

8 ITER Systems

8.1 OVERVIEW

As reported in previous Annual Reports, CCFE has been pursuing work on ITER in a number of areas of significance to the ITER heating, diagnostic and remote handling systems in particular. 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 the main customer of our work, although some work has been performed for the ITER International Organisation ('ITER IO') itself.

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 gained 100% F4E funded contracts together with 100% funded contracts from the ITER 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 five 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;
- Remote handling system, in particular the design for the Neutral Beam Hot Cell.

CCFE has also won other contracts during 2010/11 in first wall design, and control and instrumentation and has continued contract work previously won in areas such as neutronics (described below) and radwaste analysis. There is also grant work on Plasma Scenarios, and some small efforts on Plasma Control system (as third party to the Italian CREATE consortium), and detailed design of a representative port plug (as a third party to the French CEA). Overall, CCFE has won over 10 grants (either directly or with others) valued at around €10M 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 lose their energy in collisions with plasma ions and electrons, thus heating the plasma. A consortium of five European associations,

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CYCLE, has been formed to bid for ICRH activities, with CCFE as Lead Party and supplying the Programme Leader. F4E awarded grant 2009-GRT-026 to design the ITER ICRH antenna to the CYCLE consortium on 1 March 2010, with funding through to the Preliminary Design Review due in February 2012.

Significant progress has been made in developing the design during the year, with a successful Conceptual Design Review passed in May 2010. CCFE contributions to these activities have included:

- Developing the 3D models using CATIA for key components (see Figure 8.1); most notably the front housing and the Removable Vacuum Transmission Lines;
- Proposing a system for allowing a 3cm in-vacuum movement of the antenna front face;
- Consulting with external experts to finalise both the choice of ceramic for the RF windows plus the R&D programme required to validate the material;
- Assessing the provision of services to the antenna, given the constraints set by space and engineering issues;
- Contributing to discussions on grounding and reflectometry systems that will be the focus of 2011/2 activities;
- Modelling of the performance of key components under mechanical loads and/or high heat fluxes, an example of this is shown in Figure 8.2;
- Providing the initial model for the flow breakdown within the antenna (a key design issue for this antenna will be the provision of the required water flow to all components);
- Deriving radiation doses at both the RF window and the rear of the port plug using the MCNP and ATTILA codes.

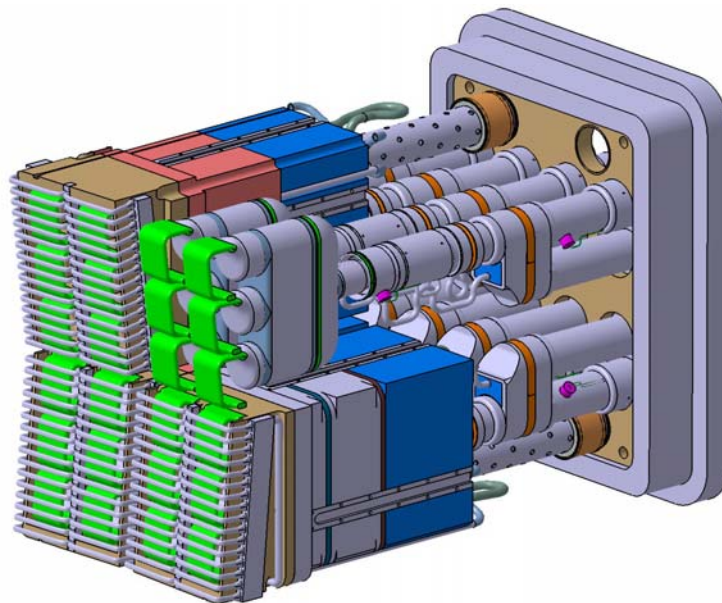
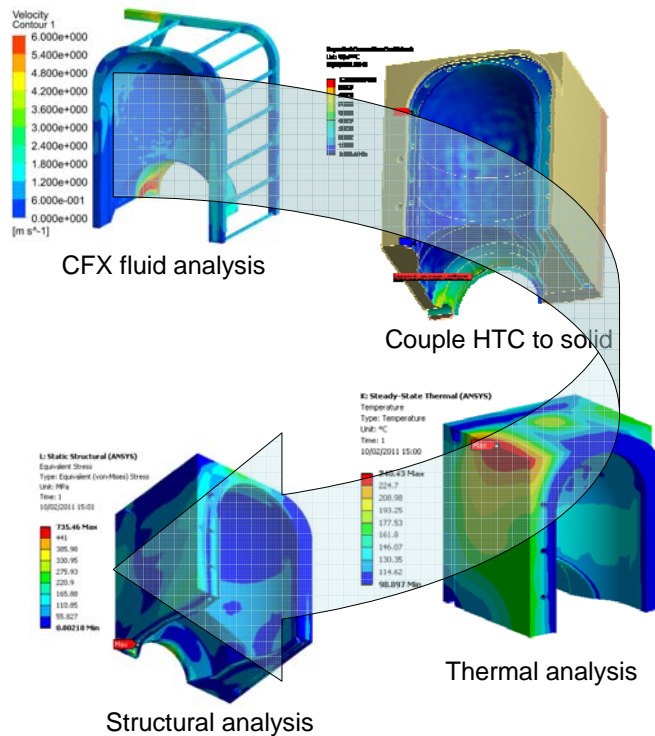


