CEFDA03-1047

Task Title: TW3-THHN-IITF1: THE FIRST ITER NB INJECTOR AND THE ITER NB TEST FACILITY: DESIGN

INTRODUCTION

At the time of the last "Technofusion" report the work on the 5 areas of physics design assigned to the DRFC had been completed.

In the period covered by this report the work foreseen under this contract on the infrastructure, including the cryo system and the cooling system, and, the beamline vessel for the Neutral Beam Test Facility (NBTF) has been completed and agreement on the designs reached with EFDA and the other EURATOM Associations involved with this work (ENEA, FZK, IPP and UKAEA).

The main purpose of this task is to make progress with the detailed design of the first ITER Neutral Beam (NB) injector and the conceptual design of the ITER NBTF. The work carried out by the DRFC in 2004 is described briefly below.

2004 ACTIVITIES

SYSTEM DESIGN

Four design areas of the NBTF have been covered:

Design of the general infrastructure

The study of the generic design of the NBTF general infrastructure was launched early 2004. The study of the experimental hall will be completed at the end of 2005. This study includes the test facility itself and the associated auxiliaries such as cooling plant, cryoplant and forepumping system. The NBTF safety requirements (neutron and X-ray production) have to be taken into account. Figure 1 shows the layout of the sytem.

Design of the dedicated beam line Vessel (BLV)

The current design of the dedicated Beam Line Vessel (BLV) allows mixed vertical and horizontal access to the beam line components was proposed and developed by the CEA.

The proposed mixed vertical horizontal option differs mainly from that proposed in 2003 in the cryopump design: This now consists of two (almost) semi-cylindrical cryopumps that are essentially identical to the 2 halves of the ITER NB cryopump. As with the previous BLV option the beamline components may be removed for maintenance either vertically or horizontally.

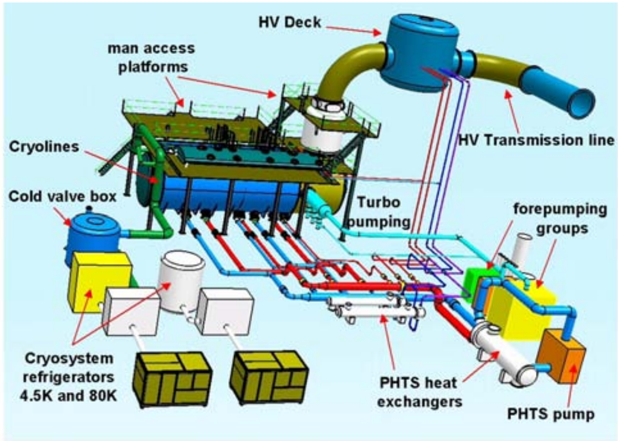

Figure 1 : Neutral beam test facility, general infrastructure (the buildings are hidden)

The upper large opening (9.50 m x 2.55 m) allows vertical maintenance and easy diagnostic and man access (see figure 2 bellow). The maximum BLV height is limited to 4.4 m for transportability consideration. The elliptic shape is connected to the BSV cylinder through a stiff circular welding. The beam line vessel volume is ≈200 m^3.

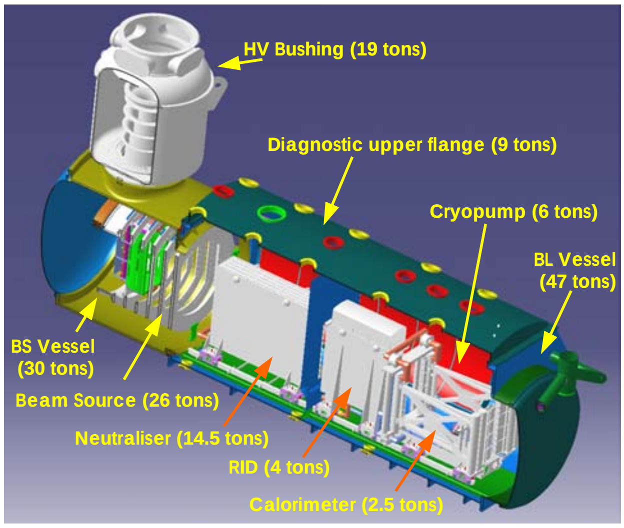

Figure 2 : The NBTF beam line vessel and beam source vessel equiped with the beam line components and semi-cylindrical cryopumps

