# Decommissioning Planning for the Joint European Torus Fusion Reactor

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## ABSTRACT

The Joint European Torus (JET) machine is an experimental nuclear fusion device built in the United Kingdom by a European consortium. Tritium was first introduced into the Torus as a fuel in 1991 and it is estimated that at the end of operations and following a period of tritium recovery there will be 2 grams of tritium in the vacuum circuit. All in-vessel items are also contaminated with beryllium and the structure of the machine is neutron activated.

Decommissioning of the facility will commence immediately JET operations cease and the UKAEA’s plan is to remove all the facilities and to landscape the site within 10 years. The decommissioning plan has been through a number of revisions since 1995 that have refined the detail, timescales and costs. The latest 2005 revision of the decommissioning plan highlighted the need to clarify the size reduction and packaging requirements for the ILW and LLW. Following a competitive tender exercise, a contract was placed by UKAEA with NUKEM Limited to undertake a review of the waste estimates and to produce a concept design for the planned size reduction and packaging facilities.

The study demonstrated the benefit of refining decommissioning planning by increasing the detail as the decommissioning date approaches. It also showed how a review of decommissioning plans by independent personnel can explore alternative strategies and result in improved methodologies and estimates of cost and time. This paper aims to describe this part of the decommissioning planning process and draw technical and procedural conclusions.

## INTRODUCTION TO THE JET PROJECT

JET is the worlds largest fusion experiment and currently the only fusion experiment in the world able to operate with a deuterium-tritium fuel mixture. The purpose of the JET machine was to study the physics of fusion and explore the practical requirements for achieving sustainable controlled fusion power.

The first JET plasma was achieved in 1983, five years after construction started, and the device was the first fusion facility in the world to achieve a significant production of controlled fusion power in 1991. This unique facility is now operated by the United Kingdom Atomic Energy Authority (UKAEA) for EURATOM under the European Fusion Development Agreement. Tritium was first introduced into the machine as a fuel in 1991 and it is estimated that at the end of operations and following a period of tritium recovery there will be a maximum of 2 grams of tritium in the vacuum circuit. The number of 14MeV neutrons will not exceed the lifetime neutron budget of $2x10^{21}$. The facility is still producing useful results that will be taken forward by the ITER project. ITER is the next step in fusion research that aims to show fusion could be used to generate electrical power. It is an international fusion research reactor that will be built in Cadarache, in France.

In April 2005 decommissioning of the facility became the responsibility of the newly formed UK Nuclear Decommissioning Authority (NDA) and under contract to the NDA, the UKAEA is well underway with preparation for decommissioning. The decommissioning will commence immediately JET operations cease and the UKAEA's plan is to remove all the facilities and to landscape the site within 10 years.

## THE PLANNING PROCESS

Work on the planning and preparation for decommissioning the JET facility is currently being undertaken by the Fusion Decommissioning Group in UKAEA Culham Division. The plans for the size reduction and packaging of the Torus form part of the overall lifetime plan of the JET site. Scope, schedule and costs are developed in detail using the UKAEA programme controls systems.

The UKAEA Company Work Breakdown Structure (CWBS) breaks down the programme of work into manageable components. The CWBS lists all work required to decommission the site and forms the basis for authorisation of work scope. The CWBS successively subdivides work scope into increasingly detailed and manageable subsidiary work components. It is a deliverable-oriented grouping of work elements that organise and define the total scope of a project.

The work breakdown structure for the site resides in a Primavera Project Planner for the Enterprise (P3e) database. P3e is the chosen UKAEA scheduling tool. Activities are entered into P3e, logic linked and scheduled to form the lifetime plan for the decommissioning of the JET site. In conjunction with the P3e scheduling tool the detailed scope of work and costs are captured in the UKAEA Scope Baseline Database.

The Scope Baseline Database is a UKAEA developed application used to define the scope of work against the work breakdown structure. It includes a basis of estimate module that allows the cost estimates to be defined that make up the scope of work for the various work breakdown structure elements. Users bound their scope of work for each activity and define the Basis of Estimate (BoE) detail cost make up within this database. The estimates are the base costs with no contingency.

The schedule data from P3e and budgeted cost from the BoE are integrated to produce a time spread BCWS (Budget Cost of Work Scheduled). Individual activities are assigned cost and schedule confidence factors. A Monte-Carlo analysis is performed, using the schedule and cost risk software PertMaster, to produce the 50% and 80% confidence values against each activity.

Good schedules and estimates are required to enable UKAEA to confidently plan for the decommissioning of the facility and to provide a robust baseline that underpins the NDA's national liabilities estimate, which is currently estimated to be £63billion.

## DESCRIPTION OF THE TORUS

The JET machine is a large tokamak device of approximately 15 metres diameter and 12 metres high. Figure 1 shows the JET machine (or Torus) in the Torus Hall and a cutaway view of the machine. The total mass of the JET machine and associated equipment is approximately 4,900 tonnes. The Torus comprises 5 main components (Figure 1):

- Vacuum Vessel;
- Toroidal Coil Assembly;
- Poloidal Coil Assembly;
- Transformer Core Assembly;

- Mechanical Structure.

## Vacuum Vessel

The vacuum vessel serves as the chamber within which the magnetically confined plasma can be brought up to fusion conditions. The vessel is constructed from Inconel 600 and Inconel 625 and consists of eight double-walled octants which are welded together to form the Torus. The vacuum vessel weighs ~100 tonnes.

Inside the vacuum vessel there is ~ 75 tonnes of equipment, including Carbon Fibre Composite (CFC) protection tiles, diagnostics and plasma heating and fuelling equipment. Figure 2 shows the main components inside the vacuum vessel. When the machine is decommissioned these components will be removed using remote handling equipment due to the high dose rates.

Beryllium is deposited onto the first wall components within the vacuum vessel using beryllium evaporators. Beryllium is used as a first wall coating material because of its excellent plasma facing material properties and low atomic number.

## Toroidal Coil Assembly

The toroidal magnetic field is produced by 32 D-shaped copper coils enclosing the vacuum vessel (Figure 1). Each coil weighs ~11 tonnes.

## Poloidal Coil Assembly

The poloidal field coils are horizontal circular coils, located outside the toroidal field coils (Figure 1). The main poloidal field coil (P1) is the inner coil wound round the central column of an iron transformer core, to act as the primary of the transformer. The P1 coil weighs ~119 tonnes. The other six copper coils are optimally placed to provide control of the plasma shape and position. The largest of these coils is 11 metres in diameter and weighs ~86 tonnes.

## Transformer Core Assembly

In common with other parts of the Torus, the general arrangement of the transformer core may be split into octants (Figure 1). Each set consists of one upper and one lower radial limb terminating in an arrow shape join with the others in the centre of the machine whilst linking at the other end by a vertical limb. All the limbs are laminated, being held together by thick steel side plates and insulated bolts. The centre of the transformer consists of two big upper and lower centre pieces, between which seven cylinders are stacked end-to-end to make the centre pillar. The transformer core assembly is mainly iron. The complete transformer core assembly weighs ~2,750 tonnes, over half the weight of equipment in the Torus Hall.

