# THE DIVERTOR REMOTE MAINTENANCE PROJECT

D MAISONNIER[1], E MARTIN[2], K AKOU[3], A ANTIPENKOV[2], R BÄTZ[4], J BLEVINS5, T BURGESS[6], G CASTELLI[7], G CERDAN[1], S CHIOCCHIO[2], C DAMIANI[8], JP FRICONNEAU[9], P GAGGINI[10], R GOTTFRIED[4], R HAANGE[6], S KAKUDATE[3], M LAMMINPÄÄ[11], S LECLERC[12], K OKA[3], A POGGIANTI[8], G POLTRONIERI[7], J SHEPPARD[13], M SIUKO[11], A TADA[3], N TAKEDA[3], Y TAKIGUCHI[3], A TESINI[6], R TIVEY[2], A TURNER[14]

1 NET, Boltzmannstr. 2, 85748 Garching, Germany
2 ITER Joint Work Site, Boltzmannstr. 2, 85748 Garching, Germany
3 JAERI, 2-4 Shirane, Shirakata, Tokai-mura, Naka-Gun, Ibaraki 319-11 Japan
4 SIEMENS AG, KWU NR-R, Freyeslebenstraße 1, 91058 Erlangen, Germany
5 CFFTP, 800 Kipling Avenue, Etobicoke, Ontario, M8Z 5S4, Canada
6 ITER Joint Work Site, Naka, Naka-machi, Ibaraki-ken, 311-01 Japan
7 BELLELI, Via G. Talierco 3, 46100 Mantova, Italy
8 ENEA, CR Brasimone, CP 1, 40032 Camugnano (Bo), Italy
9 CEA, DPSA/STR, BP6, 92265 Fontenay aux Roses Cedex, France
10 ENEA, via Martiri di Montesole 4, 40129 Bologna, Italy
11 IHA, Korkeakoulunkatu 2, Box 589, FIN-33101 Tampere, Finland
12 COMEX, 36 Bd des Oceans, 13275 Marseille Cedex 9, France
13 SPAR AEROSPACE Ltd, 9445 Airport Rd, Brampton, Ontario, L6S 4J3, Canada
14 NNC Ltd, Booths Hall, Chelford Rd, Knutsford, Cheshire, WA16 8QZ, England

**Abstract**

Remote replacement of the ITER divertor will be required several times during the life of ITER. To facilitate its regular exchange, the divertor is assembled in the ITER vacuum vessel from 60 cassettes. Radial movers transport each cassette along radial rails through the handling ports and into the vessel where a toroidal mover lifts and transports the cassette around a pair of toroidal rails. Once at its final position the cassette is locked to the toroidal rails and is accurately aligned in both poloidal and toroidal directions. A further requirement on the divertor is to minimise the amount of activated waste to be sent to a repository. To this end the cassettes have been designed to allow the remote replacement, in a hot cell, of their plasma facing components. The paper describes the two facilities built at ENEA Brasimone, Italy, whose aim is to demonstrate the reliable remote maintenance of the divertor cassettes.

## 1. DIVERTOR MAINTENANCE

Remote replacement of the ITER divertor is estimated to be required up to eight times during the life of ITER because of failure, erosion of the armour or to install alternative divertor configurations. To facilitate its regular exchange, the divertor is assembled in the ITER vacuum vessel from 60 cassettes [1], each of them being introduced into the vessel through one of four equispaced handling ports. Of the 15 cassettes installed through each port, 12 are 'standard' cassettes and two are 'second' cassettes, positioned on either side of a 'central' cassette located directly in front of the handling port. Radial movers transport each standard cassette along radial rails through a port and into the vessel where a toroidal mover lifts and transports the cassette around a pair of toroidal rails (fig. 1) to its designated position. To do so, the toroidal mover inserts, between the toroidal rail and the cassette bottom, two forks which include a set of wheels and jacks to lift the cassette by a few millimetres. The jacks are driven by pressurised water whilst the toroidal mover is equipped with pinions, driven by electric motors, operating against racks on the rails to index the cassette around the vessel. The second cassette is transported radially by the second cassette mover until it reaches the position of the central cassette, at which point it is translated toroidally by 6$^o$ along the toroidal rails. The central cassette is transported radially by an ad-hoc mover to its final position. Once at its final position each cassette is locked to the toroidal rails such that it can sustain the off-normal electro-magnetic loads and is accurately aligned in both poloidal and toroidal directions. The transport between the vessel and the hot-cell for refurbishment is performed using a transfer cask with a double door which ensures the reactor and the cask remain closed during removal of the cask to the hot cell.