The proposed "Phase I operation" of the NBTF is dedicated to the qualification of the source and beam line components with short pulse operation (≈ 30 s). During this phase the flexibility offered by the MVHO (see figure 3.1) is considered a substantial advantage compared to using a sytem allowing only horizontal maintenance and limited access for diagnostics.

At the end of the Phase I operation, it is foreseen to move to “Phase II”, which will mainly consist of a campaign with long pulses of up to 3600 s, in H_2 and D_2.

During Phase II the beamline configuaration is to be changed (figure 3.2) by linking the two sem-cylindrical cryopumps in order to have the final same configuration as the ITER NB cryopumps. This will require some adaptation of the cryopump support system which is attached to the wall of the BLV.

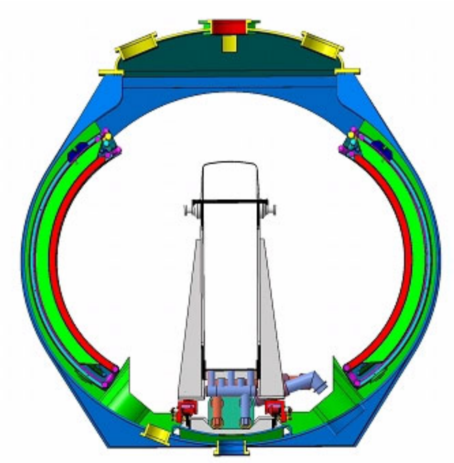

Figure 3.1 : Phase I configuration

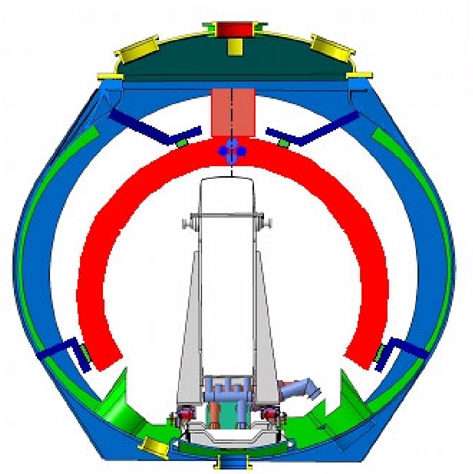

Figure 3.2 : Phase II configuration

Finalisation of the design of the cryo system

The ITER NB heating and current drive system is equipped with a cryosorption cryopump (made up of 12 half modules connected in parallel), refrigerated by 4.5 K 0.4 MPa supercritical helium.

The pump is submitted to a non homogeneous flux of H_2 or D_2 molecules, and the absorbed flux varies from 3 $Pa.m^3.s^{-1}$ to 35 $Pa.m^3.s^{-1}$. A usual and important operation of the cryopumps is the regeneration at 100 K of the cryopanels.

In the framework of the “ITER first injector and test facility”, the successive studies that where performed in 2004 are the following :

- Evaluation of the reference ITER cryogenic system designed to refrigerate the NBI (and torus) cryopumps in ITER operating conditions.

- Definition of a reliable cryogenic system able to refrigerate the NBTF cryopump in “acceptable” and “representative” operating conditions (short 20 s pulses) and long (3600 s pulses), using 4.5 K, 0.4 MPa, super critical helium for the cryopanels, and gaseous helium at 80 K at 1.8 MPa for the thermal shields and baffles.

- Evaluation of the costs and the procurement time of the proposed NBTF cryogenic system.