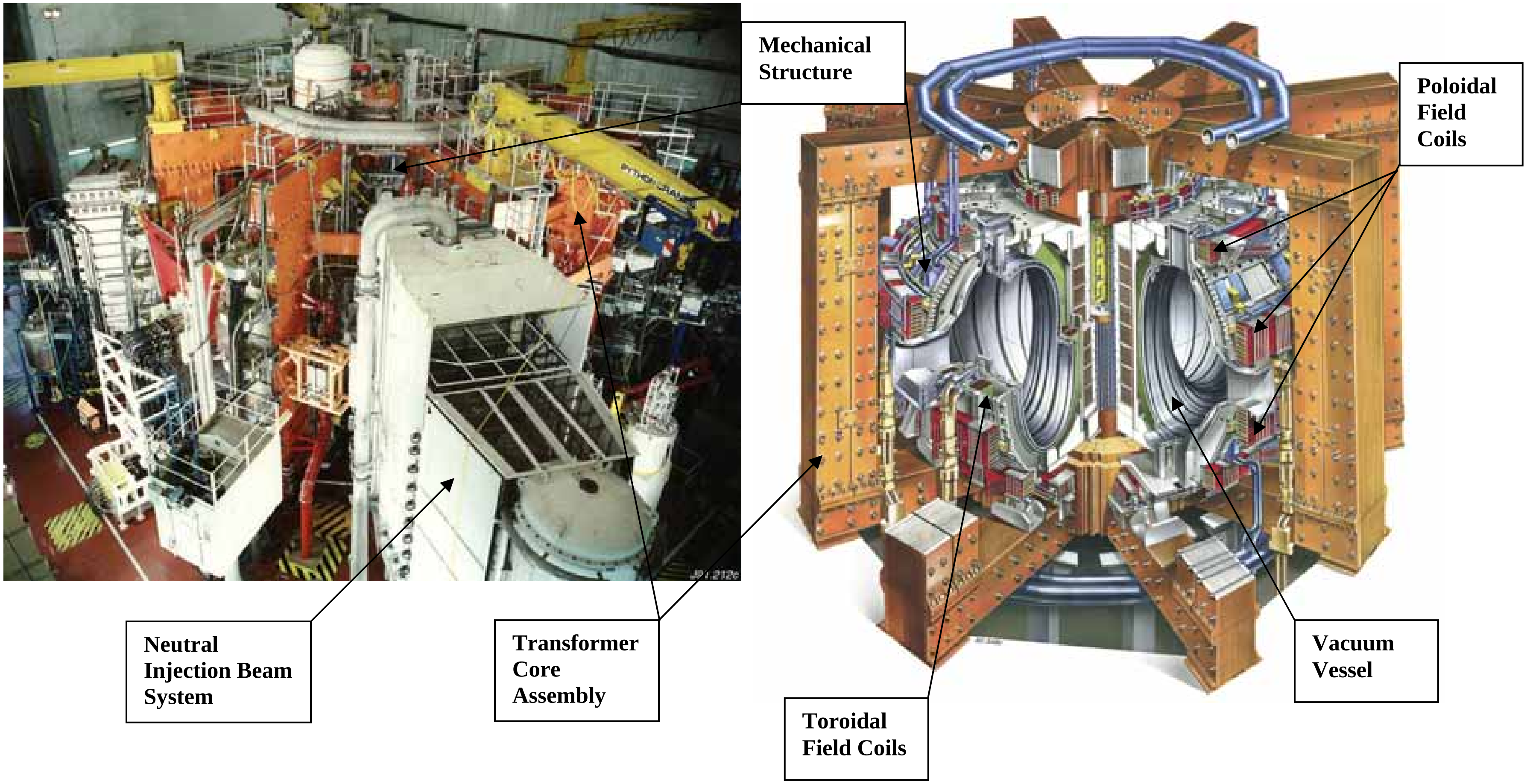

Figure 1. Construction of the JET Fusion Machine

### Mechanical Structure

The mechanical structure of the Torus is designed to provide resistance to the large forces produced due to the interaction of the electric currents and magnetic fields. The mechanical structure is shown in Figure 1. It is made up of two major components:

- Outer mechanical structure;
- Inner mechanical structure.

The outer mechanical structure comprises eight shell octants made from cast austenitic steel. The inner mechanical structure comprises the inner cylinder and the upper and lower torsion collar and collar assemblies. The inner cylinder is made from austenitic stainless steel plates.

In order to provide additional neutron shielding the external shell octants of the mechanical structure are filled with borated concrete, the borating agent being the mineral colemanite. The complete mechanical structure weighs ~520 tonnes.

## THE DECOMMISSIONING HAZARDS

The main hazards associated with decommissioning the Torus are the dose rates from neutron activated and tritium contaminated components and beryllium contamination.

### Neutron Activation

Normal operation at JET with deuterium plasmas results in a moderate level of neutron activation and, with careful neutron budgeting, does not greatly affect in-vessel work, operation in the Torus Hall or decommissioning. Operation with deuterium-tritium (D-T) plasmas has more serious consequences because of the increases in both the number and energy of the neutrons generated, which lead to higher levels of neutron activation.

Neutron irradiation of the Torus components will result in the formation of a wide range of radionuclides. The most predominant radionuclide from a radiation standpoint will be Cobalt-60 ($^{60}$Co) with a half life of 5.2 years. Although $^{60}$Co is a relatively weak beta emitter, it also emits relatively strong gamma rays. It is therefore primarily, an external hazard.

Approximately $2.5 \times 10^{20}$ 14MeV neutrons have been produced from experiments conducted at JET to date. The central planning assumption for the project is that the 14MeV neutron production will not exceed $2 \times 10^{21}$ for the operational life of JET.

Calculations have been performed to model the neutron transport throughout the JET installation using MCNP$^{TM}$, a Monte-Carlo particle transport code. A very detailed computer model of the Torus, the Torus Hall and associated additional heating and diagnostic systems has been created. 50 Activation foil packs were placed in the Torus Hall prior to the deuterium-tritium experimental campaign in 1997 to assess the computer model. Each foil pack consisted of seven to nine foils which were retrieved at the end of the deuterium-tritium experimental campaign and assayed for gamma activity. A comparison of calculation and measurement has been used to derive a semi-empirical technique for the determination of neutron activation levels throughout the Torus Hall. The technique can determine the neutron activation level at any point in the Torus Hall to within a factor of two. The same model has been used to estimate the gamma dose inside the vacuum vessel which arise from activation of the machine itself. These have been compared with health physics measurements and agree to within the experimental and calculational error bars (~20%) [1].