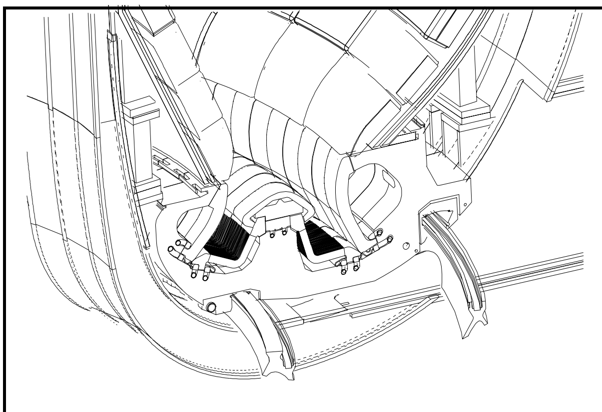

FIG. 1 *ITER Divertor Assembly*

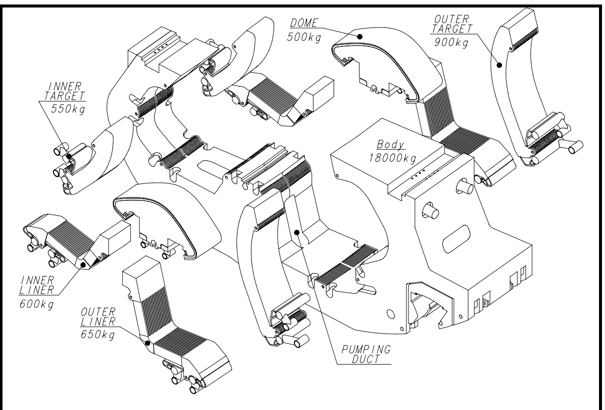


FIG. 2 *Exploded View of a Divertor Cassette*

A further requirement on the divertor is to minimise the amount of activated waste to be sent to a repository. To this ends a second element of this project addresses the remote replacement of plasma facing components (fig. 2), thus allowing the cassette bodies (~ 1000 tons of steel) to be used for the entire lifetime of ITER [2]. Each cassette comprises 10 plasma facing components (PFC's) attached to the body, and the refurbishment of a complete set of cassettes is scheduled to last 1 year.

## 2. OBJECTIVES OF THE ITER DIVERTOR MAINTENANCE PROJECT

The objectives of the ITER divertor maintenance project were to demonstrate the feasibility of divertor maintenance [3] and to set up two facilities for the future optimisation of the handling equipment, of the handling features incorporated into the components being handled, and of the maintenance procedures.

The Divertor Test Platform (DTP) allows full scale simulation of all handling operations inside the vacuum vessel. The Divertor Refurbishment Platform (DRP) allows simulation, also at full scale, of the most critical operations to be realised in the hot cell. Both facilities have been set up at the ENEA Research Centre of Brasimone, Italy.


FIG. 3 *Overview of the Divertor Test Platform*

**2.1 Objectives of the Divertor Test Platform**

The procedures for divertor cassette replacement and the related remote handling equipment have been devised taking into consideration the initial assembly, positioning and manufacturing tolerances of the ITER components ("nominal" conditions). Deviations from the initial tolerances ("limit" conditions), resulting from deformations of the components to be handled or of their supports, will be unavoidable after several years of machine operation.

The feasibility of the remote maintainability of the divertor cassettes will be demonstrated after checking the performance of the handling equipment under "nominal" conditions and after assessing their operational limits. The tests foreseen and executed to date include the commissioning of all models, mock-ups and prototypes, the validation of mover operations in nominal conditions, the validation of auxiliary remote handling systems in nominal conditions and a preliminary assessment of the operational limits of the movers [4]. Further tests, e.g. the validation of rescue procedures, will be undertaken before finalising the handling equipment and the component design.

**2.2 Objectives of the Divertor Refurbishment Platform**

The objectives of the DRP are to demonstrate the feasibility of the cassette refurbishment and to assist in the definition of hot cell procedures. The experimental validation includes the manufacture of prototypical attachments between cassette body and PFC's, the manufacture and testing of remote handling tools for handling the PFC's and their attachments and for the cutting and welding of the PFC's hydraulic connections, and a system for dimensional survey of the cassettes before, during and after the refurbishment process.