The 4.5K refrigerator

A standard industrial 4.5 K refrigerator, availab provides a cold power of 500 W at 4.5 K in pure refrigeration mode and 150 l/h in pure liquefaction mode. The optimization of the thermodynamic process to provide the 160 W required by the cryopump at 4.5 K is to be carried out by the supplier. Such a refrigerator does not supply any cold power at 80 K.

The 80K refrigerator

The Brayton cycle used by the proposed refrigerator includes a screw compressor with its oil removal unit, a counter flow exchanger, an expander equipped with an active charcoal filter in order to remove impurities, and a by-pass to adjust the temperature at the inlet of the shields if necessary (see figure 4). However, to minimise the required helium flow rate (0,175 kg/s) and consequently the power supply of the compressor, the Brayton cycle must operate with a large temperature difference (24 K) between the inlet (66 K) and the outlet (90 K) of the shields and the baffles. The Brayton cycle is well adapted to provide a progressive cool down of the shields and the baffles, as the turbo-expander can be by passed. This solution is self contained and of course independent of LN_2 deliveries.

The cryoplant layout is shown schematically in figure 4

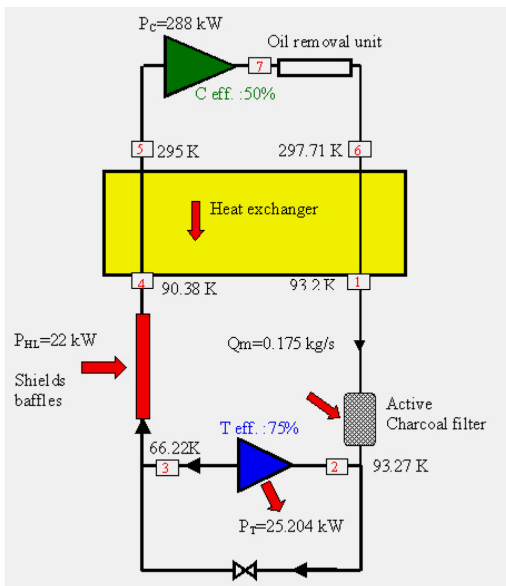

Figure 4 : The 80K Brayton cycle process flow diagram

Table 1 : PHTS characteristics

Component	Inlet Temperature (°C)	Max Averaged Outlet Temp (°C)	Max outlet Temp(°C)	Saturation Pressure (MPa)	Inlet Pressure (MPa)	In Vessel Pressure drop (MPa)	Oulet Pressure (MPa)
Neutraliser leading edge	80	132	175	0.9	2.65	0.06	2.59
Neutraliser Panels	80	132	140	0.4	2.65	0.25	2.4
RID	80	132	205	1.8	2.65	0.07	2.58
Calorimeter Closed/Open	80	106	128	0.3	2.65	2	0.65
Ion Source, Filaments and Power Supply	20	43.5		0.1	2.65	0.9	1.75
Acceleration grid, Extractor, Plasma grid	55	93.3		0.1	2.65	0.9	1.75