To assist with the decommissioning planning estimates have been made of the dose rates from the Torus following the cessation of the JET experiments. Following a lifetime neutron production of $2x10^{21}$ 14MeV neutrons it is estimated that the in-vessel dose rates will have dropped to 350µSv/hr six years after the final experiment. At these dose rates manual access will only be allowed for short periods of time. Dose rates in-vessel drop to 15µSv/hr after 25 years of decay [2]. (+/-20% uncertainty with the estimates). The decommissioning of the in-vessel components is therefore planned to be undertaken remotely following a period of tritium recovery from the vacuum circuit.

Estimates have been made of the dose rates from individual components that would be removed from the vacuum vessel [3]. There are a number of different materials in-vessel, including Inconel, copper and CFC. Of the components assessed the saddle coil assembly (Figure 2), which is made from Inconel, was estimated to be the source of the highest dose rate. After 1 year of decay the contact dose rate from the saddle coil was estimated to be 2mSv/h. The dose rate at 1m was estimated to be 65µSv/h. After 2 years of decay the dose rates were estimated to be 850µSv/h on contact and 28µSv/h at 1m.

Dose rates from a single octant, comprising 1/8th of the vacuum vessel, 1/8th of the mechanical structure and 4 toroidal field coils were estimated to be 164µSv/h at 1m after 1 year of decay and 79µSv/h at 1m after 2 years of decay.

Although the predicted dose rates are not very high (especially when compared with other operations / decommissioning projects within the UK), the significance here is that the time required to size reduce these items could lead to significant operator doses being incurred.

In terms of size reduction it is the doses from a single octant that is likely to be the most significant. Fortunately size reduction using hand held tooling is not practical given the size of the octants. Although some manual intervention will be inevitable e.g. the taking of samples for waste characterisation, the majority of the size reduction will be carried out semi-remotely.

## Tritium

Tritium is used to fuel the fusion reactions at JET. It is the only radioactive isotope of hydrogen and a low energy beta emitter. The biological hazards arising from exposure to tritium differ markedly depending on the form of tritium and the pattern of exposure. The patterns of exposure are:

- Inhalation;
- Skin uptake;
- Ingestion.

The majority of the tritium contamination in the torus hall is inside the vacuum vessel. Three mechanisms have been identified in current tokamak experiments which are responsible for in-vessel sequestration of tritium: i) surface saturation of the plasma facing first wall components, ii) diffusion into the bulk of first wall components and iii) re-deposition of eroded carbon with incorporation of tritium into the deposited film. Of these, the highest contribution arises from re-deposition. Within the vacuum vessel, where the plasma interacts with the CFC (carbon fibre composite) tiles, carbon is being eroded and re-deposited in the bottom of the vessel. The average tritium activity of the dust and flakes in the bottom of the vacuum vessel is estimated to be around 1TBq/g [4].

The CFC tiles that line the inside of the vacuum vessel (Figure 2) will also be significantly contaminated with tritium, but not to the same extent as the dust and flakes. Tiles that have been in the vacuum vessel

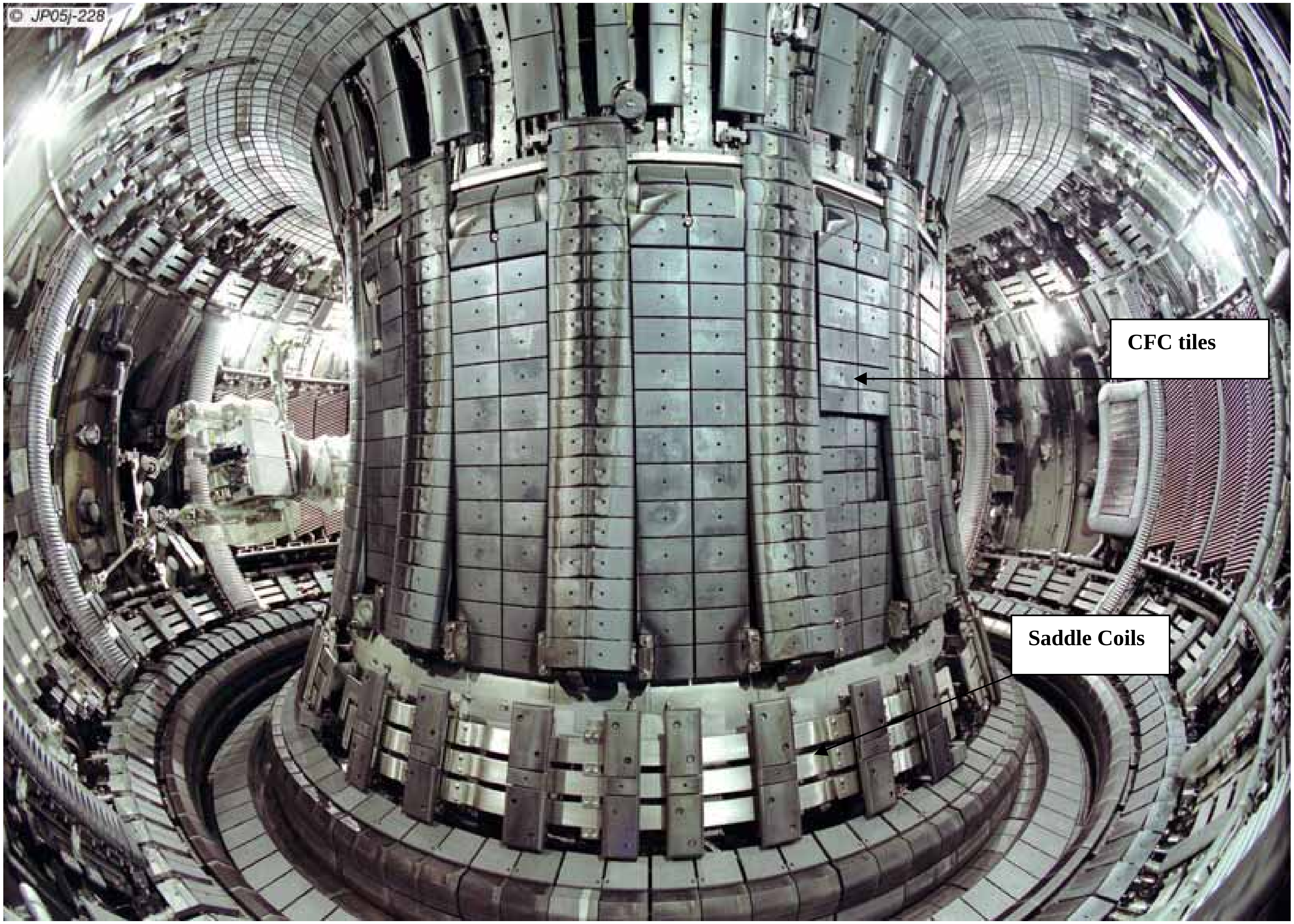

**Figure 2. – Internal components within the Torus**

during the previous deuterium-tritium experimental campaigns and removed for analysis have tritium contamination levels as high as 97GBq/tile (~20MBq/g).