Figure 8.1: CATIA model of the Antenna design as at March 2011.

In addition, as the lead organisation in the consortium, CCFE has been responsible for the project management and for the introduction of a systems engineering approach for management of requirements and interfaces.



ANSYS Model of the Front Housing

Figure 8.2: Coupled ANSYS Analysis of the ITER Antenna Front Housing 1.

8.3 NEUTRAL BEAM INJECTION

Two major areas of work related to the neutral beam systems have been progressed. In the first, 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.

In the second, 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.

8.3.1 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 (see Figure 8.3).

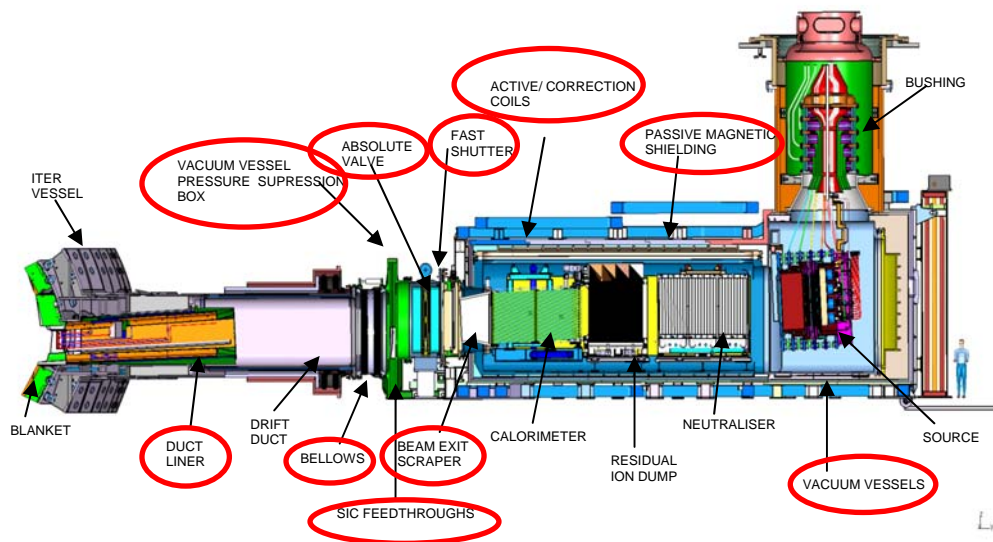


Figure 8.3: ITER Neutral Beam Heating System with integration subsystems highlighted.

The Grant is split into 3 phases:

1. Phase 0, Functional Specification development;
2. Phase 1, Development of conceptual and scheme designs;
3. Phase 2, Detailed design phase (including production of Build-to-Print drawings and technical specifications).