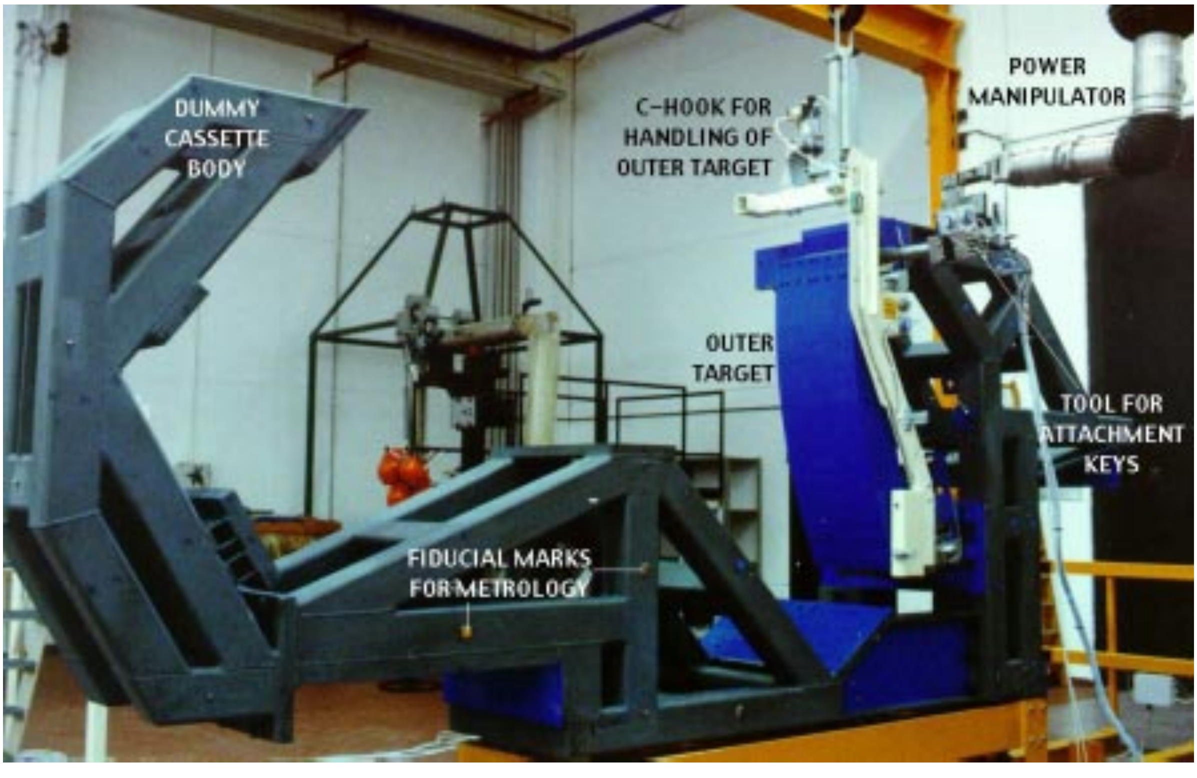


FIG. 4 *Assembly Test with an Attachment Key in the DRP*

3. TEST RESULTS

The movers have all satisfactorily met their nominal performance, thereby achieving an accuracy of positioning of the cassette better than required. The cassette toroidal mover repeatability in the toroidal direction, as measured in the DTP, is better than 0.5 mm. The final positioning of the cassette is achieved by the cassette locking system which, when actuated by the manipulator mounted onto the mover, engages into a recess in the inner toroidal rail and forces the cassette to slide to its final location. This allows positioning of a cassette with an accuracy of 0.1 mm as verified in the DTP.

The maximum, nominal, gap between rail sectors in ITER, both toroidal and radial, is 1 mm in any direction. To avoid unnecessary wear of the prototypes, this value has been reduced to 0.3 mm in the DTP and this causes no noticeable effect during mover operations. Specific sections of the toroidal and radial rails have been constructed to allow testing with gaps up to 5 mm in any direction and the successful passage over 1 mm gaps was demonstrated during the movers' commissioning. A special set up was devised to cycle the passage of a wheel over a 1 mm gap more than 1000 times, i.e. approximately the number of gaps that will be crossed by a mover when replacing the complete divertor assembly 8 times. Considering that it is more difficulty to replace a rail sector, permanently installed in the vacuum vessel, than a mover wheel, the hardness of the wheels was specified to be lower than that of the rail (25 vs. 35 HRC). Following the simulated 1000 crossings, markings on both surfaces were visible but without noticeable effects on mover performance.

The metrology system of the DRP has an accuracy of 0.04 mm with a short sensing probe and of 0.5 mm with a long probe. The repeatability is, respectively, 0.02 and 0.13 mm. The performance is compatible with the accuracy specified for the manufacture and refurbishment of a divertor cassette.

The qualification testing of a 'dumb-bell' type of key for the attachment of the PFC's to the cassette body has been successfully completed. The functional and technical requirements of the key resulted in very tight mechanical tolerances (a few hundredths of a millimetre) and, therefore, in a delicate assembly procedure. The key assembly was, however, successfully demonstrated using special purpose tools, in particular a 'key extractor' using pressurised water to provide adequate power, and suitable sensors to align the key with the cassette body and the PFC.

A new attachment concept, which uses sets of links hinged to the PFC's and to the cassette body, is being considered. This scheme allows: (i) to better distribute the electro-magnetic loads within the links than within the dumb-bell key, (ii) to limit the tribological requirements to the link/linkpin interface and (iii) to consider easier assembly procedures. Moreover, the link/linkpin scheme is considerably cheaper than the dumb-bell key system.

## 4. CONCLUSIONS

Cassette maintenance by 'movers' was originally selected because of the robustness of the concept, allowing for simple handling procedures, requiring simple handling equipment, and allowing execution of the most frequent in-vessel maintenance operation as quickly as possible. The 'divertor remote maintenance project' has been a success - all major objectives defined at the beginning of the project have been met on time, therefore confirming the validity of this concept.

The final validation and the optimisation of the divertor maintenance concept still requires work to demonstrate (i) the effectiveness of rescue procedures, (ii) the reliability of processes and procedures selected and (iii) the implementation of these processes and procedures in full remote conditions. R&D on component radiation-hardening must also continue in parallel.

This project demonstrates that it is possible to carry out complex technical activities successfully and on time within an international framework such as the ITER EDA. In practice, the additional effort required for project management is more than compensated by the increased level of competence and of resources available.

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