There are much lower levels of tritium contamination in the external structure of the Torus. Samples of metal filings from the external steelwork at octant 2 have been analysed for tritium, by full combustion, and were found to be 8Bq/g. Scrapings of paint, also from the steelwork at octant 2, have been analysed and found to contain 23Bq/g of tritium contamination. Although these are very low levels of tritium contamination they are still above the lower threshold for LLW, which is 0.4Bq/g.

### Beryllium

Beryllium is used to coat the plasma facing components in the vacuum vessel. Beryllium is a grey to silver coloured metal, notable for its lightness in weight, high tensile strength and corrosion resistance. Beryllium and its compounds are highly toxic. Exposure is dominated by the inhalation pathway.

The levels of beryllium on the vacuum vessel surfaces are in the order of a few $mg/m^2$.

## SIZE REDUCTION AND PACKAGING CHALLENGES

An overall strategy for decommissioning the JET facility has been developed through a number of option studies. The preferred "early start" decommissioning option that resulted from this process was detailed within a study published in 2005 [5]. This study identified the need to refine the detail of the size reduction and packaging aspects of decommissioning the Torus and associated equipment since this could have a major impact on project risk, time and cost. Following a competitive tender exercise, a contract was placed by UKAEA with NUKEM Limited to undertake a review of the decommissioning waste estimates and to produce a concept design for the planned size reduction and packaging facilities for the previously estimated 560 te of ILW and 4150 te of LLW. The output of the study was to include:

- Identification of suitable size reduction and packaging equipment.
- A concept layout and location of the size reduction and packaging area.
- A costed plan for the design, procurement, installation and commissioning of the size reduction area.
- A detailed operational programme for size reduction and packaging.
- Identification of the number and type of waste packages.
- A costed plan for the decommissioning of the size reduction area.

### Waste Packaging & Disposal Constraints

Within the UK there is currently one shallow disposal facility for Low Level Waste (LLW) that can accept radioactive waste up to specific activity limits of 12 GBq/te $\beta\gamma$ and 4 GBq/te $\alpha$. The waste must be packaged in sealed ISO containers with a net mass limit of 32 te and has a significant disposal cost per cubic metre. There is currently no facility for disposal of waste with a higher activity (Intermediate Level Waste - ILW). This waste must be stored until a suitable national facility is built. The budget cost for disposal of ILW is an order of magnitude greater than LLW. The resulting total waste disposal budget cost is therefore a significant proportion of the total decommissioning cost, so in addition to environmental drivers, there is a strong financial driver to minimise waste classification and volumes.

The preferred package for storage, transport and disposal of the ILW is a shielded "2 metre" box. With 100mm of concrete shielding this has internal dimensions of 2.226m x 1.757m x 1.845m, and a nett mass capacity of 13 te.

The bulk of the waste generated during JET decommissioning will arise from dismantling the large metal items that make up the main Torus and the ancillary plant. Efficient packaging of these materials into waste containers is essential due to the high cost of the disposal of ILW and the capacity limitations in the UK for the disposal of LLW. Safe and cost-effective size reduction is therefore an important aspect of the future decommissioning and waste management operations at JET.

## Range of Components

A review of the estimated decommissioning waste resulted in a total of 500 tonnes of ILW and 4883 te of LLW. The major items with their size, mass and waste classification are stated below (Table I).

**Table I. Major Components of the JET machine requiring size reduction and packaging**

| Component | Size | Mass [tonnes] | Material | Waste Classification |
|---|---|---|---|---|
| Vacuum Vessel | 8 Octants each 4.8m x 3m x 3.5m | 100 | Inconel 600 Multi-layered construction | ILW<br>Tritium, Beryllium and Activation products |
| Outer Mechanical Support Structure | 16 Segments each 6.4m x 2m x 0.6m | 350 | Cast steel and boronated concrete | ILW/LLW<br>Activation products and tritium |
| Inner Mechanical Support Structure | Central tube and top/bottom rings 8m x 6m dia | 170 | Stainless Steel and Cast Iron | LLW<br>Activation products and tritium |
| Poloidal Coils | 7 off up to 11m dia x 1m high | 410 | Copper and insulation | LLW<br>Activation Products and tritium |
| Toroidal coils | 32 off 5.6m x 3.8m x 0.34m | 350 | Copper and insulation | LLW<br>Activation Products and tritium |
| Transformer limbs | 16 off 9m x 1m x 1m<br>16 off 6.6m x 1.4m x 1m | 2750 | Steel plate and insulation | LLW<br>Activation Products and tritium |
| Neutral Injection Beam | 3 off 9.5m x 3.7m x 3.7m | 450 | Stainless Steel Iron, Ceramic, aluminium | LLW<br>Activation Products and tritium |

The balance of 800 tonnes comprises smaller items and material such as electrical cable that can be size reduced by standard equipment as required and used to fill voidage within the waste packages.

## Size Reduction Requirements & Technologies

A general review of available and proven size reduction technologies was applied to the range of materials and geometry of the major components that comprise the JET machine.

The relative benefits and disadvantages were considered against the following criteria:

- The range of and complexity of the materials and components to be cut.
- Their ease of deployment (remote and manual) and maintenance.
- Their suitability for cutting tritium contaminated components.
- Their suitability for cutting beryllium contaminated components.
- Their overall cost and work-rates.
- Secondary waste generation.

## Water Cutting

Water-jet cutting is a well established technique that has been used in the clean-up and decommissioning of fuel storage ponds. The issues of secondary waste disposal (including tritium and beryllium contaminated water) and the potential spread of contaminated water make this technology inappropriate for JET wastes.

## Hot Cutting

The previous decommissioning study had assumed that hot cutting would be used for size reduction of major ILW components. Hot cutting tools (e.g. petrol-oxygen, oxy-propane, and plasma-arc) have been successfully deployed to cut activated and contaminated components on the Windscale AGR (WAGR) and the SGHWR at Winfrith and at various sites in the USA. Although relatively quick and effective, these techniques tend to spread contamination and produce gaseous fumes and airborne particulates that present significant challenges to ventilation and filtration plant. Equipment such as HEPA filters, electrostatic precipitators and pulse-clean filters are available to remove the fine particulates generated, but it needs careful design in order to avoid large volumes of secondary wastes. Problems were encountered at Savannah River where plasma cutting fumes severely reduced the efficiency of the ventilation plant and the tritium removal plant [6]. Similar problems could arise at JET and it was concluded that hot cutting technologies for ILW / beryllium contaminated items would increase project risk. In addition it is not possible to utilise hot cutting techniques to size reduce large electrical coils (e.g. the poloidal and toroidal field coils and the pumped divertor coils) due to the high thermal conductivity of the copper.

The most activated components are the irregularly shaped vacuum vessel and mechanical support structure. These will need to be cut remotely, so for hot cutting some form of profile-following mechanism for the cutting head would be required. Although mechanised profile following would be achievable it would add significant complication and therefore risk. These risks without significant potential benefits led to the rejection of hot cutting methods in favour of "cold cutting" for the major ILW components.