CCFE has now essentially completed Phase 0, with detailed functional specifications developed for all 10 components within the scope of this grant. In parallel, conceptual design activities have begun and significant progress has been made towards Conceptual Design Reviews (CDRs) scheduled for June 2011 (mid way through the three-year grant). As part of the conceptual design phase, the following activities have been completed:

- Initial concepts supplied by ITER (via F4E) have been base-lined and reviewed against performance, manufacturability and maintainability requirements;
- Alternative, improved concepts have been generated and evaluated to select an optimum solution to take forward to the CDR (see, for example Figure 8.4);

- Performance of the new concepts has been checked against many of the “normal” operating conditions.

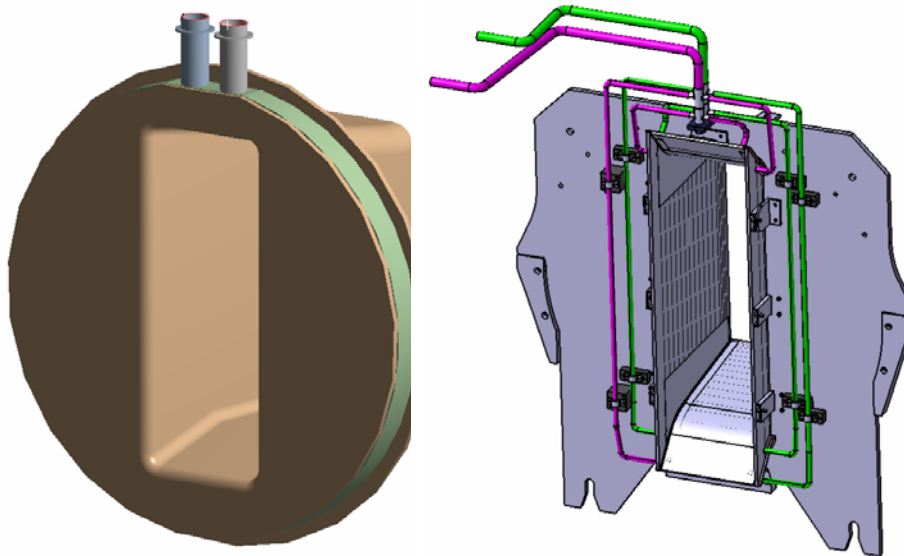


Figure 8.4: Improvements made to NB Exit Scraper concept.

The team are now compiling the presentation material and documentation required for the CDR and are reviewing it with the ITER IO and F4E technical responsible officers.

8.3.2 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 deuterium neutral atoms (flux equivalent to 40 A) accelerated up to 1MeV.

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 include:

- Engineering analysis and detailed design of the Calorimeter and Electrostatic Residual Ion Dump (ERID) beam line components (see Fig 8.5);
- Delivery of detailed 3D CAD models;
- Delivery of design substantiation reports covering design justification, description, analysis, manufacturing and assembly.

Close integration with the RFX team is essential to ensure compatibility with the broader MITICA project. In addition integration with the other CCFE neutral beam project described in 8.3.1 is required to ensure compatibility with the eventual beamline in ITER. Overall, the grant is valued at €1.5million to CCFE over two years.

This grant is due for completion 30th April 2011¹ and CCFE is on target to deliver the above scope by this date. Both the ERID and Calorimeter have been through extensive review and redesign activities, resulting in robust designs validated against all requirements set out in the customer functional specifications. This work relied on in-house expertise as well as external design consultancy supplied via the Professional Engineering Services framework set up by CCFE for this type of activity.

Key improvements to the original concepts include the following:

- Optimisation of the Calorimeter and ERID High Heat Flux surfaces;
- Assessment of both components against the ITER Design Code for all load conditions (including thermo-mechanical, structural, seismic, electro-magnetic and neutronics);
- Modifications incorporated to ensure compliance with all Remote Handling requirements;
- Full manufacturing / assembly assessments.