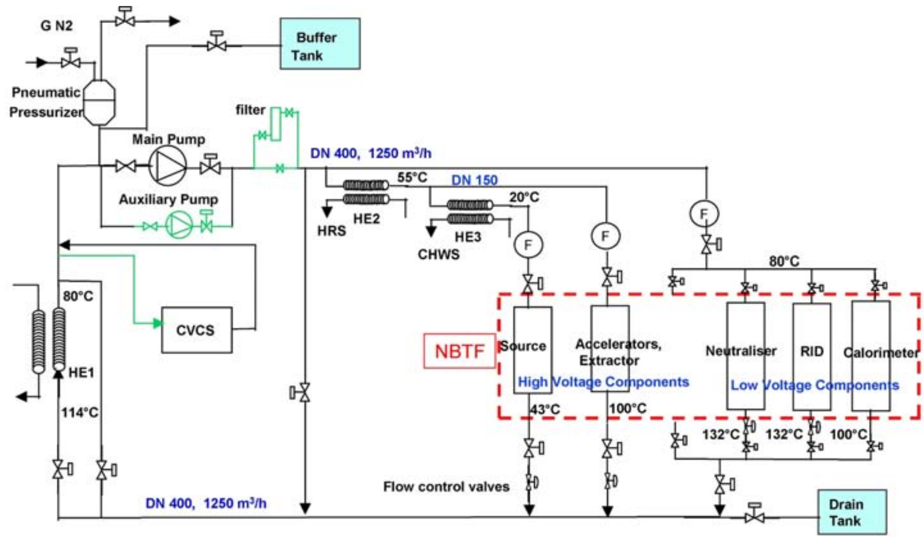

Figure 5 : PHTS process flow diagram

Final design of the cooling system

The methodology used for the NB injector cooling system starts from the review of the thermo-hydraulic data presented in the various ITER Design Description Documents (the DDD's). Then the operation conditions of the Primary Heat Transfer System (PHTS) were derived, considering that the facility is a dedicated test bed. The study performed in 2004 was divided into 4 successive steps :

- An assessment of the reference cooling plant designed to refrigerate the ITER NB injection system.
- The design of a reliable cooling system, able to refrigerate the NBTF in "acceptable" and "representative" operating conditions for short (20 s) and long (3600 s) pulses. The proposed design covers both the Primary Heat Transfer System (PHTS) and the Heat Rejection System (HRS).
- Design of the layout of the PHTS, the HRS and auxiliary loops dedicated to the NBTF.
- A survey of the potential equipment and an associated cost assessment, including the integration on the site.

The main characteristics of the PHTS are summarised in table 1 and the process flow diagram is shown as figure 5.

CONCLUSION

This contract was completed and the final reports submitted to EFDA in october 2004. A second contract continuing the design of the NBTF was let by EFDA to the same EURATOM Associations plus the EURATOM Association CIEMAT. The new contract aims at finalising many aspects of the design, such as the BLV, of which the main aspects are described in this report, and to bring to the same level as the reference design (or better) the design of the alternative concepts for the negative ion source and accelerator, both of which are being developed in Europe.

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CEFDA04-1140

Task Title: TW4-THHN-ADSD2: NEUTRAL BEAM DEVELOPMENT FOR EFDA EXTENSION

INTRODUCTION

The KAMABOKO III ion source, is being tested on the MANTIS test stand at the DRFC Cadarache in collaboration with JAERI, Japan, who designed and supplied the ion source. The ion source is attached to a 3 grid 30 keV accelerator (also supplied by JAERI) and the accelerated negative ion current is determined from the energy deposited on a calorimeter located 1.6 m from the source.

2004 ACTIVITIES

During 2004 experiments on MANTIS the following adverse effects of long pulse operation were found:

- The negative ion current to the calorimeter is ≈ 50 % of that obtained from short pulse operation.
- The caesium "consumption" is up to 1500 times that expected.

Results presented here indicate that both of these are, at least partially, explained by thermal effects.

Beam Transmission

Figure 1 shows the accelerated current and the current to the calorimeter as a function of the arc power. As can be seen from figure 1, only about 50 % of the accelerated current reaches the calorimeter.

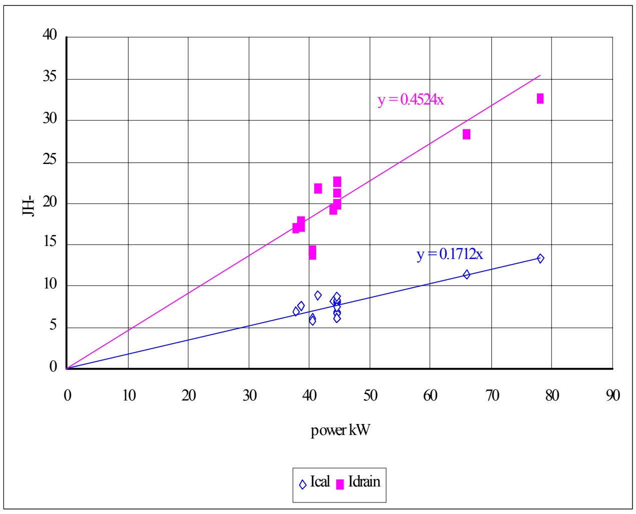

Figure 1

Possible reasons for this poor transmission are:

a) The "lost" beam is electrons, arising from either accelerated extracted electrons or electrons created by stripping in the accelerator.

Extracted electrons: Extracted electrons are deflected onto the surface of the extraction grid by the magnetic field from the filter in the ion source and permanent magnets buried in the extraction grid, but some electrons escape to the extraction region. The fraction of the accelerated electrons has been measured by operating the source in pure argon. In this situation no negative ions are produced in the discharge, but a high electron current (assumed equal to the current to the extraction grid) of 3 A was extracted. No power was recorded on the calorimeter, and the accelerated current, was 30 mA, i.e. < 1 % of the extracted current. Furthermore the current to the acceleration grid was equal (within the measurement error) to the current drain from the high voltage power supply, which means that most of the accelerated electrons were collected on that grid. As the extracted electron current during H_2 operation is typically < 20 % of the accelerated current, and approximately equal to the accelerated current in D_2 operation, extracted electrons cannot explain an accelerated electron current that is 50% of the total accelerated current.

Electrons from stripping: To a first approximation the fraction of electrons stripped during the passage of the H^- or D^- through the accelerator is proportional to the source pressure. Thus if stripping were the cause of the "lost" beam, the transmission should vary strongly with the source filling pressure. Within the experimental errors there is no variation with pressure. (Note that the calculated stripping fraction in the acceleration gap at a source filling pressure of 0.3 Pa is ≈ 3 %).

b) The beam optics are extremely bad. Careful simulations of the beam optics have been carried with assumed possible variations and errors in extraction and acceleration gaps, grid misalignment and negative ion current density and magnetic field effects. All the simulations predict beams with adequate optics to achieve transmissions of > 90 %. However it has recently been realised that the acceleration grid could be bowing under the heat load received from intercepted ions electrons. To test this hypothesis the beam transmission was measured as a function of the pulse length, see figure 2. The measured data give the average transmission for each pulse, and the blue curve on figure 2 is a "by eye" fit to those data figure 2 shows that for very short pulses, < 4 s the transmission is > 70 %.

The transmission degrades to a minimum at about 25 s, and then improves to its long pulse value of ≈ 55 %.

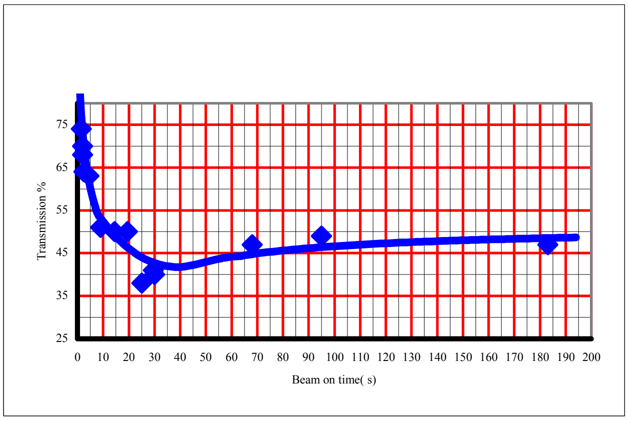

Figure 2

In order to investigate this "lost" power; a new drift duct has being fabricated and installed which is well instrumented to allow the power deposited between the accelerator and the calorimeter, and the spatial distribution of that power, to be determined. This drift duct is made of 6 copper boxes; each bow is made up of 4 copper plates. These plates are electrically connected however thermally insulated from each other. Each plate is equipped with 2 thermocouples, which allow a good measurement of the power received on each panel of the duct; giving a good spatial distribution of the "lost" accelerated power. This drift duct can be seen in figure 3.