The size reduction of large, low activity, components such as the inner mechanical support structures and the vacuum tanks of the Neutral Injector Beam (NIB) assemblies (Figure 1) is where plasma cutting might be considered. The octant 8 NIB is used to inject tritium into the plasma and will probably be too tritium contaminated for hot cutting. The octant 4 NIB is used to inject deuterium into the plasma and hot cutting techniques may be appropriate here. However, the costs and complexity of installing additional containment, ventilation and off-gas treatment systems to support hot cutting outweigh any potential benefits, so cold cutting was also recommended for these items.

## Cold Cutting

Cold cutting encompasses a wide range of technologies and equipment, many of which have been used successfully in nuclear applications remotely, semi-remotely and manually. It is not intended to provide detailed descriptions of these within this paper. Instead, the following paragraphs give a short overview of the candidate size reduction equipment for the major components from the Torus.

Successful size reduction of the majority of the Torus components will require equipment capable of cutting massive items. Candidate processes include the use of fixed-bed saw installations (e.g. band saws) and diamond wire sawing. Band saws are available to cut solid, laminated and hollow items of up to 2m x 2m in section. Machines can be supplied with integrated material handling systems such heavy duty roller conveyors to improve operability. Although band saws share many of the advantages offered by diamond wire saws, they are less versatile in terms of the geometries they can cut efficiently. Challenges also arise when a blade encounters changes in the cross-section, which can increase vibration and movement of the cutting piece. However, large, solid items such as the transformer limbs and the coil assemblies are simple shapes that are suitable for band sawing. Cutting speeds would be relatively slow. For example, it is anticipated that it will take approximately 6 hours to complete a cut through a transformer limb (1m x 1m).

Diamond-wire saws have fewer restrictions than other kinds of cutters, thereby making them versatile for cutting hollow items, complex and irregular shapes and extremely thick sections. They allow multi-cutting action, are very effective in terms of cutting efficiency and can cut metallic and non-metallic components such as concrete, plastic and composites. Other benefits include low swarf generation, low risk of flying debris and cutting is controlled away from the work-piece. Nitrogen cooled and water cooled systems have been used in heavy duty cutting applications. Cutting rates are similar to those achieved by large band saws. Although set up times are longer (up to an hour), most of this is spent at some distance from the work-piece so dose uptake should not be a significant issue. The TFTR experimental fusion reactor at the Princeton Plasma Physics Laboratory (PPPL) was successfully cut using a diamond wire saw.

## Size Reducing of Smaller Items

A large quantity of electrical cable will be recovered during decommissioning. Approximately 65 tonnes of these may be contaminated with tritium, but it is anticipated that this will be limited to the insulation. The copper was recovered from contaminated cables at INEEL by using an automated process to remove the contaminated insulation [7]. Sampling and monitoring confirmed that the copper was exempt waste and it was recycled. The contaminated insulation entered the LLW stream. It is recommended that this process is used at JET if it can be established that the copper is likely to be exempt waste.

Portable hydraulic shears are available that will rapidly cut stainless steel piping and conduit measuring up to 75mm in diameter. They produce very little secondary waste other than worn blades.

The large volume reductions achieved by super-compaction is a key aspect of the current UKAEA strategy for LLW: 200 litre drums of LLW are routinely compacted and then transferred into HISO containers for final disposal to Drigg, the UK Low Level Waste Disposal facility. However, since the waste packages are expected to be weight rather than volume limited it may be more cost effective to simply place the LLW pipe sections directly into the container to better utilise the volume. Again the final decision is best made at the time; this study assumes that the pipes will be placed into the LLW containers without super-compaction.

Other portable cutting tools are available that could aid both dismantling and size reduction. The precise applications that they could be used for will depend on a number of local factors that will be best assessed at the time. The cost estimate for the size reduction operations does however include provision for the purchase of a range of portable saws, grinders and nibblers.

### Containment and Cross contamination

The expected levels of tritium activity contained in the vacuum vessel will result in significant off-gassing at room temperature. The beryllium contamination associated with the vacuum vessel will also require a high level of containment requiring the ILW processing to be undertaken within a ventilated enclosure. Tritium contamination cannot easily be measured in real time and usually requires samples to be processed in the lab for quantification. Similarly beryllium requires off-line analysis so adherence to good entry and exit procedures is the best precaution to avoid breach of facility containment. Since beryllium control and monitoring is so onerous (and therefore time consuming), it is proposed that beryllium contaminated items are processed after all other size reduction work has taken place. This has the benefit of:

- Minimising the amount of material that could be cross contaminated with beryllium.
- Permitting operating techniques to have matured and developed resulting in less uncertainty over how the facility operates, and operators with significant experience. All this will result in a lower probability of beryllium intake and shorter overall programme.

The tritium contamination on LLW items will be much lower and could therefore be controlled using local extract.
To avoid cross-contamination separate facilities are required to process ILW and LLW.

## SIZE REDUCTION AND PACKAGING FACILITY CONCEPT DESIGN

Over the course of the three months' design phase of the study, three design meetings were held to establish design principles and agree design concepts Membership of the meetings included UKAEA staff familiar with the facility; design engineers; a Radiological Protection Adviser; and engineers with waste management and decommissioning experience.

### Layout principles

Both size reduction facilities for ILW / Beryllium and LLW components will require:

- Size reduction equipment appropriate to the items to be processed.
- Containment / ventilation systems to limit the spread of contamination.
- Equipment to safely handle / manoeuvre large items / components.
- Arrangements that allow representative samples to be taken for analysis (to enable the waste to be sentenced to the correct waste stream).
- Arrangements that enable the rapid filling of the waste disposal containers without the spread of contamination (especially to the external surfaces of the container).
- Hand tools to aid both dismantling and size reduction operations.

The choice of the major size reduction equipment has been discussed above. General design principles are discussed in the following paragraphs.

Effective containment and ventilation is essential to prevent the spread of contamination. The facilities required for processing the ILW and Beryllium contaminated components will need to be fully enclosed with air-lock arrangements for the transfer of both personnel and items into and out from the cutting area (particularly the 2 metre ILW boxes). The general layout of the Torus Hall facilities is shown in Figure 3. Air will be extracted from the area adjacent to item being cut, from the main cutting enclosure to minimise the effects of tritium off-gassing, and from the air-locks. Detailed designs should ensure that the hierarchy of flows is in accordance with best practice i.e. from areas of lower contamination into areas of higher contamination. The extracted air can be routed through air scrubbing columns to remove the tritium and high efficiency particulate air (HEPA) filters prior to discharge through an authorised discharge point.

Current JET operational experience shows there is a much lower potential to spread contamination during processing of the LLW items. Full containment is therefore unnecessary for the processing of the LLW. Instead, the combination of controlled access, simple swarf collection arrangements and local extract ventilation will be adequate.