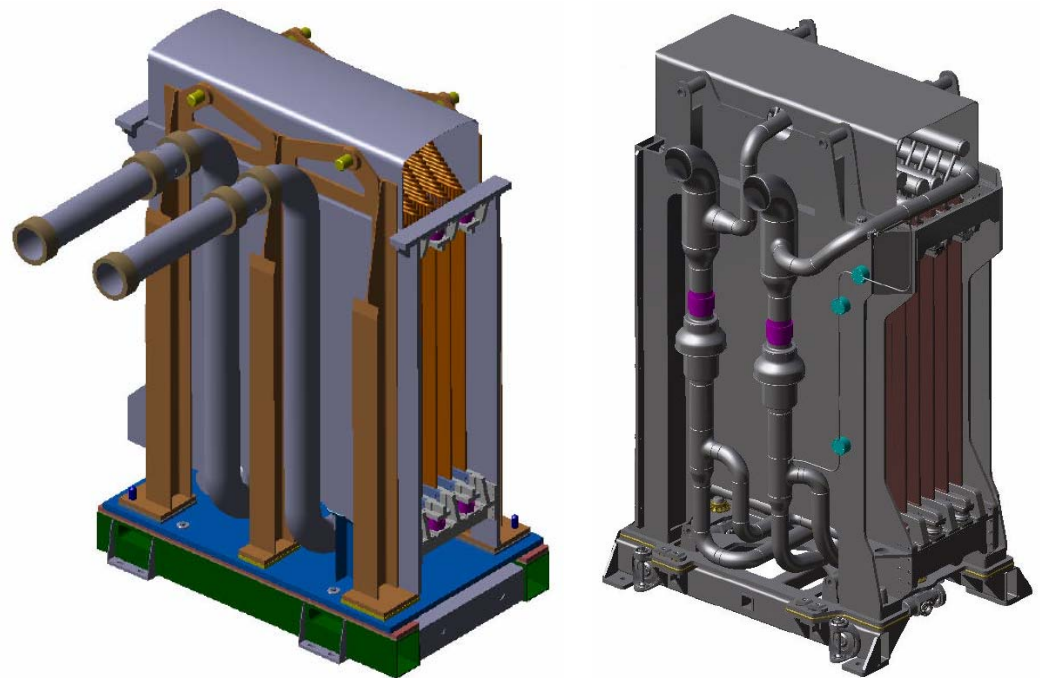


Figure 8.5: Development of ERID design (Original Concept vs CCFE Detailed Design).

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

¹ The original 24 month grant duration has been extended by six weeks to ensure a smooth handover to the follow-on grant.

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 formed a consortium² in 2010 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.

Funding arrangements for work on this diagnostic in the 2010/2011 period have been delayed due to organisational changes within F4E and IO. Currently CCFE is preparing for a contract looking at strategies to control risk and cost of the laser development strand as being an area of high cost, with a significant technical risk. The LIDAR format of the Thomson Scattering (TS) diagnostic (as used on JET) requires a very short (~300ps) laser pulse to achieve the desired spatial resolution (~7cm). The large size of the ITER plasma means that the solid angle of light collected is rather low compared to TS systems on many tokamaks. This together with the large number of optical surfaces required to transport the laser beam over the large distances in the torus hall and return the collected light to the spectrometer room, means that large energies are required from the laser (>3J) in order to give a statistically significant number of collected photons. The desire to be able to perform feedback control of plasma parameters using this diagnostic has also set a required pulse repetition frequency of this diagnostic of 100Hz. The combination of these three specifications for the laser source is beyond any commercial laser system currently available. Current high energy laser technology is based on flash pumped Nd:YAG systems. This technology is very mature and has a moderate record of reliability. Pushing the performance to the required level would significantly compromise reliability, while paralleling large number of lower power units to achieve the requirement would carry a very large cost. New technology, being developed for other large scale projects such as ELI, NIF, HILASE and HYPER, shows significant advantages with respect to flash lamp pumped technology for the achievement of the required laser performance. This new technology is based on high power diode laser pumped Yb:YAG disks. The upcoming studies will assess the merits of different strategies to see how well each align with the ITER installation schedules, operational regimes and running costs and F4E capital budget limits. Later in 2011, the European Core LIDAR consortium led by CCFE is expecting to bid for further work from F4E towards the Research and Development of this diagnostic within a Framework Partnership Agreement.

