# ITER-FEAT Vacuum Pumping and Fuelling R&D Programmes

D. K. Murdoch 1), A. Antipenkov 2), J-C Boissin 1), C. Day 3), H. Haas 3), P. Ladd 2), A. Mack 3), S.Pimanikhin 4), G.Saksagansky 5), I. Viniar 6)

1) EU-HT, EFDA-CSU, Boltzmannstr. 2, 85748 Garching, Germany.
2) ITER JCT, Garching JWS, Boltzmannstr. 2, 85748 Garching, Germany.
3) EU-HT, Forschungszentrum Karlsruhe, Postfach 3640, D-76021 Karlsruhe, Germany.
4) RF-HT, All-Russian Scientific Research Institute of Experimental Physics, Sarov, 607190, Russia.
5) RF-HT, D.V. Efremov Scientific Research Institute of Electrophysical Apparatus, St-Petersburg, 189631, Russia.
6) RF-HT, PELIN Laboratory, Ltd., 2, Admiral Makarov Str., Moscow, 125212, Russia.

e-mail contact of main author: murdocd@ipp.mpg.de

**Abstract.** The design of the ITER-FEAT vacuum pumping and fuelling systems is supported by two key R&D programs, the first directed towards the development of a steady state tritium compatible pellet injector, and the second towards the development of a supercritical helium cooled cryogenic pump for torus exhaust. While the pellet injector programme for ITER-FEAT is new, that for the cryopump has evolved from a programme that originally supported the 1998 ITER design. As the plasma exhaust parameters have remained essentially unchanged between these two machines, the R&D conducted to date remains valid. Initial test results on the prototype injector, TPI-1, which included continuous injection of Ø3 mm hydrogen pellets at 500 m/s and at 1 to 2 Hz for periods up to, are reported. A model of the cryopump has now been installed in a new dedicated test bed at the Karlsruhe Research Centre where acceptance tests have been completed and preliminary results from pumping tests obtained. An extensive test campaign to fully characterise pump performance and identify any mechanical details which require modification has started.

## 1. Introduction

An overview of the two major R&D programmes being conducted in support of the design of the ITER-FEAT fuelling and vacuum pumping systems [1] is presented. The major activity in the fuelling area is the development of a steady state tritium compatible pellet injector. This is a new activity conducted by the RF Home Team, and draws on the considerable experience developed in its domestic fusion programme. The focus of the vacuum pumping programme is the development of a supercritical helium cooled cryogenic pump providing high pumping speed and capacity, and fast on-line regeneration. This programme, conducted by the EU Home Team, builds on the R&D which originally supported the 1998 ITER design, and only minor redirection has been needed for ITER-FEAT, as the principal fuelling and exhaust parameters have not changed. The RF Home Team is investigating the performance of the sorbent bonding under tritium exposure.

## 2. Fuelling

Injection of fast pellets of solid hydrogen isotopes is the reference method for delivery of fusion fuel directly into the central part of the ITER plasma. The ITER pellet injector must comply with extremely stringent requirements for tritium safety and have the following parameters based on present-day estimates: characteristic size of pellets is 3-7 mm with speeds of 300–1000 m/s at a frequency of 2–50 Hz, and an injection reliability of 99% for 1000 s cycles.

The development activities for the ITER tritium injector were undertaken in the USA (up to 1998) and Russia. The first injector mock-up, developed at ORNL [2], was based on a piston extruder which achieved an injection frequency of 1 Hz over 13 s. Even with multiple extruders [3] the throughput was limited, and the tritium inventory of this concept is inherently high.

In the Russian-made tritium injector TPI-1, based on a design concept from Pelin Inc. (Canada) and improved by PELIN Laboratory in Russia, continuous pellet production by a screw extruder was realized. The screw extruder technology efficiency was experimentally demonstrated on the first continuous-operation injector delivering deuterium pellets ~2 mm in size for 1200 s with a frequency of 10 Hz and speed 200-600 m/s, and at an injection reliability of 99% [4].

## 2.1 Injector design

The updated TPI-1 injector diagram is shown in Fig. 1. The screw extruder is located inside the main vacuum chamber (secondary containment) of the injector. Rotation is transferred from a motor to the extruder screw through the swinging bellows unit sealed at its ends by static copper gaskets. The extruder cavity volume amounts to about 18 cm$^3$. Liquid He cools the extruder and its thermal shield. The receiving chamber is equipped with two radiation-resistant windows. The injector barrel and the chopping unit for pellet formation from the extruded rod are installed inside the receiving chamber.