Other facilities will be required to maintain safety and help minimise costs. Figure 3 shows the proposed general layout of the J1 building area during Torus dismantling and size reduction operations. The locations of the key facilities have been chosen to make best use of the available space, whilst minimising the distances that the larger items will need to be moved. The routes for these movements are also highlighted on Figure 3.

Areas will also need to be identified at the time for the set down and temporary storage of the large items of LLW. As contamination, off gassing and high radiation doses are not significant issues for the LLW, these areas will simply need barriers to restrict access.

Personal protective equipment (PPE) and respiratory protective equipment (RPE) will be required to protect operators from exposures to beryllium and radioactive materials. The precise nature of this equipment will be established by risk assessments conducted at the time. However, it is currently assumed that pressurised suits will be required when processing the ILW / beryllium contaminated items. In order to avoid potential interface issues, it is assumed that the air supplies for these will be provided from suitable (portable) compressors.

## Packaging principles

Since the waste from the facility mainly comprises a limited number of large items, it is necessary to produce a detailed packing plan for these components. Packing efficiency was to be maximised by undertaking the minimum number of cuts on the major components to produce items that could be efficiently loaded into each package. The minimum cuts were deemed to be those that would bring the loaded package mass close enough to the mass limit to permit smaller components to be loaded into the available void space.

For the ILW packages, a mechanism for the package to interface with the containment will be required to ensure that the outside of the package is not contaminated with tritium or beryllium during loading.

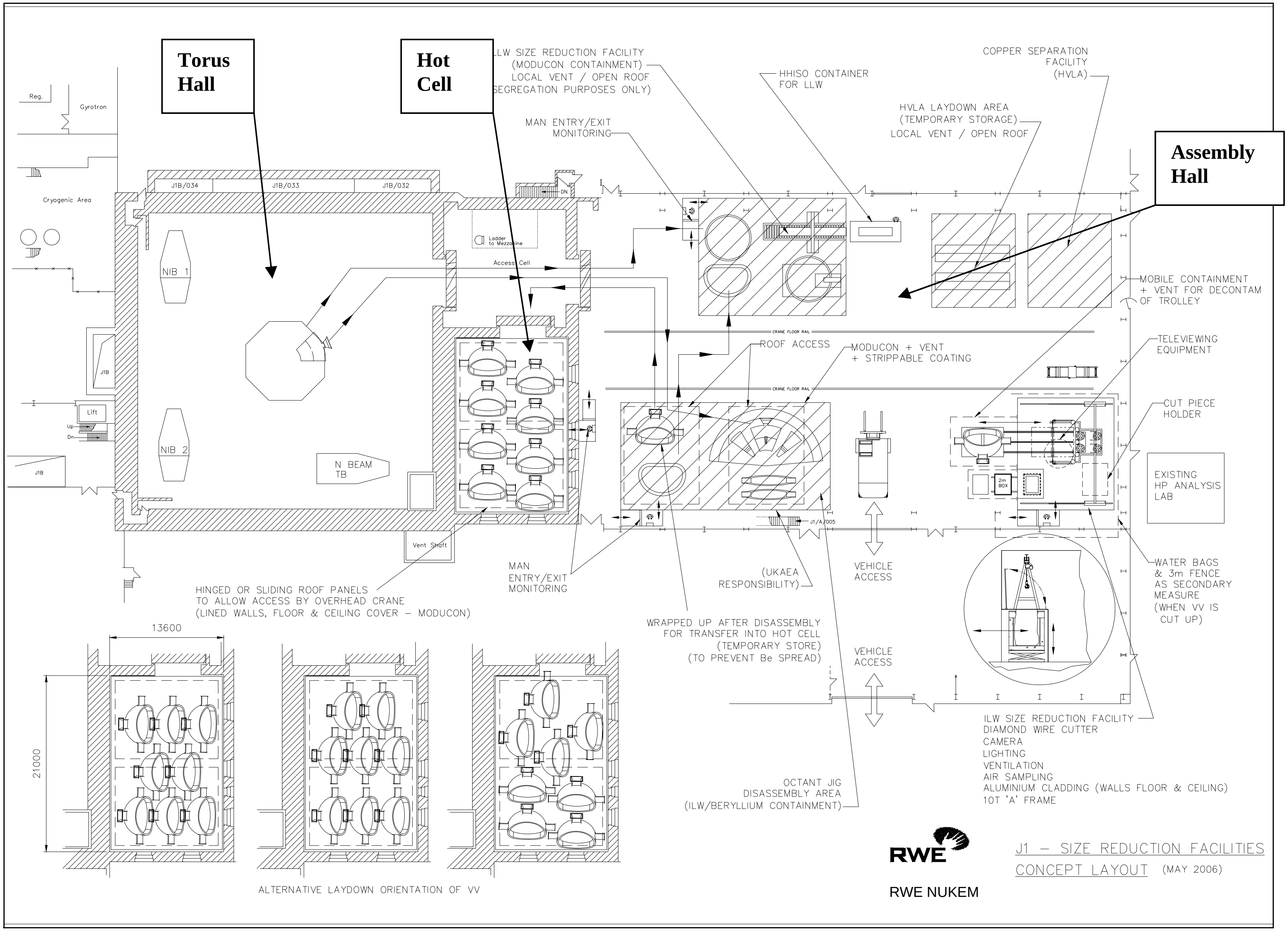

**Figure 3 Layout of the size reduction and packaging facilities within the Assembly Hall**

## ILW Size Reduction Facility

It is proposed that the size reduction of ILW / Beryllium contaminated items would be carried out in a fully contained and ventilated enclosure. The extracted air will be routed through air scrubbing columns to remove the tritium and high efficiency particulate air (HEPA) filters prior to discharge. Person access would be controlled and the entry / egress arrangements would mirror those described in the preceding paragraph. Shielding may be required to reduce radiation doses whilst processing the vacuum vessel sections. This could be achieved by simply placing water filled plastic containers around the outside of the facility.

The ILW facility will be based on the MODUCON (modular containment) containment system with roof access. This will be fitted with CCTV and ventilation facilities. An in-facility A-Frame type of crane on rails with a 10 tonne handling capacity will be made available for handling and packaging operations. The goods receipt and waste export interfaces will be engineered to minimise spread of contamination and reduce operator exposure to ILW items. The use of additional barriers and water bags can be made around the facility to further reduce exposure of personnel to the irradiated components.

It is proposed that the large items would be cut using a diamond wire saw, with the control system located inside the containment in a low doserate area. A large capacity lifting frame and hoist system would be used to move items within the containment area. Transfers in to and out from the containment will be via support cradles located on a bogey running along floor rails. Once in the containment the workpiece would be transferred onto the cutting table using the installed crane and the bogey with support cradle withdrawn into the containment extension. Decontamination of the support cradles and bogey will be critical, especially during the size reduction of the Beryllium contaminated components. This would be achieved in two stages:

> Stage 1 - initial decontamination (to achieve levels set by the RPA) within the main size reduction area.
>
> Stage 2 – final decontamination and clearance monitoring within a ventilated "mobile extension" to the main containment area (see Figure 3). This would be sealed against the main containment and ventilated when required. Strippable and tie down coatings would be used to protect the extension from contamination during its use. The extension could be removed and stored if required when not in use.