² The Consortium members are CCFE, CIEMAT(E), Consorzio RFX(I), FzJulich (D), HAS (Hu), IST(P), TNO/FOM (N), Univ of Cork (through Association Euratom/DCU)(Ir) and Univ of Basel (CH).

During 2010, various other unfunded tasks towards the optimisation of the TS diagnostic have been performed:

- i) Re-shaping of the collected light rays phase space distribution to reduce the size and cost of the collection relay optics;
- ii) Design of a low return laser beam dump (see Figure 8.6).

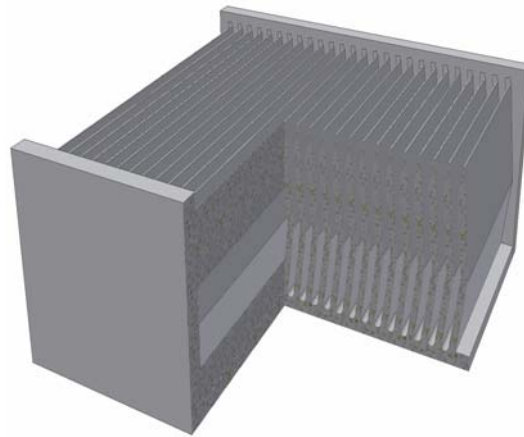


Figure 8.6: Potential laser beam dump design with obscured louvers.

8.5 CHARGE EXCHANGE RECOMBINATION SPECTROSCOPY

The primary role of the charge-exchange diagnostics on ITER is to use the light emitted from plasma helium ions which have charge exchanged with the neutral hydrogen atoms of the diagnostic beam to measure the concentration profile of the helium 'ash' in the plasma. However, these diagnostics are capable of providing many other important measurements, in particular ion temperature and plasma flow velocities. Since plasma flow has components in both the toroidal and the poloidal direction it would normally be necessary to have two observation directions in order to be able to separate these components. The edge charge exchange system, to be supplied by the Russian Federation ITER partner, does incorporate two viewing systems. However, the core-viewing charge exchange system was designed under the assumption that poloidal plasma flows in the core would be essentially zero, therefore this system is designed with only one set of observation optics. Recent experimental results have begun to challenge the assumption of zero core poloidal flow and so it has become important to assess the degree to which measurements from other diagnostics can be combined with the charge exchange measurements to obtain the total plasma flow vector. (The extra cost and difficulty in finding suitable port space for a second core-viewing charge exchange system make this an unrealistic option.) The additional information needed to resolve the flow vector would come from X-ray Doppler spectroscopy. This diagnostic has multiple sightlines, but it measures the spectral emission integrated along the

entire plasma depth traversed by these sightlines. The signals therefore require de-convolution before the local plasma parameters can be extracted and this de-convolution will tend to amplify any sensitivity differences between sightlines. Numerical simulations, as shown in Figure 8.7, show that by combining measurements from the two diagnostics, the uncertainty in the velocity components can be reduced by a factor of two or more, even compared to idealised measurements with the X-ray instruments alone.

