughout the 56 day intervention to ventilate the injector box and detritiate the exhaust stream. The ventilation kept the tritium concentration from outgassing below levels at which the pressurised suits were able to provide the protective factor necessary to keep workers' accumulated dose below routine exposure limits. The factor >1000 detritiation factor available from the EDS kept environmental discharges to around 1% of JET's authorised limits. The EDS has continued to operate ventilating the torus during the subsequent shutdown phase.

In addition, DTE1 was successful in extracting high power (≤11.5 MW) tritium neutral beams at the highest energies to date (155 keV) for long pulses (≤5s). The experiment also provided the first data on tritium retention and co-deposition in a diverted tokamak. Of the 35g of tritium injected into the JET torus, about 11.5g remained in the tokamak vessel surfaces after DTE1. This amount was larger than predicted by reservoir models based on JET's Preliminary Tritium Experiment in 1991. The amount resides mainly on cool surfaces at the inboard divertor side. After ~300 deuterium plasma pulses, the torus tritium inventory was reduced to 6.5g and a further gram was regained at the start of the shutdown by repeated purging of the torus with moist air followed by pumping. Dust and flakes from the divertor region have been recovered and are being analysed to establish their residual tritium levels.

The limited operation using D-T fuel in JET resulted in an activation level in the machine of the order of 4 mSv/h at the end of the operation period. Manned intervention in the machine, prevented after the D-T operations phase, will become progressively possible only after about one year. Consequently, the complete divertor has been successfully exchanged directly after the D-T phase in the first ever remote handling shutdown at JET. This shutdown saw the first use of the suite of remote handling equipment originally specified, designed, built and commissioned to satisfy general repair and maintenance functions for JET. The teleoperational methodology adopted is based on a man-in-the-loop controlled bi-lateral force- reflecting servomanipulator with a capacity to manipulate up to 20 Kg and capable of lifting up to 50 Kg by winch. The manipulator is transported around the torus by a 10m long articulated boom which can be positioned within several mm of pre-set points and which is housed within a contamination control enclosure sealed to the torus.

In the shutdown the 144 modules of the Mark IIA divertor were routinely and safely unbolted remotely using the manipulator, removed and transferred onto a special end-effector of a second short boom. This second boom transported the divertor modules out of the torus and placed them into specially prepared and ventilated ISO containers housed within a second contamination control enclosure. The same techniques in opposite sequence were then used to install the 192 modules of the Mark II Gas Box divertor. In addition numerous other maintenance, inspection and repair tasks were performed remotely which proved the flexibility and adaptability of the remote handling (RH) approach taken by JET. They included: the detailed visual inspection and video recording of the inside of the vessel and individual components; the remote vacuum cleaning of in-vessel components; the removal and installation of a number of diagnostic systems including the disconnection and reconnection of numerous RH electrical connectors; the removal and replacement of a number of limiter and first wall protection tiles; the remote removal of an oxide layer and cleaning of four beryllium evaporators; the first ever detailed fully remote dimensional videogrammetry survey to confirm the position, shape and integrity of the divertor structure with a point precision of < ±0.1 mm (targeted) or ±0.3 mm (targetless); and the inspection, removal and precise dimensional survey, repair and re-installation of a damaged diagnostic system.

The precise, safe and timely execution of the remote handling shutdown proved that the design, function, performance and operational methodology of the RH equipment prepared over the years at JET are appropriate for the successful and rapid replacement of components in an activated tokamak environment.

The paper will describe these technical achievements at JET and the relevance of the work to ITER and to the development of fusion energy.