Similar arrangements are proposed for recovering the filled 2 metre waste boxes. The loading of the 2 metre boxes would be as follows (see figure 4):

- Empty boxes are delivered and collected from the hall using the existing vehicle access arrangements and overhead crane.
- The lid is removed and the empty box is moved into a sealed cavity within the size reduction facility on a bogey running along floor rails.
- The box is raised to seal against an engineered surface on the underside of the waste loading port.
- The hinged lid over the loading port is opened and waste is loaded into the box.
- Once the box is loaded with waste, an internal lid is fitted to reduce the potential for tritium migration out of the box when it is lowered. An alternative strategy at this point in the process is to dry fill the box in the size reduction area.

- The box is lowered and withdrawn into the extension area described above for final monitoring and lidding. Note – if collection of the filled box is delayed, it can remain within the ventilated extension to minimise potential exposures to tritium.

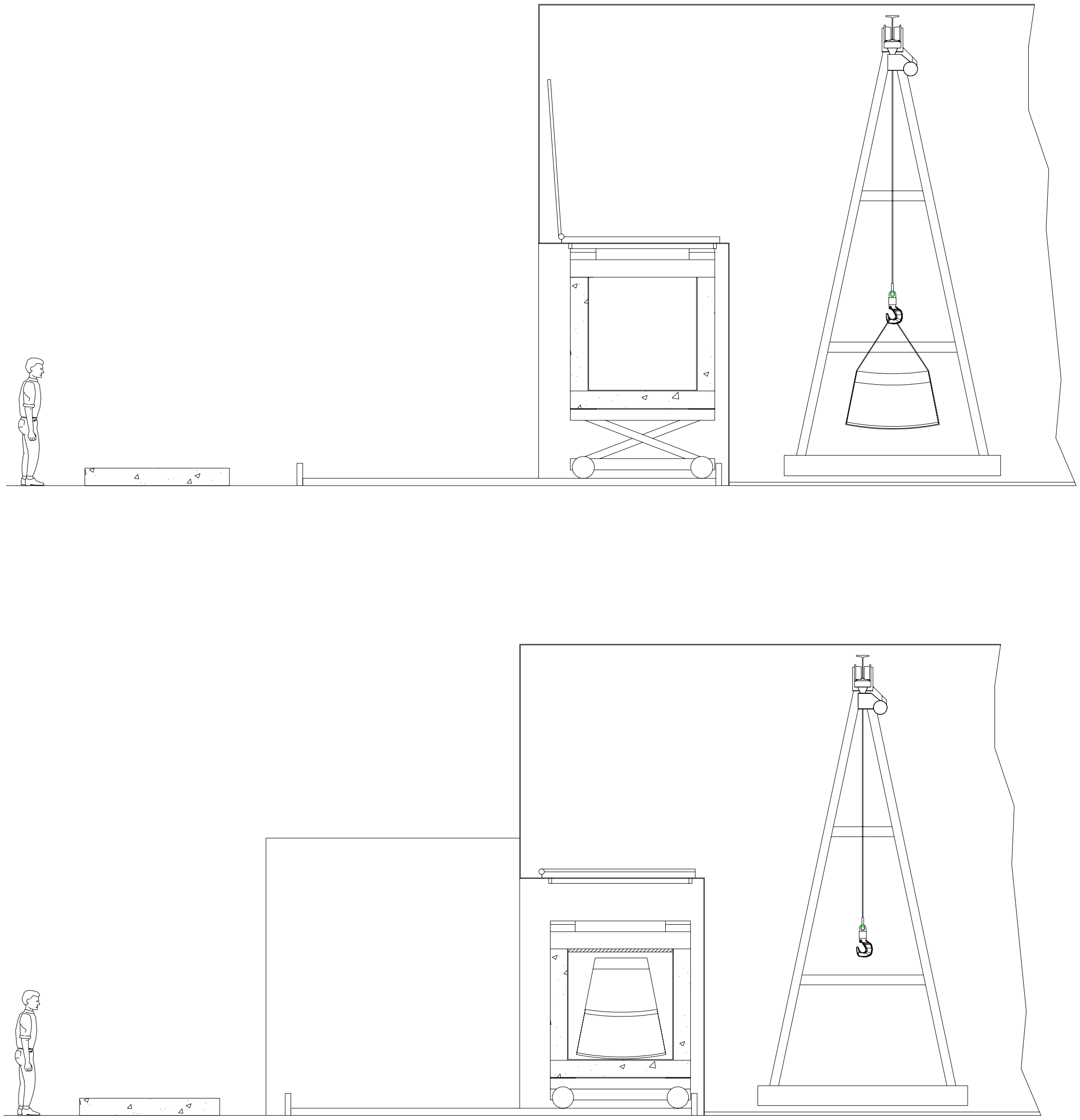

Figure 4 - Loading arrangements for ILW into 2 metre box

## Vacuum Vessel Storage Arrangements

Processing the ILW / Beryllium contaminated vacuum vessel last would keep the ILW Size Reduction Facility free of beryllium contamination until this point in time (thereby making other operations somewhat simpler). Adoption of this strategy requires that interim storage arrangements for the vacuum vessel are established whilst the mechanical support structure is processed.

The Torus decommissioning strategy requires that octants are removed and transferred to a fully ventilated containment for dismantling. It is proposed that the vacuum vessel sections are transferred to the Hot Cell area for temporary storage. The internal cell surfaces of the Hot Cell could be clad with aluminium sheet to minimise the extent of tritium migration into the concrete structure, and a retractable roof fitted over the Hot Cell to aid containment. Although tritium removal arrangements will be fitted to each of the octants within the dismantling facility, continued ventilation of the cell is recommended to minimise the potential for tritium build-up.

Beryllium contamination within the temporary store should not be an issue, since the vessel sections will be received in a condition that permit their removal from the dismantling area. Octants would be moved within the cell using the overhead crane through engineered access points provided in a roof fitted over the cell. Beryllium in air monitoring within the Hot Cell area is recommended at this stage to confirm conditions are as expected.

Entry into the storage area would be through an access port located on the side of the cell. This would include storage facilities for potentially Beryllium contaminated RPE / PPE, a change barrier with personal monitoring arrangements and provide contamination control through appropriate ventilation flows.

## LLW Facility

LLW items such as the poloidal coils would be transferred to the LLW size reduction facility using the existing 150 tonne overhead building crane. LLW components are relatively low dose rate items that are not subject to tritium off-gassing. Full enclosure of the size reduction area is therefore unnecessary.