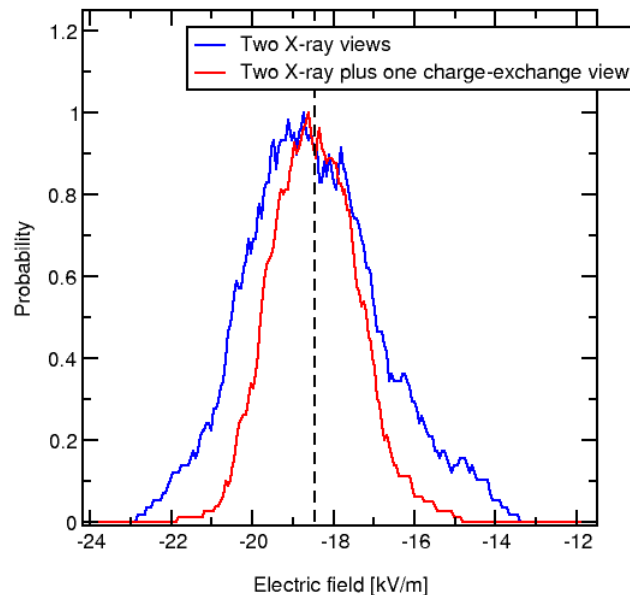


Figure 8.7: The results of simulating the measurement of plasma flow velocities using only X-ray measurements (blue) or with the inclusion of charge exchange measurements (red). Each row is a different position in the plasma. The plasma flows have been expressed as an equivalent electric field.

8.6 NEUTRONICS

Nuclear analyses are important to the design and assessment of ITER equipment and systems. Calculated parameters and applications are varied, but can typically include: neutron damage, dose and gas production for performance and lifetime analyses; nuclear heat rates for heat transfer analyses (i.e. cooling design); and activation, decay photon dose and radwaste arisings for safety and environmental studies.

During 2010, CCFE has continued work in three different 100% funded neutronics service contracts with F4E and ITER. These contracts were awarded in 2009 as a result of our unique combination of expertise in, and access to, state-of-the-art neutronics tools and parallel computing facilities. In particular, application of our flagship software MC-R2S for high-resolution activation dose analyses is still in very high demand by our customers. The analyses carried out also use the standard Monte Carlo simulation programme, MCNP, and the deterministic code, ATTILA. Below is a summary of the work developed under these contracts over the last 12 months.

- F4E-2008-OPE-02-01 framework service contract ‘Engineering support in the area of nuclear analysis of ITER systems’:
 - One completed task on activation and shutdown dose mapping of the European ITER test blanket module (TBM) systems using our in-house MC-R2S software. This work entailed the production of one of the most sophisticated and faithful MCNP models ever built using state-of-the-art CAD-based tools (see Figure 8.8);
 - One ongoing task, dealing with the optimisation of the TBM nuclear shield, which followed from the one described above. A paper reporting some of this work was presented at the 26th Symposium on Fusion Engineering (SOFT) conference.
- F4E-2008-OPE-02-03 framework service contract ‘Engineering support in the area of nuclear analysis methods, models and code development’:
 - One completed task related to the development of an accelerated neutron source for MCNP/ATTILA analysis of ITER systems. A paper reporting this work was also presented at the SOFT-26 conference.
- ITER/C4N/09/81/OLT service contract to provide 3D neutronics and activation analyses supporting the radioactive waste management of ITER. This work has been recently completed with the submission of the final deliverable. A paper on this issue will be published in the Fusion Science and Technology journal; and more conference presentations are intended in 2011.

Nuclear analysis work has also continued in support of CCFE’s involvement in ITER systems design work, such as ICRH and NBI, through F4E grants described in sections 8.2 and 8.3.

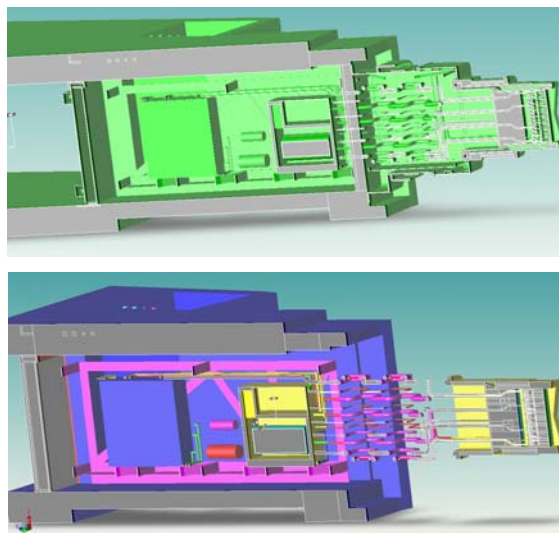


Figure 8.8: TBM systems CAD model (top) and 3D rendering of MCNP model (bottom).