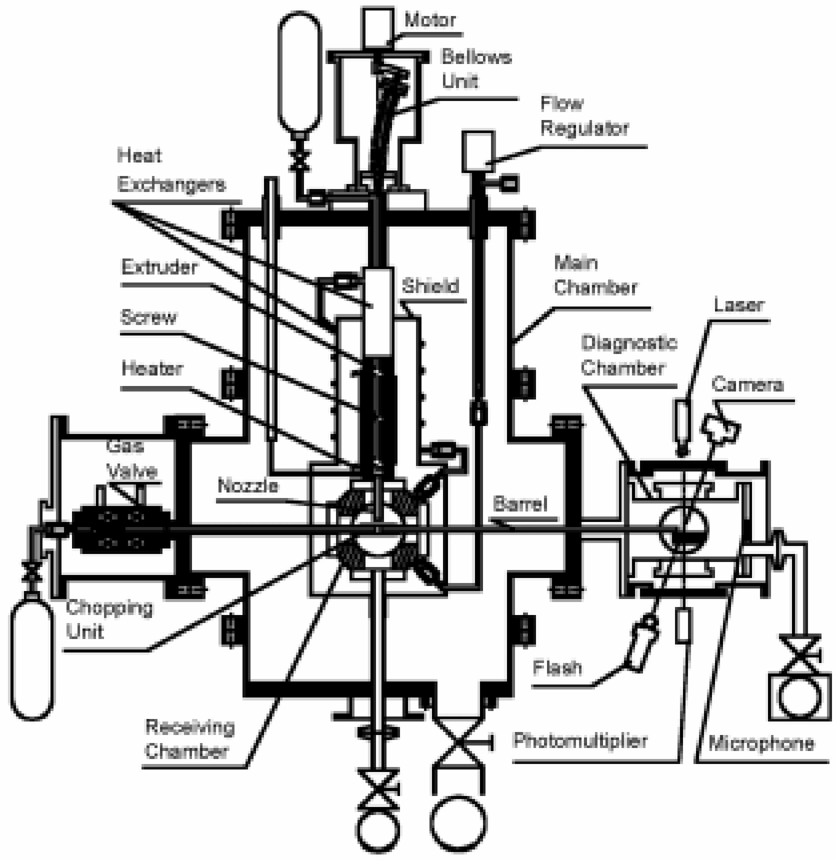

*FIG. 1. Schematic diagram of tritium pellet injector with screw extruder*

The gas valve and a tube are attached to this unit for the propellant gas admission into the barrel. (On ITER the pellets are launched by a centrifugal device.)

The inner barrel diameter is 3 mm and its length is 600 mm. Pellets are injected into the diagnostic chamber, which is connected to the vacuum pumps. This chamber has four windows for the laser and photomultiplier which record the moment of pellet in flight, as well as the flash unit and camera for video filming of the pellet. A microphone is attached to the rear flange of the diagnostic chamber to register the time of pellet impact.

An experimental vacuum-tritium complex [5] will be used for testing the injector with tritium. The system comprises the hydrogen isotope separation device, fuel preparation, storage and distribution device, a unit for collection and treatment of waste gas, and an automatic control system. The prepared fuel mixture is stored on uranium getter beds. The released gas mixture passes through a palladium filter system, to remove impurities (He-3, CO, $N_2$, $O_2$, Ar) and enters the injector through the service line system at a pressure up to 0.1 MPa. The rate of the initial gas mixture supply is ~4 Ncc/s; the volume of distributing tanks is ~185 l; the tritium content in the waste gas stream is $< 10^{-5}$ mCu/l; consumed power is up to 5 kW. The system can operate in continuous mode.

### 2.2. Injector operation and preliminary results

Once the temperature has stabilized at 10K, the gaseous fuel is delivered to the extruder at a pressure up to 0.1 MPa where it is frozen. During testing, the screw rotates in the extruder at 20 RPM, pushing out compressed solid protium. The chopping unit moves repetitively the tube into the barrel, thereby cutting off a section of the protium rod to form a pellet. In the extreme position of the tube the gas valve is opened, and the propellant gas entered the barrel accelerating the pellet. The pellet is propelled into the diagnostic chamber and impacts on the flange, generating a sound pulse. The signal of the photomultiplier recording the instant the pellet crosses the laser beam initiates the pulse flash with a duration of 180 ns, and the direct-shadow image of the pellet is recorded by the video camera. The chopping unit resets the tube, and the cycle is repeated.

