

## 8 ITER Systems

### 8.1 OVERVIEW

2009/10 saw significant progress on ITER. The platform (400m x 1000m in size) for the machine and the ancillary buildings was completed at Cadarache in the south of France, and is now ready for excavations and building to start in 2010. Fusion for Energy (F4E), the European domestic agency, which has to deliver the European 'in-kind' contributions to ITER, and is based in Barcelona, is expected to reach full complement during 2010 and has let some significant grants and contracts during the year for the European contributions 'in kind' to ITER.

As reported in previous Annual Reports, CCFE has been pursuing work on ITER in a number of areas of significance to the ITER diagnostic and heating systems in particular. Work so far has mainly been funded via F4E grants, where F4E provide approximately 40% of the funding, and the remaining 60% comes from the EPSRC block grant. CCFE has also pursued 100% F4E funded contracts together with 100% funded contracts from the ITER Organisation (IO) itself, and hopes to increase this contract work going forward (as it would release EPSRC funds for other work). Note that the work by CCFE for F4E and IO is included in this report for completeness, although formally it is not part of the work of the EURATOM / CCFE Fusion Association.

CCFE has continued its substantial role in four key ITER systems:

- Ion cyclotron resonance heating (ICRH) system;
- Neutral beam injection system;
- Core LIDAR Thompson scattering to measure the electron temperature and density profiles; and
- Core charge exchange recombination spectroscopy (CXRS) to measure the helium (ash) content, the ion temperature and flow.

CCFE has also won a number of other contracts during 2009/10 in areas such as neutronics (described below) and radwaste analysis, and the overall control and instrumentation. CCFE is also a third party to the French CEA for the detailed design of a representative port plug, and the diagnostic integration – this grant has direct relevance to the core LIDAR work as that diagnostic will use one of these ports to view the plasma. Overall, CCFE has won over 10 grants (either directly or with others) valued at around €10million in total. The following sections give further details of a number of these.

### 8.2 ION CYCLOTRON RESONANCE HEATING (ICRH)

ICRH involves the launching and absorption of high power radio waves that are primarily absorbed by ions, which are heated and then

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lose their energy in collisions with plasma ions and electrons, thus heating the plasma.

During 2009/10, CCFE has: led the CYCLE consortium that has successfully negotiated a grant from F4E; continued to develop the concept design, primarily in the area of mechanical engineering, and carried out R&D in support of the design process.