An open roof type of containment of approximately 20 m long by 14 m wide (simply to provide controlled access / egress arrangements) with local extract ventilation and swarf collection arrangements (a simple catch tray) would be adequate to perform the size reduction operations using band saw machines. The LLW facility will have to be provided with a column type of band saw machine to size reduce large simple components such as the transformer limbs and a hinged type of band saw machine for size reducing the coil assemblies. The open roof will enable handling of items by the building cranes.

The proposed locations of the main cutting equipment (large band saw and mechanical hacksaw) are illustrated in Figure 3. Heavy duty handling systems (roller conveyors, turn-table systems, etc) would support the large items during cutting.

Figure 3 also shows the proposed location of the LLW container (either a TISO-Third height ISO or a HISO-Half height ISO container) and the access arrangements for the transport vehicles. Items would be transferred from the size reduction facility into the containers using the overhead crane. It is proposed that the LLW items are size reduced using band saw cutting and the size reduced waste is packaged inside ISO containers using the existing overhead crane.

Since non contaminated / irradiated items with large amount of copper content (some 65 te) are also to be removed, the concept design has allowed for the provision of a copper separation facility for carrying out this separation process.

### Programme and costing

The size reduction and packaging programme is to a large extent controlled by the Torus dismantling sequence. Thus as components are removed from the machine they are transferred directly into the size reduction facility, reducing the storage requirements. The major departure from this philosophy emanating from the study applies to the main vacuum vessel as discussed above.

It is recommended that the first components to be size reduced in the ILW facility are the Neutral Injector Beam tanks. Although not heavily activated or contaminated, these tanks are too large for cutting on a bandsaw and so are suited to diamond wire cutting. They are also available early in the dismantling programme and can be used to test the operability of the ILW facility without the hazards associated with the ILW wastes.

The upper and vertical transformer limbs and poloidal field coils will be removed first to allow the octant assemblies to be removed from the Torus Hall. Each of the octant assemblies will be transferred to a dedicated disassembly facility constructed in the Assembly Hall. The dismantled mechanical support halves and the vacuum vessel octants will be temporarily stored at designated storage places and subsequently size reduced and packaged using purpose built facilities with cutting and sawing machines. The concept for size reduction and packaging of the above listed equipment has been based on the type of waste and the type of waste containers to be used for packaging as follows:

- ILW: Mechanical Structure
- ILW + Beryllium: Vacuum Vessel
- LLW: Transformer Limbs & Coil Assemblies
- LLW and Exempt Waste: Copper Items

For each major component set-up and cutting times were estimated for incorporation into the overall lifecycle programme for facility design, procurement, installation, commissioning operations and decommissioning. The more detailed concept design for size reduction and packaging allowed sufficient confidence to reduce the overall programme time by a year. Waste cost estimates were also reduced based on the more detailed optimisation of waste packaging.

Costs for the full lifecycle were developed from the programme with quantified risks applied to give an overall cost estimate at 50% and 80% confidence levels.

## LESSONS LEARNT AND FURTHER WORK

### Technical Conclusions reached were:

- Separate LLW and ILW facilities were required to apply appropriate techniques to different components and avoid cross contamination.
- The ILW cutting does not need to be robotic, but personnel exposure will be reduced by utilising semi-remote cutting techniques.
- Cold cutting techniques were preferred to minimise project risk by reducing contamination spread and avoiding problems of blinding ventilation filters.

- Diamond wire sawing has developed sufficiently to be used for remote cutting of complex structures and combination steel and concrete components. For simpler geometries large bandsaws are preferred.
- ILW facilities could be commissioned with minimum risk by initially utilising them for LLW operations.
- Stockpiling of beryllium contaminated items in a suitable storage area for size reduction at the end of the ILW programme reduced project risk and permitted a faster overall programme.

This information has been included in the JET decommissioning lifetime plan to increase the level of detail in the plan and provide a better estimate of the generation and off site transfer of ILW and LLW.

## Procedural Conclusions and Recommendations

- More detailed examination of the likely size reduction and packaging processes achieved the objective of increasing confidence in the overall decommissioning plan for the JET facility.
- Alternative waste strategies should be pursued to ensure the most appropriate conditioning and disposal routes are utilised as the waste industry in the UK develops. For example, much of the low activated and tritiated metals may be suitable for melting in order to concentrate the radioactive component of the waste and permit re-use of the resulting ingots. It may also be possible and cost-effective to remove tritium contaminated paint from the surface of otherwise non-active material. Samples taken show that the bulk of the tritium contamination is in the paint rather than the steelwork.
- De-tritiation methods are developing (but are not within the scope of this study) and they may eventually offer a cost-effective solution for the processing of some of the JET wastes.
- The existing space ventilation arrangements should be reviewed to assess their suitability for the changed requirements during decommissioning.
- The size reduction techniques recommended in this study should be kept under review in order to take into account rapidly developing capabilities in areas such as improved wire sawing technologies.
- The requirement to use shielded ILW disposal packages should be reviewed for much of the low activated materials that may not require the level of shielding proposed. A reduction in shielding may improve the mass of waste that could be packed into each box and thus make better use of any future waste repository.
- Sampling protocols should be further investigated when more detailed conditions for acceptance of ILW are available.
- The LLW packaging arrangements should be reviewed in the light of any changes that may occur with possible new contractual arrangements on the LLW disposal site.

## Further Work

The UKAEA Fusion Decommissioning Group at Culham work closely with the JET operations team sharing experience that is relevant to both operations and decommissioning. All proposed facility design changes are reviewed by the decommissioning team to determine the impact on the decommissioning liability. Lessons learnt from operational experience during shutdowns periods, when modifications are made to the machine, particularly with regard to health physics and waste management activities, are incorporated into the plans for decommissioning the facility.

Work is currently being undertaken to develop methods for detritiating the vacuum vessel and in-vessel components to reduce the levels of bulk tritium and tritium off-gassing. This is also of importance to the ITER project. Reducing the tritium levels in this area will reduce the worker doses during Torus decommissioning, size reduction of the components and the subsequent packaging. It will also reduce the tritium off-gassing levels from the final waste packages and subsequent levels of package contamination, thereby meeting transport and disposal requirements.

Work is being undertaken to develop the 2m box waste package for JET ILW. Concept designs are being developed for the box inner package that will be used to contain the tritium contaminated ILW. Work is also being undertaken to better understand the migration of tritium from the inside of the package. It is expected that a national ILW waste repository will not be available until 2050. All ILW produced and packaged before the repository is available will be stored in an interim store. The inner waste package will be designed to enable certain packages, whose contents have decayed from ILW to LLW, to be consigned as LLW at a later date.

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## ACKNOWLEDGMENTS

This work was funded jointly by the United Kingdom Nuclear Decommissioning Authority and by the European Communities under the contract of Association between EURATOM and UKAEA. The views and opinions expressed herein do not necessarily reflect those of the European Commission or the Nuclear Decommissioning Authority.