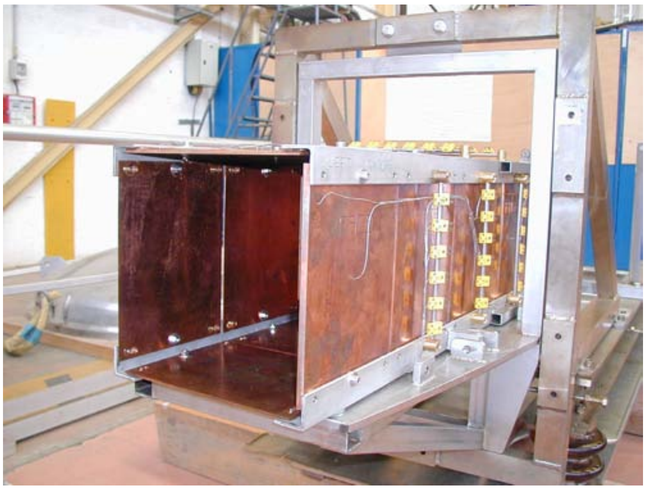

Figure 3

A new accelerator grid has been designed and the new grids are due to be delivered by the beginning of june. These accelerator grids are designed to allow dilatation under power loading. It is proposed that experimentation with this accelerator be carried out during the summer of 2005.

Cs Consumption

Very high Cs consumption rates have been found during lng pulse operation: the amount of Cs "consumed" per aperture in the PG is up to 1500 times that assumed for the ITER source, which is based on extrapolation from short pulse operation. A possible, partial, explanation is that during the operation of long pulses (>100 s), the source walls reach thermal equilibrium at a temperature (typically 75 °C) substantially higher than during short pulses (≈ 20°C). The increase in the vapour pressure of Cs on the source walls would result in an increase in the Cs flow from the walls into the discharge by up to a factor of 60, see figure 4 [1].

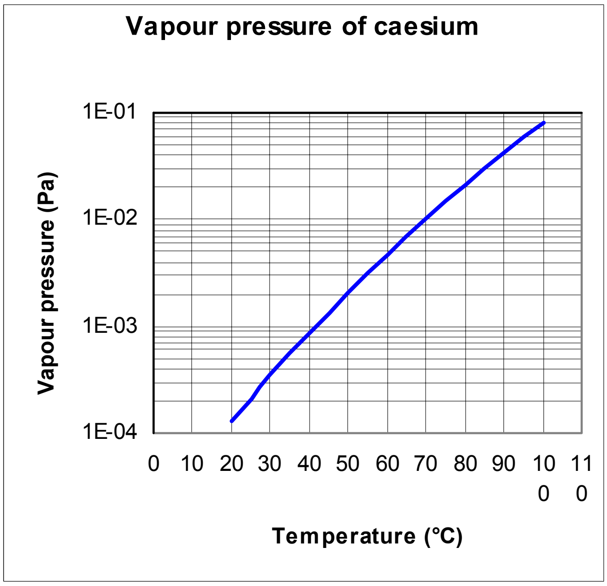

Figure 4

In order to understand better what happens to Cs injected into the ion source, when the ion source was opened after an experimental campaign it was examined carefully. The source itself was covered with what looked like a moist tungsten layer. In order to determine the percentage of Cs left in the source, it was cleaned with water, and the water kept for analysis. Initially the cleaning water was opaque, dark grey, but overnight it became clear with a grey precipitate at the bottom. Chemical analysis of the clear water showed that approx. 4.5 ± 0.9 g of Cs was inside the source when it was cleaned. The grey precipitate is presumed to be tungsten. As ≈ 5 g had been injected into the source since it was last cleaned, this shows that essentially all the Cs was still present within the source. This was unexpected as the Cs effect had started to disappear and evaporation and loss through h the accelerator apertures alone should have significantly reduced the quantity of Cs in the source. It is speculated that the Cs on the walls of the source was either covered by a layer of evaporated W or trapped in a matrix of W on the wall.