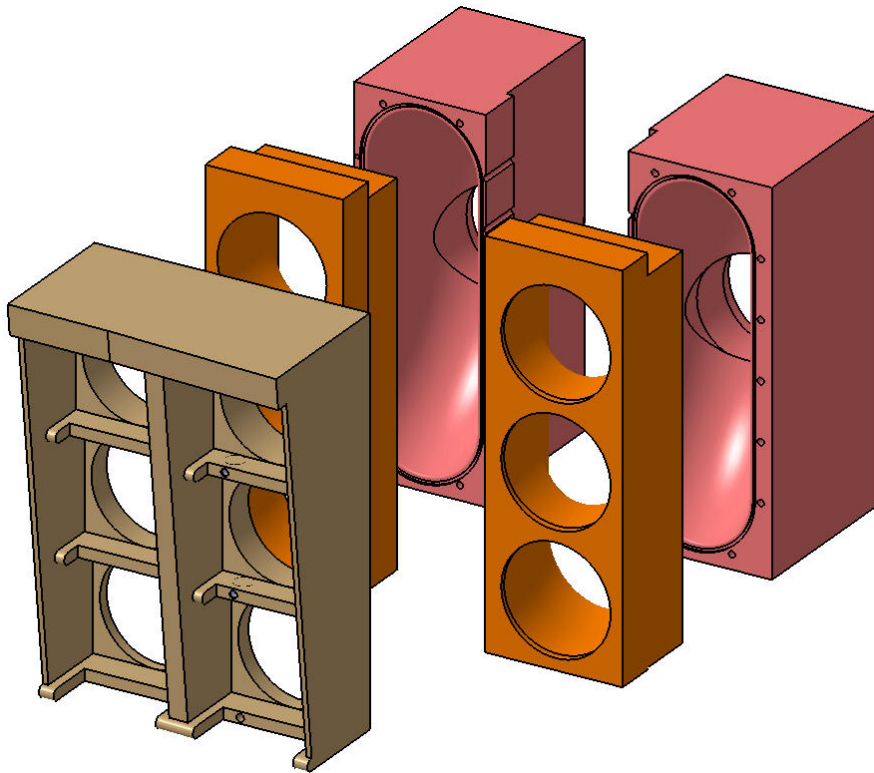
### **8.2.1 CYCLE**

A consortium of five European associations (Commissariat a l'Energie Atomique (CEA, France), CCFE, Ecole Royale Militaire (ERM, Belgium) Max Planck Institut fur Plasmaphysik, Garching (Germany) and Politecnico di Torino (Italy), CYCLE, has been formed to bid for ICRH activities, with CCFE as Lead Party and supplying the Programme Leader. During the last year this consortium submitted a bid against an F4E Call for Proposal for design activities on the ITER ICH antenna. Following a period of negotiation, this bid was successful, and the resultant multi-year grant, valued at €3.7million in total, started on 1 March 2010. The value of the work done by CCFE under this Grant is €1.7million. The consortium has also held discussions with both F4E and ITER during the year about the requirements for R&D to underpin the design grant.

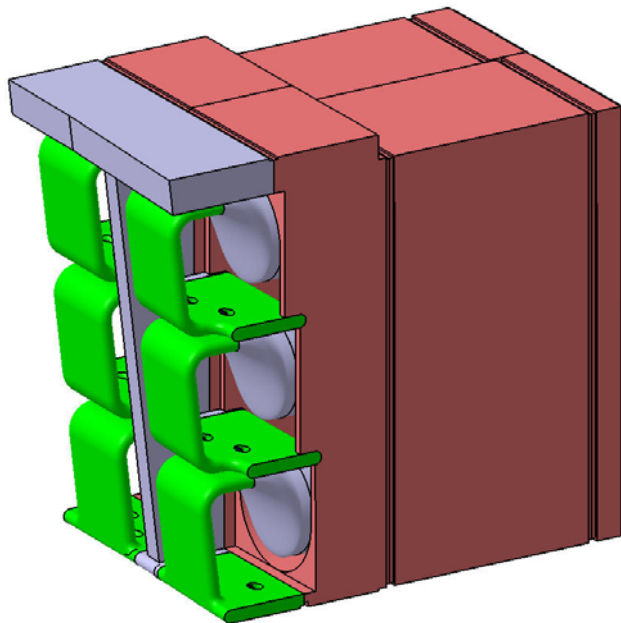
### **8.2.2 THE ITER ANTENNA DESIGN ACTIVITIES**

Although major design activities have been delayed due to the time taken to agree and place the design grant, the following design activities have proved possible during 2009/10:

- Optimisation of the RF straps has been carried out in conjunction with Ecole Royale Militaire in Brussels. This work has assessed the impact on coupling of tilting the straps and the options for handling the power levels incident on both the straps and the nearby housing;
- Revision of the section of transmission line that connects three straps to each feed line, the four port junction, has been carried out in conjunction with IPP Prague and Ecole Royale Militaire. The resultant design appears to have key advantages in terms of fabrication, and has allowed the housing change discussed below;
- CCFE has proposed modifications to the design of the forward antenna components. It was proposed until recently that the front section of the antenna that houses the key RF components could only be assembled using a 'clamshell' design (i.e. an axial split along the centreline), with consequent disadvantages in terms of possible RF current issues along the join between clamshell halves. The revised design, which utilises the revised four port junction discussed above, is now built-up in three radial sections, and should avoid the need for longitudinal seams.



**Figure 8.1:** Revised front housing design



**Figure 8.2:** Front housing quadrant assembled (including straps)

- The rear sections of the RF transmission lines within the antenna need to be removable in order to facilitate window exchange. The 2008/09 design required these sections to be

mounted as pairs, due to space limitations, with one window in each line having to be attached after installation of the antenna onto the ITER vessel. CCFE has carried out a re-assessment of design issues associated with this section of the antenna, leading to a provisional design that: (a) allows the lines to be separated; (b) includes both RF windows per line to be integrated into the removable section; and (c) simplifies the service stub that feeds water to the internal components on these removable systems;

- CCFE is assessing the feasibility of providing a short (3cm) range of shimming for the antenna. This is highly desirable from the perspective of optimising the conflicting requirements of maximising coupled power whilst maintaining an acceptable value of power incident on the antenna screen bars;
- In the 2008/09 design, it was concluded that the optimum choice of ceramic material for the RF window was beryllia. Following a request from ITER, the possibility for using alumina has been re-assessed. This has led to potential designs that can now be assessed by ITER.