8.7 REMOTE HANDLING DESIGN

CCFE was awarded a grant to complete the conceptual design of the remote handling equipment of the Neutral Beam Cell in ITER in October 2010. The neutral beam remote handling system consists of a series of two force-feedback manipulators and booms each deployed in four separate locations; special tooling for lip-seals, metal seals, pipe cutting and welding, electrical connectors; handling devices for diagnostics; a manipulation and transport system to handle and maintain the upper diagnostic plugs located in the cell; and manipulation and transport system for the neutron shield.

The main objectives of the activities under the present Grant are split into two tasks as listed below.

Task 1 requires to review, extend and complete the maintenance requirements of all the components located in the NB cell (NB injectors, diagnostic plugs and auxiliary components like mezzanine floor panels, passive magnetic shield etc). Task 2 requires to review, extend and complete the conceptual design of the set of RH devices identified so far, and to extend and complete the remote handling system design in order to cover all the above requirements.

The project budget is just over £1M of which around £421k will be funded by F4E and the remainder by EPSRC.

The project was originally scheduled to take 15 months but as a result of issues associated with the supply of contextual CAD data from ITER IO, there has been an agreed delay of eight weeks and the anticipated finish is now February 2012.

Task 1 has been completed for the heating neutral beams and is currently under review with ITER IO and F4E. Task 2 has been initiated with a particular focus on completing interface designs associated with the building. Accordingly initial seismic analysis has been completed on the beam line transporters and monorail crane. Examples of design concepts from the work completed so far are shown in Figures 8.9 and 8.10.

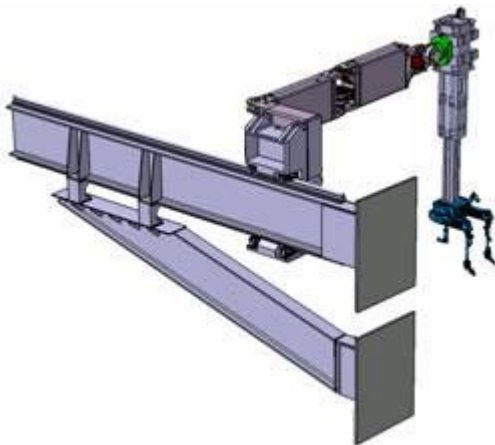


Figure 8.9: Image of the swing arm of the beam line transporter and manipulator for Heating Neutral Beamline number 1.

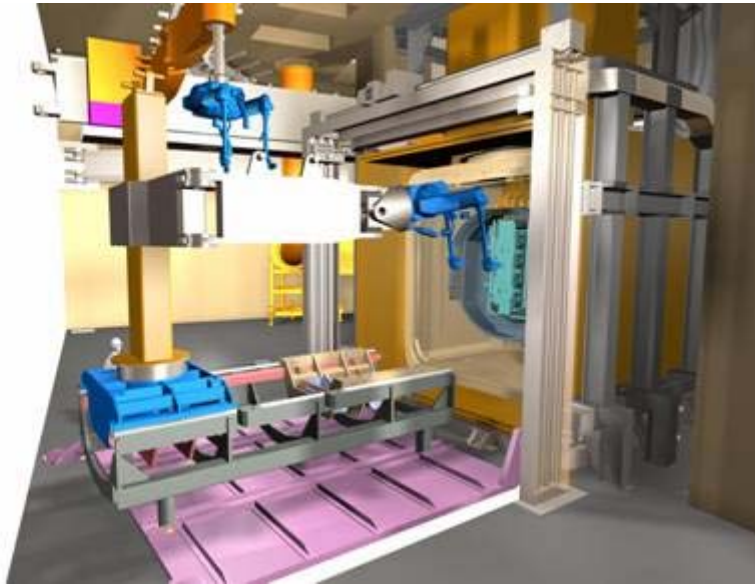


Figure 8.10: Image generated during the VR simulations used to validate the maintenance methodology of the accelerator source of HNB1 during task 1 of the project.