If the Cs is "buried", or "blocked", on the wall by W evaporated from the filaments, control of the evaporation of W could prove a key part in the operation of this source for high current density. The W filaments are operated between 2800 and 3000 K in order to obtain the required electron emission current density. At this temperature the evaporation of W from the filaments is significant: It is calculated that the W flux is sufficient to cover all the inner surface of the ion source with a monolayer of W in 125 s of operation.

It is proposed to reduce the operating temperature of the W filaments, reducing the evaporated W into the source. This could be achieved by operating at higher anode-cathode voltages and lower emission current, therefore reducing the filament temperature, or by operating with thoriated tungsten filaments, which would allow for operation at 2100 K with the required electron emission density [2].

CONCLUSIONS

- The KAMABOKO III ion source operates to the ITER specifications during short, 5 s pulses, i.e. the specified current densities of 200 A/m^2 D- and 280 A/m^2 H- have been accelerated and measured on a copper target when the source has been operated at the ITER specifications.

- A low H^- or D^- current density measured at the calorimeter on the MANTIS test bed during long pulse operation cannot be explained by lost accelerated electrons arising from either extraction from the ion source or creation by stripping in the accelerator and is attributed to poor transmission due to thermal loading leading to distortion of the acceleration grid. Operation with a new extraction and acceleration grid should alleviate this problem.

- The reduced PG temperature effect measured during long pulse operation could be partly explained by enhanced evaporation of Cs from the source walls at the equilibrium temperature reached during long pulse operation perturbing the dynamic balance between the arrival of Cs from the source walls and the evaporation from the plasma grid.

- The consumption of Cs is many times larger than expected, which may be partly explained by the increased evaporation from the “hot” source walls. However it is found that most of the Cs remains in the source even after it was expected to have been lost from the source. It is speculated that the Cs could be “blocked” on the walls either by burial under layers of tungsten evaporated from the filaments or by being trapped in a loose matrix of tungsten on the source walls.

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TW3-THHE-CCGDS1

Task Title: COAXIAL CAVITY GYROTRON AND TEST FACILITY Design, support to the industrial development and preparation of the technical specifications

INTRODUCTION

In ITER, Electron Cyclotron (EC) heating and current drive is foreseen not only as a principal auxiliary system for plasma heating and as assist for plasma start-up, but is considered essential in meeting the key requirement of neoclassical tearing mode (NTM) stabilisation. The main purpose of the task is to follow the development of this EC power generation system, for which a 2 MW CW coaxial cavity gyrotron at 170 GHz has to be developed, as well as the superconducting magnet, the High Voltage power supplies, the dummy load and the test facility.

2004 ACTIVITIES

The contribution of the Association Euratom-CEA to the Task TW3-THHE-CCGDS1 was in 2003 and 2004 the participation of one professional as an ‘expert’ to the different design review meetings.

In 2004, there was three meetings: two progress meetings in january in Garching and in june in Karlsruhe, and the final meeting in december in Garching.

Concerning the gyrotron development, the final technical specifications required for the supply contract were prepared and finalized in january. The supply contract between the European Atomic Energy Community and Thales Electron Devices was signed in may, for a total duration of 27 months, with the objective of the delivery of the so-called “coaxial cavity development prototype #1 at 170 GHz, 2 MW, 1 s” in november 2005 at the test bed in CRPP, for a period of nine months in site tests.

The contract negotiations with the selected company (Ansaldo Superconduttori) for the manufacture of the first superconducting magnet, started in march and the final agreement was reached in june. The contract between the European Community and the Supplier was signed in september for a delivery at the test bed in CRPP in november 2005.