All of the issues above are provisional, as formal design reviews with ITER had been postponed pending the award of the design grant. Preparations are now underway for a formal ITER review to assess the above issues.

### 8.2.3 R&D

Two R&D activities were completed during 2009:

- A contract to test two potential uses of honeycomb structures within the proposed antenna showed that: (a) honeycomb could be used as the basis for forming components such as straps, but that the robustness of the resultant strap will probably not meet ITER requirements; and (b) using boron carbide powder within such honeycomb structures to produce lightweight shielding panels does not appear viable;
- A second contract tested the feasibility of using diffusion-bonded (Printed Circuit Heat Exchanger) structures to achieve a water-cooled shielding system containing a high water fraction that can operate at ITER-relevant water temperatures and pressures. Figure 8.3 shows the resultant test pieces. These proved highly successful, and assessment of the wider use of such technology is underway.



**Figure 8.3:** Diffusion-bonded test pieces

### 8.3 NEUTRAL BEAM INJECTION

Two major areas of work related to the neutral beam systems have been progressed. In the first, CCFE is third party to the Italian RFX consortium for the design of components for the MITICA neutral beam test bed to be built in Italy. In the second, CCFE is the main party (with the Spanish CIEMAT association as a third party) for a grant to design the components which will integrate the neutral beam system with the ITER assembly.

#### 8.3.1 MITICA

An ITER Neutral Beam Test Laboratory is planned for Padova, Italy. MITICA (Megavolt ITER Injector & Concept Advancement) is one of two experiments which will be hosted there, and will be the prototype of the injectors to be used on ITER. The injector will be developed to emit a beam of neutral particles of deuterium accelerated up to 1MeV.

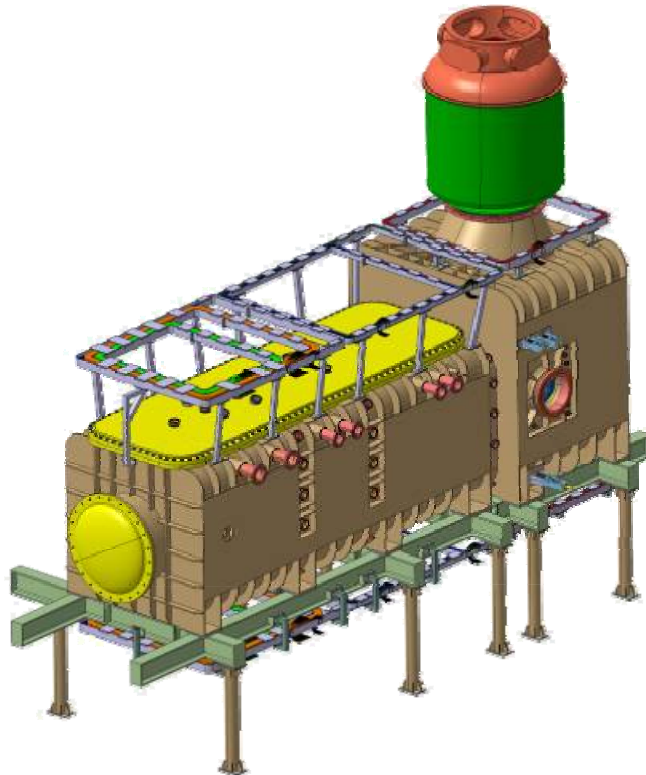
SPIDER (Source for Production of Ion of Deuterium Extracted from RF plasma) is the second experiment. It will concentrate on the development of negative ions and optimisation of the intensity and uniformity of production before MITICA starts operations (around 2.5 years before) and in parallel to MITICA operation.