Steady state injection was demonstrated with protium at an extruder temperature of 10-12.5 K. The extrusion rate was calculated by the time the lower end of the extruded rod traversed along the transparent rule attached on the receiving chamber window. The maximum production rate of the extruder was ~ 240 $mm^3/s$ of solid protium. The protium rod extruded at 11 K was transparent. Room temperature helium at a pressure of 1 MPa was used as an propellant gas for the repetitive injection. The pressure was limited by the evacuation rate of the diagnostic chamber. Protium pellets were formed and accelerated to 0.4-0.5 km/s at 1-2 Hz for 1500 s continuous steady state injection. The pellet speed was calculated by the time of flight method. The maximum frequency of pellet formation achieved was 3 Hz, which was limited due to the destruction of part of the protium rod between the cutting tube and extrusion nozzle during formation of the pellet. Because of this, a time delay was required to ensure that the residual ice fragments in the barrel had evaporated by the time the rod reached the barrel axis during the next cycle, which disturbed the acceleration dynamics. The injector tests are being continued.

## 3. Torus Exhaust Pumping

The improved divertor conductance of ITER-FEAT compared with ITER (1998), coupled with the reduction in the nominal pulse length from 1200s to 450s, has allowed the number of cryopumps of the primary vacuum pumping system to be reduced from 12 to 6 for this nominal pulse. For both machines an additional 4 pumps are needed to allow on-line regeneration for pulses greater than the nominal pulse. Longer pulse operation results in a fundamental limitation being placed on the pumping time between regeneration due to hydrogen inventory constraints, necessitating fast regeneration. This is accomplished within 300s. As the unit size and pumping speed of the pumps have not been changed for ITER-FEAT, the R&D and much of the design previously carried out remains valid.

*FIG 2. ITER Model Pump in Test Facility at FZK.*

### 3.1 Model Pump Tests

A comprehensive programme is under way to test a model pump, with 50% of the pumping surface proposed for the full scale pump, in a dedicated test bed constructed at the Karlsruhe Research Centre, as shown in Fig. 2 [6]. Acceptance testing of the pump, using helium and neon, was carried out in the earlier part of the year 2000 [7]. These tests demonstrated that the target values of 1.0 $l/s.cm^2$ and 0.50 $l/s.cm^2$ for specific pumping speed of helium and neon respectively, the latter being used in place of deuterium to avoid the use of a flammable gas in this early operation phase, were achieved. These tests were followed by pumping speed test runs with pure protium and deuterium, and mixtures containing ITER-relevant impurities including up to 10% helium, and in all cases the target value of 1.0 $l/s.cm^2$ was exceeded. Parametric pumping tests with representative gas mixtures will follow, in order to establish the performance of the pump under the operational modes foreseen, and to confirm the reliability of the pump in long term campaigns.

An important aspect of the cryopump development is the optimization of the regeneration scheme within the constraints imposed by the inventories of tritiated species and total hydrogens on the one hand and cryogen economy on the other [8, 9]. The regeneration scheme is expected to involve warming up to different temperature levels to release helium and hydrogen isotopes, methane and air-like impurities, and water-like impurities respectively. The optimum cycle will be tailored as a function of the actual gas compositions encountered and the regeneration conditions experimentally determined for each group of species.

### 3.2 Component Tests

Supporting tests on critical components, primarily the cryosorption panels, to demonstrate their ability to survive repeated temperature cycling on the ITER time scale have been successfully completed [10]. These included two series of tests, between 4K and 80K, and 80K and 300K, respectively. The tests were carried out at relevant temperature ramping rates and extended over several thousand cycles. Separate tritium exposure testing of the compatibility of the sorbent/bonding agent/substrate system at representative conditions (integrated exposure of $10^{10}$ Pa.s) has shown that small scale coupons displayed no significant deterioration. Tests of medium scale samples in pure tritium, and of ITER scale panels in tritiated gas mixtures with representative chemical impurities are being started.

## 4. Conclusions

The world's first tritium compatible pellet injector with continuous operating extruder has been developed and undergone successfully the initial stage of laboratory testing. The most important characteristic demonstrated was continuous operation that exceeds the ITER technical requirements. It is planned to upgrade the injector to increase the extruder production rate to ~400 $mm^3/s$ and conduct tests on heavy hydrogen isotopes and their mixtures in the experimental vacuum-tritium complex.

The first experimental results obtained with the ITER model pump exceed the anticipated performance with the principal gas compositions. The planned future test programme, including additional component tests in supporting facilities, will investigate a broader parameter set, and the mechanical integrity of the design in long term service.

## 5. Acknowledgements

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