The contract for both Main High Voltage Power Supply and Body Power Supply are to be signed by the European Commission at the end of 2004/ beginning of 2005. The planned delivery dates are respectively may 2006 and june 2006, followed for each PS by a delay of one month necessary for the integration at CRPP. For both power supplies, the delivery dates are after the commissioning of the gyrotron.

A temporary MHVPS will then be used for the beginning of the tests, at reduced specifications and without BPS.

The Contract for the High Voltage Solid State Switch was still in the negotiation phase at the end of the year, but this component is needed only for fast on/off modulation, and consequently not required for the first tests.

A spherical water load compatible with the RF power of 2 MW in short pulse duration has been developed by ENEA and should be delivered in time for the gyrotron tests. In parallel, the development of a CW 2 MW load is in progress.

CONCLUSIONS

The contract for the first gyrotron prototype has been signed in may 2004, this first prototype capable of producing an RF power of 2 MW during 1 s, will be delivered at the TEST bed in Lausanne in november 2005, for a test period of 9 months. The Contract for the manufacture of the prototype superconducting magnet was signed in september 2004, and will be delivered at CRPP also in november 2005. Due to the late signature of the contract for the two required High Voltage Power Supplies, they will not be available in time for the beginning of the tests of the gyrotron, an existing power supply in Lausanne will then be used during this phase. A short pulse water load will be available for the tests.

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TW3-THHI-GTFDS1

Task Title: FUSION DIACRODE, IC RF GENERATOR, IC POWER SUPPLY AN IC TEST FACILITY Design, support to the industrial development and preparation of the technical specifications

INTRODUCTION

Ion Cyclotron heating and current drive auxiliary heating method requires a Radio Frequency (RF) power source capable of an efficient continuous operation on a highly variable load, for future experiments in existing European fusion laboratories and for ITER operation.

High Standing Wave Ratio (VSWR) and RF power level are required for auxiliary heating operation in high confinement plasmas such as ITER-relevant high β plasma scenarios.

The RF power source consists of a three stages electronic tubes amplifier driven by a solid-state RF source. Although there is no problem to build low power amplification stages, no existing end stage is yet capable of the required performance. Therefore, the development of a new-generation of RF power sources is needed; it would be both a technical and a financial advantage if one single source could be developed in European Union (EU). Fusion laboratories and ITER could take benefit from it. The aim of this project is the construction by industry of a RF power source capable of the required performance.

In response to a European Fusion Development Agreement (EFDA) call of expression of interest, CEA offers to provide technical assistance to the EFDA development of the RF power source within the more general framework of a coordinated effort among European Associations, with CEA acting as the leading Association. In particular, CEA offers technical assistance as required for the industrial development and testing and full responsibility for construction and operation of a high power steady state test facility at Tore Supra (TS) Cadarache site.

A CCFW subgroup, including all interested Fusion Associations representatives has defined and agreed detailed technical specifications for a high power RF source. Everybody agreed that a technological step is required to meet the specifications of high power RF sources, which will be used on future fusion experiments as ITER, W7X, JET-EP or Tore Supra CIMES project.

The alternative using of a high power diacrode® leads to a simpler generator with less components for which maintenance and reliability appear more attractive. A call for tender has been done and EFDA is now ready to place an order for a prototype of RF high power source. The first step of the task is now completed, however, the task has been suspended as long as ITER negotiations haven't been completed.

CONCLUSIONS

Today, many parts of the task are completed. Technical specification have been written, a call for tender have been done and EFDA received an offer from the industry on july 2003.

The Technical Evaluation Group meeting took place on july 2003 and EFDA is now ready to place an order for the IC RF generator.

At the same time the ICRF system is a matter of negotiations for ITER. So EFDA decided on september 2003 to put on standby the ICRF generator R&D, pending the ITER decision, and to extend task TW3-THHI-GTFDS1 of one year till the end of 2005.

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