CCFE is acting as third party to the Italian RFX consortium in the grant awarded by F4E for the design and follow up procurement activities for the laboratory. CCFE's responsibilities are limited to the MITICA experiment, and include:

- Engineering analysis and detailed design of the Electrostatic Residual Ion Dump (ERID) and Calorimeter beam line components (other components which had originally been within the scope, such as the beam source design, neutraliser, electron dump and exit electron power deposition tasks, have been suspended by RFX due to the design maturity);

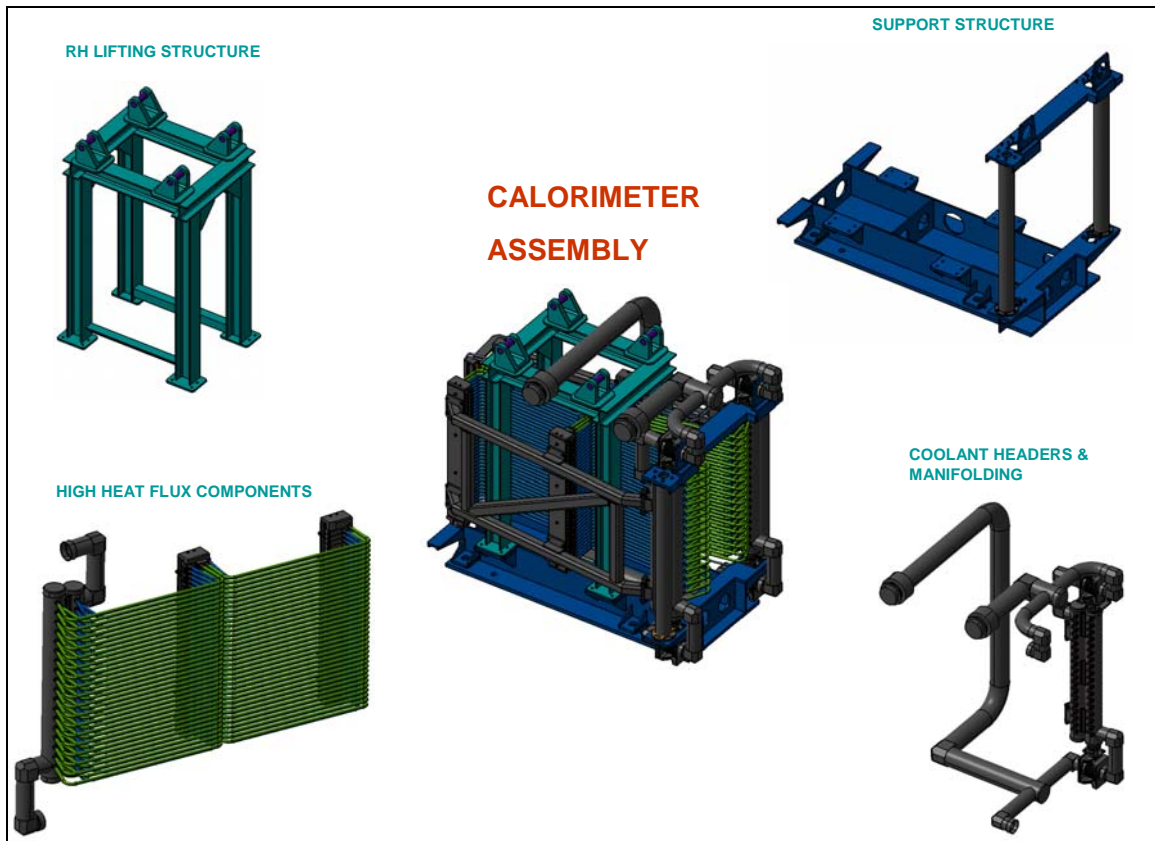
- Delivery of 3D CAD models and drawings to support Call for Tender activities;
- Delivery of a number of design substantiation reports including analysis, engineering design, procurement strategy, risk, assembly and installation.

Close integration with RFX is essential to ensure compatibility with the broader MITICA project. In addition integration with the other CCFE neutral beam project described below is required to ensure compatibility with the eventual beamline in ITER. Overall, the grant is valued at €1.5million to CCFE over two years.



**Figure 8.4:** Overview of the MITICA test facility (~15m in length)

The grant was awarded in November 2009, and the initial analysis of requirements is well underway, with a target to review with F4E and ITER IO at the end of May 2010. The preliminary design review is at the end of November 2010. Given the availability of resources and the tight project schedule, CCFE is planning to contract out some of the work packages within the Professional Engineering Services framework that CCFE set up a number of years ago.



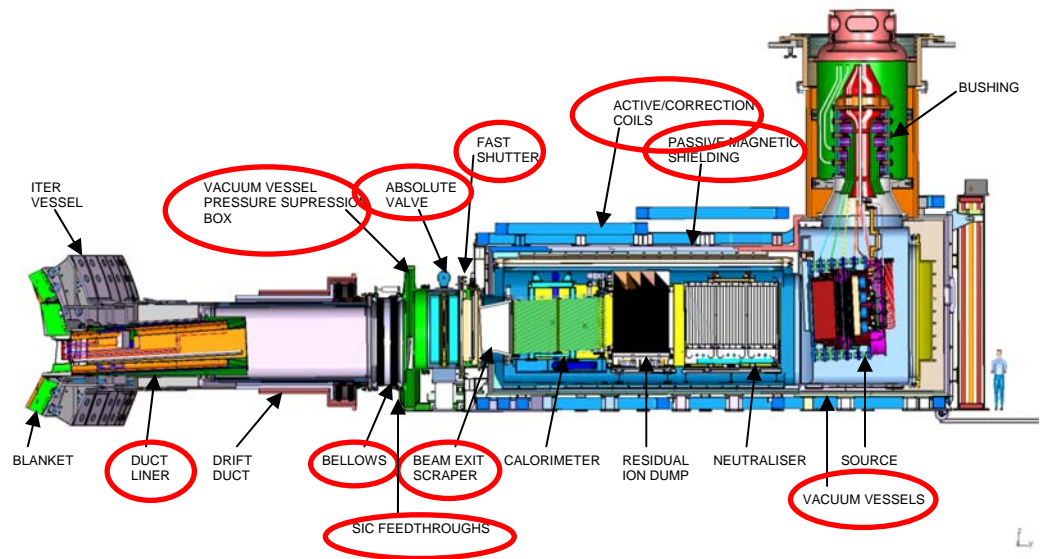
**Figure 8.5:** General arrangement of the MITICA Calorimeter

### 8.3.2 NEUTRAL BEAM INJECTOR DEVELOPMENT SUPPORT

The Neutral Beam system for ITER is composed of two Heating and Current Drive (H&CD) injectors and a Diagnostic injector (with the possibility of a third H&CD injector later). The system is based on the acceleration of negative ions and each of the heating injectors is designed to deliver 16.5MW to the plasma, giving a total of 33MW of power (with an additional 16.5MW if a third injector is installed).

CCFE, with CIEMAT as third party, won the three-year, €5.7million grant in December 2009 to design ten of the sub-systems required to integrate the Neutral Beam Heating system into the ITER assembly. These are shown on Figure 8.6.

Since the start date of 1 January 2010, CCFE has been gathering all of the relevant existing drawings and information from ITER and F4E, and significant progress has been made in outlining the procedures for configuration management, requirements analysis, interface management and others. The Development Requirement Documents for all of the sub-systems is due at the end of June 2010.



**Figure 8.6:** Overview of the ITER Neutral Beam heating system, with the integration sub-systems highlighted

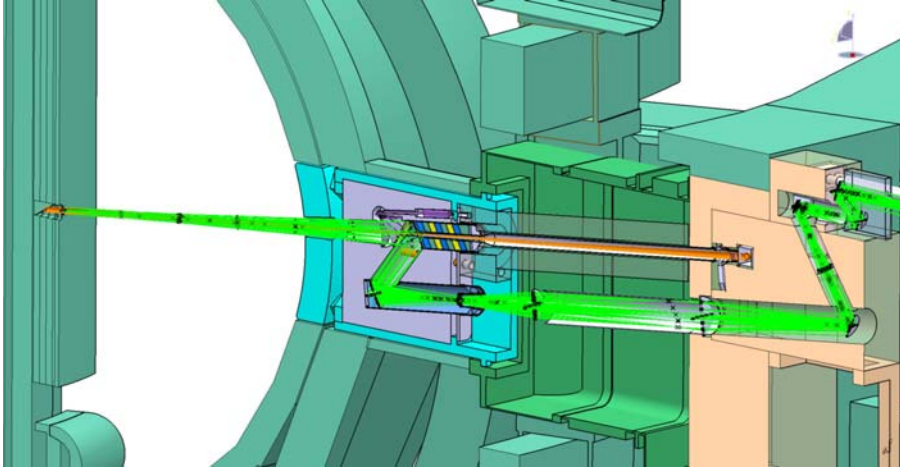
## 8.4 CORE LIDAR THOMSON SCATTERING

LIDAR Thomson scattering is a well known and utilised diagnostic technique for measuring the electron temperature and density profiles in the plasma. ITER will utilise a number of systems and as reported previously, CCFE has been pursuing work on the core LIDAR system for ITER over a number of years.

During previous years, an informal technical group of nine European organisations (both associations and universities) had been set up to work on a preliminary design study for the ITER LIDAR systems (submitted in late 2008). This informal group has now formed a consortium with CCFE as the Consortium Leader. The Chair of the Consortium Steering Committee is from the FOM Institute for Plasma Physics in the Netherlands, and CCFE has provided two of the key posts – that of Programme Leader and Programme Chief Scientist. This consortium aims to support the ongoing development of the ITER LIDAR system, and respond to F4E / IO calls as they arise.

During 2009/10 a key area of work was the preliminary optical layout of the complete system. This is shown in Figure 8.7. A 3D drawing of a proposed layout of the core LIDAR system from laser room to tokamak chamber has been produced. This drawing gives a design showing the use of multiple source lasers operating at two different wavelengths and combined using a scanning mirror based laser beam combiner. A combination of beam expanding telescopes allow a uniform laser profile to be imaged onto the ITER vacuum window.

A revised arrangement of mirrors in the collection path allow the neutronics target shutdown dose rate target to be achieved with a single Z-path focusing arrangement through the tritium window without the need for a second Z-path in the interport space.



**Figure 8.7:** Preliminary design of the core LIDAR optical layout (the tokamak vessel is on the left)

In addition, neutronics analysis (see below) of the diagnostic has been carried out. The analysis of the neutronic activation of the interport space, assuming only the configuration of the Core LIDAR part of the port, highlighted an issue with the activation of the stainless steel laser flight tube. This was controlled to be within target values for shutdown dose rate by minimising the wall thickness and providing extra concrete shielding of this tube and reducing the neutron flux from the port plug by using moderating and absorbing materials behind the plasma facing collection mirror.

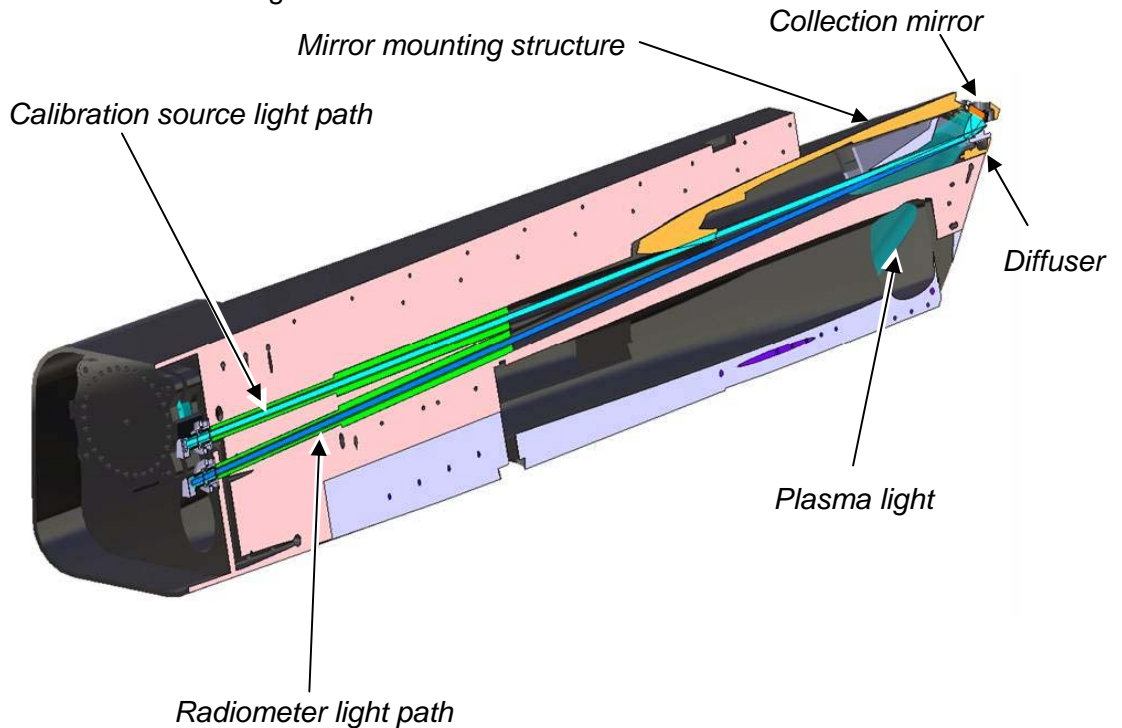
CCFE and its consortium partners expect grants and contracts for further work to be released during 2010/11, but are continuing some ancillary work in preparation in the meantime.

## 8.5 CHARGE EXCHANGE RECOMBINATION SPECTROSCOPY

ITER will be equipped with a diagnostic neutral beam (DNB), injecting 100keV hydrogen atoms. Electron transfer (charge exchange) from these hydrogen atoms to impurity ions in the plasma results in light emission from these impurities. Spectroscopic analysis of the emission line profiles yields the plasma ion temperature and flow speed. For analysis of the line intensities, to convert these to impurity concentrations it is necessary to know the relative sensitivity response of the diagnostic at different wavelengths. Furthermore, if the absolute sensitivity of the diagnostic is known, the intensity of Bremsstrahlung emission can be obtained and this used to calculate plasma effective charge. Both the absolute sensitivity and the relative sensitivity of the charge exchange system are expected to vary over the course of time due to progressive contamination and damage of the mirrors in the optical relay. This means that the diagnostic should

incorporate an in-situ calibration system which can be deployed between ITER shots to measure the response of the entire system. CCFE are designing a system for the in-situ calibration of the diagnostic which is compatible with the other optical components in the port plug.

The usual approach to calibrating a spectroscopic diagnostic makes use of secondary standard lamp sources which have themselves been calibrated against fundamental radiance standards. These tungsten filament lamps are used to illuminate a diffusing screen placed in the collecting path of the optical system being calibrated. A similar approach has been adopted by CCFE for the calibration of the ITER charge exchange system. However the situation is complicated by the fact that the diffuser must be located at the entrance of the optical system, close to the plasma, where its reflectance properties are anticipated to change under neutron irradiation. Therefore, the system being designed incorporates a calibrated radiometer mounted outside the ITER vacuum, viewing the diffuse emitting surface via a narrow duct. The use of a radiometer as the reference standard, rather than relying on an emission standard allows more flexibility in the method for illuminating the diffuser, perhaps permitting the source to also be withdrawn outside the ITER vacuum. However engineering and neutronics issues place constraints on the illumination and monitoring ducts. A cut-away diagram of one potential scheme is shown in Figure 8.8.



**Figure 8.8:** Cross section through the CXRS port. Light from the plasma enters at the right and is reflected from a mirror in the roof of the diagnostic. One of the two blue galleries provides a light path for illuminating a diffuser that is inserted into the input beam, the other provides for radiance monitoring of the diffuser surface brightness

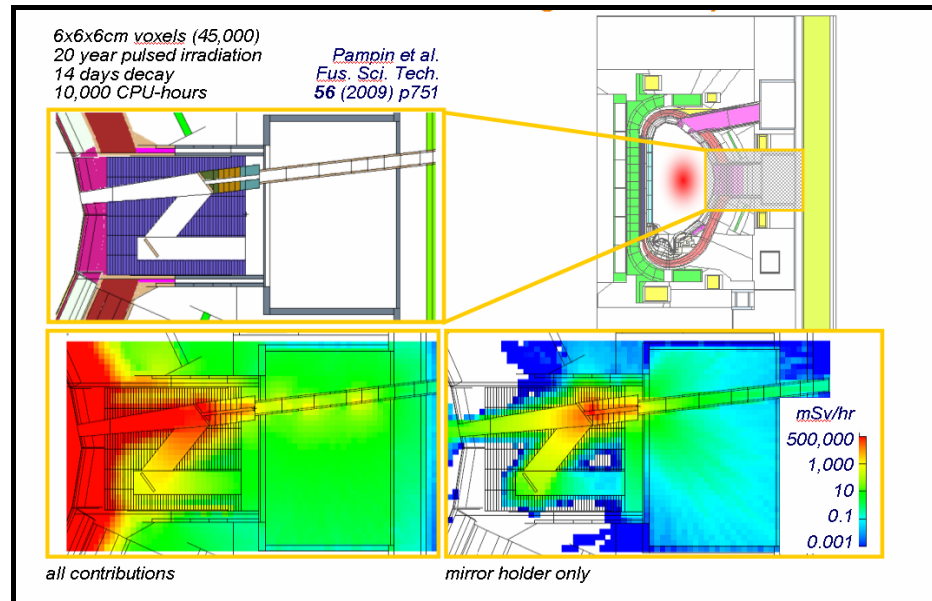
## 8.6 NEUTRONICS

During 2009/10, CCFE was awarded three different 100% funded neutronics service contracts by F4E and ITER. This resulted from the unique combination of expertise in and access to large parallel computing facilities and state-of-the-art fusion neutronics and nuclear data tools, codes and methods, available in the Neutronics and Nuclear Data Group. In particular, the use of CCFE's MCR2S software for high-resolution activation dose analyses has been in very high demand from F4E.

This is a summary of the work developed under these contracts over the last 12 months:

- In the *F4E framework service contract to provide engineering support in the area of nuclear analysis methods, models and code development*, CCFE has completed one task, with one nearing completion. Both tasks are related to the development of an accelerated neutron source for MCNP/ATTILA analysis of ITER systems;
- In the *F4E framework service contract to provide engineering support in the area of nuclear analysis of ITER systems*, CCFE has completed one task order on the activation and shutdown dose rate mapping of ITER alternative blanket concept and coolant using our in-house MCR2S software. One further task order on the activation and shutdown dose rate mapping of ITER EU Test Blanket Module systems using our in-house MCR2S software is underway. A paper reporting some of this work was presented at the ninth International Symposium on Fusion Nuclear Technology held in October 2009 in China;
- CCFE also has an ITER Organisation service contract to provide 3D neutronics and activation analyses supporting the radioactive waste management of ITER. Work is progressing, and CCFE is currently developing MCNP models to perform the first part of the task (neutronics analyses). Two deliverables have been completed on time so far.

In addition to this contractual work, and as part of the Contract of Association, groundbreaking work has been performed and is still ongoing in the area of acceleration techniques for fusion Monte Carlo radiation transport analyses. A paper on this issue was submitted to the 2010 conference of the ANS Radiation Protection and Shielding Division.



**Figure 8.9:** Example MCR2S results of shutdown dose rate for an ITER system (LIDAR)

## 8.7 FUTURE PLANS

CCFE now has a Grant and Contract portfolio of ITER-related activities stretching out to the 2012-13 timeframe, but has not yet allocated all of its projected EPSRC programme budget foreseen for this area. Our future activities over the next 12-24 months will seek to maximise the effectiveness of this budget, and will seek to complete our ITER contributions in those areas which have been our EPSRC-agreed targets for some time (the ITER LIDAR and ITER CXRS diagnostic systems), but where formal Grants and Contracts have not yet been placed. The F4E workprogramme for 2010 shows that they expect to compete these Grants in the third quarter of 2010, and CCFE and its partners will bid for this work.

In addition, we intend to move into Grant work on the first of our target areas for growth, as endorsed by the Fusion Advisory Board. This relates to Remote Handling Design for ITER, capitalising on the design skills and operational experience of the CCFE Engineering Department's Remote Handling (RH) team which has been responsible for the in-vessel RH design work on JET Shutdowns since 2000, and is currently completing the JET ITER-like Wall installation. CCFE has made a bid for a RH design Grant from F4E relating to the design of the Neutral Beam Cells at ITER, and a decision is expected in 2010.

We will also bid for 'follow-on' Grants in the areas where we are working, and for the 100% F4E contracts, which are expected to succeed these Grants when the detailed or 'Build-to-print' stages of the designs are reached.

CCFE also intends to seek to play a role in the Safety and Licensing activities of the ITER IO, where contracts are expected to be placed

in generating the 'Radiation Maps' for defining ITER maintenance and shielding policy following the device going active with deuterium-tritium fuel. This will require the neutronics and materials activation knowledge and skills which CCFE has already deployed on ITER work (see Section 8.6 above) and which is discussed in the chapter on Materials (see Chapter 7). Other work on tritium handling and dust mobilisation issues, for developing the ITER Safety Case, are expected to lead to contracts being placed to simulate, define, and measure the problems. CCFE's skills base should enable us to play a role here, perhaps in consortia with other players in the UK Nuclear area, such as National Nuclear Laboratory (NNL). Finally, and also possibly in one or more consortia, CCFE intends to seek a role in the modelling of ITER scenarios and the associated database infrastructure provision.